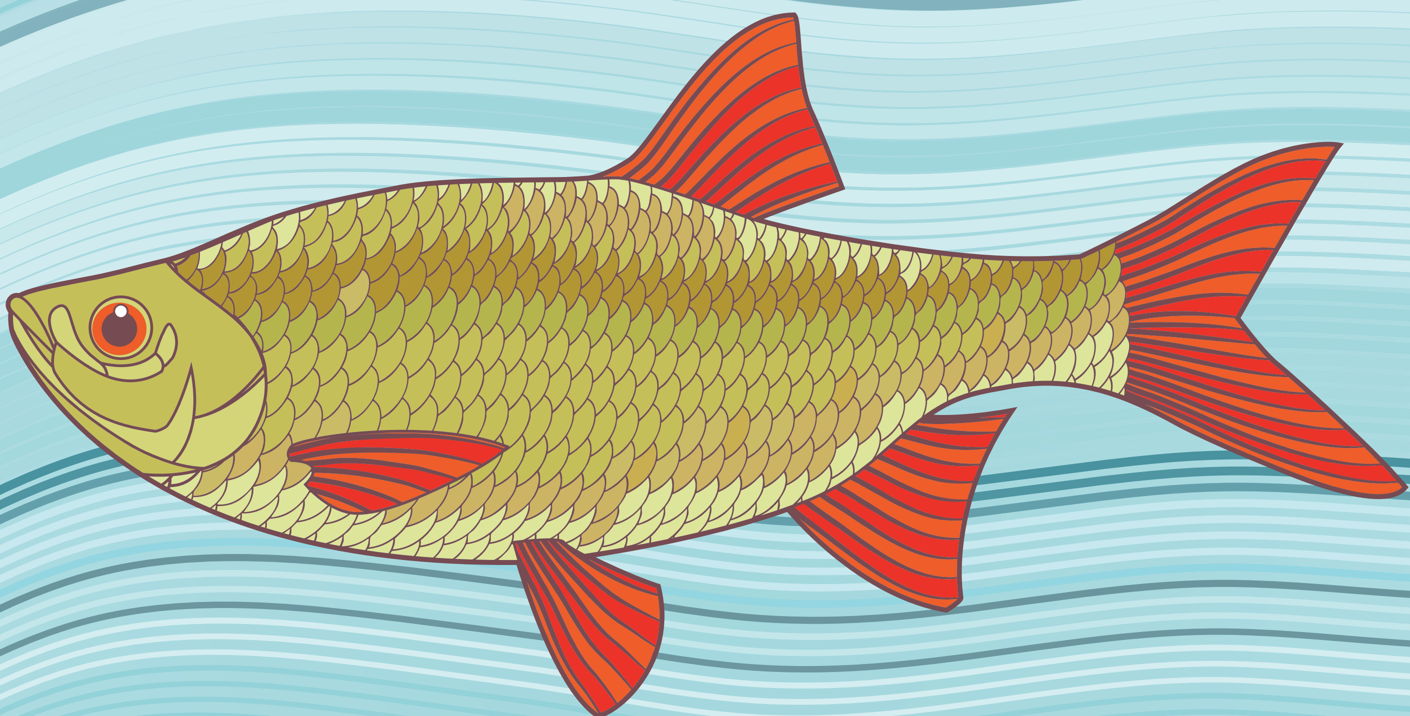
NEW ZEALAND

Invasive Fish Management Handbook

edited by
Kevin J Collier &
Natasha PJ Grainger



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Kevin J Collier &
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Lake Ecosystem Restoration
LERNZ
New Zealand

THE UNIVERSITY OF WAIKATO
Te Whare Wānanga o Waikato

Department of Conservation
Te Papa Atawhai

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Foreword

New Zealand's freshwater environments—our lakes, rivers and wetlands—are under severe pressure from a number of destabilising and damaging activities. Human-induced degradation due to land-use intensification, water abstraction for irrigation leading to habitat reduction and loss, and biosecurity threats such as unwanted organisms and diseases, are the primary agents of change. Furthermore, current signals and experiences point to a warming climate as an overarching exacerbator, driving the pace of change ever faster.

In her 2012 report on understanding the science behind water quality in New Zealand, the Parliamentary Commissioner for the Environment identified three primary drivers affecting the health of our freshwaters—pathogens, sediment and nutrients. She omitted invasive fish, a fourth serious contributor to reducing water quality and a key factor in the increasing threat status of our indigenous biodiversity.

Invasive species are not bound by government policy, lines on maps, or the determined efforts of agencies and citizens to try and confine them. They will do their own thing, wherever and whenever they want, which is why we dislike them so much! Non-indigenous freshwater fish are highly adaptable, frequently invasive, difficult to detect and notoriously hard to eradicate, so it is not surprising that control measures and technologies are poorly developed.

This handbook is a joint initiative between Lake Ecosystem Restoration New Zealand (LERNZ) and the Department of Conservation (DOC), and builds on the extraordinary success of a workshop on the same subject held in Hamilton in 2001, with expert participation from Australia and New Zealand. In 2005 The University of Waikato initiated a 10-year research programme on harmful algal blooms and pest fish (the Freshwater Restoration Outcome Based Investment or OBI, tagged LERNZ). The invasive fish workstream has, over the last decade, contributed significantly to the research knowledge base described in this handbook. Contributions to a joint LERNZ/DOC workshop held in September 2014 helped form the basis of the following material.

The handbook reviews current knowledge of the distribution, status and impacts of non-indigenous invasive fish in New Zealand waterways, control and eradication methodologies, monitoring, management and legislative implications, and invasion risks including the social dimension. Many of New Zealand's top fish and freshwater ecology experts have contributed to the development of the handbook and the recommendations outlined are supported by policy and legal expertise.

This practical handbook will be an essential item on the desks of invasive fish managers and regional council freshwater biosecurity officials for many years to come.

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1

Introduction to Invasive Fish

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Invasive species are a key threat to freshwater ecosystems, and the risk of global spread remains high with greater human population mobility and an increasingly diverse society (Dudgeon *et al*. 2010). The spread of introduced species within countries is also of concern, particularly with a warming climate that may increase the range of habitats suitable for establishment (Rahel & Olden 2008). This risk is most acute in lowland environments, particularly wetlands and lakes where declines in water quality and biodiversity are already apparent, and can be exacerbated by the proliferation of invasive fish (Strayer 2010). As an isolated landmass, New Zealand has escaped many of the more damaging international freshwater animal invaders, but several of the non-indigenous fish that have established are associated with adverse effects on the environment and native biodiversity. Indeed, New Zealand is considered one of six global hotspots for non-indigenous fish introductions (>25% of the all freshwater fish species present) (Leprieur *et al*. 2008), and their numbers have steadily increased over time (Figure 1.1).

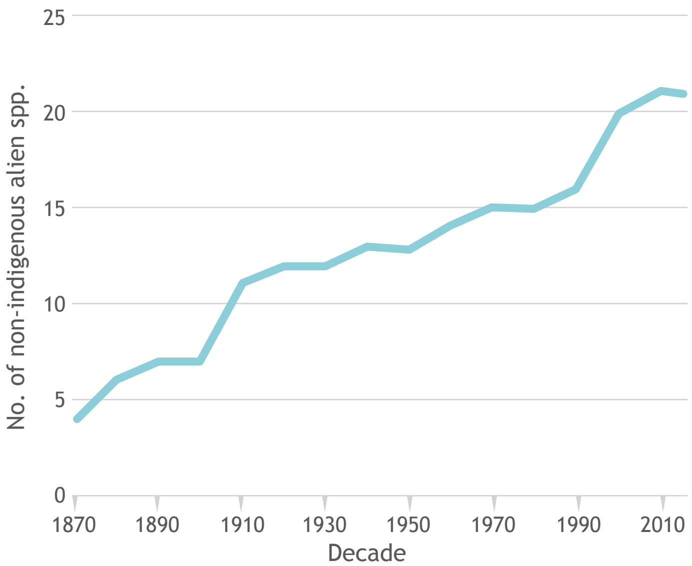


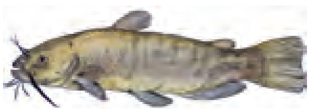
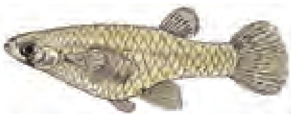
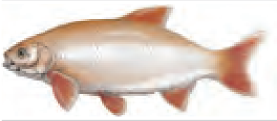
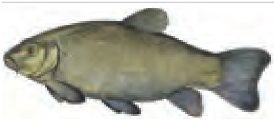
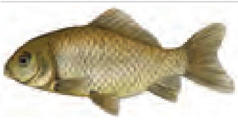
FIGURE 1.1 Decadal rate of increase in breeding populations of non-indigenous freshwater fish species in New Zealand (modified from Rowe 2014).

Goodman *et al*. (2013) list 77 extant or extinct taxa of freshwater fish in New Zealand, 20 of which they consider 'introduced and naturalised', with a further two species introduced but not considered naturalised. One of the introduced species listed by Goodman *et al*. (2013), the bridled goby (*Arenigobius bifrenatus*), is largely associated with estuaries so, excluding that species, there are 21 species of non-indigenous fish restricted to freshwater environments in New Zealand. Most of the eight species covered in this handbook (Table 1.1) are coarse fish, so-named because they have larger (coarser) scales than salmonids. Not all these fish have legal status as pests (Table 1.2), but all are dealt with in various regional council pest management plans for a range of purposes (see Table 3.1). Koi carp, gambusia, rudd and brown bullhead catfish are the invasive fish most frequently listed in those strategies. While also listed in some regional pest management plans (see below), perch and tench are also recognised as legitimate sports fish managed by Fish & Game New Zealand. These species are included in this handbook to provide an overview of all coarse fish species present in New Zealand freshwaters.

All these fish display invasive properties and, when present in high numbers, they have been associated with various impacts on water quality, aquatic habitats and native biodiversity. Despite this, there is some variability in the designation and management of invasive coarse fish among agencies around the country depending on the issues involved. For example, Auckland Council and the Auckland/Waikato Fish & Game Council have agreed to the designation of perch, tench and rudd as pest species in 11 high conservation value waterbodies, opening the way for the implementation of removal programmes (Sabetian *et al*. 2015). Rudd is classed as a sports fish in the Auckland/Waikato Fish & Game region, but is considered a noxious fish elsewhere in the country. Salmonids are also classified as a sports fish and can cause significant issues for native species in some parts of the country (Rowe & Wilding 2012); salmonids are not dealt with in this handbook as they are not coarse fish and are not listed in regional pest management plans. Other introduced fish not dealt with in this handbook are several aquarium species that do not pose a risk of wide-scale spread because they are restricted to warm-water locations, and fish that are managed for specific purposes and designated as 'restricted fish' under the Conservation Act 1987 (grass carp—*Ctenopharyngodon idella*, silver carp—*Hypophthalmichthys molitrix*).

The purpose of this handbook is to provide an up-to-date synthesis of current information on invasive fish and approaches to their management in New Zealand. It follows a joint workshop on invasive fish management held at The University of Waikato (2 September 2014), co-ordinated by the university's Lake Ecosystem Restoration New Zealand (LERNZ) research group and the Department of Conservation. The handbook presents a review of the biology of the focal invasive fish species, with an analysis of community-level impacts given that single species seldom occur in isolation. The species are dealt with in order of their Fish Risk Assessment Model ranking by Rowe & Wilding (2012). Key statutory responsibilities and organisational roles of agencies involved in invasive fish management are outlined, and examples of regional/iwi initiatives to address management are presented for a part of New Zealand bestowed with many invasive species. Control, eradication and monitoring approaches that have been used in New Zealand are assessed, and these are complemented by case studies that highlight lessons learned from management programmes aimed at different invasive fish species. An overseas case study is presented to highlight the value of sustained integrated management in controlling coarse fish invasions. Finally, we explore the human dimension of attitudes to coarse fish, how to raise public awareness, and current knowledge on future invasion risks.

TABLE 1.1 List of species covered in this handbook in order of their risk assessment scores from Rowe & Wilding (2012) (see Table 7.1 for full list).

	COMMON NAME	SCIENTIFIC NAME	LEGAL STATUS*
	Koi carp	*Cyprinus carpio*	Noxious fish Unwanted organism
	Perch	*Perca fluviatilis*	Sports fish
	Brown bullhead catfish	*Ameiurus nebulosus*	No legal status
	Gambusia	*Gambusia affinis*	Unwanted organism
	Orfe	*Leuciscus idus*	No legal status
	Rudd	*Scardinius erythrophthalmus*	Noxious fish**
	Tench	*Tinca tinca*	Sports fish
	Goldfish	*Carassius auratus*	No legal status

* see Table 1.2

** excluding Auckland/Waikato Fish & Game region where it is designated a sports fish under the Freshwater Fisheries Regulations 1983

TABLE 1.2 Legal status of selected non-salmonid introduced fish present in New Zealand. Species in parentheses are not currently present in New Zealand. Does not include prohibited species under the Hazardous Substances and New Organisms Act 1996.

	UNWANTED ORGANISM	NOXIOUS FISH
Species	Koi carp, gambusia, (gudgeon*, channel catfish)	Koi carp, rudd**, (piranah***, pike, walking catfish, tilapia)
Description	Restricted sale, distribution and propagation	Illegal to have under control, or rear, raise, hatch or consign
Legislation	Biosecurity Act 1993	Freshwater Fisheries Regulations 1983
Management responsibility	Department of Conservation, Ministry for Primary Industries, regional councils	Department of Conservation, regional councils

* reported in an Auckland pond in 2004 and eradicated, but unknown populations may be present elsewhere

** excluding Auckland/Waikato Fish & Game region where it is designated a sports fish under the Freshwater Fisheries Regulations 1983

*** held in captivity only

2

Invasive Fish Species and Communities in New Zealand

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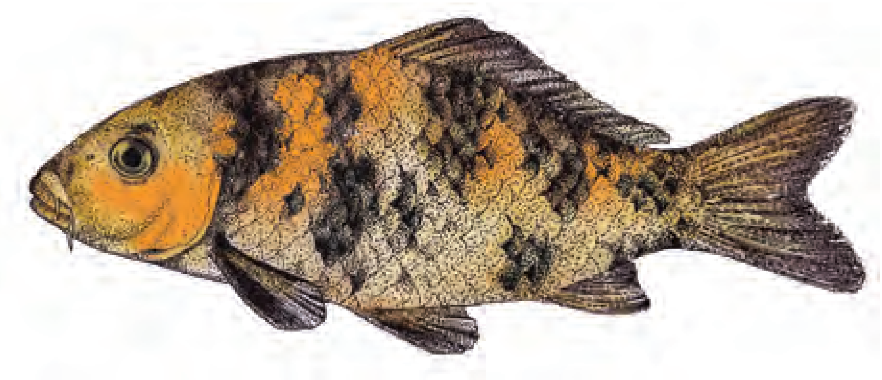
2.1 New Zealand Invasive Fish Species

Introduction

The following section summarises current knowledge on the identification, distribution, biology and ecology of the eight focal introduced fish species. Distribution maps for each species show records from 1985 to 2015 from the New Zealand Freshwater Fish Database and held on The University of Waikato's LERNZdb database. A detailed analysis of water temperature tolerances and preferences is provided in Table 7.2.

KOI CARP (*Cyprinus carpio*)

IDENTIFICATION: Blotchy colours of orange, black, red and/or white. Two small barbels at each corner of the mouth. Origin of dorsal fin is in front of pelvic fin. Large scales and less than 30 gill rakers. Koi and goldfish may interbreed; first generation hybrids have drab coloration, one pair of barbels and 30–50 gill rakers, but subsequent generations of hybrids may be highly variable.



INTRODUCTION: Koi carp, also known as European carp, Japanese koi, common carp or carp, probably arrived with goldfish in about the 1960s. They became established in ornamental ponds over the 1970–80s, and were first reported in the wild in the lower Waikato River during this time.

DISTRIBUTION IN NEW ZEALAND: Widespread in Auckland and Waikato with isolated populations in the rest of the North Island. Not present in the South Island after eradication of an incursion in ponds around Nelson in 2001–03.

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BIOLOGY: Koi carp spend their entire life in freshwater, preferring still lakes, ponds and wetlands where they are often seen on warm sunny days near the water surface. In New Zealand, they most commonly inhabit slow-flowing downstream reaches of large rivers with associated backwaters, floodplain wetlands and lakes, as far down as river deltas (Hicks & Ling 2015). They tend to do less well in deeper lakes and impoundments (Jackson *et al*. 2010). Koi carp can undertake extensive movements within rivers systems (e.g. mean of 39 km in the Waikato River), initiated by spawning behaviour and changes in river flow which influence connectivity with lateral habitats (Daniel *et al*. 2011).

From about 100 mm total length koi carp switch from feeding on zooplankton to becoming opportunistic benthic omnivores feeding on invertebrates (including chironomids, annelids, amphipods and odonates), seeds, detritus, and the spawn and juveniles of other fish (Weber & Brown 2009). They suck up sediments, sift out organic matter leaving distinctive 'pockmarks' in the sediment, and then eject the remaining material into the water. Adult carp forage in warmer shallower waters in summer but overwinter in large aggregations in deeper water (Hicks & Ling 2015).

Koi carp move into interconnected shallow lakes, floodplains and wetlands in spring and summer where they congregate to spawn in shallow, weedy areas. Spawning typically occurs when water temperature is above 16°C (Scott & Crossman 1973). Photoperiod is also an important regulator of spawning, but appears secondary to temperature. Females actively scatter eggs over vegetation and males fertilise them externally. Eggs hatch after about a week and juveniles develop in shallow floodplains and marshes (Tempero *et al*. 2006; Hicks & Ling 2015). Spawning can extend for up to eight months from September through to April under favourable conditions (Tempero *et al*. 2006). Spawning success is related to spring flooding, and multiple protracted spawning events can occur (Weber & Brown 2009). Waikato River populations of feral koi carp contained females that spawned once, and females that had the potential to spawn repeatedly within one season (Tempero *et al*. 2006). Mean total fecundity calculated from 44 running-ripe females from the Waikato was 299,000 oocytes (±195,600 SD;range 29,800–771,000).

Males typically mature at two years of age (c.250 mm long) and females at three years of age. New Zealand koi carp reach maximum length of c.600 mm by age 12 but males appear to rarely live longer than eight years (Tempero *et al*. 2006). No feral koi carp older than 12 years of age were collected from the lower Waikato River, but they have been reported to live for much longer than this in captivity. The combination of early maturation, rapid growth and ecological and trophic plasticity means koi carp populations can attain extremely high biomass (Weber & Brown 2009).

ENVIRONMENTAL TOLERANCES: Koi carp are tolerant of low oxygen (as low as 15% saturation), high turbidity, degraded water quality, and salinity of 10‰ for at least three months and up to 14‰ for short periods (Hicks & Ling 2015). Fish are able to survive from near freezing water temperatures to up to 43°C, although optimal temperatures for growth are 27–32°C (see Table 7.2).

IMPACTS: McDowall (1990) described koi carp as the least desirable fish species in New Zealand because of their ability to degrade waterways by increasing the turbidity of water and disturbing the ecology of aquatic ecosystems. Hanchet (1990) undertook the first local risk assessment of koi carp after their discovery in New Zealand, and concluded that they could affect aquatic vegetation and may destroy it entirely when they reach high densities (400 kg/ha). However, conservative biomass-impact assessments suggest that <50 kg/ha is 'safe' with variably significant impacts reported at biomass levels greater than this (Hicks & Ling 2015; Vilizzi *et al*. 2014).

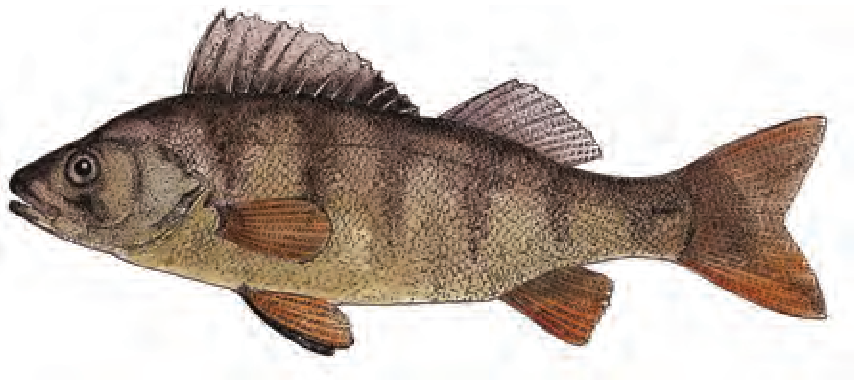
Koi carp are thought to pose the greatest ecological risk to shallow, warm, eutrophic and silty waterbodies. Their feeding actions resuspend benthic sediments and nutrients, and are associated with a change from clear water to turbid states in lakes. Koi carp therefore act as nutrient pumps by consuming nutrient-rich sediments and excreting bioavailable nutrients into the water column, potentially leading to elevated levels of chlorophyll *a* and cyanobacteria (Hicks & Ling 2015; see also Section 2.2). They rarely consume macrophytes directly but dislodge roots from fine sediment during feeding and increase turbidity which attenuates light for macrophyte growth (Weber & Brown 2009).

Consequently, koi carp feeding can result in significant declines in the diversity and abundance of macrophytes in lakes (Miller & Crowl 2006). Koi carp feeding also undermines banks and degrades benthic habitats, contributing to a negative relationship between carp biomass and benthic invertebrate taxa richness (Vilizzi *et al*. 2014).

Other impacts include competition for food with, and degradation of habitat for, native benthivorous fish, sports fish and waterfowl. Larvae feed predominantly on zooplankton and in large numbers may exert top-down pressure inducing an increase in phytoplankton, although effects of koi carp on different zooplankton groups can be variable (Weber & Brown 2009; Vilizzi *et al*. 2014). Adult fish may consume eggs of other fish and degrade habitat or disrupt spawning activities. It is also possible that koi carp feeding limits recruitment of freshwater mussel populations through ingestion of larvae settling on bottom sediments and disturbance of larval mussel habitats.

STATUS: Noxious fish (Freshwater Fisheries Regulations 1983); Unwanted organism (Biosecurity Act 1993).

PERCH (*Perca fluviatilis*)



IDENTIFICATION: Five or more dark, vertical stripes along the side of the body which is laterally compressed with a pronounced dorsal hump behind the head of adult fish. Two dorsal fins with the first fin having 13–17 sharp spines. A broad, flat spine occurs on the lower posterior edge of the gill cover. Bottom edge of caudal fin is bright red-orange and, because of this, it is sometimes referred to a redfin perch. Also known as European perch.

INTRODUCTION: First established between 1868 and 1877 in the Canterbury, West Coast, Wellington, Wanganui and Taranaki regions, and subsequently spread to other parts of the country.

DISTRIBUTION IN NEW ZEALAND: Throughout most of the west coast of the North Island and east coast of the South Island.

BIOLOGY: Perch occur in a wide range of still and sluggish freshwater environments, including lakes, ponds, reservoirs and slow-moving parts of rivers. In lakes and ponds they are found mostly around margins or shallow water close to large beds of macrophytes and/or emergent plants such as rushes. In rivers they tend to occur close to objects providing cover such as logs, tree roots and fringing vegetation.

Perch undergo several size-related shifts in their diet and habitat use, so can affect different aspects of freshwater ecosystems throughout their life cycle. In lakes, larval perch are generally pelagic zooplankton feeders that form in shoals in shallow, open waters and along littoral zones, while in rivers they tend to feed on small aquatic invertebrates in still backwaters, pools, and in the slower-flowing margins. Schooling behaviour decreases with age/size. Mid-sized perch (30–80 mm long) feed mainly on benthic macroinvertebrates until they reach larger sizes (130–180 mm) when they become predominantly solitary and piscivorous (Closs *et al*. 2003). A protrusible mouth allows them to ingest other fish up to a third of their length. Perch populations in lakes are often characterised by larger fish due to cannibalism on smaller fish.

Perch spawn during late winter-spring when they release eggs encased in long gelatinous ribbons which sink and adhere to substrates such as plants and wood (Morgan *et al*. 2002; Snickars *et al*. 2010). Females can produce 5,000–80,000 eggs, depending on their size, in late winter to early spring when water temperatures are as low as 7°C, but optimum spawning occurs at 14°C (see Table 7.2). However, recent work suggests oocytes can develop asynchronously in some New Zealand waterbodies, raising the possibility of spawning during late summer as well as spring (Sabetian *et al*. 2015). Eggs hatch in 1–3 weeks depending on water temperature (Pen & Potter 1992). In stunted populations, males mature at 2–3 years of age and females at 3–6 years, while in fast-growing populations males can mature in their first year and the majority of females in their second year (Morgan *et al*. 2002). Perch are long-lived with a maximum estimated age of 24 years (www.fishbase.org), although more typically in New Zealand perch longevity is estimated at 5–6+ years (Sabetian *et al*. 2015).

ENVIRONMENTAL TOLERANCES: Perch prefer waters around 24–27°C with water temperatures greater than 30°C considered highly stressful (see Table 7.2). Eggs die when water temperatures rapidly increase above 12°C, and consequently temperature is a key factor limiting perch distribution and growth in freshwaters. They can also exist in brackish water environments (www.fishbase.org) but do not tolerate salinities greater than 10‰. pH of 7–7.5 is preferred.

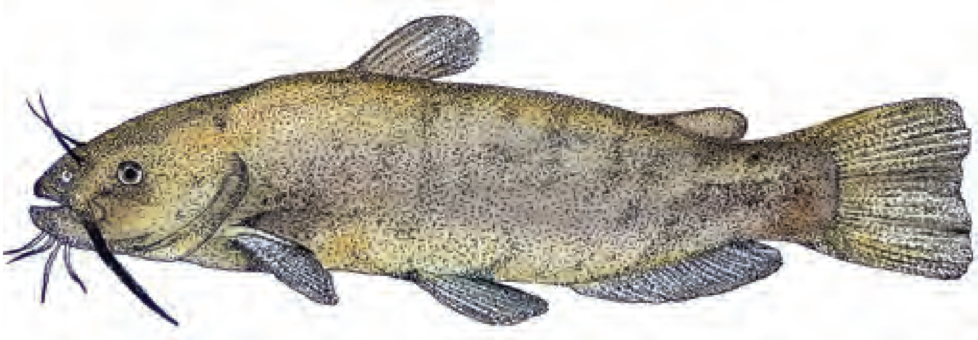
IMPACTS: European perch have been implicated in the decline of native fish species and are capable of significantly altering native freshwater communities (Cadwallader & Backhouse 1983; McDowall 1996; Closs *et al*. 2003). In particular they have been implicated in the decline of common bully (*Gobiomorphus cotidianus*) populations in ponds, lakes and small South Island tarns (Closs *et al*. 2003; Ludgate & Closs 2003). The introduction of perch to Lake Ototoa, Auckland, in 2002 resulted in a catastrophic decline in freshwater crayfish/kōura and common bully abundance, reduced rainbow trout (*Oncorhynchus mykiss*) growth rates, and the probable local extinction of the ‘at risk’ dwarf īnanga (*Galaxias gracilis*) (D Rowe, NIWA, pers. comm.). Furthermore, īnanga (*Galaxias maculatus*) and smelt (*Retropinna retropinna*) were both absent in a northern New Zealand dune lake dominated by perch even though they could readily access the lake (Rowe & Smith 2001). Impacts of perch on native fish in more complex and open river environments may be much less severe than in lakes and ponds, and turbidity in lentic environments may affect predation efficiency.

Stunted populations of perch can contribute to reduced water clarity through consumption of zooplankton and consequent reduction in algal grazing (Romare *et al*. 1999; Rowe 2007). This mechanism was proposed as a contributing factor to cyanobacterial blooms in Karori Reservoir, Wellington (Smith & Lester 2007). Reduction in adult perch numbers can lead to the proliferation of smaller zooplanktivorous fish, and overseas perch stocking has been utilised to suppress these with the aim of improving water quality. Introduced fish such as koi carp may reduce the survival of perch eggs through their feeding activities.

STATUS: Sports fish (Freshwater Fisheries Regulations 1983).

BROWN BULLHEAD CATFISH (*Ameiurus nebulosus*)

IDENTIFICATION: Dark elongate body with large head, smooth skin (no visible scales) and small eyes. Eight long barbels around mouth. Sharp spines on dorsal and pectoral fins.



INTRODUCTION: Introduced to New Zealand in the late 19th century and first released into St Johns Lake, Auckland. Stock from the original source was sent to Wellington and then Hokitika in 1885 (Champion *et al*. 2013). Since then, they have been distributed intentionally and accidentally into many lakes and rivers of the North Island (McDowall 1990). Brown bullhead catfish is the only species of catfish in New Zealand and so they are referred to hereafter as 'catfish'.

DISTRIBUTION IN NEW ZEALAND: While their range was initially restricted to Lake Mahinapua, West Coast, South Island, and several river catchments in the North Island (Wairoa, Waikato and Waihou rivers), catfish distribution has increased significantly in the last decade. The species is now widespread throughout the middle of the North Island with scattered records from the South Island.

BIOLOGY: The biology of catfish in New Zealand has not been extensively studied. They occupy a wide range of habitats including lakes, ponds, rivers, streams and wetlands, preferring slow-flowing waters possibly because of the difficulty in locating prey in fast-flowing waters. Catfish feed nocturnally with the aid of chemosensory organs (ampullary electroreceptor organs) in preference to using their small eyes (McDowall 1990). They are often regarded as opportunistic omnivores showing little discrimination between prey types (Keast 1985). However, others in New Zealand and overseas have found that they are selective in their feeding habits (Barnes 1996; Kline & Wood 1996). For instance, in Lake Taupo, catfish from weedy habitats were found to feed predominantly on gastropods, cadddisflies, cladocerans and chironomids. They have also been reported to feed extensively on crayfish in Lake Taupo and may also eat eggs of native fish (Rowe & Graynoth 2000). Elsewhere in the Waikato catchment catfish had a significant amount of detritus in their diets, although they are thought to selectively remove benthic organisms from the detritus (Patchell 1977; Wise 1990; Kane 1995).

Barnes (1996) and Dedual (2002) studied the ecology and movement of catfish in Lake Taupo, and reported that they undertake predictable seasonal migrations. Catfish form pair-bonds and are territorial during the preparation of the spawning site and during spawning (McDowall 1990). They are one of the few freshwater fish species that undertake parental care of their broods, thereby significantly increasing offspring survival (Blumer 1985). Spawning occurs in shallow depressions in bottom mud or sand excavated to an average depth of 48 cm (Blumer 1985). The eggs are guarded and fanned, usually by the male, and this is essential for their survival, taking 6–9 days to hatch at temperatures of 20.6–23.3°C (Scott & Crossman 1973). Catfish take care of their young for an average of 12 days (maximum 29 days) from the time of spawning to the end of juvenile guarding.

Catfish usually spawn between September and December (Patchell 1977; McDowall 1990; Barnes 1996). However, in two Waikato drains they spawned later, in December to February (Bannon 2001). Spawning mostly occurs from 14–21°C (see Table 7.2), although mean water temperature at the time of spawning in Lake Taupo was only 12°C (Barnes 1996). There appears to be no single extrinsic trigger for spawning, and temperature, photoperiod, the availability of spawning sites, and individual development all need to be favourable before spawning commences (Patchell 1977).

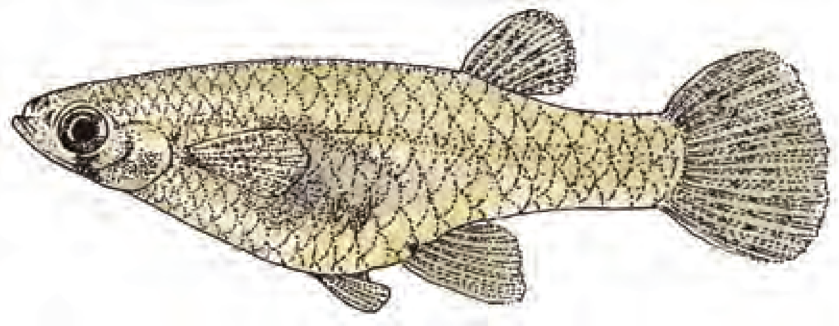
The number of mature ova in New Zealand catfish has been found to vary between 795–8,014 per female (Patchell 1977; Wise 1990; Barnes 1996), whereas overseas reported numbers have varied between 1,797 and 13,000 (Scott & Crossman 1973; Harvey & Fortin 1982; Sinnott & Ringler 1987). There has been some disagreement on whether catfish are able to spawn several times during one season. Patchell (1977) suggested that the oocytes of catfish develop continuously throughout the spawning season and that the fish spawn several times at minimum intervals of three weeks. However, others have found no evidence for continuous spawning. For example, Wise (1990) found that the egg sizes were uni-modally distributed and there was a distinct peak of the gonadosomatic indices in October, and Blumer (1985) found that the number of eggs in 23 egg masses matched the number of ripe eggs in ovaries. In New Zealand, catfish mature at the age of two years and their spawning life is estimated to be 4–5 years (Patchell 1977).

ENVIRONMENTAL TOLERANCES: Catfish live in fresh water and rarely enter brackish waters (www.fishbase.org). They can survive long periods out of water if the skin is kept moist, and are therefore extremely resilient to adverse conditions, difficult to eradicate and easy to spread inadvertently (e.g. attached to nets). Catfish can withstand wide ranges of temperature from 0°C to an upper lethal temperature of up to 38°C, depending on acclimation temperatures (Scott & Crossman 1973; www.fishbase.org). They are well-known for their ability to tolerate poor water quality, including dissolved oxygen levels as low as 0.2 ppm in winter (Scott & Crossman 1973), although Bannon (2001) found that captured catfish died in nets overnight when the levels fell to 0.2 ppm at warmer temperatures. Catfish appear able to thrive in areas where the sediments are contaminated with heavy metals, polychlorinated biphenyls (PCBs) and polyaromatic hydrocarbons (PAHs), as evidenced by significantly larger fish, higher fecundity, and larger eggs in polluted areas (Lesko *et al*. 1996). West *et al*. (2006) reported different response patterns of catfish to discharges along the Waikato River, suggesting beneficial effects from discharges with elevated heat and nutrient levels, and adverse effects from bleached pulp and paper mill effluent.

IMPACTS: Catfish have the potential to modify invertebrate communities, ecosystem processes, and nutrient status through benthic feeding and stirring up bottom sediments. Studies of the effects of benthivorous catfish on water quality found that they increased the concentration of nitrate and nitrite through resuspension of sediments (Cline *et al*. 1994). Increased rates of nutrient cycling caused by catfish may contribute to higher productivity, as has been suggested for Lake Ngaroto, Waikato (Hicks *et al*. 2001). The omnivorous nature of catfish makes them likely to both compete with carnivorous native fish, such as eels, and include native fish in their diets. Catfish have recently been implicated in the decline of kōura populations from upper Waikato River hydro-lakes (Clearwater *et al*. 2014).

STATUS: Catfish have no legal status in New Zealand. However, under the Fisheries (Amateur Fishing) Regulations 2013 catfish must be killed on capture, and under the Fisheries (Commercial Fishing) Regulations 2001 live sale is prohibited.

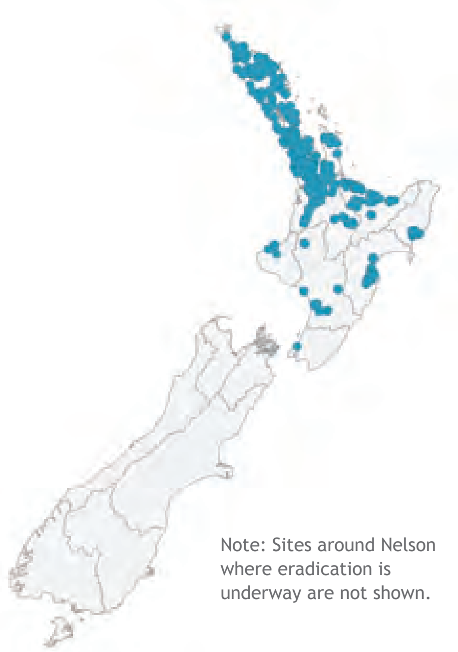
GAMBUSIA (*Gambusia affinis*)



IDENTIFICATION: Small fish with greenish-silvery sheen. Adult males (30–40 mm long) are smaller than females (50–70 mm) which may have a black blotch on their side. Males have an enlarged, tube-like anal fin (gonopodium) used for insemination. Both sexes have a rounded caudal fin and a high dorsal fin; the origin of the dorsal fin is behind the origin of the anal fin.

INTRODUCTION: Gambusia are widespread globally and have occurred in New Zealand since around 1930. They were introduced to control mosquitoes but are ineffective at this. Only one species has been introduced into New Zealand so the species is referred to hereafter as 'gambusia'; another species, *G. holbrooki*, has invaded several other countries (e.g. Australia).

DISTRIBUTION IN NEW ZEALAND: Mainly in upper half of the North Island (north of Taupo), with populations also in Taranaki, Hawkes Bay, Manawatu and Wellington. Absent from the South Island except at a few sites in and around Nelson where eradication is underway.



Note: Sites around Nelson where eradication is underway are not shown.

BIOLOGY: Gambusia proliferate in the margins of lakes, reservoirs, ponds, wetlands, rivers and streams, congregating mainly around aquatic plants in summer and autumn months. They prefer shallow waters (generally less than 15 cm deep) and often occupy habitats too shallow (1–5 cm deep) for other fish. In rivers and streams they are confined to still-water areas (<25 cm/s) because of their poor swimming ability. In New Zealand, gambusia have also been reported from saline, mangrove-swamp habitats in harbours and estuaries (Rowe *et al*. 2008); indeed the few sites where they occur in Nelson border Tasman Bay.

Pyke (2005) noted preferences for waters 5–15 cm deep, dark over light substrates (for the smaller fish), and areas without any floating vegetation, consistent with requirements for foraging near the water surface. Gambusia are voracious predators on a wide range of aquatic invertebrates including dragonfly and other insect larvae, worms, crustaceans and snails, as well as terrestrial spiders and insects that fall onto the water surface (Ling 2004; Pyke 2005).

Fish are short-lived and fast-growing, making the species able to colonise new habitats rapidly. They are particularly abundant during warm months, but disappear from littoral margins during late autumn when females move into deeper waters of lakes and ponds for over-wintering (Rowe & Graynoth 2000; Pyke 2005). They are not known to undertake active migrations, but downstream movement can be facilitated by floods (Haq *et al*. 1992). Congdon (1994) reported that large female gambusia show a preference for downstream movement compared with smaller fish, consistent with the role of large females as the principal colonisers of new habitats (Robbins *et al*. 1987).

Gambusia become sexually active when water temperatures exceed 16ºC (Wakelin 1986; Pyke 2005). Each year, females can produce multiple broods of live young, which typically reach maturity at around 4-6 weeks of age (Lloyd *et al*. 1986), although the gestation period can be as short as 2–3 weeks (Pyke 2005). Consequently, a single pregnant female is all that is required to start a new population; females are able to store viable sperm and so have great flexibility in terms of when eggs are fertilised. Each female is capable of producing up to 130 live young, and can produce 2–3 broods between November and April each year. However, this varies with fish size and up to nine broods over 6–7 months have been reported (Pyke 2005). With rapid growth under ideal conditions, a population of only 10 females could give rise to five million descendents within six months (Hicks *et al*. 2010). Fish live for 10–12 months, with males maturing around 21 mm and females at 28 mm in length.

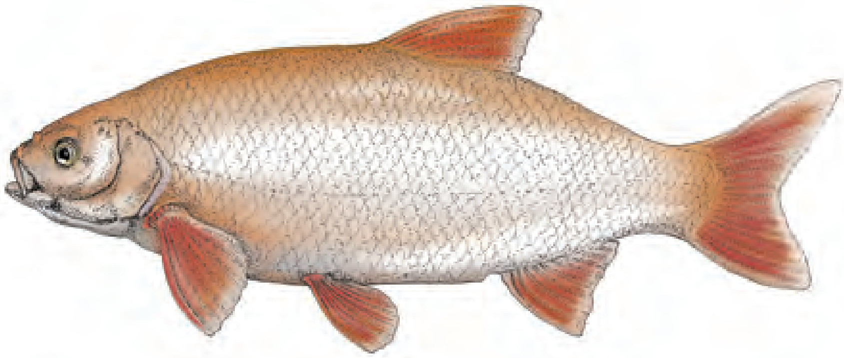
ENVIRONMENTAL TOLERANCES: Gambusia are tolerant of a wide range of environmental conditions including high water temperatures, ice cover, oxygen depletion and high salinities (McDowall 1990). Critical thermal maximum temperature is around 44ºC, and optimal growth occurs around 30ºC (see Table 7.2). They can tolerate dissolved oxygen concentrations as low as 0.3 mg/L and salinities equivalent to seawater depending on acclimation period (Pyke 2005).

IMPACTS: High numbers of gambusia have been associated with negative effects on a range of fish, invertebrate and amphibian species worldwide, through direct predation or competition (Lloyd *et al*. 1986). They are cannibalistic and are known to aggressively attack fish larger than themselves, particularly in laboratory conditions (Rowe 1998; Ling 2004). They attack native fish by nipping at their fins and eyes, and preying on their eggs, with whitebait and mudfish particularly vulnerable because they share similar habitats. There are reports of gambusia feeding on juvenile black mudfish (*Neochanna diversus*) and fry in captivity, affecting mudfish growth rates, aggressively attacking dwarf īnanga in a dune lake, and competing with native fish such as common bully and common smelt for space and food in shallow margins when they occur at high densities (Barrier & Hicks 1994; Rowe 1998; Ling 2004; Ling & Willis 2005; Pingram 2005).

However, the magnitude of the impact of gambusia on native fish is variable, as they appear capable of coexistence with some of these species in other locations. As a result of this observation, Ling (2004) suggested that gambusia, through selective removal of invertebrate grazers, may pose a greater threat to ecosystem processes than to native fishes directly. This conclusion is supported by observations by Nagdali & Gupta (2002) for a eutrophic lake in India where a fungal infection eliminated >80% of the gambusia population. Following mortality, zooplankton numbers doubled leading to reduced phytoplankton abundance, lower phosphorus concentrations and greater water clarity. Following recovery of the population, plankton communities and nutrient levels reverted to their pre-mortality states.

STATUS: Unwanted organism (Biosecurity Act 1993).

ORFE (*Leuciscus idus*)



IDENTIFICATION: Similar to rudd, but with smaller scales and lacking the small projection at the base of pelvic and pectoral fins. No teeth.

INTRODUCTION: Native to northern Europe. Illegally introduced to New Zealand in the 1980s.

DISTRIBUTION IN NEW ZEALAND: Orfe are only known from Blackmores Pond near the Waitemata Harbour, Auckland (McDowall 2000), but may also be in other ponds on private property around Auckland. However, orfe have not been seen by fisheries managers or scientists for many years. Also referred to as golden orfe or ide.

BIOLOGY: Because of their recent introduction to New Zealand and limited occurrence, there is virtually no information on the natural history of orfe in New Zealand (McDowall 1990). Moore (1988) is the only New Zealand publication that was completed not long after the discovery of orfe, so most of the background biology of orfe is derived from overseas sources. This literature indicates that they typically inhabit slow-flowing or still waters in rivers and lakes, and are migratory if possible, not staying in lakes permanently (Koli 1984).

Orfe often feed in shoals near the surface, but in cold or windy conditions they retreat to deeper waters (Koli 1984; McDowall 2000). Juvenile orfe feed on plankton, but adults include a variety of food items in their diet (McDowall 1990, 2000). Orfe appear quite adaptable to feeding on benthic prey, in both mid-water and from the water surface (Koli 1984; Brabrand 1985). Benthic prey include snails, some crustaceans, and insect larvae including caddisflies and midges. Terrestrial insects on the surface of the water are also captured. Their ability to switch to plant food when animal food is scarce could provide a competitive advantage over other fish species. The importance of aquatic vegetation in the orfe diet appears to increase as fish grow larger, and at the same time they decrease the proportion of zooplankton in their diet (Brabrand 1985). A small number of fish are included in the diet of large orfe, but these appear to be limited to juveniles and fry (Koli 1984; Brabrand 1985).

Spawning occurs in spring at depths of 0.5–1.5 m, and may involve migrations upstream into rivers and streams (Mutenia 1978; McDowall 1990). Eggs are laid over gravel, weed beds or muddy substrate, and adhere to stones, aquatic vegetation and other debris (Mutenia 1978; Koli 1984). In Finland, the water temperature at the time of orfe spawning was reported to be 8–10°C; egg development can take about five days at 14°C, nine days at 12.5°C and 23 days at 9°C (Mutenia 1978; McDowall 1990). Maturation may occur as early as two to three years if growth is fast, but maturity may not be reached until year five or six when growth is slow. In Finland, they reach maturity at six to seven years. Fish may live up to 15 years.

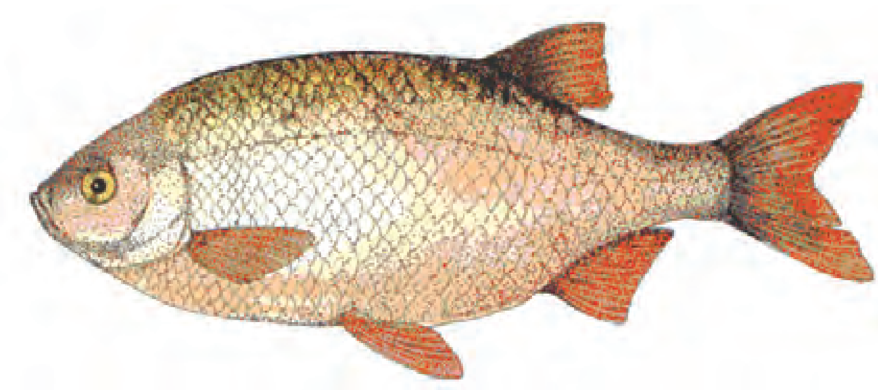
ENVIRONMENTAL TOLERANCES: Orfe have high tolerance to salinity and are able to live in both fresh and brackish water (McDowall 1990), but are less tolerant of pollution than other cyprinids (Koli 1984). Orfe can tolerate very low temperatures, and could therefore survive and breed in most New Zealand freshwaters.

IMPACTS: It is likely that orfe would share habitats with many native fish species if it were to become widespread in New Zealand. Native fish that are likely to occur in lakes and rivers with still or slow-flowing waters are smelt, īnanga, bullies and eels (McDowall 1990). All of these native fish are carnivores and, given the ability of orfe to utilise the entire water column for feeding, it is likely that orfe would compete for food with them. As orfe can tolerate brackish waters, it has the potential to colonise the lower, tidally-influenced regions of rivers where it could have an impact on īnanga.

Effects on water quality are likely to be similar to those of rudd (i.e. browsing on macrophytes), with the added possibility of stirring up bottom sediments because of their benthic feeding habits. Detrimental effects on plants may occur directly, through consumption of young shoots, and indirectly through a deterioration of water quality. As orfe can increase their intake of plant material in times of increased competition for animal food, it seems likely that they would be capable of having an effect on the nutrient levels in the water (Brabrand 1985). In addition, orfe may indirectly increase the number of phytoplankton in waterways through consumption of zooplankton. To date, there are no studies indicating that orfe has been instrumental in the transition of clear, macrophyte-dominated lakes to turbid lakes devoid of macrophytes and dominated by phytoplankton, as has been shown for other cyprinid fish species such as rudd (Ravera & Jamet 1991).

STATUS: Orfe have no legal status in New Zealand.

RUDD (*Scardinius erythrophthalmus*)

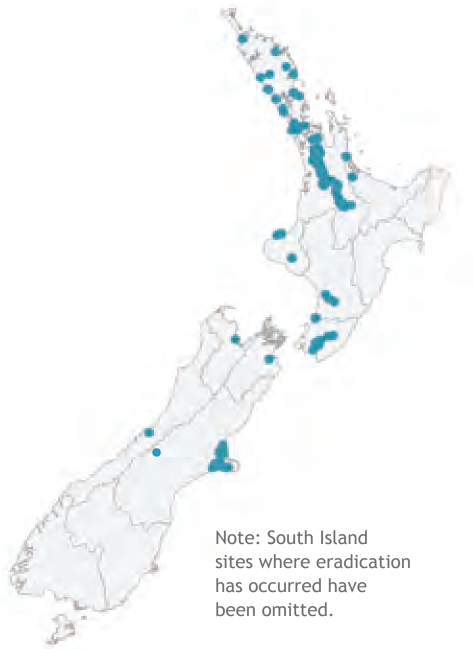


IDENTIFICATION: Red-to-orange coloured fish, silver when young, darker on the back than the belly. Bronze highlights when light catches the scales. No barbels around the mouth. Red-orange fins; single dorsal fin originates behind pelvic fin; no stout spine in dorsal fin. No teeth.

INTRODUCTION: Rudd were introduced illegally to New Zealand in 1967 and have further spread by clandestine liberations. It is thought the aim of the introduction was to establish a popular game fish in waters that were unsuitable for trout (Cadwallader 1977; Wells 1999).

DISTRIBUTION IN NEW ZEALAND: Throughout the upper half of the North Island (Northland to Waikato) and down the western side of the North Island from Taranaki to Wellington. In the South Island, populations are scattered from Nelson to South Canterbury. There has also been a recent incursion into

Lake Ianthe on the West Coast. Some of the South Island populations are the subject of eradication measures.



Note: South Island sites where eradication has occurred have been omitted.

BIOLOGY: Rudd inhabit lakes, reservoirs, ponds and wetlands, but also occur in the large, weedy pools and margins of rivers and streams, preferring still waters or very little current (Wheeler 1969; Cadwallader 1978; Koli 1984; www.fishbase.org). They prefer larger lakes with high alkalinity, and their growth is slower in rivers and small ponds (Kennedy & Fitzmaurice 1974; Lane 1983). Larvae hide in shallow fringing vegetation in the littoral zone, while juveniles and adults school in the littoral zones and larger fish occupy deeper water (Rowe & Graynoth 2000).

The diet of rudd varies with age. Juveniles (up to 75 mm in length) consume mostly zooplankton, whereas sub-adults (75–135 mm) consume mainly aquatic and terrestrial insects, and detritus. Rudd consume increasing amounts of plant material as they grow from 100 to 300 mm. Adults are mostly herbivorous, feeding on terrestrial grasses and seeds, blue-green algae and aquatic macrophytes. Large rudd may also be piscivorous at times, and have been reported to feed on common bullies (McDowall 1990; Rowe 1984). Plant preferences of adult rudd (228–245 mm) were established experimentally by Lake *et al*. (2002) as, in order of preference: *Nitella hookeri* > *Potamogeton ochreatus* > *Elodea canadensis* > *Lagarosiphon major* > *Egeria densa* > *Myriophyllum propinquum* > *Ceratophyllum demersum*. In the wild, the food selection of rudd may not be solely dictated by palatability, but also by net energy gained by foraging on plants that are easily found (Prejs 1984; Lake 1998). For instance, Kane (1995) found that, in the absence of aquatic macrophytes, rudd in Hamilton Lake consumed emergent plant species such as *Iris pseudacorus*, *Nymphaea* and *Baumea articulata*. Recent work has indicated plant preferences by rudd are related to percentage carbon and carbon:nitrogen ratios (Kapuscinski *et al*. 2014).

In New Zealand, rudd spawn in mid-September to October and in January to February at temperatures above 18°C (Lane 1979). Wise (1990) found a peak in the gonadosomatic index of rudd in Hamilton Lake in October when the surface temperature was about 17°C. Some rudd populations can spawn twice per year and a portion of female rudd spawn on both occasions (Lane 1983; Wise 1990; Lake 1998). Egg numbers in New Zealand rudd vary between 2,000 and 60,000 per fish (Lane 1983; Wise 1990). The eggs are attached to various rooted macrophytes (e.g. *Myriophyllum*, *Ceratophyllum* and *Potamogeton*) in shallow water (0.15–1.0 m) (Holcík 1967; Kennedy & Fitzmaurice 1974; Lane 1983). Depending on the incubation temperature, the eggs hatch in 5–15 days. Hatched larvae are 4.5–5.9 mm in length and have adhesive organs on their heads to help them cling to vegetation (Wheeler 1969; Kennedy & Fitzmaurice 1974).

The maturation of rudd in New Zealand has been reported to occur extremely early, at 1+ year for both sexes (Lane 1983), although McDowall (1990, 2000) suggested that most females mature at the age one to two, when they are longer than 70 mm.

ENVIRONMENTAL TOLERANCES: Rudd are fairly hardy and can tolerate poor water conditions (Kennedy & Fitzmaurice 1974). They prefer pH of 7.0–7.5 (www.fishbase.org). In Ireland, Britain and Finland, rudd have been observed in brackish water at salinities ranging from 1 to 10‰ (Wheeler 1969; Kennedy & Fitzmaurice 1974; Koli 1984).

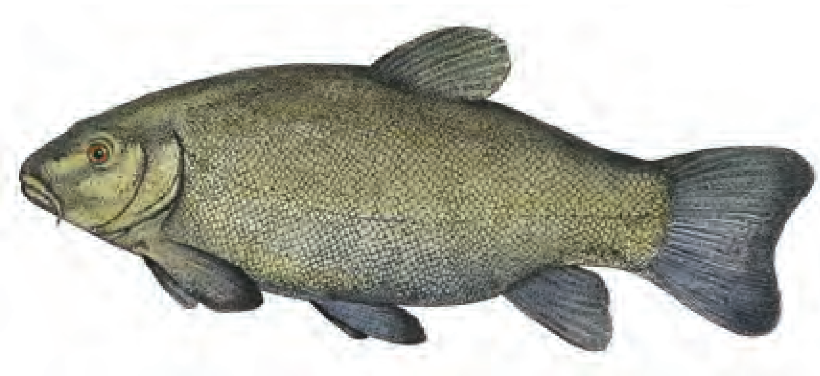
IMPACTS: Rudd consume macrophytes and preferentially eat native species over introduced species (Lake *et al*. 2002). This preference for native species would give invasive macrophytes such as *Ceratophyllum* a competitive advantage, resulting in a significant impact on macrophyte community structure (Lake 1998; Wells 1999). Their feeding may suppress the regeneration of macrophytes in turbid lakes, and may prevent re-establishment of native species such as *Nitella* and *Potamogeton ochreatus* in restoration efforts because they preferentially graze on young plants or the growing tips of plants (Lake *et al*. 2002). Their feeding has been implicated in the collapse of macrophytes in several Waikato lakes (de Winton & Champion 1993).

High densities of rudd may also indirectly contribute to reduced water clarity in shallow lakes through increased wind disturbance following macrophyte loss and a reduction in large zooplankton as a result of larval feeding, although the zooplanktivorous stage is relatively short. Because they only digest about 30% of the plant material ingested, a large proportion is returned to the environment degraded but undigested (Ravera & Jamet 1991). Consequently, phosphorus is released into the water from the breakdown of fish faeces and leakage of nutrients from macrophytes injured by grazing fish (Prejs 1984; Hansson *et al*. 1987). These nutrient releases may mean that rudd can promote succession from submerged macrophytes to algal dominance and eutrophication in lakes.

The diet of small rudd (56–65 mm fork length) overlaps significantly with common smelt and shoaling galaxiids (e.g. dwarf īnanga and kōaro (*Galaxias brevipinnis*)) which feed in mid-water and at the surface, suggesting the possibility of competition for food resources with some native fish (Cadwallader 1977; Lake *et al*. 2002). There is also potential for competition between rudd and īnanga, dwarf īnanga and kōaro, which are lake-dwelling and feed on zooplankton or macroinvertebrates for at least some stage of their lives (Lake 1998). Predation on the free-swimming larvae of landlocked galaxiids has also been suggested (Cadwallader 1977).

STATUS: Noxious fish (Freshwater Fisheries Regulations 1983). Sports fish in Auckland/Waikato Fish & Game region (Freshwater Fisheries Regulations 1983).

TENCH (*Tinca tinca*)



IDENTIFICATION: Olive-green with small bright red-orange eyes. A golden variety is thought to be present in some lakes of the Auckland region. One small barbel at each corner of mouth. Fins are thick and fleshy. No teeth.

INTRODUCTION: First introduced to New Zealand in 1867, probably in Auckland, and later (1950s) stocked in waters near Oamaru and Otaki near Wellington.

DISTRIBUTION IN NEW ZEALAND: Northland, Auckland and Wanganui in the North Island, and Nelson, Canterbury and Otago in the South Island.

BIOLOGY: Adult tench inhabit shallow lakes, reservoirs, ponds and wetlands, and the lower reaches of large rivers and associated habitats (including oxbows and deltas), characterised by low water velocity, soft substrates (e.g. mud, silt, or sand), and the presence of some aquatic vegetation. They inhabit the shallower regions of these habitats, although large (20–30 cm long) fish have been captured in nets at depths of 7–15 m in several New Zealand lakes (D Rowe, NIWA, unpubl. data). Juvenile tench inhabit shallow water with silty bottoms (Copp 1997).

Tench are a benthivorous fish that feed mainly at night, consuming benthic invertebrates and detritus, although some fish can feed solely on zooplankton (Rowe & Graynoth 2000). Fish have been observed feeding by squirting water onto the benthos in an apparent effort to suspend small animals into the water column where they are more accessible. This feeding method may account for the observation that the main prey species of large tench in a small New Zealand lake was a small cladoceran that fish may have filtered from near the sediment surface (Rowe 2004). In addition to small crustaceans, tench can feed on amphipods, decapods, leeches, molluscs, and benthic insects including chironomids, odonates, mayflies and aquatic bugs.

The seasonal timing of tench spawning appears to be controlled by both water temperature (>18°C) and photoperiod. They are batch spawners and 3–9 spawnings may occur over the spawning season (Alas & Solak 2004). Males are believed to be attracted to the females through pheromones released into the water via the gills. Eggs are broadcast over aquatic vegetation such as macrophytes and reeds, or hard substrates such as wood, in shallow (usually <1 m deep) waters. The small eggs (0.9–1.0 mm in diameter) stick to the vegetation and are green coloured (Rowe 2004). Tench require aquatic plants, wood debris or some hard substrate for successful recruitment. Eggs hatch within 2–3 days, depending on water temperature, and the larvae have an organ that allows them to latch onto the under-surfaces of plants. Exogenous feeding occurs after 11 days at a length of 5.6 mm (Peňáz *et al.* 1981), and tench larvae can be expected to be free-swimming beyond this size. Tench can mature at 2+ years old.

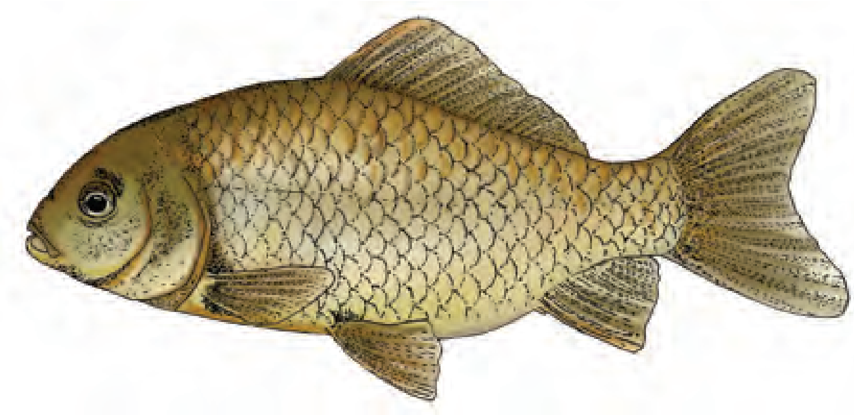
ENVIRONMENTAL TOLERANCES: Tench are rarely found in waters over 25°C (Perez Regadera *et al.* 1994). They have been reported to tolerate waters up to 37°C for brief periods, with reported lethal temperatures of 39°C (Weatherley 1959; see Table 7.2). Tench can survive oxygen levels as low as 0.7 mg/L and moderately saline water (<12‰). They prefer pH in the range 6.5–8.0 and mortality increases at pH below 5 and above 11. Tench thrive in both clear and turbid waters, so the high suspended solids levels occurring in turbid lowland New Zealand lakes are unlikely to affect them.

IMPACTS: Giles *et al.* (1990) indicated that, on the basis of their diet and food preferences, trophic overlap could occur with perch and waterfowl in shallow waters. Trophic overlap was also expected between tench and common bullies in Lake Parkinson, Auckland, because both species are benthic omnivores, but the density and size of common bullies was relatively high in that lake despite the presence of tench (Mitchell 1986; Rowe & Champion 1994). Generally, tench seem unlikely to have direct effects on other fish, but have been implicated in reduced densities of some invertebrates. They are also known to be selective planktivores and so may exert top-down effects (i.e. a reduction in zooplankton) on some lake ecosystems, thereby increasing phytoplankton and reducing water clarity. There was no direct evidence for an effect of tench on water clarity in Lake Parkinson, although water clarity did improve immediately after removal of all fish, including tench (Rowe & Champion 1994).

Tench may also change lake ecosystems through bottom-up effects on food webs, for example by stimulating greater periphyton growth on macrophyte surfaces leading to reduced macrophyte production (Bronmark 1994; Beklioglu & Moss 1998; Williams *et al.* 2002). The increase in periphyton may have been related to removal of browsing gastropods by tench, and/or to stimulation of periphyton growth through the increased cycling of inorganic nitrogen through tench excreta. Such effects have only been recorded when densities of tench were relatively high, and Williams *et al.* (2002) indicated that a tench biomass in excess of 200 kg/ha may be required for macrophyte reduction.

STATUS: Sports fish (Freshwater Fisheries Regulations 1983).

GOLDFISH (*Carassius auratus*)



IDENTIFICATION: Drab olive/bronze colour with deep body; some fish can retain ornamental colours of orange, white and black as adults. No barbels around mouth. Single dorsal fin originates directly above pelvic fin. Last spine in dorsal fin is stout and serrated. Large scales and greater than 50 gill rakers. Goldfish and koi carp may interbreed; first generation hybrids have drab coloration, one pair of barbels and 30–50 gill rakers, but subsequent generations of hybrids may be highly variable.

INTRODUCTION: Brought to New Zealand in consignments during 1864 and 1867, and subsequently released into the wild in a number of places for a variety of reasons (McDowall 1990). Commonly referred to overseas as Crucian carp.

DISTRIBUTION IN NEW ZEALAND: Throughout North and South islands but much more numerous in the North Island. Present in only a few South Island lakes, e.g. Ellesmere, Brunner (Rowe & Graynoth 2000), but distribution is likely to be more extensive than these records indicate.

BIOLOGY: Little research appears to have been done on goldfish biology in New Zealand. They are known to commonly inhabit shallow areas of ponds, lakes, reservoirs and wetlands where macrophytes occur. They also occur in the slow-moving, weedy areas of rivers and streams, and are likely to be spread among aquatic habitats during floods. Adults are omnivorous, feeding on benthic plant material, organic detritus, and small insects and crustaceans, although larvae are likely to feed on zooplankton. Gut content analysis of goldfish (28–386 mm in length) from a western Australian river revealed a wide range of food items, including larvae of damselflies, other flies and beetles, nematodes, gambusia, green algae, diatoms and terrestrial insects (Morgan & Beatty 2007).

Sex ratios can be extremely unbalanced, with some populations overseas having a strong dominance of females, reflecting an ability to reproduce by means of gynogenesis, a form of parthenogenesis (Lorenzoni *et al*. 2010a). Spawning occurs in spring and summer among macrophytes in river backwaters and shallow margins of lakes (Hicks *et al*. 2010), and is apparently initiated by pheromonal cues. Large females can produce 300,000 eggs that hatch within about one week. Reproduction occurs at temperatures above 15ºC and optimal spawning occurs at 21ºC (see Table 7.2). Most females become sexually mature at two years, while males can mature earlier (Lorenzoni *et al*. 2010a), and some can spawn at the end of their first year of life (Morgan & Beatty 2007). Overseas studies suggest lifespan is typically 6–7 years, with an eight year old individual caught in a western Australian river (Morgan & Beatty 2007), although they can live much longer in captivity.

ENVIRONMENTAL TOLERANCES: Goldfish can withstand very low oxygen levels and temperatures from freezing to 44ºC. At low temperatures, they can survive months of complete anoxia using unique metabolic pathways that convert metabolic wastes into alcohol. Laboratory results indicate tolerance of pH in the range 4.5–10.5, and a preference for pH 5.5–7.0 (Szczerbowski 2001). Adults thrive well in salinities up to 6‰ (Canagaratnam 1959), and larger goldfish have been captured in waters with salinities as high as 17‰ (Schwartz 1964), although long exposures above 15‰ can be fatal (Lockley 1957). Eggs and fry are not particularly tolerant of saline water.

IMPACTS: Goldfish have been associated with adverse impacts on water quality through resuspension of sediment and nutrients during feeding, in a similar way to koi carp. Although adult goldfish are smaller than koi carp, their effects nationally could be significant because of their widespread distribution and higher numbers in some freshwater systems. Notwithstanding this, goldfish have been present in many lakes for many years without apparent declines in water quality (McDowall 1990). It has been shown that growth of cyanobacteria is stimulated by passage through goldfish intestines (Kolmakov & Gladyshev 2003), suggesting that goldfish may contribute to the development of algal blooms in enriched waterbodies (Morgan & Beatty 2007). The main impact on native fish in New Zealand is likely to be through competition for food and other resources and, in fact, they have been reported to compete with koi carp in their home range (Lorenzoni *et al*. 2010b). It has also been suggested that goldfish could act as vectors for non-native parasites that may infect native fish (Morgan & Beatty 2007).

STATUS: No legal status in New Zealand but listed in Waikato and Greater Wellington regional pest management plans.

2.2 Invasive Fish Community Impacts

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Community Composition

Invasive fish species seldom occur in isolation, especially in lowland waterbodies of northern New Zealand where a suite of non-indigenous species is typically present along with native species. Illegal fish introductions have been less extensive in the South Island, meaning that invasive fish communities are much simpler and may comprise just 1-2 species. Rowe (2007) reported that around half of the small lakes investigated in northern New Zealand contained two or more introduced fish species, with rudd and goldfish the most prevalent, and up to six introduced fish species found in some lakes. Drake *et al*. (2010) caught up to five introduced fish species in any lake during a survey of New Zealand shallow coastal lakes, and concluded that a larger proportion of introduced fish species relative to native species occurred in more disturbed catchments. Generally, catfish tend to occur more frequently with goldfish than any other species, whereas tench only occurred with rudd, which was also often associated with perch. Where koi carp were present, there was an 86% chance that goldfish were also present; a similar relationship was reported for gambusia and tench near Nelson (Dean 2003).

The varying combinations of introduced fish species present in particular waterbodies reflects the history of illegal releases and connections among infested waterbodies. For example, Garrett-Walker (2014) found that constructed floodplain ponds had significantly higher biomass of catfish, goldfish and koi carp if they flooded annually (i.e. became connected to waterways each year) compared to ponds that never or only occasionally flooded (Figure 2.8). High connectivity

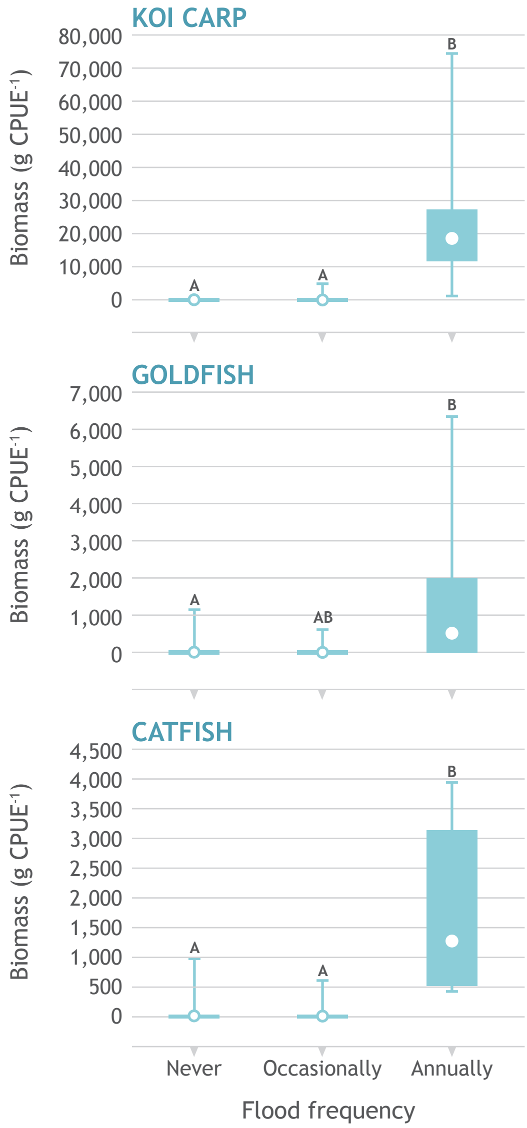

FIGURE 2.8 Box plots of koi carp, catfish and goldfish biomass between flood frequency classes in 34 constructed ponds on the lower Waikato River floodplain. Classes with the same letter above box plots are not significantly different (from Garrett-Walker 2014).

SUGGESTED CITATION FOR SECTION 2.2: Collier KJ, Allan M, Rowe D 2015. Invasive Fish Community Impacts. Section 2.2 in Collier KJ & Grainger NPJ eds. New Zealand Invasive Fish Management Handbook. Lake Ecosystem Restoration New Zealand (LERNZ; The University of Waikato) and Department of Conservation, Hamilton, New Zealand. Pp 23-28.

can enable mass summer spawning of multiple invasive species in suitable waterbodies, leading to extremely high densities of zooplanktivorous fish larvae. There are few natural controls on populations of non-indigenous lacustrine fish in New Zealand, as occurs in many northern hemisphere lakes, and the extended and sometimes synchronous spawning of multiple invasive species has the potential to significantly impact lake ecosystem processes.

Tables 2.1 and 2.2 summarise spawning preferences of individual species and their environmental impacts. These tables highlight closely-linked reproduction and cumulative impact pathways that can occur in multi-species assemblages, making single species impacts difficult to disentangle (Rowe 2007). It is not known whether interactions among these species lead to additive, synergistic, or even antagonistic effects on native species and ecosystem health. However, it is clear that impact pathways can be complex when several species from different feeding guilds or occupying different niches occur together, potentially affecting various levels of biological organisation and habitat complexity.

TABLE 2.1 Summary of spawning characteristics of the invasive fish covered in this handbook. N/A = not applicable. See Table 7.2 for summary of spawning temperature preferences.

COMMON NAME	TIMING	PREFERRED HABITAT	PREFERRED SUBSTRATE	INCUBATION TIME
Koi carp	Spring-summer	Shallow, sheltered margins & floodplains	Plants	c.1 week
Perch	Late winter-early spring	Sheltered basins & bays	Plants, sticks, logs	1-3 weeks
Catfish	Summer	Shallow water	Benthic depressions	c.1 week
Gambusia	Spring-autumn	Littoral margins	N/A	>2 weeks
Orfe	Spring	Water <1 m deep	Plants, logs, stones	5-10 days
Rudd	Spring	Littoral margins	Plants	5-15 days
Tench	Spring-summer	Littoral margins	Plants, organic debris	2-3 days
Goldfish	Spring-summer	Littoral margins	Plants	c.1 week

TABLE 2.2 Summary of potential impacts of introduced fish when present in freshwater habitats at high densities. Relative degree of severity: +++ = high; ++= moderate; + = low; L = as larvae and juveniles (otherwise as all life stages).

COMMON NAME	NUTRIENT EXCRETION[1]	BIOTURBATION[2]	LOSS OF MACROPHYTES[3]	PREDATION[4]	FOOD-WEB MODIFICATION[5]	INTERSPECIFIC AGGRESSION
Koi carp	+++	+++	+++	+	+++(L)	+
Perch	++	+	+	+++	+++	++
Catfish	++	++	+	+	+++	+
Gambusia	+	+	+	+	+++	+++
Orfe	++	++	++	+	++(L)	+
Rudd	++	+	+++	++	+	+
Tench	++	++	+	+	++	+
Goldfish	++	++	++	+	+++(L)	+

[1] on an individual basis; assumed to be related to size; [2] stirring up of sediment releasing nutrients and increasing turbidity; [3] herbivory or uprooting; [4] on other fish; [5] feeding on benthic invertebrates or zooplankton, competing with native fish

The main impacts of multiple species assemblages (Figure 2.9) relate to (i) bioturbation through feeding which can affect water clarity; (ii) excretion which can influence nutrient levels; (iii) food-web impacts through predation and grazing, which can modify biotic assemblages, as well as water clarity and habitat; and (iv) direct effects on indigenous biodiversity through competition and habitat modification (see Section 2.1 for individual invasive species impacts).

Bioturbation and Food-webs

Invasive fish can decrease water clarity through bioturbation of bottom sediments during benthic feeding (bottom-up effects) or selective consumption of large zooplankton, which releases phytoplankton from grazer control (top-down effects). Predation on plankton-feeding fish can also have cascading effects on water clarity by releasing zooplankton from planktivore control, although the only non-indigenous fish species in New Zealand to fill this predation role is perch (Figure 2.9). In addition, herbivorous fish can reduce macrophyte cover, making bed sediments more readily mobilised in shallow lakes through wind disturbance. Consequently, water column shading from macrophytes is reduced, potentially leading to increased phytoplankton growth. Loss of macrophyte beds can also affect habitat for indigenous fish and invertebrate species. Invasive fish communities dominated by benthic-feeding koi carp, goldfish, and catfish are likely to be those most likely to reduce water clarity through bioturbation, whereas waterbodies dominated by herbivorous rudd and benthivorous koi carp are most likely to experience reductions in water clarity through loss of macrophytes. Tench, perch and rudd are also known to disturb sediments when feeding, and may contribute to elevated suspended sediment levels through bioturbation when present in high numbers in shallow lakes. As well as affecting turbidity through sediment resuspension, bioturbation can disturb benthic habitats for native biota (e.g. freshwater mussels), mobilise nutrients and recruit resting cyanobacterial colonies into the water column (Adámek & Maršálek 2013).

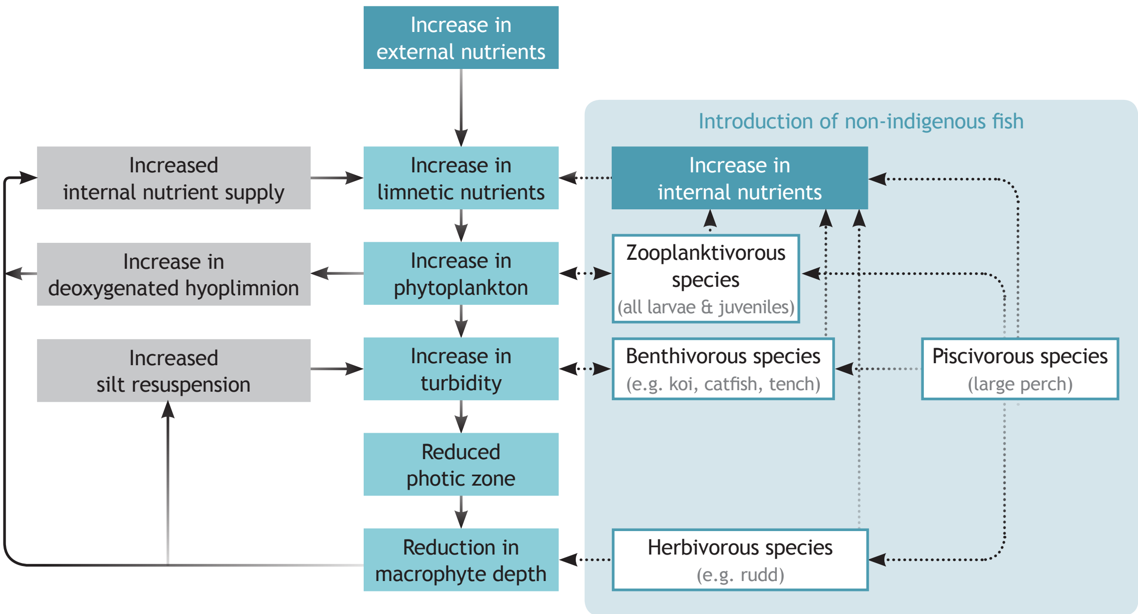

FIGURE 2.9 Representation of main mechanisms by which non-indigenous fish affect processes in small (by volume) New Zealand lakes. Dotted lines represent effects of different feeding guilds (double arrow heads indicate potential effects of predation on population numbers). Solid lines represent feedback cycles through which increases in nutrients affect lake trophic processes; external nutrients are derived from the catchment and internal nutrients from excretion and bioturbation (adapted from Rowe 2007).

All invasive fish have zooplantivorous larval and juvenile stages, and mass hatchings of fish ova during spring and early summer can be expected to have marked impacts on zooplankton grazer populations. Habitats that provide ideal conditions for large-bodied zooplankton, such as pelagic zones, lake margins, river backwaters and wetlands, also provide larval rearing habitat at times of year when secondary production is accelerating. Jeppesen *et al.* (2000) reported a negative relationship between fish abundance and zooplankton in 25 shallow South Island lakes, including for *Daphnia* biomass and average cladoceran weight. However, chlorophyll *a* concentration was only weakly related to zooplankton biomass leading them to conclude that cascading effects on phytoplankton were relatively modest in shallow, oligotrophic/slightly eutrophic lakes, even though fish have a major influence on zooplankton biomass and community structure in the pelagic zone. However, it is unclear how these findings relate to highly eutrophic, shallow North Island lakes where pest fish communities are more diverse and attain much higher biomass. Nevertheless, following an analysis of northern North Island lakes, Rowe (2007) concluded that the effects of top-down control may not be as significant as observed in the northern hemisphere.

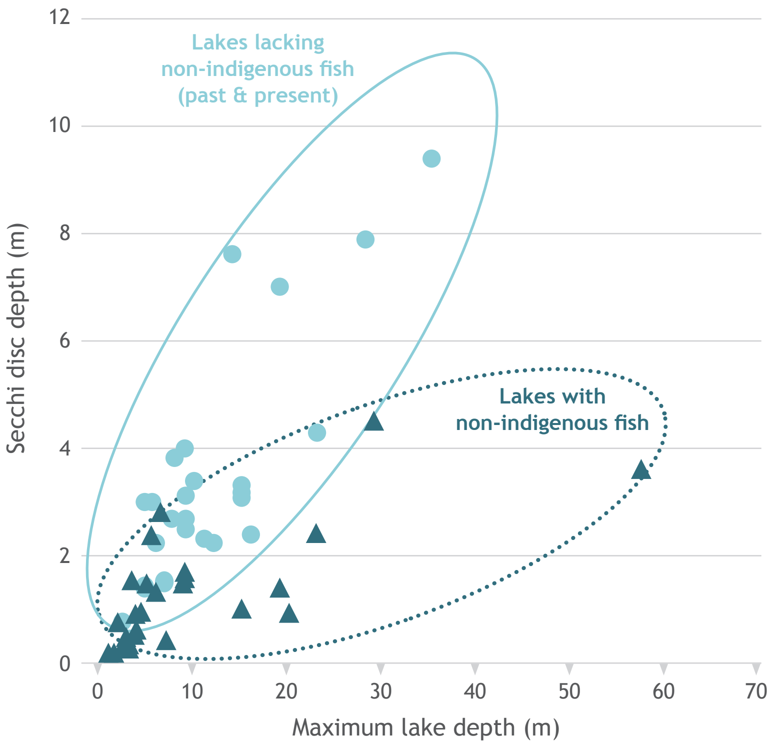

FIGURE 2.10 Relationships between water clarity and maximum depth of lakes with or without introduced fish (from Rowe 2007).

Rowe (2007) reported that not only did the presence of invasive fish in small North Island lakes affect the relationship between water clarity and lake depth (Figure 2.10), but that the relationship was dependent on the number of fish species introduced. Furthermore, the addition of invasive fish species into some lakes where only one species was previously reported was associated with a decline in water clarity, providing qualitative evidence for synergistic impacts. Rowe (2007) concluded that control of just one species may not result in an improvement in water clarity because of the interacting effects of multi-species assemblages on lake trophic processes, highlighting the need to understand community-level interactions and trophic linkages to predict ecological and water quality outcomes of invasive fish control. Accordingly, a range of manipulations involving selected introduced fish may be required to accompany nutrient controls and macrophyte restoration in order to restore water clarity (Rowe 2007; but see following section).

Nutrient Contributions

Fish can contribute to internal nutrient loads directly through excretion and indirectly through feeding activities, thereby having a direct influence on primary productivity via nutrient recycling (Villéger *et al.* 2012). Benthic foraging activity translocates nutrients from the sediments to the water column, while fish metabolism produces waste which is excreted in the forms of ammonia and phosphate, both of which are directly available to microbes and primary producers (Vanni 2002; Schaus *et al.* 1997). Koi carp dominate fish community biomass in many lowland lake systems in northern New Zealand, and manipulation experiments have shown that carp nutrient excretion can be a primary mechanism of water quality deterioration (Matsuzaki *et al*. 2007). The combined effects of entire non-indigenous fish communities, coupled with native biota, on nutrient contributions to lake and wetland ecosystems is not known.

Morgan & Hicks (2013) demonstrated that mass-specific excretion rates of nutrients decreased with size of koi carp and were higher in summer, but that the proportion of dissolved nutrients increased with fish size. Low N:P ratio of carp excretion may favour the growth of cyanobacteria (Havens *et al*. 2003) and thereby modify population structure of phytoplankton. However, cyanobacterial dominance associated with low N:P ratios is a controversial topic, and other authors have suggested that cyanobacterial blooms are more strongly correlated with total phosphorus (TP), total nitrogen (TN) and standing algal biomass (Downing *et al*. 2001). Little information is available on excretion of other invasive fish species in New Zealand, however, overseas studies have demonstrated that large bream are capable of translocating around one-quarter (27%) of the external load from the benthos to the water column via benthic feeding (Persson 1997). Nutrient excretion rates of other invasive fish species in New Zealand (catfish, goldfish, rudd) are currently being calculated (B Hicks, The University of Waikato, unpubl. data).

Application of a processed-based, one-dimensional, ecologically-coupled, hydrodynamic model (DYRESM-CAEDYM-DYCD) was used to quantify the relative effects of external and internal (excretion) nutrient loads on a eutrophic Waikato lake (Lake Ohinewai) that has undergone a programme of pest fish removal (see Section 5.2 for further details). The model was used to test lake management scenarios in order to compare the effect of simulated carp removal versus the effect of reducing external nutrient loads (Table 2.3). Accordingly, simulations run were the effects of: (i) no fish; (ii) no fish and a native forested catchment; (iii) 50% reduction in internal and external nutrient loading (with current koi carp population); (iv) a post-invasive fish removal scenario producing carp biomass of 21 kg/ha; and (v) a pre-invasive fish removal scenario with carp biomass of 242 kg/ha.

The simulations indicate that, for the high carp biomass scenario, there was an increase in TN and TP concentrations, and an increase in the magnitude of cyanobacterial blooms. In that scenario, carp contributed 32% of TP load and 12% of TN load via nutrient translocation (Table 2.3). The major proportion of this load was due to carp excretion and equates to about half the external loading. The application of empirical resuspension rates (Breukelaar *et al*. 1994) indicated that carp resuspended significant amounts of suspended sediment (101 g m^2/day) in the high density scenario, which increased light attenuation and decreased water clarity. Decreased water clarity in itself is a major negative impact but, in addition it negatively affects macrophyte survival, growth or potential for re-establishment (Canfield *et al*. 1985; Gallegos 2001). Submerged macrophytes have the potential to

TABLE 2.3 Lake Ohinewai nutrient budget (as a percent of total tonnes per year) and change in Trophic Level Index (TLI version 4) under different koi carp control and catchment management scenarios. External sources of nutrients are from lake catchment runoff, and internal nutrient sources are from sediment release. TP = total phosphorus, TN = total nitrogen.

SCENARIO	CURRENT LANDUSE/ NO FISH	NATIVE VEGETATION/ NO FISH	50% REDUCTION IN TN & TP	KOI CARP BIOMASS 21 kg/ha	KOI CARP BIOMASS 242 kg/ha
External TN	27.48	27.32	33.10	27.80	25.34
External TP	87.26	86.03	82.31	84.08	58.92
Internal TN	72.52	72.68	64.98	71.14	63.05
Internal TP	12.74	13.97	11.14	12.04	8.60
Koi carp TN	0.00	0.00	1.91	1.06	11.60
Koi carp TP	0.00	0.00	6.56	3.88	32.47
TLI change from current	-0.07	-1.31	-0.56	0.00	0.14

modulate lake ecosystem structure, in particular their ability to stabilise a clear-water, alternate-stable state, to influence nutrient dynamics and to increase habitat diversity (Scheffer 1998; Dokulil & Teubner 2003). Resuspension explained a projected decrease in concentrations of total suspended solids post-fish removal in Lake Ohinewai.

The simulations presented here show that, while carp were predicted to have a significant negative effect on water quality in Lake Ohinewai, carp removal alone would not be sufficient for any significant restoration of lake water quality, as the simulated Trophic Level Index (TLI) under the no fish scenario was only 0.07 less than under current conditions (Table 2.3). In order for lake water quality to be significantly restored, integrated catchment management would be required to decrease the external load (e.g. a simulated 50% reduction in external nutrient load would decrease the TLI by 0.56). The cumulative excretion and resuspension rates of multiple invasive species cannot currently be factored in these models, but this will be possible in the near future and provide an improved basis for incorporating the cumulative effects of invasive fish communities into model predictions.

3

Statutory Responsibilities for Invasive Fish Management

A range of agencies exercises responsibilities for invasive fish management under various statutes. These responsibilities apply at the national level for some government departments such as the Department of Conservation and Ministry for Primary Industries, and at the regional/rohe level for other agencies, including Fish & Game New Zealand, regional councils and iwi authorities. This section outlines the responsibilities and approaches of these various groups to invasive fish management, using examples from the Waikato area to highlight approaches where invasive fish are a major problem and several species co-exist. The perspectives presented are ordered according to spatial extent, starting with the border, followed by national level and then regional council and iwi boundaries.

3.1 Statutory Responsibilities: Ministry for Primary Industries Perspective

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Legislative Requirements

In New Zealand, the Ministry for Primary Industries (MPI) is the lead agency charged with managing biosecurity risk. As such, it administers the Biosecurity Act 1993, which is the primary legislation providing a range of powers, duties and obligations for biosecurity. Other legislation, however, may take precedence or may need to be applied in conjunction with the Biosecurity Act. For example, MPI also enforces the Hazardous Substances and New Organisms Act 1996 in respect of new organisms not yet present in New Zealand, and the Fisheries Act 1996 to manage New Zealand's fisheries resources. The Conservation Act 1987 is also applied in some instances (see also Section 3.2). These acts enable MPI, in conjunction with other government departments and regional councils, to manage the introduction and spread of harmful organisms (such as unwanted organisms and pests) into and within New Zealand.

As part of this mandate, MPI:

- oversees the implementation of the legislation;
- undertakes border control;
- manages national surveillance programmes;
- carries out responses to incursions;
- manages several national control programmes;
- manages New Zealand marine and some freshwater fisheries and land-based aquaculture;
- controls the movements of live aquatic life where the species already exists; and
- issues special permits for the management or eradication of unwanted aquatic life ('unwanted aquatic life' includes any species determined by a Chief Technical Officer).

A 'pest' is defined in the Biosecurity Act as any organism specified as a pest in either regional or national pest management plans. An unwanted organism is defined under the Biosecurity Act if a Chief Technical Officer believes it is capable or potentially capable of causing harm to any natural and physical resources or human health. Declaring species as pests or unwanted organisms authorises MPI and/or other agencies with legislative powers to manage them.

PRE-BORDER: Import Health Standards are documents created by MPI under s22 of the Biosecurity Act to ensure that the risk of importing goods into New Zealand is minimised and managed effectively. An Import Health Standard exists for the importation of ornamental fish and marine invertebrates.

SUGGESTED CITATION FOR SECTION 3.1: Pande A , Pullan S, Milne J 2015. Statutory Responsibilities: Ministry for Primary Industries Perspective. Section 3.1 in Collier KJ & Grainger NPJ eds. New Zealand Invasive Fish Management Handbook. Lake Ecosystem Restoration New Zealand (LERNZ; The University of Waikato) and Department of Conservation, Hamilton, New Zealand. Pp 30-35.

This standard specifies the legal requirements, and also includes guidance for importation (including permits, transport, biosecurity authorisations and quarantine requirements), and the process for subsequent biosecurity clearance. Lists of approved species are provided in the Import Health Standard for ornamental fish (see Ministry of Agriculture and Forestry 2011).

BORDER AND POST-BORDER: The Biosecurity Act also provides the framework under which MPI operates for control at the border, aimed at preventing first incursions of unwanted organisms into the country, surveillance to detect organisms once they have arrived, and control and eradication of these organisms if they become established. Inspectors or authorised persons can enact powers under the Biosecurity Act to investigate or contain the risk of spreading an invasive organism. This is explained in more detail in the following section.

Movement of freshwater aquatic life around New Zealand is governed by different legislation, depending on the category under which it falls. For example, while the legitimate transfer of invasive fish species is rare, people wishing to do so will need to request approval under the appropriate legislation, particularly if the species is listed as a pest or an unwanted organism. Under s52 and s53 of the Biosecurity Act, unwanted organisms cannot be transported, bred, displayed or sold without prior approval from a Chief Technical Officer. This approval is usually only requested for the movement of aquatic life where unwanted organisms may incidentally be moved as well, such as the movement of salmon from a fish farm where didymo (*Didymosphenia geminata*, an aquatic algal species that is an unwanted organism) is present to a marine fish farm or release site where didymo is also present. Approval is required in case of incidental spillage in didymo-free areas whilst en route. Requests for approval to transfer unwanted aquatic life (i.e. pests or unwanted organisms) are rare, but would be subject to the same sections of the Biosecurity Act (see Figure 3.1). These sections are also invoked for transfer of unwanted aquatic life between islands, most often required when transferring specimens to a research facility for scientific purposes.

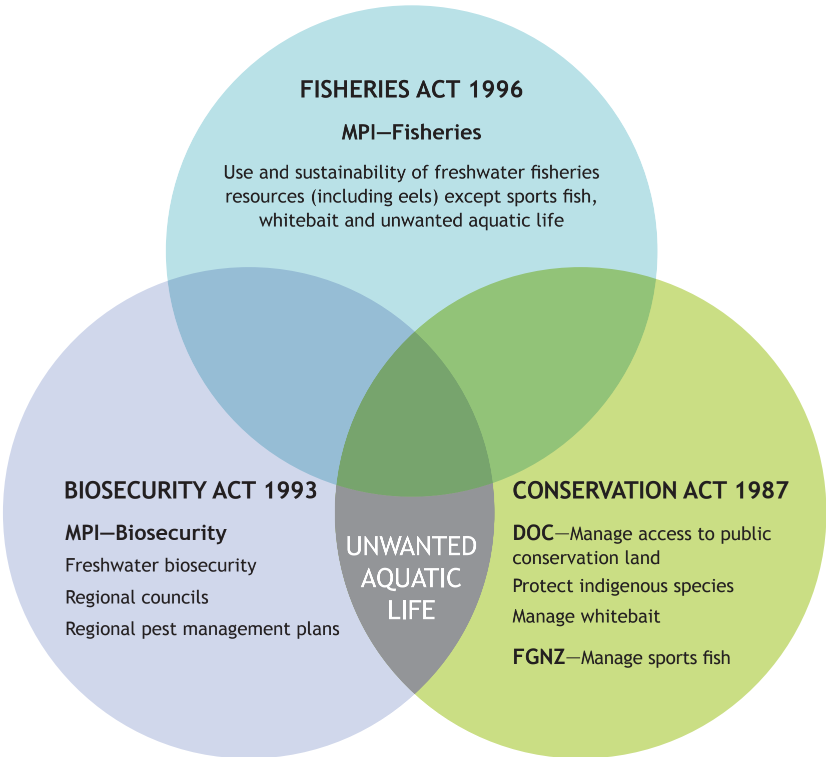

FIGURE 3.1 The intersection of the legislation used to protect indigenous freshwater species, recreational and commercial fisheries and their habitats, and where 'unwanted aquatic life' fits within this. MPI = Ministry for Primary Industries; DOC = Department of Conservation; FGNZ = Fish & Game New Zealand.

Persons wishing to transfer and release live (freshwater) aquatic life to freshwater environments must also apply for approval under s26ZM of the Conservation Act 1987. DOC processes these applications if the organism does not exist in the release location (s26ZM(3)), and MPI will process the application if the organism does exist in the release site or if the release is between the islands of New Zealand. DOC and MPI work together closely where applications under s26ZM of the Conservation Act are concerned. MPI's role is specifically s26ZM(2). There are two parts to that subsection:

- s26ZM(2)(a): Approval is required to transfer and release aquatic life to a site where it already exists. Most applications are to transfer and release native fish and grass carp, and are only very rarely used for invasive fish.
- s26ZM(2)(b): Approval is required to transfer and release aquatic life between the islands of New Zealand.

Additionally, DOC needs to provide approval for the transfer under regulation 63(1) of the Freshwater Fisheries Regulations 1983. In some situations Fish & Game New Zealand need to give approval under regulation 59. Note that, generally, Fish & Game councils are not required to obtain approval when releasing sport fish, as they hold authority under the Freshwater Fisheries Regulations to manage sports fish. However, s26ZM(6) does provide that DOC/MPI can require Fish & Game councils to comply with s26ZM of the Conservation Act. Under current policy, Fish & Game councils are encouraged to advise MPI of any upcoming transfers in case a biosecurity risk could be identified by MPI. As a consequence, many Fish & Game councils, especially in the South Island, regularly contact MPI notifying the intent to transfer/release fish.

MPI also operates under the Fisheries Act 1996. Under s89 of the Act, an authority is required to 'take' aquatic life unless exempted in this section of the Act. 'Taking' in this case is defined as fishing, and 'take' and 'taken' have corresponding meanings. A special permit (under s97 of the Fisheries Act 1996) is required to take aquatic life for purposes outside the provisions of s89, such as using prohibited harvesting methods or taking undersized fish (for instance for the purpose of research). Unwanted aquatic life is exempt from the Fisheries Act, meaning one can harvest it. However, under the Biosecurity Act, an unwanted organism cannot be transferred around the country. For example, to take koi carp (an unwanted organism), a special permit is required under the Fisheries Act if the method of capture is prohibited and/or large amounts of by-catch are likely. Disposal provisions are specified in the special permit, such as sale of the dead fish. For koi carp specifically, a DOC licence is required under the Freshwater Fisheries Regulations for harvesting within the containment area, in addition to a special permit (if required), whereas to harvest other pest fish only a fishing permit under the Fisheries Act may be required.

Fish farming and associated fish movements on land falls under the Freshwater Fish Farming Regulations 1983. Under these regulations MPI can control and mitigate illegal and accidental releases of pest fish from general (non-pest fish farm species) fish farm movements by placing conditions on fish transfer authorisations for the movement of farm stock. These conditions would usually take the form of visually inspecting fish for signs of pests and diseases, and not moving any pests and fish that appear to be ill. The regulations apply to all fish farming above the mean-high-water mark, and include cage farming in freshwater canals and farming inside buildings. Farming on land using seawater or brackish water (either pumped in from the sea or circulated around the farm) is also subject to the regulations. The regulations do not cover marine farms such as mussel and oyster farms, or finfish sea cages below mean-high-spring water (primarily managed under the Resource Management Act 1991). Additionally, consents and approvals for a land-based aquaculture farm may be required under the Resource Management Act, the Biosecurity Act and the Conservation Act. The pest species koi carp, gambusia, rudd and catfish are not able to be farmed in New Zealand. Permission is required under the Freshwater Fisheries Regulations 1983 and s52 of the Biosecurity Act 1993 to have koi carp in one's possession.

The HSNO Act 1996 may also be relevant where unauthorised release or trade of genetically modified (GM) organisms is suspected. An example of this has been several instances of trade in genetically-modified *Danio rerio*. Researchers developed the fluorescent zebra danios as pollution indicators in biomonitoring programmes. The fish were engineered to fluoresce in response to pollutants such as oestrogen, heavy metals and toxins (Loughnan *et al*. 2007). These fish are very brightly coloured compared to the non-GM danio and have found their way into the aquarium trade. MPI has been trying to eradicate all genetically-modified danios that may still be in New Zealand. Unlike the Biosecurity Act, the purpose of the HSNO Act (with respect to new organisms) is to protect the environment, and the health and safety of people and communities, by preventing or managing the adverse effects of new organisms. This is primarily done through assessment of the potential effects of those organisms prior to their intentional importation, development or release.

The Biosecurity Act is the preferred legislation for the management of existing, recently-arrived and established unwanted organisms, and those new organisms that have arrived in New Zealand unintentionally or illegally. For example, if someone wanted to import a new species of fish, they would first need to apply to the Environmental Protection Authority (EPA) for a HSNO Act approval. The EPA would assess the risks of the new fish species and impose appropriate controls (if required) to manage any adverse effects prior to approval to import. The applicant would then need to apply to MPI for a permit to import. MPI would not only assess the risks of the new fish species itself but also what other risks (organisms) may be associated with the fish, as per the appropriate Import Health Standard. The permit will then impose conditions to manage those risks. Transfer and release provisions under the Conservation Act would then apply.

Operational Activities

BORDER: Verification services staff at the border check that all consignments of imported fish are accompanied by the correct documentation and certifications. Physical checks are performed on arrival to verify species identity, and are also carried out during quarantine at transitional facilities to check for any signs of potential exotic diseases that ornamental fish might be carrying. Verification staff are finally responsible for clearance of the consignment of fish after the requisite quarantine period has been completed.

POST-BORDER: Post-border operational activities by MPI include several surveillance programmes, mostly targeted at early detection of specific pests or diseases. Currently, the primary targeted aquatic surveillance programme in New Zealand is the national marine high risk site surveillance programme. The programme examines 11 ports biannually and monitors these for the presence of target marine pests, or the occurrence of new organisms in these locations. Regular monitoring for food safety purposes occurs in some waterways and at a number of aquaculture facilities around the country, primarily to provide assurance to our trading partners that our aquatic animal products are pest- and disease-free. However, this surveillance also contributes significantly to the passive surveillance system that provides a catch-all method by which all non-indigenous pests, diseases and suspected new organisms can be reported to MPI and investigated (Figure 3.2).

The principal mechanism of the passive surveillance system is the MPI Exotic Pest and Disease Hotline (0800 80 99 66). This hotline is active 24 hours a day, 365 days a year, so that anyone can report a sighting of a suspect introduced pest or disease. Notifications are assessed to ascertain the level of risk associated with the report. Based on the initial risk assessment, notifications are either stood down (if no risk is determined), passed on to another relevant agency (if it is not a biosecurity issue being reported), or investigated (if a biosecurity risk remains). An investigation might involve a field visit and/or the collection of samples for identification. This may involve pathway analysis to see how the organism have entered or could have been spread around New Zealand. If an organism is identified that may pose a significant risk to New Zealand, a formal response may be launched by MPI. Response options such as eradication, controlling spread (movement control), or suppression of the population may be considered to mitigate the risk the organism poses. Further information, such as an in-depth risk analysis, and/or surveillance to delimit the population, may be required to inform these decisions and provide direction to the response.

Long-term incursion management comes into play if it is not possible to eliminate the organism but long-term control practices could minimise the impact over time. Long-term incursion management and response programmes are sometimes developed to manage a species when the initial response has not been successful at eradication or elimination. Examples are the National Interest Pest Response to the aquatic pests *Hydrilla verticillata* and *Salvinia molesta*, and the didymo long-term management programme. Additionally, the proposed Pet Trade Accord, which is being developed, will provide a mechanism to control the breeding, distribution and sale of some pet species within New Zealand.

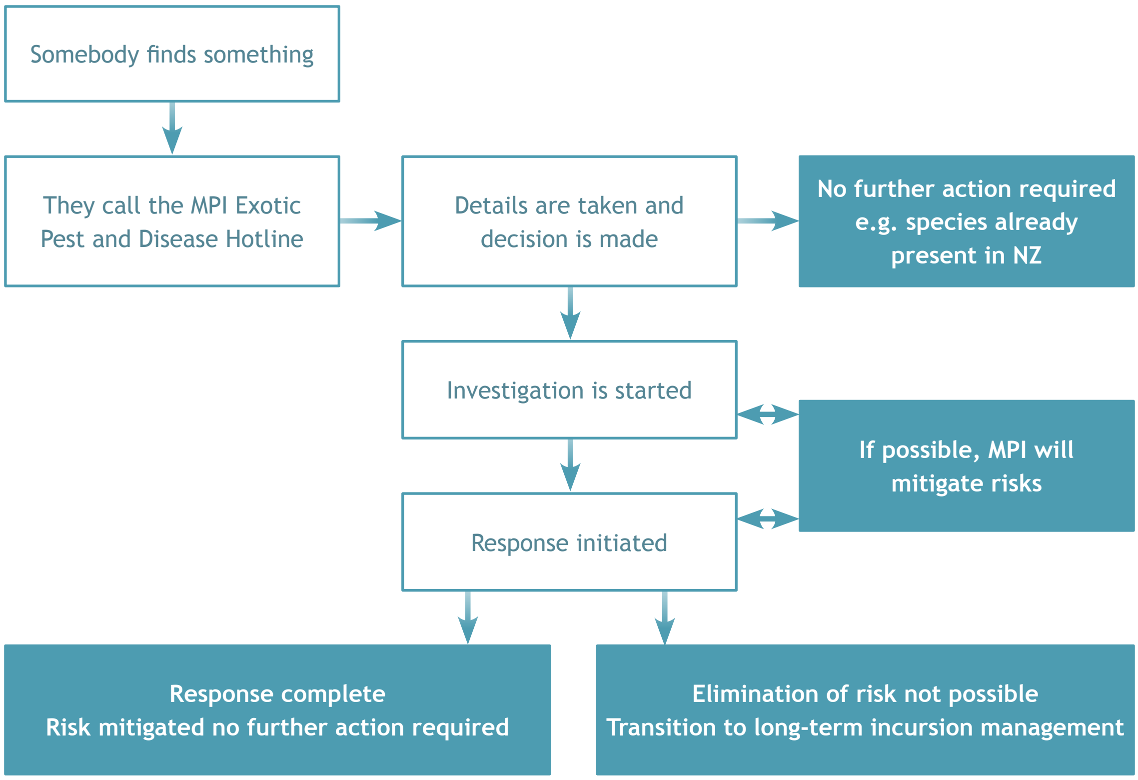

FIGURE 3.2 The Ministry for Primary Industries investigation and response process.

Issues, Challenges and Gaps

PRE-BORDER AND BORDER ISSUES: Despite the existence of Import Health Standards for the importation of fish, non-compliance with the Import Health Standard and illegal smuggling of fish into the country does occur, thus creating a larger biosecurity risk. Issues with bringing fish in legally include the limited number of approved transitional/quarantine facilities, and inspectors not always having the expertise to recognise fish species or signs of disease in fish. In the case of signs of disease being evident, destructive sampling of a certain number of fish may be required to ascertain freedom of disease, which is an issue and an expense both for the importer and MPI.

POST-BORDER MANAGEMENT ISSUES: Non-compliance of fish movement reporting carries a level of risk. While non-compliance is low, better reporting and compliance would be useful to help track fish movements in the event of a biosecurity response. Addressing this issue is a consideration of the Land-based Fish Farming Review, currently underway. Fishing practices are also an issue. Poor fishing/husbandry practices increase the risk of incidental movement of unwanted species with permitted farm species or the collection of wild species (e.g. gambusia can easily be transferred with grass carp, and didymo or fish pathogens with salmon or eels).

An issue often faced, before an investigation can even occur, is the reluctance, or the lack of awareness, to notify authorities of the suspected presence of a new pest. Delays in notification may mean that options to respond are limited, for example if an organism is left to spread unchecked. This issue is being addressed by building awareness and relationships with stakeholders, so they can have confidence in the incursion investigation and response process.

Incursions by new pest species are often new situations for all agencies and stakeholders involved, and there can be considerable challenges associated with these novel scenarios, often requiring lateral thinking, on-the-job learning, and the need for some trial and error. It can be difficult to find the right tools to manage the risk, and when it comes to invasive fish, this can be compounded by the fluid, three-dimensional and challenging nature of the aquatic environment. The impact of the pest species must also be weighed against the impact of the response; for example, there may be limited value in trying to eradicate a pest species if the method used consequently wipes out native species as well. The desired response outcomes also must be very clearly stated; if different stakeholders have different priorities then these can be difficult to align.

Other challenges lie around deciding when transition from the immediate incursion response to long-term incursion management should occur and how it should be implemented. One of the challenges for long-term management of an organism is building relationships and agreement to work together from all the stakeholders to enable a nationwide management plan. Confirming the points at which a decision needs to be made on whether to continue the programme or not can also be a challenge.

3.2 Statutory Responsibilities: Department of Conservation Perspective

Natasha Grainger

Department of Conservation, Hamilton, New Zealand

Legislative Requirements

The Department of Conservation (DOC) was established in 1987 and received most of its freshwater responsibilities in the Conservation Law Reform Act 1990. DOC is responsible for the management of established invasive freshwater fish species under the Conservation Act 1987 and the Freshwater Fisheries Regulations 1983. The Conservation Act (s6(ab)) mandates DOC to (i) preserve indigenous freshwater fisheries (as far as practicable); (ii) protect recreational freshwater fisheries; and (iii) protect freshwater fish habitats. It should be noted that the preservation of indigenous freshwater fisheries and the protection of recreational freshwater fisheries are not necessarily complementary.

Section 53 of the Act enables DOC to advocate for the conservation of aquatic life and freshwater fisheries generally, and provides general powers to control any introduced species causing damage to any indigenous species or habitat, subject to landowner consent. The Conservation Act also has provisions to prevent fishing by closing the season for fishing, and by controlling the use of explosives, any electrofishing device, toxic gas, or toxic, poisonous or narcotic substances. One of the legislative tools under the Conservation Act is freshwater fisheries management plans (s17J) which could be used to implement general policies and establish objectives for the management of freshwater fisheries within an area.

Part VB of the Conservation Act relates to freshwater fisheries and has sections that are relevant to invasive fish. A key threat to freshwater ecosystems and species is the movement (transfer or release) of freshwater species between waterbodies. The movement of freshwater species is managed through s26ZM of the Conservation Act by both DOC and the Ministry for Primary Industries (MPI). All transfers of live freshwater species to new locations (including fish farms) require approval from the Minister of Conservation, while movements of live freshwater species between sites where they already occur and between islands of New Zealand require approval from the Minister of Fisheries. The possession of restricted fish, grass carp and silver carp, is controlled by s26ZQA, if s26ZM does not apply. Statutory documents developed under the Conservation Act, such as the general policy, conservation management strategies and freshwater fisheries plans, may provide guidance on some species in some places. DOC's Statement of Intent sets out the department's intentions and measures to assess progress over the medium term (3–5 years).

The Freshwater Fisheries Regulations 1983 have controls relating to management (Part 8), which includes additional controls on the movement of live aquatic life and provisions relating to noxious fish, as listed in Schedule 3 of the regulations. Part 8A deals specifically with koi carp, including the establishment of the containment area (New Zealand Gazette 1990; Appendix 1). The containment

SUGGESTED CITATION FOR SECTION 3.2: Grainger N 2015. Statutory Responsibilities: Department of Conservation Perspective. Section 3.2 in Collier KJ & Grainger NPJ eds. New Zealand Invasive Fish Management Handbook. Lake Ecosystem Restoration New Zealand (LERNZ; The University of Waikato) and Department of Conservation, Hamilton, New Zealand. Pp 36–40.

area (Figure 3.3) allows for the control/management of koi carp within it and eradication (if possible) outside. Harvest (recreational and commercial) was considered a viable control method within the containment area, with a limited entry policy adopted for commercial operators. The development of the containment area for koi carp was supported by management policies that focussed on preventing the further spread of koi carp beyond its feral range, reducing its distribution where possible, and minimising the effects of koi carp on aquatic biota and habitats.

In addition to national legislation, New Zealand is a signatory to several international conventions, including the Convention on Biological Diversity and the Ramsar Convention on Wetlands, which have provisions relating to invasive freshwater fish. These provisions are reflected in national policy pertaining to invasive fish. In part, to fulfil New Zealand's commitments under the International Convention of Biological Diversity, The New Zealand Biodiversity Strategy (2000) outlines a multi-agency approach to stop the decline of biodiversity in New Zealand. There is an objective in the Freshwater Theme pertaining to invasive fish:

> *'Objective 2.2 — Managing pests in natural freshwater habitats and ecosystems: Prevent, control and manage plant and animal pests that pose a threat to indigenous freshwater biodiversity'.*

DOC and regional councils are identified as the lead agencies for the actions to achieve this objective.

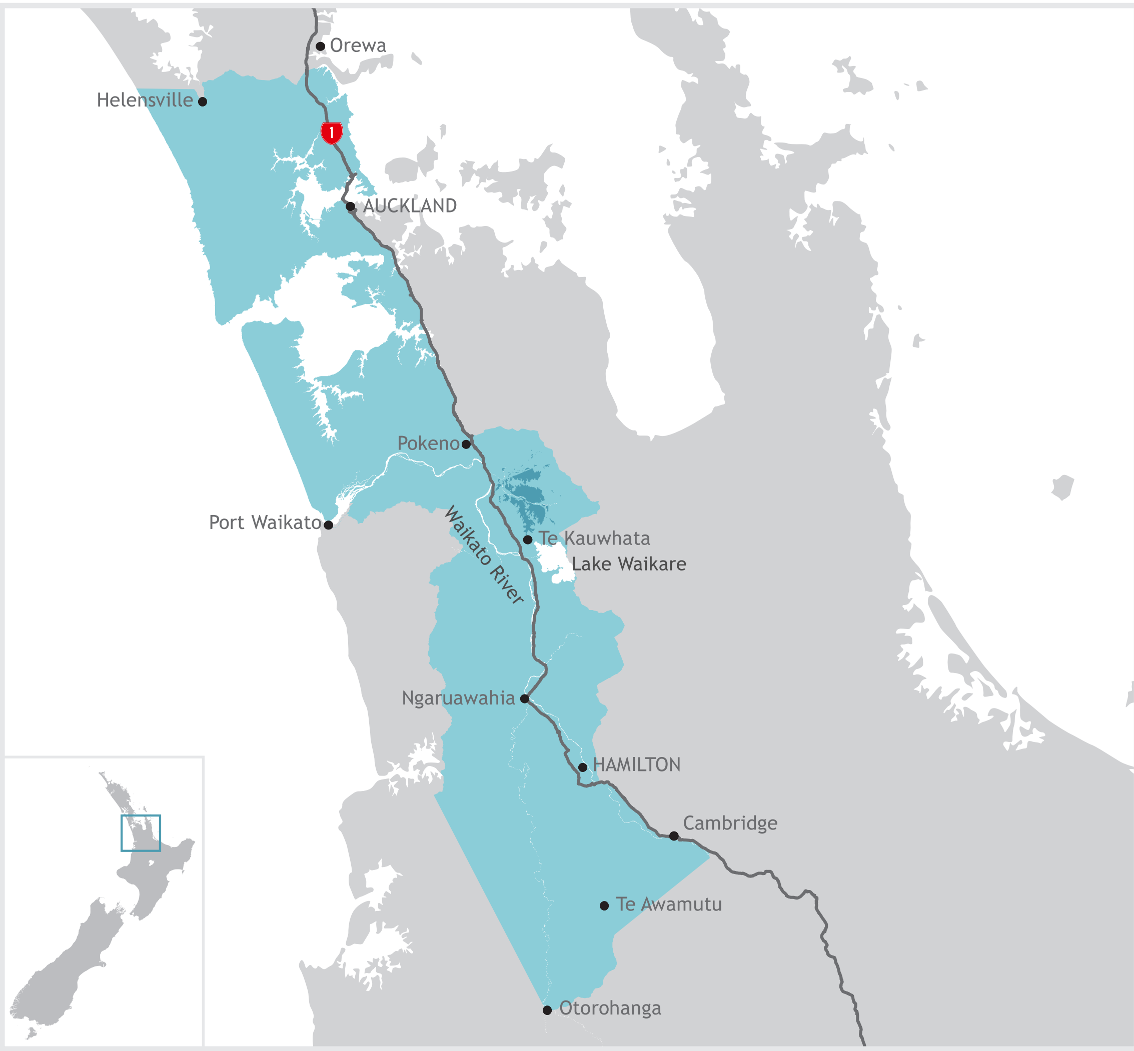

FIGURE 3.3 Koi carp containment area (New Zealand Gazette 1990: refer to Appendix 1 for full gazette notice).

Operational Activities

DOC's invasive fish work initially focussed on managing the permitting system for the commercial harvest of koi carp within the containment area and regulating transfers of aquatic life. In 1999, DOC recognised that the spread of invasive fish needed to be halted and work commenced to increase public awareness, determine the national distribution of pest fish, and develop a pest fish management strategy/framework. New funding associated with the implementation of The New Zealand Biodiversity Strategy (2000) enabled DOC to commence a national public awareness strategy and undertake a full delimitation survey of the South Island (Studholme 2002, 2003), following the detection of koi carp and gambusia in the South Island for the first time (see Section 5.3). A more targeted distributional survey was undertaken in the North Island (Keys *et al.* 2003).

In 2001, DOC hosted a workshop for New Zealand and Australian scientists and fisheries managers to identify priorities for future management and research (Department of Conservation 2003). The interim objectives established to guide funding allocations have remained in place. They are:

- Preventing the establishment of new invasive fish populations.
- Containing existing invasive freshwater fish to current distributions to prevent further spread.
- Eradicating (and controlling) invasive freshwater fish from sites where practicable.
- Managing invasive freshwater fish at high priority sites to prevent and minimise adverse effects.

Since 2000, DOC has implemented a reasonably comprehensive approach to invasive fish management. Operational activities include:

- Engaging in public advocacy activities to raise awareness of pest species and their impacts on native biodiversity and freshwater ecosystems (e.g. school visits, attending events such as boat shows, working with coarse fishing clubs—see Section 7.4).
- Surveying for new species, either as planned work or responding to sightings from members of the public or other agencies.
- Controlling or eradicating populations of invasive fish at the edges of their known range (e.g. gambusia eradication programme in the South Island—see Section 5.3), or at high value sites (e.g. rudd control in Rotopiko (Serpentine) lakes, Waikato—see Section 5.4).
- Monitoring the outcomes of control or eradication programmes.

To support operational staff, a range of best practice documents, standard operating procedures, guidelines and protocols have been developed. When necessary, DOC has conducted or commissioned science providers to undertake work to ensure that these support tools are underpinned by robust science. Most of the resources available to DOC staff via the Department's intranet are 'living' documents and are regularly updated. The most relevant resources are included in this handbook to make them more accessible (appendices 2–4). The other documents referred to can be requested from DOC.

SURVEY AND MONITORING DOCUMENTS:

- Biodiversity Inventory and Monitoring Toolbox (Greene & McNutt 2012)—describes a selection of standardised methods for sampling fish populations, including invasive species. www.doc.govt.nz/getting-involved/run-a-project/our-procedures-and-sops/biodiversity-inventory-and-monitoring/freshwater-fish.
- Invasive Fish Inventory and Monitoring—Best Practice Guidance (Grainger *et al.* 2014)—provides additional information to the Biodiversity Inventory and Monitoring Toolbox for targeting invasive fish (Appendix 2).

Protocols to decontaminate freshwater gear (Grainger & McCaughan 2014a) and prevent the unintentional capture of diving birds (Grainger & McCaughan 2014b) have also been developed (appendices 3 and 4). The development of these documents has drawn on work done by Dugdale & Wells (2002) and Matheson *et al*. (2007).

CONTROL AND ERADICATION DOCUMENTS:

- Pest Fish Control Tools: Choosing the Correct Technique—describes control tools and when they could be used.
- Rotenone Pesticide Information Review (Fairweather & Dean-Speirs 2012)—an overview of current knowledge of rotenone.
- Pest Fish Eradication Best Practice: Handlaying or Aerial Application of Rotenone (Grainger 2013)—gives guidance on how to plan and undertake rotenone operations.
- Invasive Fish Inventory and Monitoring: Best Practice Guidance (Grainger *et al*. 2014)—provides guidance on criteria to confirm eradication of target species (includes eradication criteria; Appendix 2).

The development of these documents has drawn on work done by Clearwater *et al*. (2008) who reviewed molluscicides and piscicides, and Ling (2003) who looked at the toxicity of rotenone (updated by Fairweather & Dean-Speirs 2012).

DOC has invested in obtaining approvals and registration for rotenone to be used as a piscicide in New Zealand under the Hazardous Substances and New Organisms Act 1996 and the Agricultural Compounds and Veterinary Medicines Act 1997. The applications pulled together a comprehensive package of information about rotenone and its uses, drawing on local work and international literature. This information is publicly available and is useful for resource consent applications (see also Section 4.1).

DOC has involved partners such as regional councils, iwi, Fish & Game councils and MPI, as well as stakeholders such as landowners and community groups, to help implement its invasive fish management programme. DOC has a broad freshwater mandate and it relies on a collaborative approach to enable this work to happen on and off public conservation land.

Issues, Challenges and Gaps

There are legislative issues that remain unresolved, particularly around aquatic transfers and releases where there can be four decision makers for some species in some places. It is not easy to state who is responsible for holding, taking, or the movement of species because it depends on the place, the species, and the specific action being undertaken. Possession of koi carp and gambusia also require multiple permissions. Overlapping jurisdiction has, in some cases, led to fragmented management.

About 20 people within DOC hold a current Approved Handlers Test Certificate for rotenone. While DOC has recently obtained approval under the Agricultural and Veterinary Medicines Act 1997 to allow other agencies to use rotenone, there may be some barriers to this because of a lack of test certifiers to train, assess and issue Approved Handler certificates for rotenone. DOC's test certifier is unable to assess non-DOC staff, limiting the capacity of other organisations to use rotenone as a management tool.

There has been variable commitment, capacity and interest around the country to implement invasive fish control and response measures. Those areas without an invasive fish problem have been less likely to engage in invasive fish work and are less likely to be prepared or able to respond to local incursions. In addition, there is no national strategic plan to provide guidance on how to prioritise this work. While DOC has developed support systems to help staff undertake the work, there is relative autonomy on what is done locally so there is no guarantee that work will be done to contribute to the national programme. The funding obtained for invasive fish work as part of the implementation of The New Zealand Biodiversity Strategy in 2000 was essential to build DOC's capacity and expertise in the management of invasive fish. DOC has worked closely with other research agencies, such as the Australian Invasive Animals Centre for Cooperative Research and the Lake Ecosystem Restoration New Zealand (LERNZ) Outcome Based Investment run by The University of Waikato, to facilitate research in this area.

The aquarium trade remains a significant vector for fish species that could become aquatic pests, particularly in geothermal areas despite the legislative controls in place. The effects of climate change are likely to increase the available habitat and likelihood of more species surviving in natural freshwater ecosystems, and continued vigilance is required. To date, considerable management effort has been focussed on the South Island to manage incursions of koi carp and gambusia, the spread of rudd in Canterbury, and the spread of rudd, tench and perch into Nelson and Marlborough regions. Despite work on outlying fish populations in the North Island, there has been continual creep of some species distributions into Northland and the lower North Island. While eradication is still feasible at some of the sites at the edges of the regional expansion of ranges, they need to be dealt with promptly.

Enabling and resourcing operational staff to act with partners and stakeholders to deal with local incursions can be challenging. Invasive fish are one of many threats to freshwater ecosystems and species, but they are a threat that is not yet present in all freshwater ecosystems. Co-ordinated inter-agency work with relevant partners and stakeholders is essential to prevent and minimise the environmental damage invasive fish can do.

3.3 Statutory Responsibilities: Auckland/Waikato Fish & Game Council Perspective

Adam Daniel

Fish & Game New Zealand, Auckland/Waikato Region, Hamilton, New Zealand

Background

Fish & Game New Zealand comprises 12 regional Fish & Game councils and a national council made up of a representative from each of the regions. The structure of Fish & Game New Zealand allows for very effective management of regional sports fish and game species to benefit licence holders, but does not easily allow for national policy that fits the needs of all regions. Therefore, the following sections represent the current view of the Auckland/Waikato Fish & Game region only, and other regions may have different policies that meet the needs of their licence holders.

Legislative Requirements

The Conservation Act 1987 requires Fish & Game New Zealand to manage sports fish and game, and their habitats, on behalf of anglers and hunters in New Zealand. The Conservation Act 1987 does not directly address the responsibility of Fish & Game New Zealand to combat invasive species aside from protecting and enhancing fish and game bird habitat. The Auckland/Waikato Fish & Game region is unique in that rudd is considered a sports fish, along with rainbow trout, brown trout (*Salmo trutta*), tench and perch. As coarse fish are well-established in the region, and are seen as a recreational species by a significant proportion of anglers there, inclusion of some coarse fish as sports fish has allowed Fish & Game council staff to engage in productive conversations with coarse fishers (see Section 7.2). Auckland/Waikato Fish & Game Council believes this open dialogue and representation has greatly reduced the threat of further illegal introductions and created an atmosphere of self-regulation rather than encouraging alienation. The inclusion of coarse fish as sports fish in the Auckland/Waikato region is not an endorsement to further illegal spread of coarse fish.

Operational Activities

Auckland/Waikato Fish & Game Council manage existing wild populations of coarse fish, and do not release or propagate any fish other than trout. The only introduction of coarse fish Auckland/Waikato Fish & Game would potentially endorse at the current time would be the establishment of a hydrologically separated and secured fishery (e.g. a tench fishery in a disused quarry outside of a floodplain). Fish & Game believe that if a quality fishery is provided in an ecologically safe manner, and the coarse fishing community is engaged in the management of the resource, the incentive to conduct illegal releases is greatly reduced.

SUGGESTED CITATION FOR SECTION 3.3: Daniel A 2015. Statutory Responsibilities: Auckland/Waikato Fish & Game Council Perspective. Section 3.3 in Collier KJ & Grainger NPJ eds. New Zealand Invasive Fish Management Handbook. Lake Ecosystem Restoration New Zealand (LERNZ; The University of Waikato) and Department of Conservation, Hamilton, New Zealand. Pp 41–42.

Auckland/Waikato Fish & Game Council will support the eradication of any illegal spread of coarse fish in the region if the removal can be carried out without jeopardising other recreational values. The decline of water quality through intensive farming in the Auckland/Waikato region (Quinn *et al*. 1997) is likely to have converted historic waterfowl and trout habitat to habitat more suitable for coarse fish, which can further impact water quality (Driver *et al*. 2005; Kloskowski 2011). Restoration of waterfowl habitat could involve the removal of some coarse fish. Inclusion of these fish as a sports fish could potentially result in conflicting management priorities within the Auckland/Waikato Fish & Game region. For example, lake restoration aimed at improving waterfowl production could include the removal of rudd and tench to restore or protect invertebrates and aquatic plants. Likewise the removal of perch as a top-down control to improve water quality in lakes or wetlands could also pose a conflict between fish and waterfowl management. In these situations Auckland/Waikato Fish & Game Council is likely to favour water quality over preserving coarse fish if:

- there is a high probability of improving water quality;
- water quality improvements will enhance the habitat of game birds or other sports fish; and
- there is a high probability of maintaining improved water quality.

For example, Auckland/Waikato Fish & Game Council does not oppose the ongoing restoration efforts at the Rotopiko (Serpentine) lakes, Waikato, and Lake Wainamu, Auckland, that include the removal of coarse fish. Similarly, Auckland/Waikato Fish & Game staff are actively looking for a means of removing perch from Lake Ototoa to restore the highly-valued dwarf īnanga and rainbow trout populations.

Auckland/Waikato Fish & Game Council has prepared a decision planning document to speed the process of responding to invasive fish incursions. However, the organisation's ability to conduct field removal operations is limited by its funding source as Fish & Game New Zealand is solely funded by licence holders. This financial separation from central government makes Fish & Game New Zealand unique in that they are the only agency officially advising the Ministry for the Environment that is not directly funded by the government. Lack of funding from central government means that Fish & Game councils do not have access to emergency funding to respond to incursions in the same way the Department of Conservation or Ministry for Primary Industries theoretically have. This lack of emergency or external funding drastically limits the ability of Fish & Game councils to play a lead role in responses to new or existing incursions of invasive fish.

Issues, Challenges and Gaps

The overall capability of New Zealand government agencies to respond to invasive fish incursions is weak due to the absence of a rapid response programme necessary to prevent the establishment of most invasive species. Currently, if an invasive fish were detected tomorrow in the Auckland/Waikato Fish & Game region, it would be weeks or months before a response plan could be agreed on. To create a functional response programme there would have to be regional response plans, trained staff, availability of an effective piscicide (e.g. rotenone—see Section 4.1) capable of rapid application, pre-approved procedures, existing permits (e.g. pre-approval from relevant agencies to use rotenone in case of emergency in selected habitats), and appointed delegates from lead agencies. Moreover, the tools necessary to detect and control or eradicate an invasive fish are not available in most regions. For example, Auckland/Waikato Fish & Game Council reported a potential new incursion of koi carp in a gravel pit within the floodplain of the Whanganui River in 2011, but that report has never been officially confirmed or investigated despite the site being on the banks of a nationally significant river.

Auckland/Waikato Fish & Game Council generally supports restoration efforts that involve the removal of coarse fish if there is a high likelihood of long-term water quality improvements, and/or improvements in the habitat of waterfowl or other sports fish. Although Auckland/Waikato Fish & Game Council has a limited ability to respond to new or existing invasive species incursions, it is willing to support in an advisory role and would welcome a national response programme for new and existing aquatic invasive species.

3.4 Statutory Responsibilities: Regional Council Perspective

David Byers

Waikato Regional Council, Hamilton, New Zealand

Background

New Zealand has seven regional councils in the South Island and nine in the North Island (Figure 3.4). Regional councils are primarily concerned with environmental resource management, flood control, air and water quality, pest control, and, in specific cases, public transport, regional parks and bulk water supply. However, councils can differ widely in relation to activities they undertake, as long as they have consulted their communities in making the decisions. As a result, there is considerable diversity in the range of activities that councils provide reflecting different regional circumstances, and this is certainly the case for non-indigenous invasive fish.

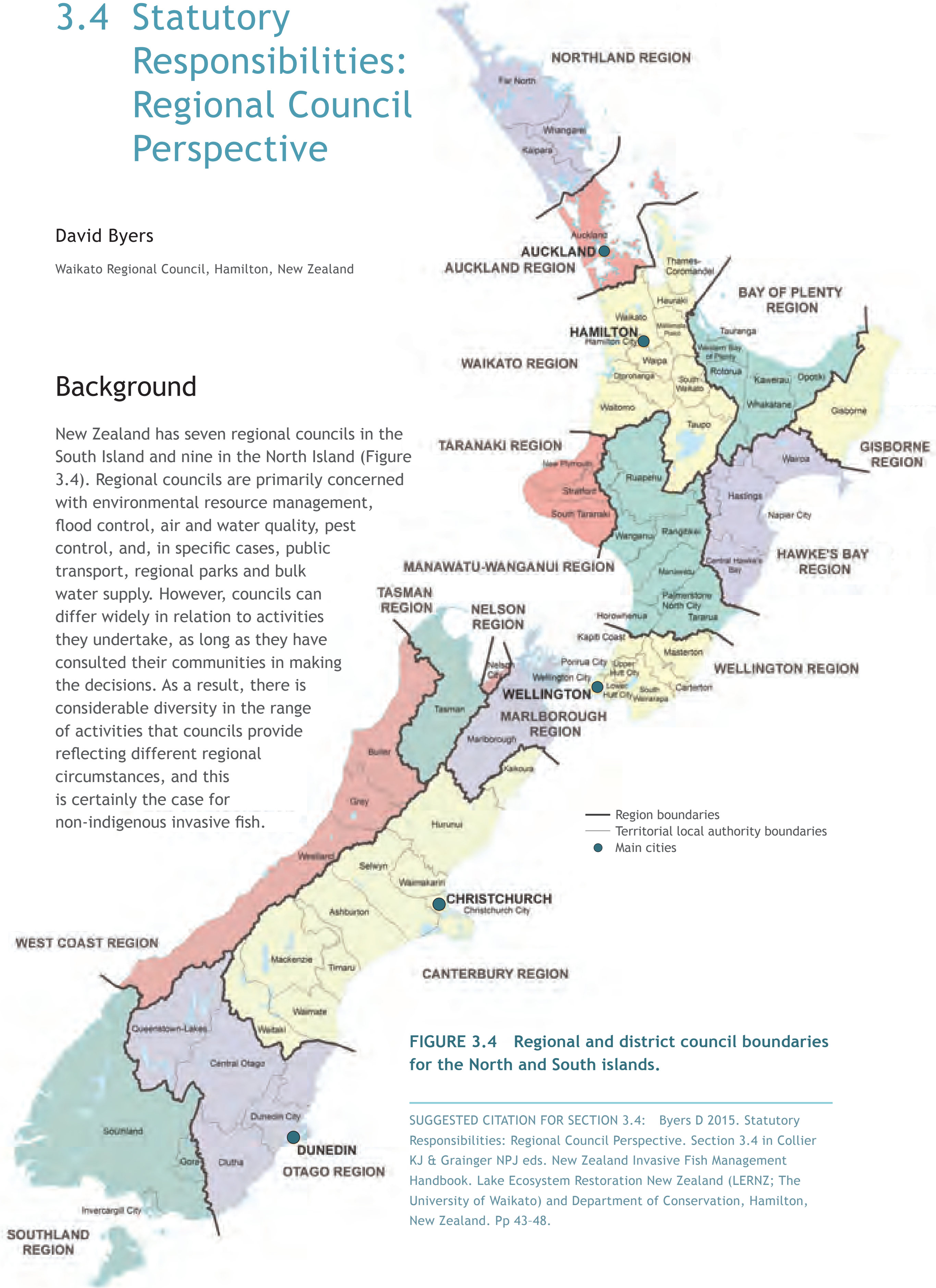

FIGURE 3.4 Regional and district council boundaries for the North and South islands.

SUGGESTED CITATION FOR SECTION 3.4: Byers D 2015. Statutory Responsibilities: Regional Council Perspective. Section 3.4 in Collier KJ & Grainger NPJ eds. New Zealand Invasive Fish Management Handbook. Lake Ecosystem Restoration New Zealand (LERNZ; The University of Waikato) and Department of Conservation, Hamilton, New Zealand. Pp 43-48.

Legislative Requirements

RESOURCE MANAGEMENT ACT (RMA) 1991: An amendment to the RMA (s30(1)(ga)) in 2003 gave regional councils the ability to provide specific functions, as follows:

> *'The establishment, implementation, and review of objectives, policies and methods for maintaining indigenous biological biodiversity'*.

In order for councils to give effect to this section, they must maintain water quality and habitat for indigenous fish species to survive, breed and migrate. The RMA also provides for the management of aspects of indigenous biodiversity through the following sections:

- Safeguarding the life-supporting capacity of air, water, soil and ecosystems (s5(2)(b)).
- Protection of areas of significant indigenous vegetation and significant habitats of indigenous fauna as a matter of national importance (s6(c)).
- Having regard to the intrinsic values of ecosystems (s7(d)). In this case, intrinsic values include genetic and biological diversity (s2(1)).

Local authorities provide for these matters through district and regional plans, and regional policy statements (under the Act). This has relevance to invasive fish management as it may form a component of a larger objective, such as lake and wetland protection, enhancement and restoration, in response to public expectation, central government water policies and crown-iwi co-management legislation.

BIOSECURITY ACT 1993: The Biosecurity Act 1993 was amended in 2012 to give regional councils the ability to prepare regional pest management plans (RPMP, previously termed pest management strategies) and regional pathway management plans, although the latter are largely untested at the time of writing. The amended Biosecurity Act also provides for national policy direction to ensure that activities described in the RPMP align with one another to contribute to the achievement of pest management.

RPMPs are not mandatory and a council may decide it does not want to have a RPMP or regional pathway management plan. The Act does, however, promote the expectation that regional councils will take a leadership role in the prevention, reduction or elimination of harmful organisms. A RPMP sets out the strategic and statutory framework for a regional council to undertake management of identified pest plants and animals within its region. Any person may also propose a RPMP to a council, and if the council is satisfied that all criteria and statutory tests are met, may approve such a plan and appoint a management agency.

It is worth noting that there may be significant variation in identified pests between plans (Table 3.1). A pest may already be present within a region and therefore requires rules for ongoing management. If the pest is confined to a known area within the region and not in the whole of the region, the management plan may have rules designed to prevent its further spread. A pest may not currently be present within a region but is noted in a plan so that rules can be applied to discourage its introduction or enable action to be taken if found to be present. A pest species known not to be present in a region may be noted in an RPMP, and rules developed to discourage release and propagation.

TABLE 3.1 Invasive fish listed in regional pest management plans at the time of publication.

REGION	KOI CARP	PERCH	CATFISH	GAMBUSIA	ORFE	RUDD	TENCH	GOLDFISH	TOTAL
Northland*#	C	C	Sp	Sp	Ex	Sp	C	NL	7
Auckland*	C	C+	C	C	C	C+	C+	NL	7
Waikato	Er/C	Er/C	Er/C	Er/C	NL	Er/C	Er/C	Er/C	7
Bay of Plenty	Ex/Er	Ex/Er	Ex/Er	R	NL	C	C	NL	6
Gisborne	Sv	Sv	Sv	TC	NL	Sv	NL	NL	5
Taranaki	Sv	NL	Sv	Sv	NL	Sv	NL	NL	4
Horizons (Manawatu)*	S-l	NL	S-l	S-l	NL	S-l	NL	NL	4
Greater Wellington	S-l	NL	S-l	S-l	NL	S-l	NL	S-l	5
Tasman-Nelson	PC	PC	NL	PC	NL	PC	PC	NL	5
Southland	Ex	NL	Ex	Ex	Ex	Ex	Ex	NL	6
No. councils	10	6	9	10	3	10	6	2	

* Gudgeon also listed; # Caudo also listed; + High value waterbodies only; NL = not listed

Purposes listed:
Ex = Exclusion; Er = Eradication; C = Containment; Sp = Suppression; R = Restricted; PC = Progressive control; TC = Total control; Sv = Surveillance; S-l = Site-led

Operational Activities: Waikato Region Case Study

WAIKATO REGIONAL PEST MANAGEMENT PLAN: Waikato Regional Council plan rules for introduced fish are outlined in Table 3.2. In an operational sense, the council relies on reported sightings and enquiries from the public to investigate possible breaches of these rules. The level of surveillance depends on the resources (funding and staff) available. Equally, it is known that the range for koi carp has extended beyond the gazetted range identified by the Department of Conservation (see Appendix 1). In many cases there is uncertainty about the known range for various species. The interconnecting nature of rivers, lakes and drains is a real challenge for preventing or containing the spread of this species. Good neighbour rules are designed to address the external effects of pests spilling over from crown land onto adjacent properties and can bind the crown (s69(5) and s154N(19) of the Biosecurity Act 1993). Good neighbour rules have not been applied to pest fish on Waikato crown land because of the complexity and uncertainty of managing invasive fish within this region.

OBLIGATIONS UNDER THE RIVER SETTLEMENT: Settlement and co-management legislation for the Waikato River requires council to co-manage the Waikato River and its catchment area with several iwi (Figure 3.5). This is reflected in a document titled The Vision and Strategy for the Waikato River (2008) that was adopted into the Waikato Regional Policy Statement. This means that any rules and strategies developed in the RPMP must have particular regard to The Vision and Strategy for the Waikato River when carrying out its functions under the Biosecurity Act. Many of the invasive fish species listed in Table 3.1 need to be managed if objectives to restore the river and its catchments are to be realised.

TABLE 3.2 Plan rules and strategies for introduced fish in the Waikato Regional Pest Management Plan.

PLAN RULES	
6.9.8	The occupier is required, on direction from an authorised person, to destroy all koi carp in isolated ponds, wetlands and ditches on the land occupied. The authorised person shall determine which methods are realistic, including draining/poisoning or electric fishing.
6.9.9	No person shall release koi carp, brown bullhead catfish, gambusia or wild goldfish into any waterbody within the Waikato region outside the known current range for the species concerned. Consideration will be given to any relevant licences sought under the Freshwater Fish Farming Regulations 1983.
6.9.10	No person shall release perch, rudd or tench into any waterbody within the Waikato region where the introduction has not previously been legally authorised. Consideration will be given to any relevant licences sought under the Freshwater Fish Farming Regulations 1983.
6.9.11	The occupier is required, on direction from an authorised person, to destroy all perch, rudd and tench in isolated ponds, lakes, wetlands and ditches on the land occupied. The authorised person shall determine which draining/poisoning methods are realistic. A breach of these rules will create an offence under section 154N (19) of the Act. Enforcement will be in accordance with section 11.3.1 of the plan. Exemptions to a rule may apply, as outlined in section 11.3.2 of the plan.
GOOD NEIGHBOUR RULE	The good neighbour rule does not apply.
DIRECT CONTROL	Waikato Regional Council in conjunction with Fish & Game New Zealand and DOC may undertake direct control of koi carp, brown bullhead catfish, gambusia and wild goldfish in any waterbody where they are having negative impacts, in accordance with section 11.4 of the plan. Waikato Regional Council in conjunction with Fish & Game New Zealand and DOC may undertake direct control of perch, rudd or tench in any waterbody in which they have become established, in accordance with section 11.4 of the plan.
MONITORING AND SURVEILLANCE	Waikato Regional Council in conjunction with Bay of Plenty Regional Council and DOC may undertake monitoring and surveillance of koi carp, brown bullhead catfish and gambusia to determine the extent of populations, in accordance with section 11.2.2 of the plan. Waikato Regional Council in conjunction with Fish & Game New Zealand and DOC may undertake monitoring and surveillance of perch, rudd and tench to determine the extent of populations, in accordance with section 11.2.2 of the plan.
INFORMATION AND ADVICE	Waikato Regional Council will provide advice and information on the threat of these pest fish, in accordance with section 11.1 of the plan.
MANAGEMENT PARTNERSHIPS	Waikato Regional Council may undertake management of koi carp and brown bullhead catfish in association with the Department of Conservation, Waikato River Authority, Genesis Energy, the Ministry for Primary Industries, the National Institute of Water and Atmospheric Research and other appropriate partners.

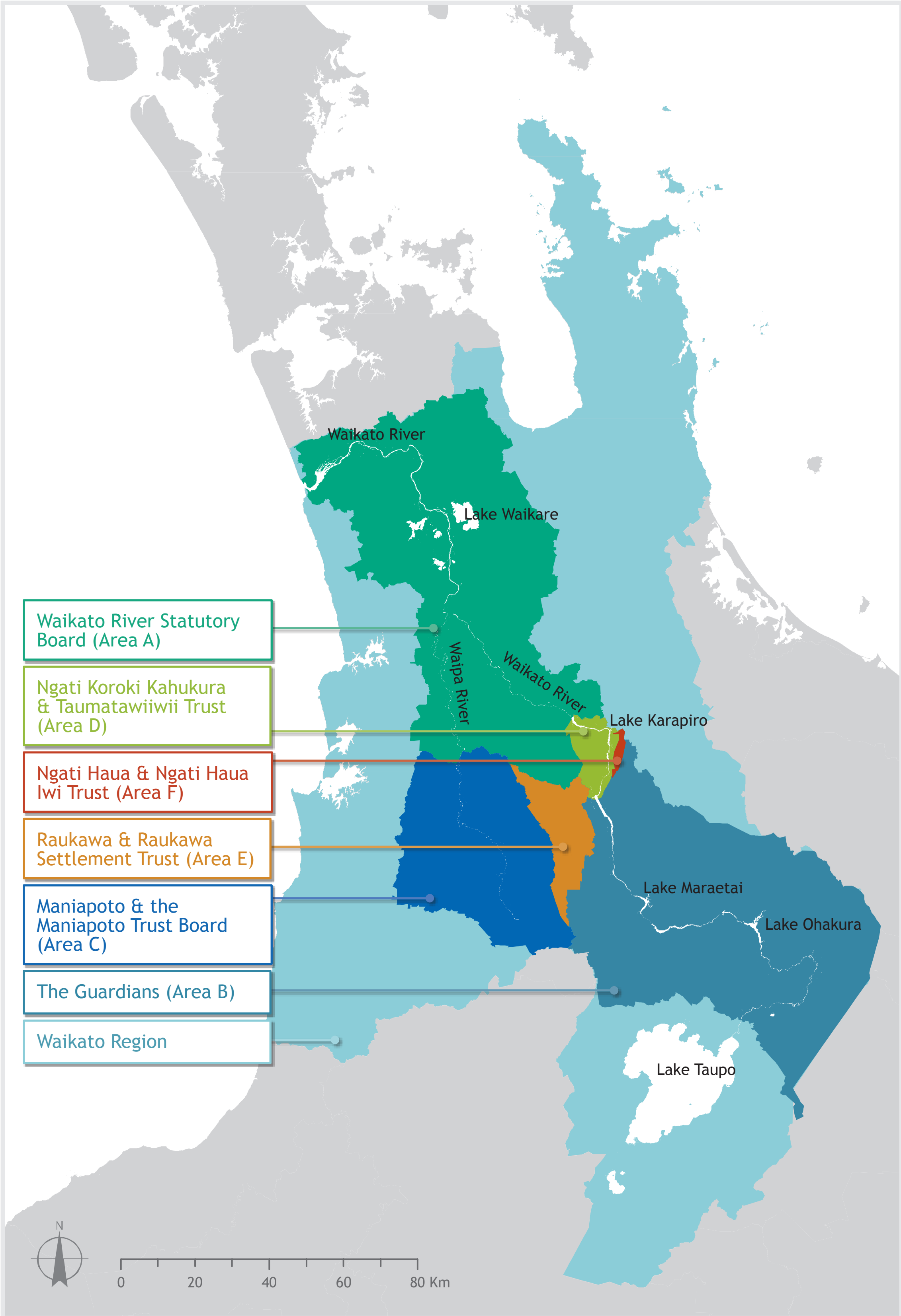

FIGURE 3.5 Legislated Waikato River iwi co-management jurisdiction areas in the Waikato Region (2014).

Issues, Challenges and Gaps

Inter-agency co-operation remains a challenge when managing invasive fish. Responsibilities of management agencies often overlap and require a multidisciplinary approach. Policing the rules applying to capture and killing of invasive fish is under-resourced and, as a result, large numbers of live catfish in particular are regularly caught and transported from Waikato region waterways to Auckland and surrounds by recreational fishers. This is where regional pathway management plans may be beneficial if spread is to be prevented and impacts minimised.

Koi carp is an example of a significant invasive species present within this region to give an idea of the scope of the challenge ahead. The total area of waterbodies in the Waikato region is estimated at 160,000 ha. Koi carp currently occupy approximately 11,300 ha of waterways and lakes, including 3,700 ha of the lower Waikato River, 1,300 ha of lower Waikato River tributaries, 6,000 ha of lakes in the lower Waikato basin, and 300 ha of the Waipā River. There is potential for further spread within the Waipā catchment through dispersal, and to other catchments in the region through human-mediated spread from deliberate releases. A large-scale, strategic co-ordinated approach is needed to prevent further spread of koi carp.

3.5 Statutory Responsibilities: Waikato-Tainui Perspective

Terina Rakena

Waikato Raupatu River Trust, Waikato-Tainui Te Kauhanganui Incorporated, Hamilton, New Zealand

Background

In 1863 the crown unjustly confiscated over one million acres of Waikato-Tainui land and resources that spanned from Taamaki Makaurau through to the Waikato. This confiscation resulted in the Waikato Land Wars that led to significant loss of life and property, and crippled the welfare, economy and development of Waikato-Tainui. Prior to raupatu (confiscation), the region was renowned for the abundance of natural resources that lay within the rivers, lakes, wetlands, and their catchments and ngahere (native forests). The alluvial soils, sands and gravels carried and deposited by the rivers provided the beds and materials for Waikato-Tainui maara (gardens). Manu (birds) such as kiwi, kookako, kaakaa, tuuii, kereruu and hihi were found commonly throughout the ngahere. Valued weaving resources such as harakeke, kiekie, and ngaawhaa graced many of the riverbanks and wetlands. Furthermore, Waikato-Tainui traditions speak of when the lakes and wetlands teemed with large numbers of tuna (eel), kooura (crayfish), whitebait and kaeo (freshwater mussels).

Over 200 species of flora and fauna are now in decline or threatened with extinction in the Waikato region (Environment Waikato 1998). Losing an indigenous species has an impact on the whakapapa (genealogy) of the Waikato-Tainui landscape and threatens the viability of Waikato-Tainui culture and traditional activities. Extinctions or declines in a species or habitat also have an impact on maatauranga (knowledge) of the ecosystem and environment, and the information that can usefully be passed on to future generations.

Loss of habitat and spread of introduced pests are major reasons for the decline and extinction of many native plant and animal species. Many of these introduced species are invasive pests (plants, animals and micro-organisms) that have caused harm to the environment, economy, and/or human health. Waikato-Tainui culture, tikanga (protocols) and kawa (formalities) have evolved with the indigenous flora and fauna of the tribal area. Waikato-Tainui are part of the natural heritage of the land and are at risk when the resources and taonga (treasure) around them become depleted, degraded or destroyed. The continued threat to the delicate balance of the indigenous ecosystem from invasive species is also a threat to the Waikato-Tainui way of life.

To prevent the continued decline of remaining natural areas, it is necessary to remove pest species, or reduce their numbers and prevent new incursions. Several of the non-indigenous fish species found in Waikato rivers, lakes and wetlands pose a substantial threat to aquatic ecosystems. Koi carp, in particular, cause considerable damage to habitat, degrade water quality and exclude native fish species. Waikato-Tainui aspires to the restoration of the environment to the state that Kiingi Taawhiao observed when he composed his maimai aroha (Taawhiao’s lament for his land and people), and therefore aspires to the eradication of all introduced pest fish in our waterways.

SUGGESTED CITATION FOR SECTION 3.5: Rakena T 2015. Statutory Responsibilities: Waikato-Tainui Perspective. Section 3.5 in Collier KJ & Grainger NPJ eds. New Zealand Invasive Fish Management Handbook. Lake Ecosystem Restoration New Zealand (LERNZ; The University of Waikato) and Department of Conservation, Hamilton, New Zealand. Pp 49–52.

Legislative Requirements

TAI TUMU, TAI PARI, TAI AO—WAIKATO-TAINUI ENVIRONMENT PLAN: For the purposes of the Resource Management Act (RMA) 1991 particularly of s35A, Waikato-Tainui Te Kauhanganui Incorporated (WTTKI) confirms that it is the iwi authority for Waikato-Tainui and that the Tai Tumu Tai Pari Tai Ao (the Waikato-Tainui Environment Plan) represents the Waikato-Tainui environmental planning document. WTTKI is to be considered the iwi authority for all relevant sections of the RMA.

The vision of the plan is taken from a maimai aroha of the second Maaori King, Taawhiao, where he laments with a heavy heart his longing for and adoration of the taonga-natural resources of his homeland. The maimai aroha of Kiingi Taawhiao is the key driver and indicator of environmental health and well-being in the Waikato-Tainui Environmental Plan.

FISHERIES REGULATIONS: The Waikato-Tainui Raupatu Claims (Waikato River) Settlement Act 2010 enabled Waikato-Tainui and the crown to establish the Waikato-Tainui (Waikato River Fisheries) Regulations 2010 to manage customary fishing and provide Waikato-Tainui input into fisheries management. The regulations provide for Waikato-Tainui to create local fisheries by-laws to manage fishing within the Waikato-Tainui Fisheries Area (see Figure 3.6) of the Waikato River catchment.

FIGURE 3.6 Waikato-Tainui Fisheries Area.

PERMIT PROCESSES: The Waikato River Settlement has also enabled Waikato-Tainui to sign accords with the Ministry for Primary Industries (MPI; Waikato-Tainui Fisheries Accord 2008) and the Department of Conservation (DOC; Waikato-Tainui Conservation Accord 2008). Under both accords, MPI and DOC have specific obligations to provide early and effective engagement with Waikato-Tainui on permit applications that directly affect the Waikato River and its catchment.

Special permits (issued under s97(1) of the Fisheries Act 1996) provide a mechanism to authorise activities where no other option is available, or practical, under current legislation. In recognising MPI's obligations regarding processing special permit applications under that Accord, the Spatial Allocations Section of MPI and Waikato-Tainui have worked collaboratively to develop an agreed operational policy for processing special permit applications, or part applications, that are proposed within the Waikato River catchment. The agreed operational policy is presented in a special permit process flow chart published in the Waikato-Tainui Environmental Plan.

Operational Activities

TAI TUMU, TAI PARI, TAI AO—WAIKATO-TAINUI ENVIRONMENT PLAN: Under the environmental plan, the biosecurity objective for Waikato-Tainui is that priority plant and animal pests are appropriately identified, managed and/or controlled to a level where their impacts are minor or, where possible, they are eradicated. The methods to do this are outlined below.

- Effective pest plant and animal control (as measured by retention or enhancement of indigenous flora and fauna), to be undertaken in all areas of vegetation that are regionally, culturally, and/or spiritually significant to Waikato-Tainui, including those habitats occupied by taonga or threatened species.
- Application of pest control tools will be undertaken in a manner that manages adverse effects on waterways, hauanga kai and indigenous species.
- Waikato-Tainui shall be consulted on all pest management strategies developed, and pest control operations planned, on public land within the rohe.
- Appropriate monitoring of (i) the effectiveness of pest management; (ii) the effectiveness of control and eradication operations in protecting priority ecosystems and increasing the extent and abundance of taonga species; and (iii) the improvements in the ecological health of terrestrial indigenous habitats, rivers, lakes, wetlands and coastal areas.
- Investigation by relevant authorities or agencies into mechanisms and/or incentives that could facilitate greater support from private landowners in implementing pest management strategies.
- Investigation by relevant authorities or agencies into public education and promotion initiatives, voluntary measures, and/or regulatory mechanisms to restrict the release of ornamental and exotic plant and animal species along Waikato-Tainui rivers, their tributaries, wetlands and lakes. This may include reviewing and, if necessary, developing amendments to regulations relating to biosecurity and bio-protection for nurseries and orchards, zoos and animal parks, and tourism operators.
- Organisations responsible for pest management encourage people to report sightings of pest species.

FISHERIES REGULATIONS: Waikato-Tainui, together with other Waikato River iwi, will be investigating ways of making it easier for people to capture and eradicate pest fish species, whilst at the same time reducing any incidental and unintended impacts on native fish. Waikato-Tainui view the fisheries bylaws as a mechanism not only to prohibit or restrict fishing for cultural and sustainability reasons, but also to enable communities to target pest fish species that affect waterways.

PERMIT PROCESSES: When granting permits (applied for to DOC and MPI) to applicants, Waikato-Tainui provides the following positions where those applications are related to targeting invasive fish species:

- Support the removal of invasive fish species. However, this has to be managed in a manner that does not lead to further degradation of our awa tuupuna (Waikato River).
- Support killing all koi carp at point of capture.
- Do not support the export of live exotic/pest species outside of New Zealand.
- Do not support the transfer of live koi carp to areas outside the koi containment area (see Figure 3.3).
- There must be no negative impacts on native flora and fauna or waahi tapu from the applicant's activities when managing invasive fish species.
- The applicant should provide sufficient information in the application, so that a well-informed decision can be made.
- The application must demonstrate consistency with the Waikato Tainui Environmental Plan—Tai Tumu, Tai Pari, Tai Ao.

Conclusion

The control of pest fish in the Waikato-Tainui rohe should be undertaken in a manner that is consistent with all parts of the Waikato-Tainui Environmental Plan, with eradication being the ultimate goal.

4

Control and Eradication of Invasive Fish

The use of methods for invasive fish control will be dependent on the target species, specific objectives of the exercise, and the context of the site (e.g. its size, connectivity and conservation value). Typically, a combination of different methods will be used to achieve the most effective result, coupled with surveillance monitoring to determine success (see Section 6). The methods presented in the following section range from toxicants to enable eradication, cages to enable directional trapping and mass harvest, installation of barriers to prevent re-invasion, and electrofishing as a tool for fishing down populations. Netting will also be part of any invasive fish control programme, as highlighted in the various case studies (see Section 5) and in an analysis of the cost-effectiveness of different methods (Section 6.3).

4.1 Piscicides and Drainage for Management of Invasive Fish

David West

Department of Conservation, Christchurch, New Zealand

Background

Piscicides and drainage are options for invasive fish eradication if the following criteria are met:

- Flow of water through the site is negligible or can be controlled.
- Risk of invasive fish spreading from the site is high.
- The site is outside or at the edge of the known range of target invasive species.
- The available piscicide is effective at killing the target invasive species.
- Native aquatic communities at the site affected by the piscicide are not of high value or can be moved temporarily or permanently from the site.
- Suitable expertise and equipment for eradication exist within range of the site.
- Factors such as water temperature, inflows, adjacent landuse and weather are favourable.
- Regulatory approvals are obtained.

Piscicides

There are two categories of piscicides: (i) specific compounds with some species selectivity; and (ii) treatments that kill all freshwater life in the treated area. Toxins were trialled in New Zealand from 2000 onwards when high numbers of new invasive fish incursions were discovered. The two types of toxin for which early trials have been documented are lime (calcium hydroxide ($Ca(OH)_2$) and rotenone (cube root powder; rotenone 6-9%). There are anecdotal stories of the use of chlorine in private ponds but these have not been documented.

LIME: Lime was used successfully on five occasions before rotenone was able to be used in all parts of New Zealand (Table 4.1). Almost all use of lime has included some drainage to drop levels of small ponds before spraying on a mixture of water and hydrated lime using fire pumps and tanks. Target pH of greater than nine was achieved and held for 1–2 days. The use of lime as a piscicide was stopped once rotenone became more readily available and lime was fully assessed as a piscicide (Clearwater 2005). The main limitations to lime use were the lack of data on toxicity to native or invasive species, the need to maintain pH >12 for 4–5 days to be sure of killing invasive fish, and the broad range of organisms killed by lime, including aquatic plants that then caused additional water quality impacts as they decayed.

SUGGESTED CITATION FOR SECTION 4.1: West D 2015. Piscicides and Drainage for Management of Invasive Fish. Section 4.1 in Collier KJ & Grainger NPJ eds. New Zealand Invasive Fish Management Handbook. Lake Ecosystem Restoration New Zealand (LERNZ; The University of Waikato) and Department of Conservation, Hamilton, New Zealand. Pp 54–59.

TABLE 4.1 Department of Conservation invasive fish eradications using toxins and/or drainage showing methods by year. Note: excludes brown trout removals from streams.

METHOD	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	TOTAL
Lime	0	3	0	2	0	0	0	0	0	0	0	0	0	5
Rotenone	1	17	3	8	3	4	9	9	2	1	14	4	6	81
Drainage	1	1	0	0	1	0	0	12	0	2	0	0	0	17

ROTENONE: Although rotenone was used in a 1981 research trial by Ministry of Agriculture and Forestry to remove grass carp from Lake Parkinson (Tanner *et al*. 1990), use only began in a concerted way after 2000 when koi carp and gambusia were found in the northern South Island. This was followed by a review of rotenone as a piscicide (Ling 2003) and ongoing assessment of alternatives to rotenone (Clearwater *et al*. 2008). Ling (2003) concluded that rotenone is very toxic to fish compared to other non-target aquatic fauna, quickly broken down to natural non-lethal constituents, and has been widely used in the USA for several years—all features of a good piscicide. However, in a recent test of eight indigenous and non-indigenous New Zealand fish species, goldfish were least susceptible to rotenone with an estimated 6-h LC_{50} of >400 µg/L (Ling 2013).

The American Fisheries Society's handbook for rotenone use was cited as providing the detail to help with successful use of rotenone. This highlighted the need for knowledge of the target area and method used to apply the toxin as key factors in the success of any operation. Examination of available piscicides or molluscicides by Clearwater *et al*. (2008) showed only one compound other than rotenone, the comparatively expensive AQUI-S, was registered for use in New Zealand. Based on those reviews, DOC chose rotenone as its preferred piscicide to use, and obtained the appropriate approvals under the Hazardous Substances and New Organisms Act (HASNO) 1996, and the Agricultural Compounds and Veterinary Medicines Act 1997. There are two current trade names for rotenone but DOC staff only use Cube Root Slurry (CRS—containing 1.2–1.8% rotenone).

The Department of Conservation (DOC) is the only agency currently seeking approvals and setting standards for the use of rotenone, and DOC staff are the only persons currently permitted to use rotenone in New Zealand. DOC trainers have completed the American Fisheries Society's Successful Rotenone and Antimycin Projects courses, are test certifiers (under the HSNO act), and lead the training of operational staff, with people passing the course obtaining an approved handler test certificate. Standards are maintained via adherence to DOC's Standard Operating Practices for Animal Pests, including the Pest Fish Eradication Best Practice (Grainger 2013) and performance standards for application methods. DOC also has a series of data packages (chemistry, toxicology, residue and efficacy) to support the use of rotenone as a vertebrate toxic agent under the Agricultural Compounds and Veterinary Medicine Act (see Plate 4.1 for label).

The most common method of application for small ponds is by spraying a mixture of rotenone slurry and water onto the surface at a rate commensurate with water depth (Plate 4.2). Clean water can be trucked in if the water from the ponds being treated is not clean enough. In larger ponds or lakes, helicopter boom spraying can be used. Since 2000, over 81 rotenone operations have been undertaken from Northland to as far south as Timaru (Table 4.1). The majority have been small ponds, although three lakes from 10–17 ha in area (Table 4.2) have been treated in the Nelson-Marlborough regions using helicopters. The drains treated have all been in Motueka with gambusia being the target species. There was one successful experimental trial using rotenone slurry in the upper reservoir and stream tributaries of the Karori Sanctuary, Wellington, in 2011. The dosing of streams was carried out using a 'dam, divert, dose and discharge system' in headwaters of the tributaries above barriers to trout (Figure 4.1).

WARNING

Keep out of reach of children. Read label before using.

CUBE ROOT POWDER IN AQUEOUS SLURRY

Contains 12-18 g/kg rotenone

HSNO Approval Code: HSR007970 **Classifications: 6.1D, 6.3A, 6.4A, 6.9B, 9.1A, 9.3B, 9.4B**

WARNING: Toxic if swallowed or inhaled. Causes skin and eye irritation. May cause damage to blood or blood cell production through prolonged or repeated exposure. Ecotoxic.

PRECAUTIONS: Wear protective clothing including overalls, face protection, rubber gloves and boots. Use only outdoors or in well-ventilated area. Avoid breathing mist or spray. Do not eat, drink or smoke when using product. After use, wash hands and exposed skin thoroughly with soap and water. Wash protective clothing and dry before reuse

SYMPTOMS OF POISONING: Ingestion may result in symptoms such as stomach ache, nausea, abdominal cramps, muscle tremors and vomiting. Inhalation of spray or mist may cause respiratory stimulation followed by depression and convulsions.

FIRST AID: Contact a doctor immediately if poisoning is suspected. For further advice contact the National Poisons Centre, Phone 0800 POISON (0800 764 766). Have product label at hand.

IF SWALLOWED: Rinse mouth. Do NOT induce vomiting.

IF INHALED: Move victim to fresh air, keep comfortable and at rest. If breathing is difficult, oxygen may be beneficial. If person has stopped breathing give artificial respiration.

IF ON SKIN OR IN EYES: Rinse with plenty of water for at least 15 minutes, removing contact lenses after 5 minutes if present and easy to do.

STORAGE: Store product securely in a dry, cool, well-ventilated area out of direct sunlight, away from children, animals, pets and foodstuffs.

SPILLAGE: Contain and prevent spillage from entering drains or water courses. Recover product into labelled containers that can be sealed for recycling or disposal.

DISPOSAL: Unused product must be disposed of at an approved disposal facility. Empty containers must be triple rinsed with water before disposal at an approved disposal facility or returned for refilling. Do not use the empty container for any other purpose. Avoid contamination of any non target waterway when washing equipment or containers.

ENVIRONMENTAL INFORMATION: Very toxic to aquatic life. Toxic to terrestrial vertebrates and terrestrial invertebrates. Ensure warning signs remain in place and livestock excluded until rotenone residues fall below 0.25 µg/L in the waterbody.

DIRECTIONS FOR USE: ***Preparation and application:*** Stir contents well before removing them from the pail. Final mixing concentration of rotenone in the target waterway should be 4 - 5 x the LC$_{50}$ for the target species, but must not exceed 200 µg/L. To ensure complete kill of target fish, the rotenone must be dispersed throughout the waterbody.

Shore/boat application: May be applied by hose, spray unit, knapsack sprayer or gravity-fed dosing tank.

Aerial application: Use an aircraft equipped with suitable spray equipment or monsoon bucket.

SUPPLY AND USE LIMITATIONS: This product can only be used by a Warranted Officer or holder of a permit under s26ZR of the Conservation Act 1987.

The user must hold a special permit under s97 of the Fisheries Act 1996.

Only APPROVED HANDLERS (or person under the supervision of an Approved Handler) can mix and apply this product.

REGISTERED TO Department Of Conservation, 18 - 32 Manners Street, WELLINGTON 6011. PHONE: 0800362468

REGISTERED PURSUANT TO THE ACVM Act 1997, No. V9584. See www.foodsafety.govt.nz for registration conditions.

TRANSPORT INFORMATION: Proper Shipping Name: ENVIRONMENTALLY HAZARDOUS SUBSTANCE, LIQUID, N.O.S (contains rotenone); UN NUMBER 3082; HAZCHEM 3Z; PACKING GROUP III

NET CONTENTS 17 kg

Batch No.:

Expiry Date:

PLATE 4.1 Official rotenone slurry label (July 2014) showing the HSNO Act 1996 approval code and safety information. Note: there are different labels for powder supplied to factories which mix it up into slurry.

PLATE 4.2 Typical slurry mixing and tank pumping set-up used to spray rotenone onto the water surface (upper Karori Reservoir, Wellington). Green lidded buckets contain rotenone slurry as supplied from the factory.

TABLE 4.2 Types of habitat from which invasive fish have been eradicated in New Zealand.

HABITAT	NUMBER	AREA (ha)		
		MEAN	MIN	MAX
Drain	13	1.71	0.01	5.00
Pond/lake	101	1.45	0.0005	16.70

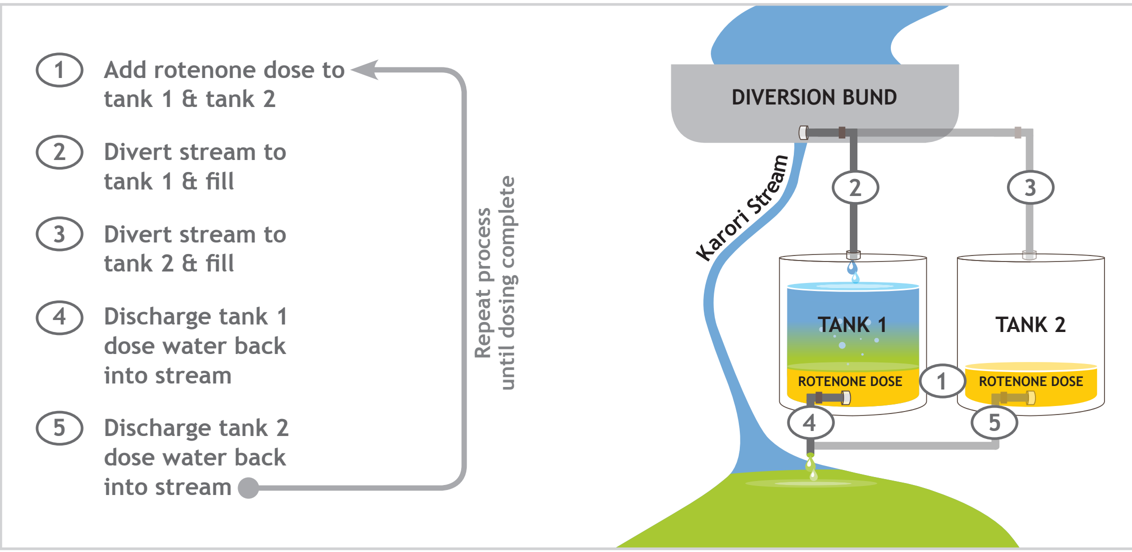

FIGURE 4.1 Dosing method used for Karori Stream rotenone treatment trial.

Although native freshwater communities were affected as expected, recovery was rapid and banded kōkopu (*Galaxias fasciatus*) populations have increased following the removal of trout (Pham *et al*. 2013).

Assays of rotenone concentration in treated waterbodies are undertaken on water samples from sites around the waterbody. There is a laboratory assay method for rotenone accredited by the International Accreditation New Zealand (IANZ), but no field or rapid detection method. Although original guidance on target rotenone concentrations in waterbodies was based on sensitivity (LC_{50}) of target fish to rotenone, current guidance is to aim for a 200 µg/L concentration throughout the waterbody. This dose is based on experience that conditions in waterbodies (e.g. suspended sediment), and difficulties in applying rotenone to achieve targeted levels, often result in lower than target doses of rotenone.

Thus far, locations of most operations have not been pristine so effects on sensitive species and ecosystems have not had to be fully assessed. The majority of habitats have been small ponds (Table 4.2) able to be closed off from flowing or larger waterbodies before treatment. Invasive non-indigenous fish species targeted were gambusia, koi carp, rudd and tench (Table 4.3); perch was also a by-kill. Gambusia has been the species most often targeted for eradication with rotenone. Koi carp is the second most treated species although, as surveys for pest fish have increased, more populations of illegally introduced noxious species (i.e. rudd), and sports fish such as tench have been found. Recent failures to eradicate gambusia from some South Island sites has been attributed at least in part to the presence of springs within drains and ponds treated with rotenone. Failures could also be due to other factors such as saline water, warm water discharges to drains acting as winter refuges, low (c.10°C or lower) water temperatures in parts of treated drains, and the possibility that live young gambusia survive treatment while inside pregnant females (see Section 5.3).

TABLE 4.3 Department of Conservation eradications of non-indigenous invasive fish showing target species by year (experimental brown trout removal using rotenone in 2011 not included).

TARGET SPECIES	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	TOTAL
Gambusia	1	18	3	7	3	3	1	3	1	0	6	1	6	53
Koi carp	1	5	0	4	3	4	1	14	0	2	3	0	0	37
Tench	0	0	0	0	0	0	0	7	1	0	6	3	0	17
Rudd	0	0	1	0	0	1	8	1	1	1	0	0	0	13
TOTAL	2	23	4	11	6	8	10	25	3	3	15	4	1	120

Drainage

Where waterbodies have no significant inflows or existing ones can be diverted, drainage is the best option. However, it should be noted that resource consents may be required for damming and diverting waterways. Complete drying (for approximately two weeks) of residual pools, sediments and macrophytes is necessary to avoid any risk of target fish or their eggs surviving. Disposal of drained water is also an important consideration with a variety of inlet and outlet screening required to minimise risk of entraining target species and spreading them to other waterbodies. The best option is to pump onto dry land well away from waterbodies or utilise existing irrigation takes to lower or drain a pond. A variety of pumps is available for this purpose, ranging from small portable fire pumps to large industrial pumps as shown in Plate 4.3. Drainage is also a good technique to reduce volumes of rotenone needed for subsequent eradication and to reduce risk of marginal vegetation providing refuges for target fish species.

PLATE 4.3 Large industrial pump used to drain Centennial Park ponds, Timaru. Note: in this case the residual ponds were then treated with rotenone.

Issues, Challenges and Gaps

The use of toxins such as rotenone will continue to evoke negative reactions even if used in a safe and responsible manner. Accordingly, alternatives are being and will continue to be sought by DOC. The toxicity of rotenone and sodium nitrite ($NaNO_2$) to koi carp in oral solutions was documented by Morgan *et al*. (2014), so development of baits containing these compounds may be justified where targeted delivery of poisoned baits can be accomplished. The alternatives available at this time, such as draining, are only able to be applied in limited circumstances, often with an increased investment of money and time, and a decrease in eradication certainty. Experience, procedures, tools and science developed around rotenone use gives New Zealand a sound basis for its use in standing waterbodies for eradicating non-indigenous invasive fish species. However, its use in streams for targeting invasive fish needs more work in the permissions, methods and benefits areas.

4.2 Tools for Drafting, Counting and Trapping Invasive Fish

Bruno David

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Background

Invasive non-indigenous fish such as koi carp and catfish tend to be highly mobile within river networks. They often undertake mass migrations at particular times during the year, frequently in response to particular environmental triggers such as flow and temperature. This aspect of their life-history presents an opportunity to identify key migration routes and 'bottleneck' areas to enable more efficient and targeted removal of these organisms from priority locations by traps and/or barriers. The use of traps and barriers for this purpose needs to consider the potential for effects or incidental capture of non-target organisms that may be using the same migratory pathways. Most of the recent development in cage and barrier design for point source control and restriction of movement of invasive fish has occurred in Australia and the USA. In Australia, these tools have primarily been developed to control koi carp (e.g. Conallin *et al*. 2008; Smith *et al*. 2009), and have also recently been applied in an attempt to prevent silver carp from accessing the Great Lakes of North America.

This section describes some of these relatively recent tool developments, including some New Zealand modifications to better accommodate local species' requirements and minimise non-target captures. Although a wide range of devices and prototypes have been developed and tested internationally, this section focuses on the utility of the following physical and non-physical options:

- Carp separation cages (CSC)—(i) evolution of the Williams' cage Mark I–IV (hereafter 'Williams CSC'); and (ii) the South Australian Research and Development Institute cage (hereafter 'SARDI CSC').
- Carp exclusion screens (CES) and one-way barriers (one-way 'finger' style element traps—Thwaites *et al*. 2007, 2010).
- Bubble curtains and acoustic fence combinations.

Carp Separation Cages

The carp separation technology known as Williams CSC after the original idea by Alan Williams, exploits the innate jumping behaviour of carp when confronted by an obstruction to passage. Australian native fish tend not to exhibit this behaviour at structures, and hence this behavioural difference has been explored to isolate invasive carp from native fish at Murray-Darling Basin fishways (Stuart *et al*. 2003). Numerous iterations to the original design have been undertaken, with Mark III (non-automated) and Mark IV (automated) designs having been tested and refined (Stuart *et al*. 2006). The Mark IV system has been further refined for the separation of carp and automatic release of native fish. In one investigation

SUGGESTED CITATION FOR SECTION 4.2: David B 2015. Tools for Drafting, Counting and Trapping Invasive Fish. Section 4.2 in Collier KJ & Grainger NPJ eds. New Zealand Invasive Fish Management Handbook. Lake Ecosystem Restoration New Zealand (LERNZ; The University of Waikato) and Department of Conservation, Hamilton, New Zealand. Pp 60–66.

the cage successfully separated 83% of adult carp (500+ individuals) into a confinement area while enabling the safe passage of 19,641 native fish (>99.9%) through the Williams' cage and the fishway (Stuart *et al*. 2006). The SARDI CSC incorporates similar separation technology but the superstructure of their CSC has been designed differently to provide alternate options for fish transfer, cleaning, safety and security at remote sites.

The largely 'stand-alone' automated aspect of the SARDI CSC design was considered advantageous for use at a Lake Waikare fish pass bottleneck site in the Waikato region, where a modified version of the SARDI CSC was commissioned for deployment. Separation technology was excluded from the design as a good understanding of the size of non-target fish species at this locality suggested that the vast majority of fish would most likely negotiate the structure without it. Depth and width measurements of a wide range of fish captured within the Lake Waikare fish pass were used to optimise the shape and size of the final screen mesh panels for the inner cage. The largest native fish of concern were shortfin and longfin eels (*Anguilla australis* and *A. dieffenbachii*, respectively). A smoothed edge diamond shaped plastic mesh (30 x 30 mm) was selected to maximise retention of small invasive fish and minimise retention of the majority of eels likely to be passing through this locality.

The Lake Waikare carp separation cage (Waikare CSC) demonstration site (Plate 4.4) was fully operational in December 2012 and removed around 10 tonnes of invasive fish in its first two years of operation. Fewer than 20 individual non-target fish were captured during that period. Non-target fish included one brown trout, five perch, six rudd, two giant kōkopu (*Galaxias argenteus*) and two shortfin eels. Upstream netting within the fish pass indicates that large numbers of smaller native and also small invasive species (particularly small catfish and goldfish <200 mm long) are passing through the cage design unharmed (H Molesworth, Massey University, unpubl. data), suggesting that the fish pass is an effective and reliable tool for mass adult invasive fish harvest with minimal by-catch at this locality.

Options may exist to refine cage mesh sizes and gaps to further optimise retention of smaller invasives, but there is likely to be a trade-off whereby greater numbers of non-target fish will also be retained if mesh size is decreased. Table 4.4 shows species numbers and biomass of invasive fish removed during the two years from December 2012 (non-target fish captured are not displayed). An additional 20 tonnes were removed from this locality during initial development testing and prior to the site becoming fully functional in December 2012, indicating the high biomass of invasive fish moving through this one locality and confirming the suitability of the locality for mass harvest.

PLATE 4.4 Waikato Regional Council 'Carp-N neutral Project' demonstration site at Lake Waikare showing the carp separation cage structure in the fish pass channel with thermophilic digester to process captured invasive fish on the right.

TABLE 4.4 Numbers and biomass (where indicated) of invasive fish trapped in the Lake Waikare carp separation cage from December 2012. The trap's gantry scale became operative in November 2013, hence N/A (not applicable) data for trap weights prior to this time.

DATE	NUMBER OF KOI CARP	NUMBER OF CATFISH	NUMBER OF GOLDFISH	TRAP WEIGHT (kg)
Dec 2012	1,875	891	8	N/A
Jan 2013	1,821	7	39	N/A
Feb 2013	Trap closed due to drought			
Mar 2013				
Apr 2013				
May 2013				
Jun 2013	220	0	5	N/A
Jul 2013	Trap closed			
Aug 2013	12	101	7	N/A
Sep 2013	155	49	1	N/A
Oct 2013	263	11	7	N/A
Nov 2013	1,221	241	230	1,940
Dec 2013	822	264	225	1,424
Jan 2014	304	0	96	538
Feb 2014	77	0	19	30
Mar 2014	149	0	5	275
Apr 2014	Trap closed			
May 2014	16	6	41	26
Jun 2014	7	1	0	13
TOTALS	6,942	1,571	683	N/A

Carp Exclusion Screens and One-way Barriers

These devices were originally explored and developed by Thwaites *et al*. (2007, 2010) to enable the directional movement and trapping of carp by exploiting their pushing behaviour (Plate 4.5). They can be utilised in various ways depending on project objectives. For instance, they may be used to enable fish to leave a particular locality but not get back in (see also Section 5.2), or they could be used to enable fish to access a particular locality and not get back out. A typical application is to use these devices in combination with a fish trap or automated cage system to trap and remove invasive fish from priority areas.

An important aspect to consider for the CES is the spacing distance between fingers to optimise the potential for unimpeded passage of native biota but to limit the access of invasive species, particularly larger, reproductively mature individuals. Having a reasonable understanding of the different fish species likely to be moving through particular localities, including their size (body width and depth), is important for optimising finger spacing and ultimately screening the smallest possible invasives while allowing access for the majority of native fish. In Australia, enabling the passage of larger-bodied native species such as *Nematalosa erebi* has necessitated the use of wider spaces in vertical bars (42 mm for that species) at some sites to accommodate passage and minimise by-catch (Connalin *et al*. 2008).

In contrast, New Zealand's native freshwater fish are typically much smaller than the dominant invasive non-indigenous fish, with koi carp, goldfish and catfish being either deeper-bodied and/or wider in cross-section than most native species. Effectively, smaller bar and finger spaces (30 mm wide) may be used in many (but probably not all) areas to improve retention of a greater proportion of invasive fish without compromising native fish passage. In the lower Waikato River basin, due consideration to some native species with wider cross-sectional body shapes, in particular grey mullet (*Mugil cephalus*), giant kōkopu and banded kōkopu, is likely to be required at some sites if this tool is to be widely used for invasive fish control.

Notwithstanding the potential presence of these species at some specific sites, an opportunity to utilise the one-way finger element structure (as designed by Thwaites *et al*. 2010) as a remote, primarily invasive fish 'counter' was proposed by Waikato Regional Council. The primary purpose for developing the counter was to assess whether information on invasive fish migration activity and timing could be collected remotely, and potentially establish what other environmental cues were responsible (e.g. lake level or water temperature, which can be monitored continuously with loggers). By coupling this device with a modified SARDI CSC, a secondary objective was to establish whether levels of activity could be used to optimise personnel response for emptying and managing upstream cage captures. A remotely operative radial gate for controlling lake levels at Lake Waikare also provided opportunities to undertake experimental flow releases and to observe the speed and strength of invasive fish response to that stimulus.

The counter provided a coarse assessment of invasive fish activity, however, there were a number of issues that disrupted data continuity and hampered a more robust assessment of the counter. Some issues with debris affecting the magnetic switches, and wider telemetry network issues (unrelated to the site), are still being resolved and improved. For instance, a 12-volt sealed lead acid battery as back-up power has now been installed if the mains telemetry system goes down, and recent improved screen design has minimised the build-up of debris on the structure.

PLATE 4.5 Waikato Regional Council's 'automated' one-way finger trap based on South Australian Research and Development Institute's finger element design. When a fish pushes through any finger, a stainless bar is raised resulting in the activation of a magnetic switch that sends a signal to a telemetered box nearby. This system enables the remote monitoring of primarily invasive fish activity at a site.

During experimental flow releases, general observations and remote finger counts demonstrated a relatively rapid (within six hours) response, primarily for koi carp. It was not possible to conclusively assume the increase in counter activity shortly following the flow release was due to this stimulus as a comparable control site to evaluate activity without the flow stimulus was not available. However, it seems likely that it was due to flow given what is known about the sensitivity of koi carp to hydrological changes and the lack of fish activity prior to the flow release.

At other times, activity responses appeared far from predictable, with high activity possibly associated with both increases and recessions in lake level or outlet flows (see Figure 4.2—upper panel). Again, without a control, it is difficult to evaluate factors influencing those movements with confidence. Other general observations from the counter device suggest that large runs of primarily gravid invasive fish in spring appeared to be influenced by rainfall or flow (possibly in association with temperature) but not diel period, whereas later migrations (from around early December) suggested that fish preferred to move through the counter and pass under the cover of darkness. Activity was very low during the day and noticeably higher between dusk and dawn, with the pattern often repeated over numerous consecutive nights (e.g. see Figure 4.2—lower panel).

In general, the high activity displayed by the counter typically resulted in high captures of invasive fish in the Waikare CSC. There is a deeper purposely-designed fish holding area between the finger counter and the Waikare CSC, which was created to take advantage of large directed early season runs into the lake. This approach enables some flexibility in humanely retaining large runs of invasive fish locally for removal if the cage itself is already at capacity and/or if more time is required to process fish. Consequently, there can be reasonable variance between finger counts in any 24-hour period and captures in the CSC itself, with many ‘counted’ fish able to continually stack up and ‘stage’ between the fingers and the CSC (see Plate 4.6).

PLATE 4.6 Invasive fish accumulating in the Lake Waikare fish pass holding area having passed through the carp exclusion screen finger counter. Fingers are located underwater (below hurricane mesh). The Waikare carp separation cage is approximately 40 m upstream.

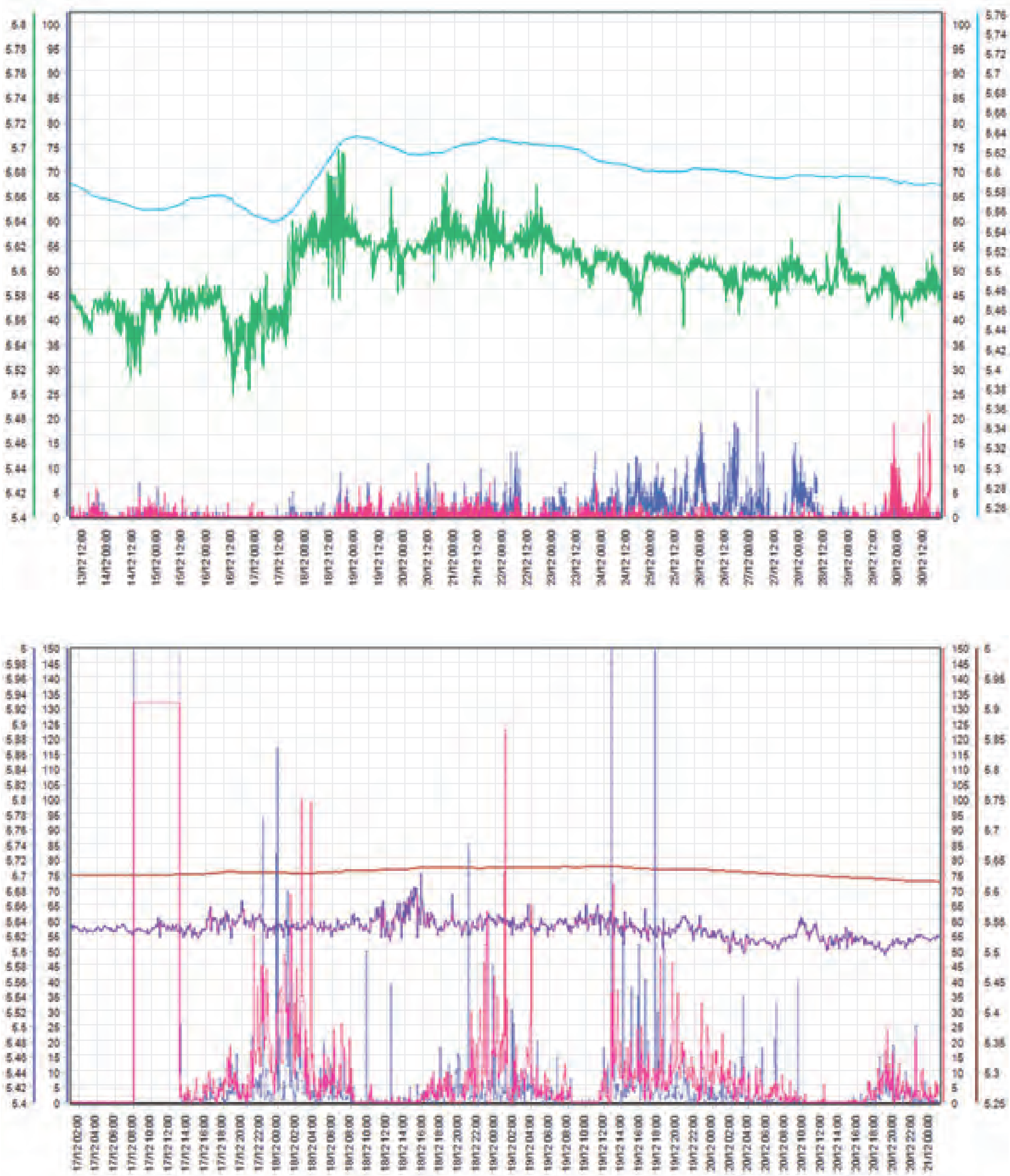

FIGURE 4.2 Telemetered data from Lake Waikere fish counter.

Upper panel: one-month plot depicting invasive fish counter response (blue = left gate, red = right gate' (no. counts per unit time)) to an increase in lake height over time (day/month hour:minute) in December 2014 (upper blue line = smoothed lake height (m), green line = raw lake level (m)).

Lower panel: four-day plot showing diel movement of invasive fish during December 2012. Note: increased activity occurs during low light levels (smoothed and raw lake level shown above fish counts). Units as for upper panel.

Bubble Curtains and Acoustic Fence Combinations

The idea to use bubble curtains to hinder the movement of fish is not new, but few studies have specifically investigated how or why they may work. A recent study by Zielinskia *et al*. (2014) evaluated their potential use for controlling movement of koi carp. In that investigation, the researchers examined the performance of fine, graded and coarse bubble curtain types in a laboratory setting. Results indicated that the graded and coarse bubbles reduced directional (upstream and downstream) movement of koi carp past the curtain by 75–85%. Additionally, the researchers used acoustic monitoring gear to identify the frequencies generated by the bubble curtain types and noted that frequencies around 200 Hz (c.130 dB) were recorded, well above the hearing threshold for koi carp. Following some further tests with speaker arrays and lighting, it was concluded that sound and fluid motion were more important than visual cues for restricting movement past bubble curtains. Although yet to be tested under field conditions, Zielinskia *et al*. (2014) consider this relatively inexpensive tool to be a viable deterrence system for limiting koi carp movement.

There appears to be considerable potential to combine various technologies and innovations for directing or preventing non-indigenous invasive fish movement. For instance, the Bio-acoustic Fish Fence (BAFF) is a recently-developed integrated acoustic system incorporating a concentrated acoustic field and a bubble curtain. This system consists of an electromagnetic or pneumonic sound transducer coupled to a bubble sheet generator, and causes sound waves to be propagated inside the bubble curtain forming a multi-layered carp barrier. However, BAFF systems are quite expensive to implement, typically amounting to about $US1.2 million (Brammeier *et al*. 2008). Conceivably, various combinations of these systems and frequencies, in association with graduated electric barriers, may provide useful non-physical tools to guide and direct particular invasive species either away from high priority conservation areas or towards strategically located trap and removal devices.

Implementation of Tools for Control or Eradication

It is apparent and well-recognised that invasive fish are more susceptible to capture at certain times of the year than at other times, and that a number of key factors may be involved. Species such as koi carp and catfish are known to be highly responsive to changes in hydrology, rapidly exploiting newly-inundated areas for feeding and spawning. In the Waikato region, responses appear to be particularly strong during warmer months (from early September), and especially during periods of inundation following extended periods of stable lower flow. A number of researchers have taken advantage of this behavioural characteristic by manipulating water levels to induce directed movement and sabotage carp spawning (Shields 1957; Verrill & Berry 1995; Smith 2005). Such a strategy is likely to be highly effective in many parts of the Waikato region where opportunities to also control catfish through regulated lateral inundation may be significant. It is important to understand, however, that strategies to minimise entrapment of eels, which are similarly responsive to lateral inundation events, need to be carefully considered during implementation. Certainly, opportunities to exploit differences in eel body morphology, behaviour, and climbing ability exist to reduce non-target capture of these species in such situations.

Historically, efforts to control koi carp have focussed on removing large adult fish, with assessment of turbidity often being used to evaluate success in relation to biomass removed. Recent work suggests that even larval-juvenile fish can have a trophic impact on water clarity by altering food web structure and function (Vilizzi *et al*. 2014; see also Section 2). Thus, preventing large gravid fish from entering and successfully spawning in lakes may have a greater benefit for water clarity than first realised unless recruitment success is being controlled by density-dependent processes.

4.3 Role of Screens and Barriers for Management of Invasive Fish

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Background

Fish barriers or screens are sometimes required to prevent new fish invasions or to exclude fish following removal to restore degraded habitat. Vertical barriers can be as simple as a timber weir or a perched culvert, and can be split into ‘high head’ (>1.0 m) or ‘low head’ (<1.0 m) barriers. The climbing ability of many migratory native fish and the inability of the current suite of invasive species to pass barriers >1 m high make vertical high-head barriers ideal for invasive fish exclusion in most parts of New Zealand. Native fish passage can be facilitated if necessary using ramps with brush material or other climbing material such as mussel spat ropes (David *et al*. 2009; Jackman 2009).

In situations where a fall height of only 0.5 m or greater can be achieved, it is unlikely that species with the ability to jump will be effectively excluded without additional passage prevention. A low cost solution to this problem could be a weir design similar to that shown in Figure 4.3 with an additional gabion basket (filled with 200+ mm aggregate) to remove the plunge pool or prevent fish from accessing the area below a barrier. However, many shallow lakes are connected to other waterbodies via drains with little vertical fall. In such situations, self-cleaning screens (Neitzel *et al*.1991), electrical barriers (Verrill *et al*. 1995; Gumbley 2010) and one-way barriers (Thwaites *et al*. 2007; see also Section 4.2) can be very effective, requiring little or no head. Self-cleaning

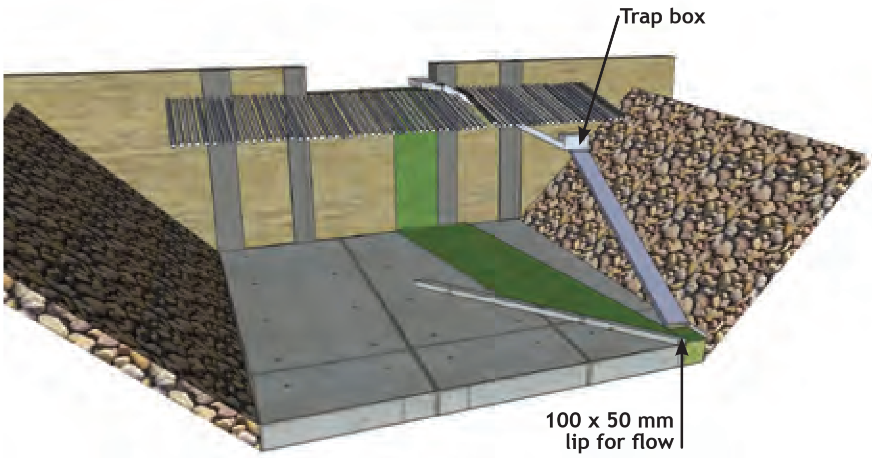

FIGURE 4.3 Conceptual design showing the cross-section of a stream with a timber weir installed. Stream banks are armoured with gabion baskets and a stilling basin to prevent undercutting. This design shows both a brush-type fish passage material in green and an elver ramp with transition box on the right-hand side. Bars shown near the top of the weir are to block fish from jumping in case of standing water in the stilling basin.

SUGGESTED CITATION FOR SECTION 4.3: Gumbley J, Daniel A 2015. Role of Screens and Barriers for Management of Invasive Fish. Section 4.3 in Collier KJ & Grainger NPJ eds. New Zealand Invasive Fish Management Handbook. Lake Ecosystem Restoration New Zealand (LERNZ; The University of Waikato) and Department of Conservation, Hamilton, New Zealand. Pp 67-71.

rotating drum screens would be effective in stopping future fish invasions or preventing recolonisation after fish removals (Daniel & Morgan 2011), but also need to consider native fish passage. Self-cleaning screens and electrical barriers have not been widely implemented in New Zealand due to the cost and maintenance required. One-way fish barriers are cost-effective for the exclusion of large adult invasive fish as they can be easily retrofitted to culverts.

Examples of Successful Fish Barriers

To date only two fish barriers have been installed in conjunction with shallow lake restoration programmes in the Waikato region—a wood weir at the Rotopiko (Serpentine) Lake complex and a one-way steel gate on the outlet drain of Lake Ohinewai. Both lakes are Department of Conservation wildlife management reserves surrounded by planted riparian margins. Lake Ohinewai and the Rotopiko (Serpentine) lakes have ongoing fish management programmes aimed at reducing the impact of invasive fish on native plants and animals (see sections 5.2 and 5.4). These lakes represent both ends of the restoration spectrum with the Rotopiko (Serpentine) lakes holding good biodiversity values requiring protection and Lake Ohinewai in a severely degraded state requiring restoration.

LAKE OHINEWAI ADULT KOI CARP SCREEN: The outlet of Lake Ohinewai is a man-made drain that flows into Lake Rotokawau and then Lake Waikare, which in turn is connected to the Waikato River. Following installation of a screen, an invasive fish draw-down in 2011 achieved a 50% reduction in invasive biomass using a range of fishing techniques (Daniel & Morgan 2011; see Section 5.2). It was hoped that placement of a one-way barrier (Plate 4.7) would prevent large (adult) koi carp from migrating up into the lake, while enabling all fish to exit the lake, ultimately leading to an improvement in lake condition (but see Section 2.2). Large eels (up to 600 mm) can still enter and exit the lake through the barrier. Based on previous telemetry data (Daniel 2009), there was an expectation that up to 75% of adult koi carp would leave Lake Ohinewai in any given year, reducing the lake biomass without further manual removal, although koi carp recruitment might compensate for the loss of adult fish.

When closed, the screen enables fish of up to 30 mm width to move upstream, allowing most native fish to pass freely. The uni-directional bars can be pushed open in a downstream direction by any fish larger

PLATE 4.7 Lake Ohinewai outlet drain fitted with a one-way gate showing adult koi carp attempting an upstream pass (left panel), and screen lifted for inspection and clearing of debris (right panel).

than the aperture. To ensure the screen stays shut, any weed or debris accumulation in the screen enclosure can be cleared by raising the screen (Plate 4.7), and the screen can be forced open in a severe flood to prevent blockage. Since its installation in 2012, debris removal has been infrequent (less than six times a year), and any accumulations can be easily unblocked via a hand winch system installed in 2012. DOC has committed to applying for resource consent to manage the screen, and will continue assessing the effectiveness of this one-way barrier by monitoring fish abundance in the lake.

ROTOPIKO (SERPENTINE) LAKES INVASIVE FISH BARRIER: With the possibility of invasive fish control (or eradication) being implemented in the Rotopiko (Serpentine) lakes, the need for construction of an invasive fish barrier was identified. Further, the possibility of other invasive fish, particularly koi carp, entering the lake complex could not be discounted. Discussion about what kind of barrier might be constructed was wide-ranging. Having a barrier that was relatively low cost and low maintenance was essential, but it was also noted that the lake-complex outlet was surrounded by flat, thick peatland that is flood prone. On-going peat shrinkage could be expected and any structure was likely to be built on private farmland, potentially inhibiting long-term access. Hydrological modelling identified a suitable site for placement of a barrier about 2 km downstream of the lake outlet (Mulholland 2010). The site presented an appropriate fall height and was downstream of a farm culvert, reducing the risk of flooding in severe or extended storm periods. Agreement of the local drainage committee and landowner was obtained through extensive consultation.

Advice was sought from a registered engineer and fisheries scientists, resulting in the design of a vertical slotted-timber structure (Plate 4.8). An early design was not accepted because it had a concrete barrier which was considered too inflexible in terms of ease of raising or lowering the crest. There were also issues around de-silting behind the structure (although this could have been remedied by use of a mud pump), and the cost which was likely to be at least 4–5 times that of a wooden structure. Another concern was that the structure was to be built on private land and the landowner was unwilling to enter

PLATE 4.8 Invasive fish barrier on Rotopiko (Serpentine) lakes outlet drain immediately following construction in early 2012. Left photo shows slotted timber construction, Reno mattress and grill bars. Right photo shows the upstream close-up view of the barrier.

into a legal agreement to provide surety of access. The accepted design provided for elver passage through the use of black nylon brushes centrally placed on the v-notch. Construction of the barrier was completed in early 2012 and it became operational in the autumn of that year (Plate 4.9). Having a sound working relationship with the landowner, sharemilker and farm manager, as well as other farmers in the catchment, was critical to the success of the project as it was just one part of a wide-ranging programme of lake ecosystem conservation management in the area.

From April to May 2012, there was a sustained period of rainfall that was sufficient to cause overflow of drains and flooding of pasture. Farmer concern that the barrier may be contributing to pasture flooding and damage resulted in his reducing the height of the barrier to lower drain water levels. Further surveying and revised hydrological modelling by Waikato Regional Council (M Mulholland, Waikato Regional Council, pers. comm.) confirmed that the (consented) height of the barrier needed to be lowered in order to avoid flooding of pasture upstream, primarily in the area of the former Round Lake (Peters 2008). A revised barrier plan, which retains the principal design elements of having a Reno (concrete) mattress on the stream bed, horizontally-placed timber in a vertical structure with adjustable centre panels, and nylon brushes to provide for elver passage, has subsequently been approved. The key difference to the original design is the lower crest level, reducing the minimum fall height of the barrier to <1 m, and requiring a rock gabion basket that is intended to extend the full length of the Reno mattress to remove invasive fish access immediately below the barrier (Figure 4.4).

PLATE 4.9 Rotopiko (Serpentine) lakes outlet drain invasive fish barrier operating in April 2012.

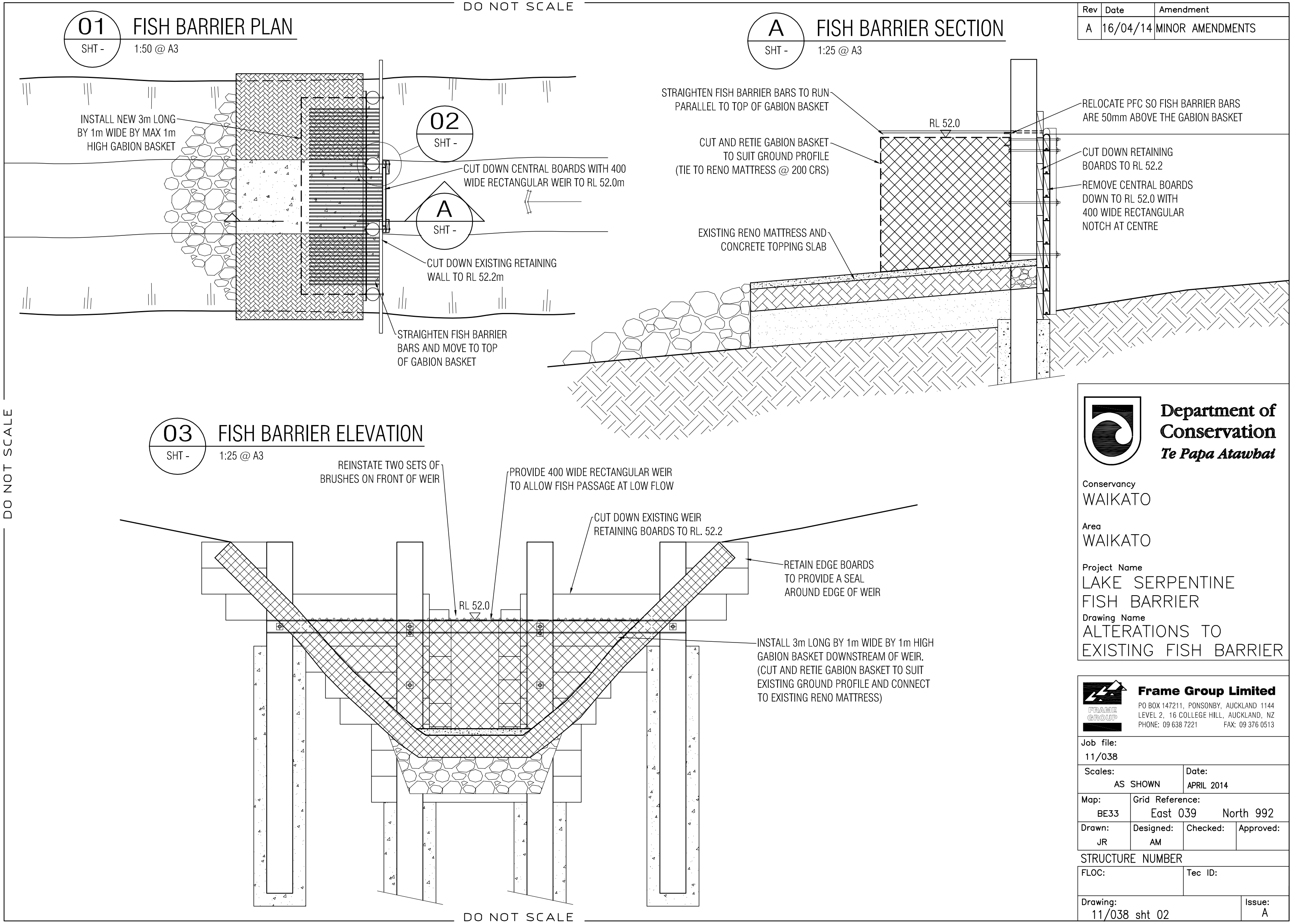

FIGURE 4.4 Proposed (modified) Rotopiko (Serpentine) lakes outlet drain invasive fish barrier showing a gabion basket placed on top of the Reno mattress positioned on the stream bed. This design is suitable for drains and road culverts with a fall height of <1.0 m.

4.4 Use of Electrofishing for Capturing Invasive Fish

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Background

Electrofishing is the use of electricity to capture fish. The response of fish to pulsed direct current (DC) occurs in five phases, as shown in Figure 4.5. Electrotaxis occurs as a result of the electrical effect on fish muscles that contract with each electrical pulse, rather than its effect on the central nervous system. Each pulse of electrical current in a pulsed DC field causes the fish's body to flex; it then relaxes between each of the pulses. This flexing and straightening action accentuates the involuntary swimming towards the anode (galvanotaxis). Pulsed DC causes tetany and narcosis at a much lower voltage gradient than continuous DC, so this is the preferred current delivery (Brousseau *et al*. 2005). Because invasive fish species inhabit a wide variety of non-wadeable habitats, this chapter will focus on boat electrofishing.

New Zealand has a light-handed approach to the regulation of electrofishing. Users are required to inform those responsible for fish conservation and management of the existence of devices, and when and where electrofishing is to occur. Electrofishing devices must be authorised by the Director General of the Department of Conservation, and authority is required from the Fish & Game council for use of an electrofishing machine in a specific region under the Freshwater Fisheries Regulations 1983. Under the Fisheries Act 1996, permission is required from the Ministry for Primary Industries (MPI) for the capture of fish by methods other than those allowed by recreational fishing regulations. Capture of fish by electrofishing, though legal as a research tool, is not a permitted recreational method and thus requires a special permit from MPI issued under s97 of the Fisheries Act 1996. Ethical considerations for the capture and handling of fish fall under the Animal Welfare Act 1999, and are usually administered at institutional level.

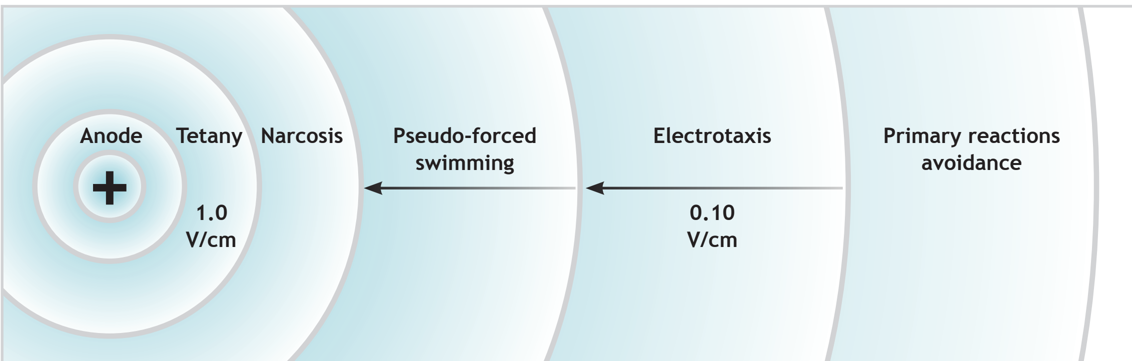

FIGURE 4.5 Generalised behaviour patterns of fish in pulsed direct current with approximate voltage gradient thresholds of fish (Lamarque 1967). Adapted from Vibert (1963).

SUGGESTED CITATION FOR SECTION 4.4: Hicks BJ, Jones MH, de Villiers JE, Ling N 2015. Use of Electrofishing for Capturing Invasive Fish. Section 4.4 in Collier KJ & Grainger NPJ eds. New Zealand Invasive Fish Management Handbook. Lake Ecosystem Restoration New Zealand (LERNZ; The University of Waikato) and Department of Conservation, Hamilton, New Zealand. Pp 72-79.

Electrofishing Boat

BOAT OPERATION: Currently, the only electrofishing boat in New Zealand is run by The University of Waikato (Plate 4.10). Their boat was built in 2003 based on the experience of Australian fishery researchers. It comprises a custom-built, 4.5 m long, 2.0 m beam, aluminium hull of pontoon design with a 6° V-shape to improve handling in choppy water (Orca Engineering and Marine Ltd, Rotorua, New Zealand). The boat electrofishing gear consists of a 5 kilowatt petrol-powered pulsator (GPP model 5.0, Smith-Root Inc, Vancouver, Washington, USA) powered by a 6 kilowatt custom-wound Honda generator. Two anode poles, each with an array of six 1 m long stainless steel wire droppers, create the fishing field in front of the bow, with the boat hull acting as the cathode. For standard operation in boat electrofishing, the pulsator is set to low range (50–500 V) or high range (50–1000 V), depending on the ambient electrical conductivity of the water, with pulsed direct current and a frequency of 60 Hz (pulses per second). The range of conductivity in which electrofishing is generally effective is about 50–500 µS/cm, which includes most lowland waters in New Zealand, although fishing habitats with up to 2,800 µS/cm (Muddy Creek, Hawkes Bay, in 2003) has been successful. The percent-of-range setting of the pulsator is adjusted to give a consistent applied current of 3–4 amps root mean square, adjusting the setting as necessary as the boat travels through water of different ambient conductivity.

From past experience (Hicks *et al*. 2006) an effective fishing field in which fish are immobilised equates to >1 V/cm. Fish affected by the field at depth (1–2 m below the surface) often float to the surface, still narcotised, beside the boat. Combined with the reach of the netters, the effective fishing field extends to about 2 m either side of the centre line of the boat (Figure 4.6), and the boat therefore fishes a transect 4 m wide, which is generally consistent with behavioural reactions of fish at the water surface. The boat's fishing path is tracked and linear distance fished estimated with a hand-held Garmin GPSMAP 60Cx global positioning system. The area fished is calculated by multiplying this length by the assumed width of the fishing field (i.e. 4 m).

PLATE 4.10 The 4.5 m long, aluminium-hulled electrofishing boat developed by The University of Waikato in 2003, showing the anode poles at the bow, the generator at stern positioned under the boat driver's seat, and fibreglass-handled dip nets for retrieving fish.

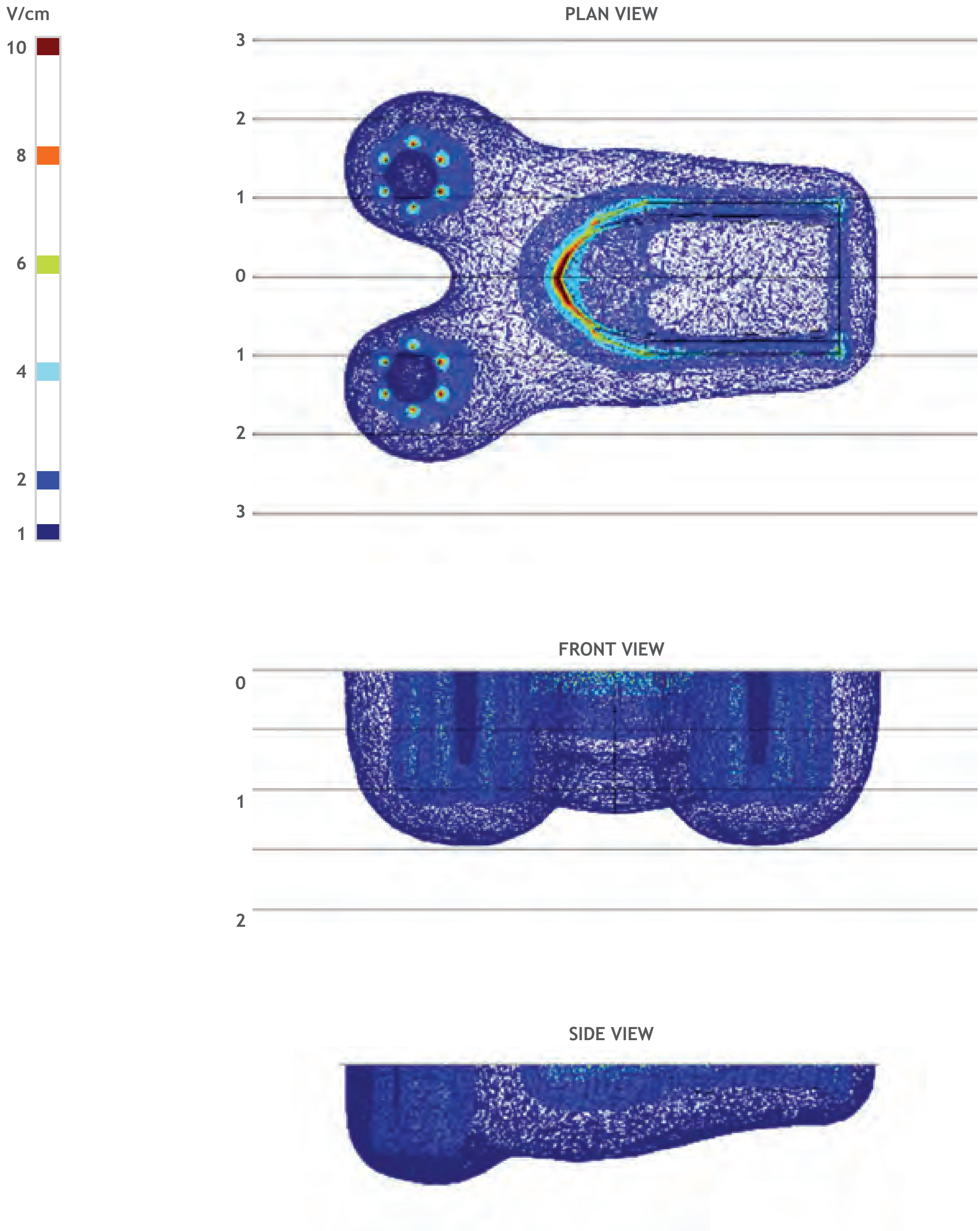

FIGURE 4.6 Simulated isosurface plot of voltage gradients ≥1 V/cm around The University of Waikato's electrofishing boat. The boat has bow-mounted anodes of two hexagonal drop-tail clusters (1 m drop) and a pulsator output of 500 V peak output drawing 5.0 A root mean square in water with ambient conductivity of 170 µS/cm. Source: Jones (2010).

PELAGIC ELECTROFISHING WITH SCOOP NETS: To maximise effort for pelagic species fine-meshed scoop nets were added to the electrofishing boat. These were aluminium-framed whitebait nets constructed from hexagonal polyester mesh (2 mm) and an ovoid mouth opening area of 0.79 m^2. These nets are deployed from the bow of the boat with a hinged, T-shaped attachment, with each scoop net positioned behind an anode (Plate 4.11).

PLATE 4.11 The first author (right) lowering fine-meshed scoop nets into position to fish for pelagic species.

HEALTH AND SAFETY: To address safety concerns, the boat's emergency shutdown circuits were designed in close cooperation with the Energy Safety Service of the then Ministry of Economic Development, the electricity safety regulator at the time. Two fishers at the bow are required because each has a foot switch, both of which must be depressed to activate the fishing field. The fishing crew wears rubber footwear and rubber gloves to insulate against possible electroshock. A cardiac defibrillator is a standard piece of equipment on board the boat for first aid in the event of an electrical accident.

EFFECTS OF WATER CLARITY AND VISIBILITY: The effectiveness of electrofishing is directly dependent on water clarity because in general fish have to be seen to be caught by the netters. A vertical Secchi disc depth measurement is the usual way of measuring water clarity from the surface (Tyler 1968; Preisendorfer 1986), but has the limitation that in some shallow habitats the bed is visible before the critical Secchi disc depth occurs. Horizontal black disk distance measurements provide a practical alternative to Secchi disc depths, and have a well-established relationship (Davies-Colley 1988). Before each boat electrofishing occasion we measure black disk distance to quantify the contribution of water clarity to the effectiveness of boat electrofishing. In lowland aquatic habitats, most black disc distances during electrofishing have ranged from 0.2 to 1.9 m.

Quantitative Fish Abundance Estimates

CAPTURE EFFICIENCY: Electrofishing captures only some of the fish encountered by the electric field because a proportion display the primary avoidance response before encountering the ranges of voltage gradients that produce galvanotaxis, narcosis, forced swimming or tetany (Figure 4.5). Thus, one goal of quantitative electrofishing is to estimate capture efficiency, which can be determined from comparisons of removal population estimates (Otis *et al*. 1978; White *et al*. 1982) and the number of fish caught in the first removal or pass.

Previous studies have used multiple-removal boat electrofishing, and Meador (2005) found that the first pass achieved 66% of the total species richness. Mitro & Zale (2000) compared first removals to multiple removal population estimates for the Snake River, Idaho, and found capture probabilities of 0.73–0.76. Bayley & Austen (2002) estimated capture efficiency from comparisons of boat electrofishing and independent population estimates of warm-water fishes in Illinois lakes by a combination of toxicants, explosives and drainage. They concluded that maximum catchabilities (fish capture efficiency) by taxon ranged from 0.0018 to 0.14, and also varied with fish length. One study used multiple removal boat electrofishing to estimate fish biomass directly in a Massachusetts river, without first calculating density, and concluded that total biomass equated to mean single-pass biomass in g/m^2 x 4.002 (Thompson *et al*. 2002).

For The University of Waikato boat, capture efficiency of single-pass boat electrofishing (first removal/population estimate, ± 95% confidence interval) averages 0.48 ± 0.10 (37 species' comparisons). Total population estimated from the Zippin method (Y) was significantly related to the number of fish caught in the first removal (X) (adjusted r^2 = 0.86, n = 37, P <0.001; Figure 4.7). However, the relationship was non-linear for increasing number of fish in the first removals, as shown by least-squares regression converted from the log-linear form in Figure 4.7:

$$\text{Removal population estimate} = 1.87\ (\text{First removal})^{1.129} \qquad \text{(Equation 1)}$$

This relationship can be used to estimate the population size from a single pass of the electrofishing boat.

REPRESENTATIVENESS OF CATCH: The representativeness of boat electrofishing from 770 samples at sites throughout the North Island gives a unique view of fish community composition and relative abundance. On this basis, koi carp and goldfish are by far the most numerous and widespread invasive species (Table 4.5). The mean catch rates for koi carp from 205 fishing occasions in which they were found was 714 g/minute, or 0.46 fish/minute. Goldfish usually co-occur with koi carp and were more numerous (1.06 fish/minute), but had a much lower biomass because of their smaller size. Catfish and rudd were caught at fewer sites and with similar catch rates. Tench had a very restricted distribution, and were caught with koi carp on only three out of 13 fishing occasions when tench were caught. These were in the Paramuka Ponds, west Auckland, in 2007 and the Hikutaia Cut, eastern

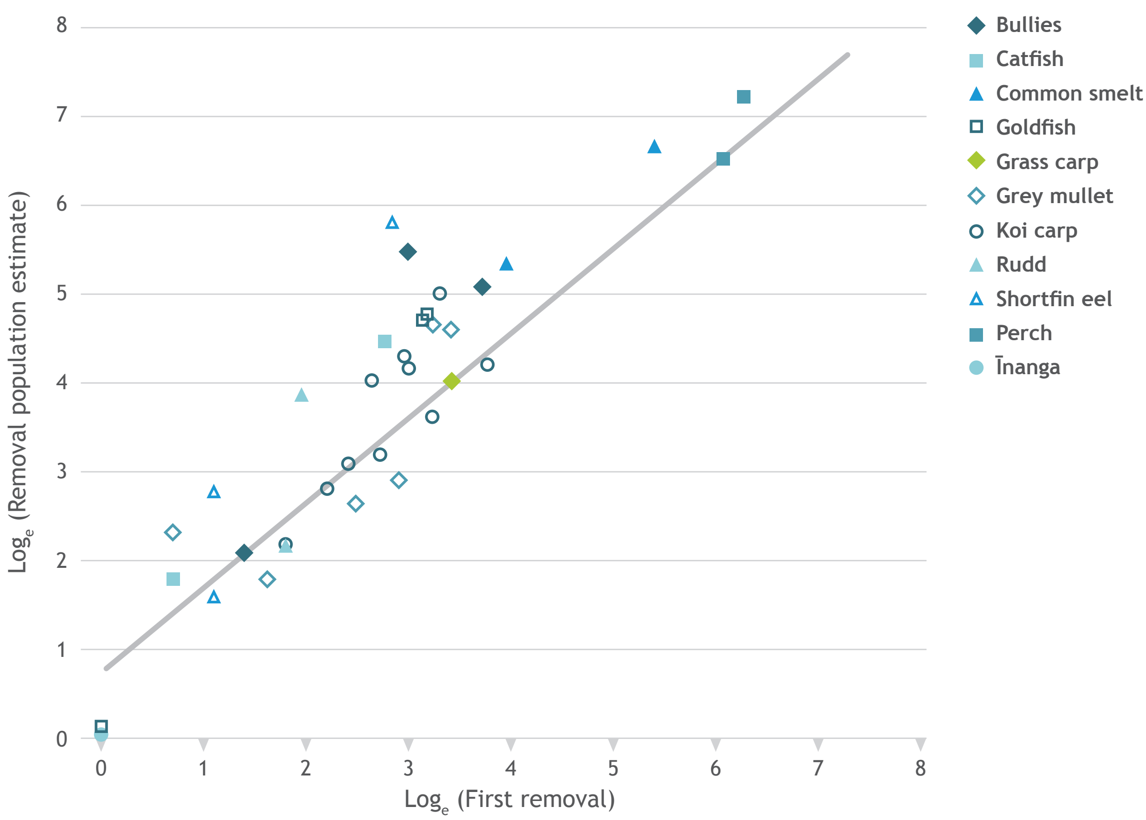

FIGURE 4.7 Relationship of first removals to population estimates from multiple-removal boat electrofishing.

Waikato, in 2003, 2006 and 2013. When the Hikutaia Cut was fished in 2014 and 2015 koi carp but no tench were caught, suggesting that the tench have disappeared. Given that tench occurred in the Whangamarino Wetland before the spread of koi carp (Strickland 1980) but no longer occur there (Hicks *et al*. 2008; Lake *et al*. 2009), koi carp appear to eventually exclude tench in the Waikato.

OPTIMISING TIME AND DURATION OF FISHING: Night fishing greatly increases catch rates of perch. In the lower Karori Reservoir, Wellington, and Lake Rotokare, Taranaki, where perch dominated the fish communities, catch rates were on average 12 times greater at night than during the day, though highly variable (Table 4.6). In Karori Reservoir, catch rates began to increase on dusk, presumably as fish moved into the shallow littoral zone and into the range of the electrofishing field (Hicks *et al*. 2007).

In Australia, fishery researchers have developed a protocol of 2-minute fishing shots, principally to fish around large woody debris (snags) in the water. Successive increases in the duration of fishing shots were evaluated by comparing mean catch rates in fish/minute for 2, 5 and 10 minute boat electrofishing shots in water of 0.8–1.5 m depth (Table 4.7). Catch rates increased with increasing time up to 10 minutes/shot. Given that 10 minutes plus handling time for each catch allows 3-5 shots/hour, we consider that 10 minutes/shot is optimal for most boat electrofishing in New Zealand. Occasionally 20 minute shots are more appropriate where replicates are less important than handling time.

TABLE 4.5 Number of sites and catch rates of key invasive fish species caught by boat electrofishing in 770 samples between July 2003 and February 2010 in the North Island.

SPECIES	N	CATCH RATE	
		(g/minute)	(fish/minute)
Koi carp	205	714	0.46
Goldfish	205	98	1.06
Catfish	115	36	0.17
Rudd	91	14	0.18
Perch	66	54	0.71
Tench	13	62	0.26

TABLE 4.6 Catch rates of perch in the lower Karori Reservoir, Wellington (20-minute shots), and Lake Rotokare, Taranaki (10-minute shots), during the day and night.

LOCATION	SITE	DATE	NUMBER OF FISH/SHOT		NIGHT/DAY
			DAY	NIGHT	
Karori Reservoir	K4	Feb 2007	230	522	2.3
	K5	Feb 2007	26	430	16.5
	K5	Feb 2007	105	430	4.1
	KD15	Feb 2008	29	115	4.0
	KD16	Feb 2008	1	31	31.0
Lake Rotokare	1/6	Feb 2013	8	125	15.6
MEAN					12.2

TABLE 4.7 Mean catch rates for boat electrofishing shots of 2, 5 or 10 minutes/shot in Lake Waahi, Waikato, during the day and 10 minutes/shot at night on 8 March 2007.

SPECIES	CATCH RATE (fish/minute)			
	2 MIN, DAY	5 MIN, DAY	10 MIN, DAY	10 MIN, NIGHT
n samples	3	3	5	6
n species	3	7	9	10
NON-INDIGENOUS SPECIES				
Goldfish	0.50	1.07	3.24	1.28
Koi carp	0.17	0.20	0.28	0.18
Rudd	0.00	0.07	0.20	0.23
Catfish	0.00	0.00	0.18	0.25
Perch	0.00	0.13	0.14	0.03
Gambusia	0.00	0.60	0.06	0.13
Grass carp	0.00	0.00	0.02	0.00
INDIGENOUS SPECIES				
Shortfin eel	0.33	0.33	1.70	1.43
Common bully	0.00	0.07	0.26	0.13
Common smelt	0.00	0.00	0.00	0.18
Īnanga	0.00	0.00	0.00	0.02
TOTAL	1.00	2.47	6.08	3.88

Fish Injuries

Electrofishing has a reputation for injuring fish and boat electrofishing is no exception. The real question, however, given that invasive fish control involves removing fish, is how injury rates for non-target species from electrofishing compare to rates for other capture methods. For instance, Reynolds & Holliman (2004) found spinal damage in 60% of 18 American eels (*Anguilla rostrata*) electrofished at 30 Hz pulsed DC, but in only 15% of 20 trap-netted eels. Haemorrhages were found in 30% of the electroshocked fish but in none of the trap-netted fish. The ambient conductivity was not given in that study.

Spinal damage was detected in only 8–12% of 25 shortfin eels (395–734 mm total length) caught with The University of Waikato electrofishing boat at 60 Hz on low range (50–500 V), compared to 0–4% of 25 trap-netted eels. Haemorrhages immediately after electrofishing were inconsistent (0% in eels from Lake Areare and 28% in eels from Lake Rotongaro, Waikato region). A possible cause of this difference was the water depth during fishing, which was c.1 m deep for Lake Areare and up to 2 m deep for Lake Rotongaro. As a consequence, the anode tails touched the lake bed during fishing in Lake Areare, which may have dissipated the electrofishing field. Recovery from haemorrhaging was rapid, as only 4% of a separate sample of eels from Lake Rotongaro had haemorrhages 30 days after electrofishing (de Villiers 2013).

Grey mullet (229–436 mm fork length), captured by boat electrofishing (*n* = 29 fish) and gill netting (*n* = 25 fish), were also analysed for injury. Spinal injury rates were 14% for boat electrofishing and 12% for gill netting, and were not significantly different. However, haemorrhaging occurred in 24% of electrofished grey mullet but only 8% of gill-netted mullet (de Villiers 2013). Common smelt (38–109 mm long), captured by boat electrofishing (*n* = 1,224 fish) and seine netting (*n* = 1,278 fish), were analysed for spinal damage, haemorrhaging and survival after a post-capture holding period of 30 minutes. Spinal injury rates were 10% for electrofished smelt and 5% for seine-netted smelt, but these rates were not significantly different. Smelt mortality after 30 minutes in 20ºC aerated water following capture was 5% for electrofishing and 7% for seine netting. Haemorrhages were not detected in smelt from either capture method.

Summary

Boat electrofishing is a valuable tool for conducting population estimates of several invasive fish species because of their high catch rates, particularly for koi carp and goldfish in shallow water, but also for tench and perch. Eels and catfish, however, are under-represented in electrofishing catches compared to fyke netting (see Section 6.3). Boat electrofishing can provide rapid, quantitative estimates of fish density and biomass in non-wadeable rivers and lakes on an areal basis, and is far more efficient than other techniques such as mark-recapture. Large areas can be surveyed, which increases the representativeness of the sampling dramatically.

Electrofishing provides a unique view of the fish communities in littoral zones and shallow lakes because it has fewer biases than other capture techniques. Novel methods such as fine-mesh scoop nets extend the boat's sampling capability to pelagic fish near the surface, and lights permit night fishing which increases the catch rate of perch. Rates of spinal injury for non-target shortfin eels, grey mullet, and common smelt are similar to other capture methods that target these species, but the rate of haemorrhaging in eels and grey mullet can be greater for electrofishing. However, eels held for 30 days showed that this haemorrhaging apparently healed rapidly. The current limitation of this method is that New Zealand has only one electrofishing boat.


KOI
Photo: Nadine Gibbs (DOC)


GAMBUSIA
Photo: Denise Goodman (DOC)


TENCH
Photo: David West (DOC)

5

Invasive Fish Control Case Studies

Several examples of invasive fish control exist in New Zealand and internationally, focussed primarily on single-species. These initiatives have achieved varying levels of success and have sometimes yielded ecological surprises. The lessons learned from these efforts provide valuable insights into what works and what doesn't, and the long-term outcomes of sustained invasive fish management. This section presents a series of case studies from New Zealand and Australia, each with different approaches to invasive fish management. They range from rapid responses to new incursions aimed at eradication, to fishing down numbers to reduce ecological impacts, and pre-emptive actions to prevent new incursions into valued ecosystems.

5.1 Managing and Eradicating Carp: A Tasmanian Experience

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Management Issues

Tasmanian inland waters are home to a diverse array of native fauna and flora, many of which are unique, with some threatened or endangered. These waters also support a recreational angling industry and commercial eel fishery of significant importance to the State's economy. Invasion by pest species poses a serious threat to the natural values and resources. In the mid-1970s and again in 1980, European carp were found in a number of farm dams on the north-west coast of Tasmania, allegedly stocked by a local farmer to feed pigs. Being mainly contained within a single catchment, they were eradicated promptly by rotenone poisoning. In 1995, the discovery of carp in two large lakes, Crescent and Sorell, on the eastern edge of the central highlands, and their potential for spread to other waterbodies across the State, posed a more severe threat to a range of environmental, economic and recreational values. Given that carp are highly fecund and adaptable, all freshwater resources were considered vulnerable to the invasion, as was previously demonstrated by successful carp invasion of the Murray-Darling basin (Gehrke *et al*. 1995; McKinnon 1997), following their introduction to mainland Australia in 1859.

Lakes Sorell and Crescent (Figure 5.1) are large, shallow and interconnected, located in the south-eastern corner of the Tasmanian Central Plateau (Lake Sorell: 147°17'E 42°11'S; Lake Crescent: 147°16'E 42°18'S). They are situated at 800 m Australian Height Datum at the head of the Clyde River catchment, and cover about 5,310 ha and 2,305 ha in area, respectively (Heffer 2003). At full supply, both lakes have extensive wetlands connecting to the main lake bodies that are described as the largest areas of shallow water in Tasmania (Kirkpatrick & Tyler 1988). A lakeside reserve in the north-west corner of Lake Crescent is listed under the Ramsar convention as a wetland of international significance. The wetlands around the lakes provide habitat for a diverse range of animals such as invertebrates (including the endemic snail *Austropyrgus* sp.), frogs (with populations of the endangered southern bell frog previously recorded), snakes, waterbirds, platypus, water rats and the endangered endemic golden galaxias (*Galaxias auratus*).

Initial Incursion Response

Carp was presumed absent in Tasmania since its earlier incursion and eradication in 1975–80. Over a decade later, a recreational angler found (28th January 1995) and presented (30th January 1995) remains of a fish (apparently being eaten by a sea eagle), suspected to be a carp, to the Inland Fisheries Service. This triggered a series of back-pack electrofishing surveys confirming the presence of carp in Lake Crescent (1st February 1995). Immediately, the outflow from Lake Crescent was closed and downstream

SUGGESTED CITATION FOR SECTION 5.1: Wisniewski CD, Diggle JE, Patil JG 2015. Managing and Eradicating Carp: A Tasmanian Experience. Section 5.1 in Collier KJ & Grainger NPJ eds. New Zealand Invasive Fish Management Handbook. Lake Ecosystem Restoration New Zealand (LERNZ; The University of Waikato) and Department of Conservation, Hamilton, New Zealand. Pp 82-89.

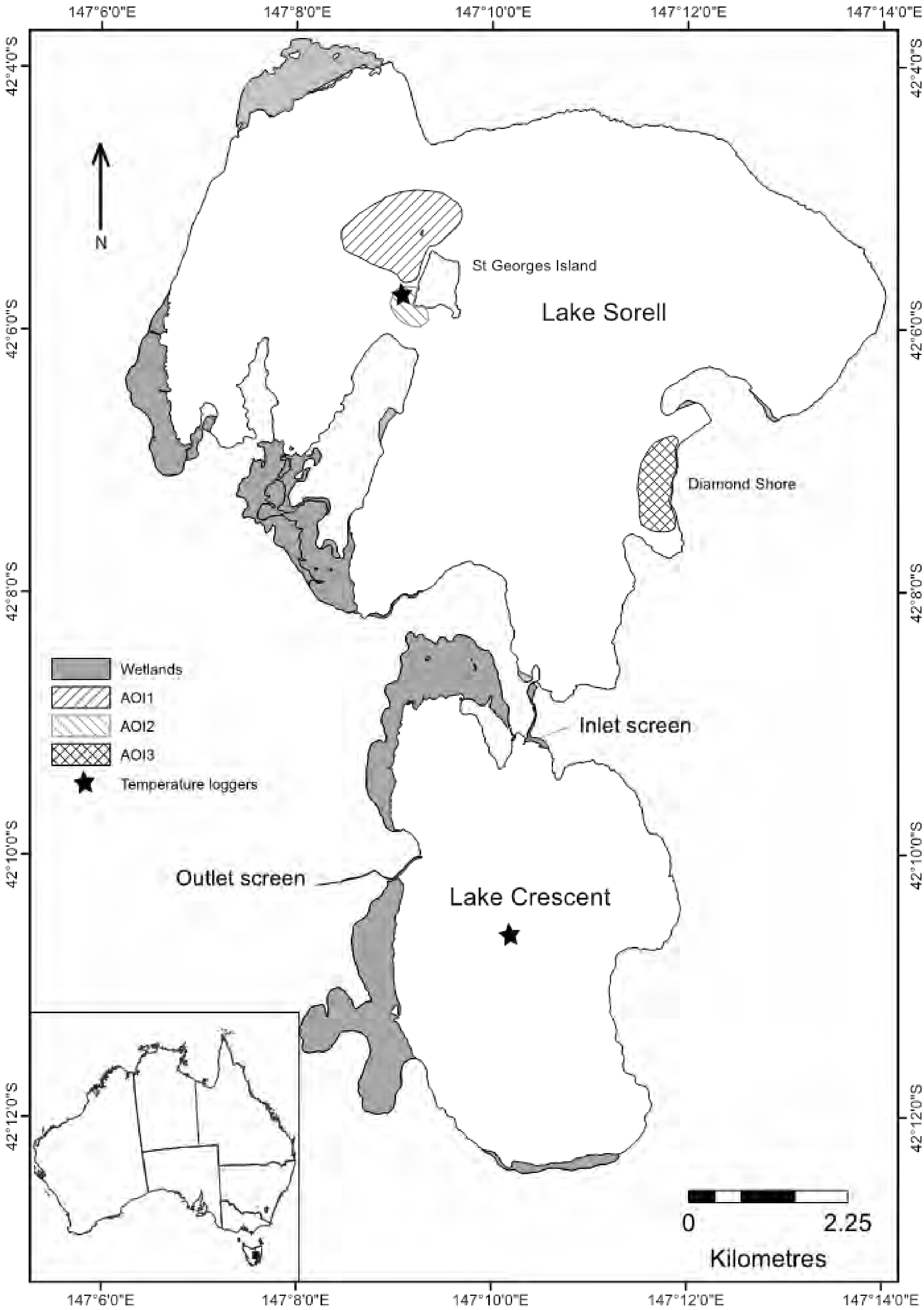

FIGURE 5.1 Map of lakes Crescent and Sorell, Tasmania, showing wetlands and areas of interest (AOI 1-3) that are prime carp habitats.

surveys began. Under legislation, Lake Crescent was closed to the public on 18th February. The outlet structure at Lake Crescent was secured with an internal 1-mm screen and the outflow was re-opened on the 24th February to supply water for downstream domestic and stock use. Electrofishing boats from New South Wales and Victorian fisheries agencies were shipped in and used for sampling in the surrounding lakes. On the 6th March, carp were caught by electrofishing in the upstream Lake Sorell. Lake Sorell was closed to the public on 9th March.

A task force was established consisting of members from the then Inland Fisheries Commission, Parks and Wildlife, Rivers and Water Supply Commission, Central Highlands Council, Clyde Water Trust and anglers via the Freshwater Anglers Council of Tasmania (Inland Fisheries Commission 1995). This task force was refined to a Carp Working Group, which prepared a cabinet submission for funding. On 1st June 1995, the Tasmanian State Government approved a budget of $A1,027,000 for two years. This budget supported a number of activities including:

- appointing a well-resourced four-person field control/eradication team;
- infrastructure development with regulated sluice gates, security screens and field accommodation;
- major equipment purchase, such as an electrofishing boat;
- communication, education, quarantine and recreational fisheries management activities; and
- engaging a consultant to assess the feasibility of mass eradication rotenone poisoning.

In hindsight, this immediate funding and mobilisation of resources at a time of limited knowledge and long-term uncertainties was critical for the successes of the programme to come.

Control Programme

Given the alarm and concerns in the community at large, the Tasmanian Government initiated a multi-agency approach to address the problem with the Inland Fisheries Service as the lead organisation. The working group of expert representatives identified the following objectives:

- Contain carp to the lakes Sorell/Crescent catchment.
- Develop a water management plan that provides for and protects the water supplies for Bothwell, Hamilton and irrigators to achieve the first objective, and assist with the next two objectives below.
- Reduce the existing carp population.
- Eradicate carp.
- Prevent introduction to new waterbodies, and the re-introduction to cleared waters from both inter- and intra-state sources.
- Undertake legislative and communication strategies to minimise damage to tourism, while facilitating the above objectives.
- Improve the capacity of the containment screens.
- Protect native flora and fauna threatened by carp and carp management practices.
- Gain an understanding of biology and factors contributing to the success of carp in the lakes.
- Develop guidelines for recreational and commercial access to the lakes.

A number of questions needed to be addressed or evaluated before a suitable management option could be adopted. These ranged from '*What is the extent of carp distribution within the State*?' to '*Is eradication possible*?' and also '*Can re-introduction be prevented*?'

The range of options that was considered for the lakes included: do nothing, contain the carp within lakes Sorell and Crescent, or eradicate carp by draining, poisoning and physical removal. To do nothing was considered unacceptable given the impacts observed on mainland Australia, particularly the Murray-Darling Basin. A similar risk to the diverse Tasmania aquatic environments, industries, and endemic species was real and feared. Given the lack of knowledge, extent of the problem and resource intensive nature of pest eradication programmes around the world, containment/control was identified as the immediate option. However, it was clear that containment would have to be sustained long-term, with the likely chance and concern that carp would escape at some stage.

Three main eradication options were considered, namely draining, poisoning and physical removal. Draining the lakes was ruled out because it was deemed impossible to achieve given the large flat-pan geography of the lakes. Moreover, the impact on rare and endangered species and the recognised Ramsar status of the nearby Interlaken Lakeside Reserve wetland precluded draining as an option. Further, the lakes were/are the source of domestic water supply to the townships of Bothwell and Hamilton, as well as for farming in the Clyde River valley, making draining an unviable option.

Poisoning was evaluated through a consultancy with Prentiss Inc., a rotenone manufacturer from the USA. Despite being assessed as technically feasible at a cost of $US4.8 million (1998), this option was ruled out due to problems associated with its application to a large waterbody, the lack of any other case study where treatment had been successful on this scale, and the adverse environmental impact that it would have on the site, not to mention the need to procure all of the world's rotenone production at the time and the need to drain the lakes to a low level.

Physical removal was deemed the most feasible option, and was underway from the outset as part of evaluating carp distribution, biology and population structure in Tasmanian waters. It became apparent within the first 12 months that physical removal was having a significant impact on the carp population, raising the possibility of eradication. The risk of natural re-introduction following eradication in the lakes was assessed to be low, given the lakes are situated at the head of the Clyde River catchment. However, a possibility of human interference was not discounted. As prevention of re-introduction is critical for any successful eradication programme (Bomford & O'Brien 1995), suitable state fisheries management legislation was enacted to prevent human mediated re-introduction. This included closing the lakes to the public.

It was difficult to undertake a cost-benefit analysis, another of the key criteria for eradication rather than control. However, it was clear that control would have to be sustained for perpetuity with a likely chance that carp would most likely escape containment at some stage. Again, this was a risk that was deemed too great to take. The socio-political support was firm and sustained from the outset, with a funding commitment by the State government through its forward estimates '*for the life of the programme*'. This is evident by the sustained bipartisan political support over the past 20 years, another key criterion for any eradication programme to be successful.

To date, physical removal remains the best option to eradicate carp from the Lake Crescent-Sorell system and thus from Tasmania. Although the demands of physical eradication of carp can be challenging, this remains possibly the most cost-effective and environmentally benign option in the Tasmanian circumstances. The strategies and techniques that were successfully implemented to eradicate carp from Lake Crescent and continue to be employed for their removal from Lake Sorell are detailed below. The integrated strategies were adaptive, evolved over time, and focussed on exploiting the biological vulnerabilities of carp (including their specific behaviours) and optimising capture methods.

An Integrated Approach

Containment of carp was achieved by the construction of screens at the outflow, the closure of the lakes to the public, and an active compliance and education campaign. Initial distribution surveys indicated that carp had not spread outside of lakes Crescent and Sorell.

The physical removal of an invasive fish species from a lake system as large as lakes Sorell and Crescent had not previously been recorded, either in Australia or elsewhere in the world. However, as noted earlier, during the initial stage of investigating options for eradication and control, Inland Fisheries Service had been intensively fishing down the carp population and this was having a significant impact. Initial carp removal strategies were very basic, relying on visual observations of fish aggregations and non-targeted electrofishing (back-pack and boat) or net fishing (gill and seine nets). However, as the population size declined, the ability to locate aggregations of fish was reduced dramatically. At this point there was no, or very little, knowledge on biology, habitat preference or movement of carp under the local conditions. To fill this knowledge gap and to increase the efficiencies of fishing, an integrated strategy incorporating emerging concepts and refining of ongoing monitoring practices was sought and adopted.

A key emerging strategy was to deploy radio-tagged carp to serve as 'Judas fish'. These are carp with surgically implanted radio-transmitters that provide a means to reliably locate carp aggregations. Only male Judas carp were deployed as a strategy to minimise recruitment risk. The Judas fish became a valuable tool not only to target carp aggregations but also to understand carp behaviour, movement and habitat choice. The radio telemetry enabled delineation of inter-seasonal and inter-annual patterns of carp movement and habitat choice in response to changes in lake water level and water temperature, establishing key 'areas of interest' (see Figure 5.1) that carp frequent (Taylor *et al*. 2012). The resulting knowledge was effectively used for fish removal, identifying life cycle vulnerabilities and opportunities for recruitment sabotage.

As the strategy evolved from control to eradication, the prevention of recruitment became a high priority. This was accomplished by deploying purpose-built polyethylene barrier nets to exclude mature carp from their preferred spawning habitats with high macrophyte cover. Deployment of traps and purpose-built super-fyke nets (Plate 5.1) set along the barriers at key wetland/spawning access points enabled the capture of mature carp attempting to push into the wetlands.

PLATE 5.1 A section of the barrier net with a fyke net.

Choice, selectivity and combination of gear were critical for a number of management practices, including removal and population estimation of carp. Crucially, it was established that different life stages of carp are vulnerable to capture by different mesh-sized gill nets (Donkers *et al*. 2011). Gear selectivity, in combination with population structure data and habitat mapping, proved valuable in making advanced decisions on choice of gear, time of deployment, recall and service. Typically, appropriately-sized gill nets, when used in combination with radio-tracking and electrofishing, are extremely effective in capturing carp. Standard fyke nets were very efficient for assessing recruitment strength, fish-down of juvenile cohorts, and passive capture of adult fish during the spawning period.

Although the integrated programme relied heavily on physical removal, biological and chemical approaches were selectively employed. Specifically, deployment of 'odour donor' carp as a 'lure' during the breeding season was found to assist in attracting and trapping mature carp (Patil & Wisniewski 2006). Similarly localised application of lime and rotenone were effective in killing/poisoning unhatched carp embryos and juveniles, respectively.

To be effective, the rate of removal needs to exceed the rate of increase at all population densities (Bomford & O'Brien 1995). When carp numbers are reduced to low levels, the remnants of the cohort are generally the 'smart' fish that have evaded capture and are sensitised to standard or routine fishing techniques. This has been observed time and time again when targeting aggregations of carp in Tasmanian lakes. For example, some radio-transmitter fish have shown that they are easily spooked when approached by boat, by wading and while attempting to set fishing gear on them. An accidental bang in the boat, wading splash, movement of rocks underwater, and even the sound of net leads tumbling out of the bin whilst being deployed have all spooked and dispersed aggregations quickly.

An exception to this spooky behaviour and capture evasion is at times of breeding aggregations. Consistent observations that mature carp are attracted to one another, particularly in the breeding season, and that even the 'smart' carp become vulnerable to capture during such aggregations prompted the idea of developing a chemo-attraction-based capture technique. The deployment of live odour donor fish timed with warming water (>15ºC), rising water levels, and calm conditions have produced the best results at luring wild carp (Patil & Wisniewski 2006). The odour donor fish are primed using either pituitary extract from other mature carp (a technique known as hypophysation) or Ovaprim® (Syndel Labs, Canada).

Continual estimation of population size, age structure and growth allowed planning of fishing effort, choice of gear, allocation of resources and tracking of different year classes (Donkers *et al*. 2011). For example, length-frequency data allowed prediction of suitable gear types (e.g. gill net mesh size) to use in coming seasons. Length-weight data, when combined with gonad somatic index information, allowed forecasting of the reproductive status of a cohort or year class in advance. Such forecasting helped decide when and where to deploy passive gears and specialised capture techniques such as the odour lures for trapping 'smart carp'.

Despite substantial effort placed on spawning sabotage, it is inevitable that some cryptic, and at times large, recruitment events occur. Nonetheless, it is essential to detect the frequency and strength of these recruitment events in order to plan long-term management or eradication strategies. It is particularly important to identify these events as early as possible to implement (i) appropriate intervention, such as liming of spawned eggs; (ii) isolation and/or spot poisoning of nursery grounds; and/or (iii) choice of appropriate capture gear for targeting. It is also important to predict when a new cohort will become sexually mature so as to direct resources for future spawning sabotage.

In order to completely eradicate carp, it is important to understand their vulnerabilities and focus on opportunities for control. Knowledge of specific weakness/amenability at different stages of the life cycle, from eggs through to larval, juvenile and mature stages, is valuable. For example, in Tasmania, temperature limits spawning with a narrow window of success between October and January (3–4 months) when the adults become more mobile and susceptible to passive techniques. Similarly, a thorough knowledge of the lake habitat is critical. Carp have shoaling/schooling tendencies driven by feeding, spawning, and/or temperature cues and habitat attributes. Generally, soft, organic-rich bottoms tend to attract carp feeding aggregations, hence a good knowledge of the lake habitat is invaluable in implementation of capture strategies. Collectively, an environmentally sensitive and integrated carp management strategy has been responsible for eradication of carp from Lake Crescent and their current containment to Lake Sorell.

Lessons Learned

With sustained effort, it is possible to achieve the six key criteria required for eradication of a pest species. These criteria are (Bomford & O'Brien 1995):

- Rate of removal exceeds the rate of increase at all population densities.
- Immigration rate is zero.
- All animals must be at risk.
- Populations can be monitored at all densities.
- Discounted cost-benefit analysis favours eradication over control.
- Suitable socio-political environment prevails.

The successful eradication of carp in Lake Crescent suggests that it is possible to meet all these criteria in a large lake, predominantly employing physical removal approaches. In the Tasmanian situation, perhaps the most difficult criterion to meet was that of *'The rate of removal exceeds the rate of increase at all population densities'*. Through the control programme, it has been shown repeatedly that the size of any given cohort or year-class can be reduced to the point of eradication within a window of about seven years. However, the most difficult task was blocking spawning despite having reduced the population to very negligible size. Somewhat fortuitously, the eradication of the last cohort in Lake Crescent coincided with long spells of drought allowing successful sabotage of breeding events. The last wild carp was removed from Lake Crescent in December 2007 (Figure 5.2).

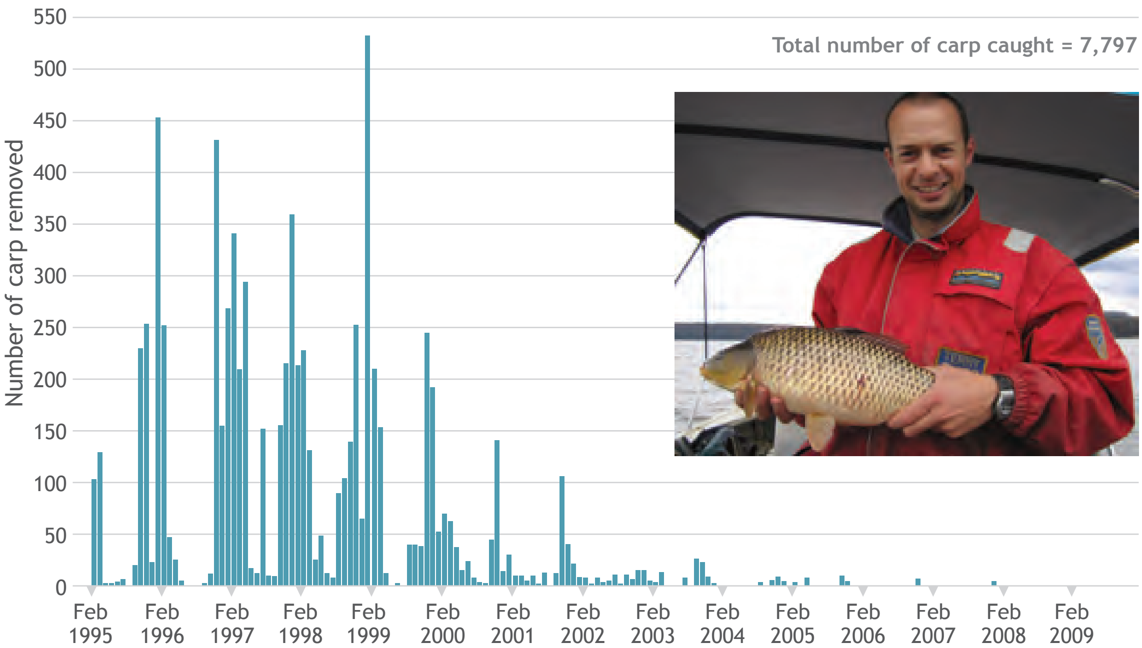

FIGURE 5.2 Progress of koi carp eradication in Lake Crescent. Last carp (inset) was caught in December 2007.

Eradication of carp from Lake Sorell has not yet been achieved, although the population was reduced to <50 in 2009. Lack of eradication can be attributed to its relatively larger size and diversity of habitat compared to Lake Crescent, further compounded by resource limitations brought on by split effort between the two lakes. Despite being close to complete eradication, repeated recruitment events have occurred in Lake Sorell. In particular, 2009 was a wet year, resulting in high lake levels, exposing much greater spawning habitat in both the lakes. Noting that Lake Crescent was not yet declared free of carp in 2009, the available resources were stretched to the limit, forcing compromises. Specifically, the barrier netting was insufficient to protect all key spawning habitat in both the lakes, forcing a section of the spawning habitat in Lake Sorell to be left unprotected, albeit with the knowledge that it was more accessible by road and any inadvertent spawning could be intercepted and treated more readily. However, this compromise proved disastrous, and resulted in spawning in the unprotected habitat. The area was systematically scouted, heavily limed and subject to rotenone poisoning. Despite this intervention, a large cohort of juveniles was detected in the lake, setting the eradication effort back.

Nonetheless, the eradication of carp from Lake Crescent has now allowed increased effort and resources to be focussed on Lake Sorell. The recruitment event of 2009 resulted in increased funding, allowing refocussed tactics, including implanting juvenile carp with radio-transmitters, more barrier nets and a greater effort to capture the remnant population. It is also recognised that the radio-transmitter-implanted male Judas carp contributed significantly to the 2009 recruitment as they were found in spawning aggregations dominated by wild females. To prevent a repeat occurrence, we have now developed and deployed surgically sterile Judas carp (Patil *et al*. 2014). Failure of subsequent recruitment despite high lake levels (since 2009) suggests that the increased resource level and management strategies are working. The aim is to now fish down the remaining portion of the 2009 cohort, whilst preventing any further recruitment.

5.2 Removal of Invasive Fish and Exclusion of Koi Carp from Lake Ohinewai

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Management Issues

The lower Waikato River floodplain contains many shallow lakes. The floodplain has been highly developed for pastoral agriculture, primarily dairy farming, resulting in extensive drainage and flood control measures to regulate river and lake levels. Most lakes have degraded water quality as a result of nutrient and sediment enrichment, and the additional impacts of pest fish such as koi carp, goldfish, catfish and rudd have generally contributed to the total collapse of submerged macrophytes and progression to a highly eutrophic state. Of all New Zealand lakes monitored regularly for water quality, around 25% of those categorised as supertrophic or hypertrophic are on the Waikato River floodplain (Verburg *et al*. 2010).

Lake Ohinewai is a shallow (4.5 m depth), 16.8 ha lake on the floodplain. The lake has a 331 ha catchment that is primarily flat and dominated by intensive pastoral farming with several inlet drains. A single outlet drain leads to Lake Waikare via Lake Rotokawau and passes through a circular road culvert 930 m from the lake outlet. Lake Ohinewai deteriorated from a stable oligotrophic (macrophyte-dominated) state to a stable eutrophic (algal-dominated) state during the early 1990s, and now lacks aquatic macrophytes. In 1981, 80% of the lake was covered in aquatic macrophytes but by 1991 none remained (Edwards *et al*. 2005). Invasion by koi carp over this period was implicated in this change of state.

Control Approaches

To remove koi carp and other invasive fish, three mark-removal events were carried out in Lake Ohinewai in early 2011, late 2011 and late 2014. Three additional removal-only events occurred in early 2013, mid-2013 and late 2013. Fishing methods included boat electrofishing, fyke netting, automated feeder-traps and beach seining; dates for mark-removal and fishing effort are given in Table 5.1.

Boat electrofishing (see Section 4.4) was conducted in 20-minute sampling periods and concentrated on shallow-water habitat near the shore. A mixture of baited and unbaited large and small-mesh fyke nets were set at sites distributed evenly around the lake shore and in the outlet, with fishing effort ranging from 122–240 net nights during the first two mark-removal events. Fyke netting effort was reduced for the final mark-removal event (Table 5.1) as fyke netting was found to be highly effective for eel capture but often produced comparatively low invasive fish catch per unit effort (CPUE) at lower pest

SUGGESTED CITATION FOR SECTION 5.2: Tempero G, Ling N, Daniel AJ, Morgan D 2015. Removal and Exclusion of Koi Carp from Lake Ohinewai. Section 5.2 in Collier KJ & Grainger NPJ eds. New Zealand Invasive Fish Management Handbook. Lake Ecosystem Restoration New Zealand (LERNZ; The University of Waikato) and Department of Conservation, Hamilton, New Zealand. Pp 90–94.

fish densities (<50 kg/ha). Feeder traps ('pod traps'; see Section 6.3) were deployed during the removal phase in late 2011. These traps were found to be highly effective but required a pre-capture feeding period to maximise catch rates, making comparisons of CPUE difficult; consequently they were not deployed in late 2014. Beach seining was attempted during the removal phase in early 2011 using a 100 m fine-mesh seine, however this was abandoned due to obstructions on the lake bed and very low catch rates (two fish from three seines).

Fish were marked using left pectoral fin clips (rudd, goldfish and koi carp) or dorsal spine removal (catfish) and released on the western end of the lake. To satisfy the assumptions of a Lincoln-Petersen mark recapture study (closed population), the fish population was isolated using a temporary barrier in the outlet drain consisting of 30 mm-mesh netting. Population estimates were calculated using the Lincoln-Petersen method with the program Mark-recapture (www.bioquest.org/esteem). Biomass estimates are for fish >75 mm due to the bias of sampling methods toward larger fish.

Following the removal operation in 2011, a permanent adult pest fish barrier was installed on the 1,400 mm diameter culvert under Tahuna Road to block upstream movement of adult invasive fish into Lake Ohinewai (Daniel & Morgan 2011). Telemetry tracking of koi carp in the lower Waikato River and riverine lakes has suggested that up to 75% of koi carp will leave lakes at some point in their life history (Daniel *et al*. 2011). Following installation of the barrier (see Plate 4.7), a second mark-recapture study was undertaken over November 2011 to February 2012 to assess the status of pest fish populations in the lake. In November and December 2014, a third mark-recapture study was undertaken to assess the long-term effectiveness of the barrier.

TABLE 5.1 Fishing effort and timing of three mark-removal and three removal events of non-indigenous invasive fish from Lake Ohinewai. N/A = not applicable.

EVENT	DATE	MARK/ REMOVAL	FISHING METHOD/INTENSITY			
			BOAT ELECTROFISHING (minutes)	FYKE (net nights)	FEEDER (POD) TRAP (net nights)	SEINE (net pulls)
Early 2011	17 Jan 2011-19 Jan 2011	Marking	220	80	N/A	0
	24 Jan 2011-28 Jan 2011	Removal	400	160	N/A	3
Mid-2011	1 Feb 2011-16 Jun 2011	Removal	N/A	N/A	186	N/A
Fish barrier installed on outlet						
Late 2011	17 Nov 2011-21 Nov 2011	Marking	220	240	1	N/A
	29 Nov 2011-16 Jan 2012	Removal	220	122	81	N/A
Early 2013	7-8 Jan 2013	Removal	100	10	N/A	N/A
Late 2013	2 Dec 2013	Removal	130	N/A	N/A	N/A
Late 2014	18 Nov 2014-20 Nov 2014	Marking	360	56	N/A	N/A
	2 Dec 2014-4 Dec 2014	Removal	360	59	N/A	N/A

Monitoring

The initial mark-removal effort in early 2011 reduced the invasive fish biomass by 1.11 tonnes comprising koi carp (84.3%), goldfish (6.5%), catfish (9.5%), rudd (0.4%) and carp-goldfish hybrids (0.2%). Initial biomass estimates for these species at the start and end of this period are given in Table 5.2, along with biomass estimates determined in subsequent fish removals. A further two tonnes of exotic fish biomass (90% koi carp, 7% goldfish, 3% catfish) were removed between February and June 2011. These efforts resulted in more than 79% of the koi carp biomass being removed during this period, reducing the estimated biomass to below 100 kg/ha. Following this removal and the installation of a one-way pest fish barrier, a further mark-removal programme was conducted from November 2011 to January 2012. Initial estimates of koi carp biomass showed a further reduction in biomass to <50 kg/ha indicating significant loss of carp biomass from the lake in the intervening period, presumably resulting from downstream movement of carp through the one-way barrier.

Adult koi carp are known to undertake significant migrations between suitable feeding and spawning habitat as adults. It is therefore inferred that the reduction in carp biomass occurred as a result of adult carp leaving the lake during winter. The lake outlet barrier appeared to have reduced the biomass of carp only, as the biomass of other invasive species in the lake remained largely unchanged. Poor recapture rates in late 2011 for both marked and unmarked goldfish resulted in population estimates with unacceptably wide confidence intervals, therefore population and biomass estimates are not presented for that species (Table 5.2). By late 2014 the koi carp biomass had further reduced to 13 kg/ha, and following removal of a further 44 kg of biomass, estimated koi carp biomass was 10 kg/ha, 3% of the original biomass in the lake. It should be noted that the mean weight of captured koi carp reduced from 0.889 kg prior to the removals to 0.614 kg, indicating a reduction in large breeding fish from the lake. Reductions in biomass have also been observed in catfish (-39%) and goldfish (-63%) from initial estimates in early 2011 compared to late 2014.

Outcomes

The reduction in invasive fish biomass has been associated with modest improvements in water clarity, with Secchi disc depth increasing from 0.30 m to 0.45 m between 2011 and 2014. Following extended periods of settled weather during the early summer, Secchi depths of up to 0.9 m have been recorded. Positive changes in the eel population have also occurred, with small increases in shortfin eel fyke net CPUE from 9.8 fish/net/night in early 2011 to 15.3 fish/net/night in late 2014. Longfin eel CPUE increased from 0.2 fish/net/night to 0.3 fish/net/night for the same period. Further analysis of eel population structure is still being conducted, but anecdotal observations suggest an increase in the number of large eels in excess of 1 kg. Rudd numbers have remained stable with only a handful of individuals caught each year. Other introduced species, such as perch and tench, remain absent from the lake. Although there have been no quantitative assessments, it is clear that macrophytes are regenerating along lake edges, although these are primarily non-indigenous species of *Myriophyllum* and *Ludwigia*.

Lessons Learned

It is highly likely that the biomass of koi carp in this lake contributed to persistently poor water quality and the algal-dominated eutrophic state. Eradication of a population of koi carp from a waterbody is unlikely using active fishing methods without resorting to options such as poisoning, and the costs required to reduce biomass by active fishing rise exponentially as fish biomass declines. Thus, it is much cheaper to fish a population biomass from 400 to 300 kg/ha than it is to fish a population from 200 to 100 kg/ha. Cheap and effective devices that reduce fish biomass in passive ways are therefore highly cost-effective if they can exploit particular fish behaviours such as migration.

TABLE 5.2 Total biomass (kg) of koi carp, goldfish and catfish removed from Lake Ohinewai during three removals and three mark-removals conducted between 2011 and 2014. Population estimates and biomass (95% confidence limits in parentheses) of invasive fish in Lake Ohinewai prior to and following fish mark-removals are also presented. A one-way barrier was installed on the lake outlet following the mid-2011 removal. N/A = Not available.

	TOTAL BIOMASS REMOVED (kg)	INITIAL POPULATION (*n*)	POPULATION FOLLOWING REMOVAL (*n*)	INITIAL BIOMASS (kg/ha)	BIOMASS FOLLOWING REMOVAL (kg/ha)	BIOMASS REMOVED (%)
KOI CARP						
Early 2011	938	8,831 (533-12,129)	7,509 (4,211-10,807)	374 (234-513)	318 (178-457)	15
Mid-2011	1,814	N/A	N/A	N/A	N/A	N/A
Late 2011	149	1479 (796-2,163)	1187 (504-1,871)	45 (24-66)	36 (15-57)	20
Early 2013	35	N/A	N/A	N/A	N/A	N/A
Late 2013	24	N/A	N/A	N/A	N/A	N/A
Late 2014	44	490 (215-764)	392 (117-666)	13 (6-20)	10 (3-18)	20
CATFISH						
Early 2011	105	1566 (1,277-1,854)	896 (607-1,184)	15 (12-17)	8 (6-11)	43
Mid-2011	54	N/A	N/A	N/A	N/A	N/A
Late 2011	33	1407 (1,042-1,772)	1,176 (811-1,541)	12 (9-15)	9 (7-13)	16
Early 2013	11	N/A	N/A	N/A	N/A	N/A
Late 2013	2	N/A	N/A	N/A	N/A	N/A
Late 2014	29	815 (609-1,020)	658 (452-863)	9 (7-11)	7 (5-10)	19
GOLDFISH						
Early 2011	62	942 (332-1,551)	530 (0-1,139)	9 (3-14)	5 (0-10)	44
Mid-2011	145	N/A	N/A	N/A	N/A	N/A
Late 2011	24	N/A	N/A	N/A	N/A	N/A
Early 2013	6	N/A	N/A	N/A	N/A	N/A
Late 2013	1	N/A	N/A	N/A	N/A	N/A
Late 2014	19	471 (283-659)	295 (107-483)	3 (2-4)	2 (1-3)	37

In this study, the installation of a simple barrier to allow adult carp to leave but not return to the lake appears to have achieved an effective reduction in biomass from an estimated ~100 kg/ha in mid-2011 to <50 kg/ha in late 2011, thereby removing some 850 kg of carp biomass from the lake during this six month period through passive measures. Further reductions in koi carp biomass have occurred due to active removal and ongoing passive exclusion by the outlet barrier. The cost of actively fishing the population with a wide range of methods, including 40 fyke nets, multiple other large nets and traps, seining and electrofishing over several months, was estimated at around 1,288 person hours and in excess of $40,000 to achieve a reduction in biomass from 374 kg/ha to c.100 kg/ha. The installation of the carp exclusion screen, which achieved a further c.50 kg/ha biomass reduction, was therefore highly cost-effective at around $5,000. Furthermore, it required relatively little maintenance at around six visits per year to clear debris and ensure that the hinged weighted bars were still moving freely. Such devices may be effective aids to reduce carp biomass if installed at locations that allow the migratory movement of adult carp to be exploited.

5.3 Control of Invasive Fish Incursions in the Northern South Island

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Management Issues

In March 2000 the first South Island report of gambusia was confirmed in a private pond. This report was followed in July by the discovery of the first South Island record of koi carp in Queen's Gardens, central Nelson (Shaw & Studholme 2001). Both of these populations were eradicated within a month of being discovered. In July 2000, in response to the South Island incursion of koi carp and gambusia, the Department of Conservation (DOC) declared both species to be unwanted organisms under the Biosecurity Act 1993. Koi carp were already classified as a noxious fish under the Freshwater Fisheries Regulations 1983, but unwanted organism status provided additional powers under the Biosecurity Act to require eradication and access to private properties.

A technical working group was established to review the programme and advise on the best way to deal with the response, including a methodology for the delimitation survey to determine the extent of the incursion. This survey was supported by a compliance and law enforcement programme. Stakeholders such as the Fish & Game council and Tasman District Council were involved from the beginning. A total of 219 waterbodies and 54 waterways was surveyed in the region between September and March 2000–01. Koi carp were found at one additional site and gambusia were found at 19 more places. Interestingly, other introduced fish species not previously known from the Nelson/Marlborough region were also discovered, often co-occurring. The koi carp location also had gambusia, rudd, tench and perch, while only six of the 19 gambusia sites did not have rudd, tench and/or perch. The rudd, perch and tench sites always had at least one other non-indigenous invasive fish species present.

Most of the sites did not have high freshwater biodiversity values. Fish were mostly found in small, enclosed horticultural irrigation ponds, and sometimes in drains and ponds on golf courses, and council parks and reserves. In 2001, DOC and the local council were aware of 100 ponds on private property in the area, but it quickly became apparent that many more ponds existed as a result of changes in landuse as grapevines replaced hops, and stone-fruit and pip-fruit orchards. The area was surveyed from the air over three summers and DOC now has 871 ponds on its database.

Following the first summer's delimitation survey, the technical advisory group recommended to DOC that eradication of koi carp and gambusia should be attempted. Initially, the eradication programme focused on these two species for the following reasons:

- They were considered the greatest threat to freshwater ecosystems and species in the South Island.
- Eradication was considered achievable.
- The use of rotenone as a piscicide was restricted to koi carp and gambusia.

SUGGESTED CITATION FOR SECTION 5.2: Grainger N 2015. Control of Invasive Fish Incursions in the Northern South Island. Section 5.3 in Collier KJ & Grainger NPJ eds. New Zealand Invasive Fish Management Handbook. Lake Ecosystem Restoration New Zealand (LERNZ; The University of Waikato) and Department of Conservation, Hamilton, New Zealand. Pp 95–99.

Following the initial incursion, it was realised that rotenone was only registered in New Zealand for use as an insecticide. Temporary approvals were quickly sought to enable the initial incursion to be dealt with, as the legislation governing piscicide use was changing.

Control Approaches

The invasive fish programme has continued since 2000 in the Nelson/Marlborough region. It has consisted of public awareness campaigns, compliance and law enforcement, surveys for new sites, eradication operations, and monitoring the success (or otherwise) of eradicated sites. Public awareness helped identify new sites and prevent releases due to ignorance. The Fish & Game council was very supportive of the programme and has continued to keep the coarse fishing season closed to reduce the incentive to establish coarse fish (rudd, tench, perch, koi carp) populations. Despite undertaking compliance and law enforcement operations, nobody has been prosecuted for transferring or releasing fish, although there has been a successful prosecution of somebody who was fishing for coarse fish.

A variety of techniques has been used to eradicate invasive fish species from the Nelson/Marlborough region sites, including rotenone, drainage, chlorine, explosives, netting or a combination of those techniques. Rotenone, often combined with drainage, has been used in the majority of eradication operations (see Section 4.1). As the programme has developed, and the koi carp and gambusia populations have been reduced, the decision to attempt regional rudd eradication was made. Tench and perch are sports fish and are managed by Fish & Game New Zealand, so the mandate for DOC to eradicate them was less clear. However, a very supportive local Nelson/Marlborough Fish & Game Council do not want a coarse fishery established, let alone one based on illegal releases, and regional eradication of perch and tench is now being attempted.

The eradication programme is supported by an inventory and surveillance monitoring programme. Every year, new sites are surveyed to determine whether invasive fish are present, but equally important is the monitoring of sites where eradication has been attempted to determine success or otherwise. With over 870 sites to manage, a priority scoring system is used to make sure that all sites are adequately covered. Sites are given a score based on risk (Table 5.3); high risk sites are monitored on an annual cycle and the lowest risk sites on a five-year cycle. A standardised sampling methodology has been developed to detect invasive fish. Sites need to be clear for three summers before eradication can be declared successful (Grainger *et al*. 2014). The methods employed are a balance between time, effort and certainty of catching fish.

TABLE 5.3 Scoring system used to prioritise sites for identifying invasive fish sites and implementing post-eradication surveying following treatment of ponds with rotenone.

PRIORITY	DESCRIPTION	CYCLE
1	Pond is known to have invasive fish	Annual
2	Pond has been treated with rotenone	Annual
3	High risk sites adjacent or nearby to treated sites	2-yearly
4	At risk sites capable of harbouring invasive fish	3-yearly
5	Low risk sites not considered capable of harbouring invasive fish, or with difficult access	5-yearly
6	Pond no longer exists (i.e. drained, filled in)	No longer necessary

Monitoring

Between 2000 and 2013, invasive fish were found at 69 sites and eradication was attempted at 65 of those using various techniques (Table 5.4); eradication criteria have been met at 30 sites (Table 5.5). Nineteen sites have not met the eradication criteria and require further netting, or it is too early to assess eradication success. Table 5.6 shows the number of sites with invasive fish still present and the number of sites from which they have been removed. Twenty sites are considered active. Of these, three have gambusia, 14 have tench only, one has tench and perch, one has tench and rudd, and one has rudd only. There are no known sites with koi carp which has been eradicated from all six sites where it was detected. Gambusia has been eradicated from 49 of the 52 sites where it was recorded. Rudd has been eradicated from 15 of the 16 sites where it was found, and perch has been eradicated from five of the six sites. Tench, which was the last species to be targeted, has to date been removed from 17 of the 33 sites where fish have been caught.

TABLE 5.4 Management action taken at each site with invasive fish.

ERADICATION TECHNIQUE	NUMBER OF SITES
Rotenone	58
Drainage	2
Scoop netting	2
Chlorine	1
Explosives	1
Chlorine and explosives	1
No action	4
TOTAL	69

TABLE 5.5 Status of sites where eradication has been attempted.

STATUS	NUMBER OF SITES
Eradicated—no koi carp, rudd, tench, or perch detected in three years	30
Further netting required	15
Too early to declare eradication; further netting required	4
Active sites	20
TOTAL	69

TABLE 5.6 Number of sites where invasive fish species are still present or have been eradicated. Note: totals are not presented as fish are found at overlapping sites.

SPECIES PRESENT	STILL PRESENT	ERADICATED	TOTAL SITES
Koi carp	0	5	6
Gambusia	3	39	42
Rudd	1	15	16
Perch	1	6	7
Tench	17	16	33

Outcomes

There are two hypotheses to account for the introduction of these non-indigenous invasive fish to the northern South Island. The first is that coarse fishermen introduced gambusia as a forage food for koi carp, rudd, tench and perch when they tried to establish populations of those fish. The second is that the orchardists introduced gambusia to control mosquitoes and backswimmers, although this hypothesis did not explain why there was a high correlation with the other fish species. It was very fortunate that most of the sites were small and contained ponds rather than being large flowing systems, making eradication feasible. There have been some failures, however; sites with springs, tidal influences and warm-water discharges from industry were the most challenging for eradication as they provide refuge or aid more rapid breakdown of rotenone.

There have also been issues with fish being re-introduced to sites, as species that were not present at the time of rotenone operations have been detected in subsequent monitoring. While there is general landowner support for the eradication programme, fish are still being spread illegally, probably by very few individuals and without landowner consent. Awareness in the area is high but information is not being passed to DOC to enable offenders to be caught. The programme is ongoing; koi carp has been eradicated from the South Island and gambusia eradication is still thought possible. Regional eradication of rudd, tench and perch is still underway.

Lessons Learned

Before the discovery of koi carp and gambusia in the South Island, DOC had very limited expertise in how to detect and eradicate an incursion of invasive fish compared to its expertise in terrestrial pest management. Similar principles are used for terrestrial and aquatic systems to determine whether a pest-led or site-led approach is required to manage an incursion, but it is essential to understand the area, potential sites, habitats within sites, and the biology of the places and species involved. To build expertise, field staff have benefited from regular programme reviews and the development of support tools and protocols, such as best practice for eradication operations, surveillance and determining eradication success (see Appendix 2). Support with public awareness, and development and dissemination of educational material, has also been valuable to help ensure a greater chance of success. This work is often hard, repetitious and at times unrewarding; knowing that the work is contributing to a larger programme has helped maintain momentum.

DOC now has expertise in eradicating fish using rotenone and has obtained appropriate approvals for rotenone to be used as a piscicide in New Zealand (n.b. resource consent is still often required locally along with approval from DOC and Ministry for Primary Industries). DOC has also developed a training programme, and continues to develop new techniques that are incorporated into the rotenone best practice guideline (Grainger 2013). The incursion in the Nelson/Marlborough region has been much easier to manage as the use of rotenone is a permitted activity under the regional plan, enabling easier use than in places where resource consent(s) are otherwise required for use of rotenone.

There will always be a competing demand in terms of time and resources as to whether to prioritise the identification of new sites, eradicate fish from known sites or monitor eradicated sites. The development of standardised methodologies and criteria has helped staff to be efficient when they are in the field. The potential development of new technologies such as environmental DNA (eDNA; see Section 6.4) has the potential to significantly simplify and speed up detection of species if they can be developed to provide reliable and consistent results.

Illegal re-introductions have been problematic, and nobody has been caught spreading fish to these sites despite it being clear that illegal liberations are still occurring. A comprehensive public awareness programme, including education of groups such as coarse fishers and recent immigrants, backed up with an appropriate compliance and law enforcement programme, is essential. This has been challenging to achieve in the Nelson and Marlborough regions on top of a substantial field monitoring programme.

The Nelson/Marlborough region incursion could have benefited from a management plan being developed earlier, particularly for the species designated as sports fish. While the koi carp and gambusia range expansion was significant given they were the first South Island records, it was less clear what should be done about the noxious fish rudd that is present in Canterbury, and the sports fish tench and perch that are also present in the South Island but not the Nelson/Marlborough region. The presence of defined boundaries and management objectives would help mobilise management action and prevent creeping distributions. A national invasive fish strategy would have provided guidance as to which species to target.

Recent major changes in DOC, particularly with respect to resource allocation and responsibilities of staff, can put programmes without clear objectives and goals at risk. There has been an emphasis by DOC to protect and manage prioritised ecosystems and threatened species within them. However, there is less imperative to prioritise pest-led work off public conservation land, which ultimately benefits high conservation value freshwater ecosystems. Pest-led programmes such as these are fundamental in protecting high value places.

Funding for the invasive fish control programme in Nelson/Marlborough has not been secure and has been subject to an annual bidding process. While the incursion was significant, it would be preferable to have certainty of funding and commitment to the programme to enable multi-year planning. Finally, it has been absolutely essential that key partners such as the Fish & Game council, Tasman District Council, landowners and iwi have been involved throughout the programme. Without their continued support and expertise, much less would have been achieved.

5.4 Effects of Rudd Control in Rotopiko (Serpentine) Lakes

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Management Issues

The Rotopiko (Serpentine) Lake complex, located to the south of Hamilton, is the remnants of a larger lake (Lake Rotopiko) that was lowered by drainage, leaving three lakes remaining: North Lake, East Lake and South Lake. North Lake has a maximum depth of 4 m; East Lake 4.4 m; and South Lake 3.6 m. From data collected over 2012–14 (Waikato Regional Council unpubl. data), all three Rotopiko lakes are eutrophic (nutrient rich) based on the Trophic Level Index of Burns et al. (1999). The lakes have high conservation value due to their healthy indigenous macrophyte communities, which are rare in lowland Waikato lakes. North Lake has a national LakeSPI ('Lake Submerged Plant Indicators'; Clayton & Edwards 2006) ranking of 17th of 244, South Lake ranks 39th, and East Lake 42nd (de Winton 2014), although South Lake has gone through periods when aquatic plants were absent (de Winton 2014). Also of note is the marginal terrestrial and wetland vegetation that is dominated by native species.

Indigenous fish species include shortfin eel, longfin eel, common smelt, common bully (McDonald & Lake 2006) and black mudfish. Common smelt, though indigenous, were not originally found in the lake and were first reported in the 1970s. The lakes contain the non-indigenous invasives catfish, rudd, goldfish and gambusia. Rudd is of most concern to conservation values because adult fish consume plants (Lake *et al*. 2002) and thus have the potential to threaten macrophyte populations (de Winton & Dugdale 2003), especially where additional threats such as invasion by non-indigenous macrophyte species are present.

Control and Monitoring

A restoration programme for the lakes involving various agencies has been ongoing for several years. As part of this, the Department of Conservation (DOC) has carried out a netting programme for invasive fish in the lakes since 2001, with the aim of protecting and enhancing the indigenous plant communities. Rudd are the main target of this netting campaign. Fine-mesh monofilament gill nets measuring 15 m by 1.8 m have been employed, although methods have varied over the course of the programme. From 2005, the combination of mesh sizes used on the first night of netting was standardised to allow better comparisons of catch per unit effort (CPUE) between netting events (Table 5.7). The CPUE during the first night of netting provides a relative measure of abundance between years. Subsequent nights of netting aimed to remove as many non-indigenous invasive fish as possible; these results do not provide a useful measure of abundance between years as they are influenced by how many fish were taken out previously. A more detailed description of netting methods employed in different years is provided in Lake (2010).

SUGGESTED CITATION FOR SECTION 5.4: Price J, Gumbley J 2015. Effects of Rudd Control in Rotopiko (Serpentine) lakes. Section 5.4 in Collier KJ & Grainger NPJ eds. New Zealand Invasive Fish Management Handbook. Lake Ecosystem Restoration New Zealand (LERNZ; The University of Waikato) and Department of Conservation, Hamilton, New Zealand. Pp 100–104.

Submerged aquatic vegetation was monitored twice yearly using the Quick Survey and LakeSPI methods (de Winton *et al*. 2006). LakeSPI is a system for characterising lakes by the composition of native and invasive plants growing in the lake and the depth to which they grow (Clayton & Edwards 2006).

TABLE 5.7 Methods of netting employed in Rotopiko (Serpentine) lakes over 2001–14 (summarised from Lake 2010 and DOC unpubl. data).

NETTING PHASE	TIME PERIOD	METHODS
Experimental phase	Spring 2001–Spring 2003	Netting twice annually around March and September; regular aquatic vegetation monitoring initiated; experimental evaluation of net locations and sizes (Neilson *et al*. 2004).
Control phase	Autumn 2003–Spring 2006	Netting carried out twice annually; methods became more standardised to allow comparison between lakes and years.
Adaptive management phase	Autumn 2007–Spring 2010	Netting effort different in each year and lake depending on vegetation condition and previous fish densities; netting concentrated in spring to remove fish for benefit of macrophytes prior to stressful summer period.
Monitoring trial	Spring 2011	Netting carried out in September, November and December.
Monitoring phase	2012–14	Netting carried out once a year in spring for monitoring purposes; net sizes standardised within lakes but varied between lakes; nights of netting different between years.

Outcomes

In all three lakes, first-night CPUE for all species was initially high, then declined in the following years (Figure 5.3). Rudd CPUE was initially higher in North and South lakes compared to East Lake. Catfish populations briefly peaked in 2005 in East Lake, and in 2006 in South Lake. In comparison, North Lake did not show this spike in catfish CPUE, but instead showed a temporary increase in rudd numbers in 2005. After 2005, fish CPUE remained fairly constant in East and North lakes until 2013, whereas South Lake showed increasing catfish numbers that spiked in 2010.

Macrophyte communities in North and East Rotopiko lakes are generally in very good condition, with a high percentage of native species (Figure 5.4). South Lake in comparison has tended to switch between a vegetated and an unvegetated state. The reason for this switch is unknown, but such sudden changes in shallow lakes are often brought on by the effects of increased nutrient levels, including a reduction in light in the water column due to increased phytoplankton growth or suspended sediment (Scheffer & Carpenter 2003). In East and North lakes, LakeSPI scores and native index scores remained fairly steady until a decline in 2009 and 2010, respectively, when the invasive bladderwort *Utricularia gibba* became established. No improvement in LakeSPI scores was evident following initiation of fishing in 2001, though the absence of data collected before fish removal makes drawing conclusions difficult.

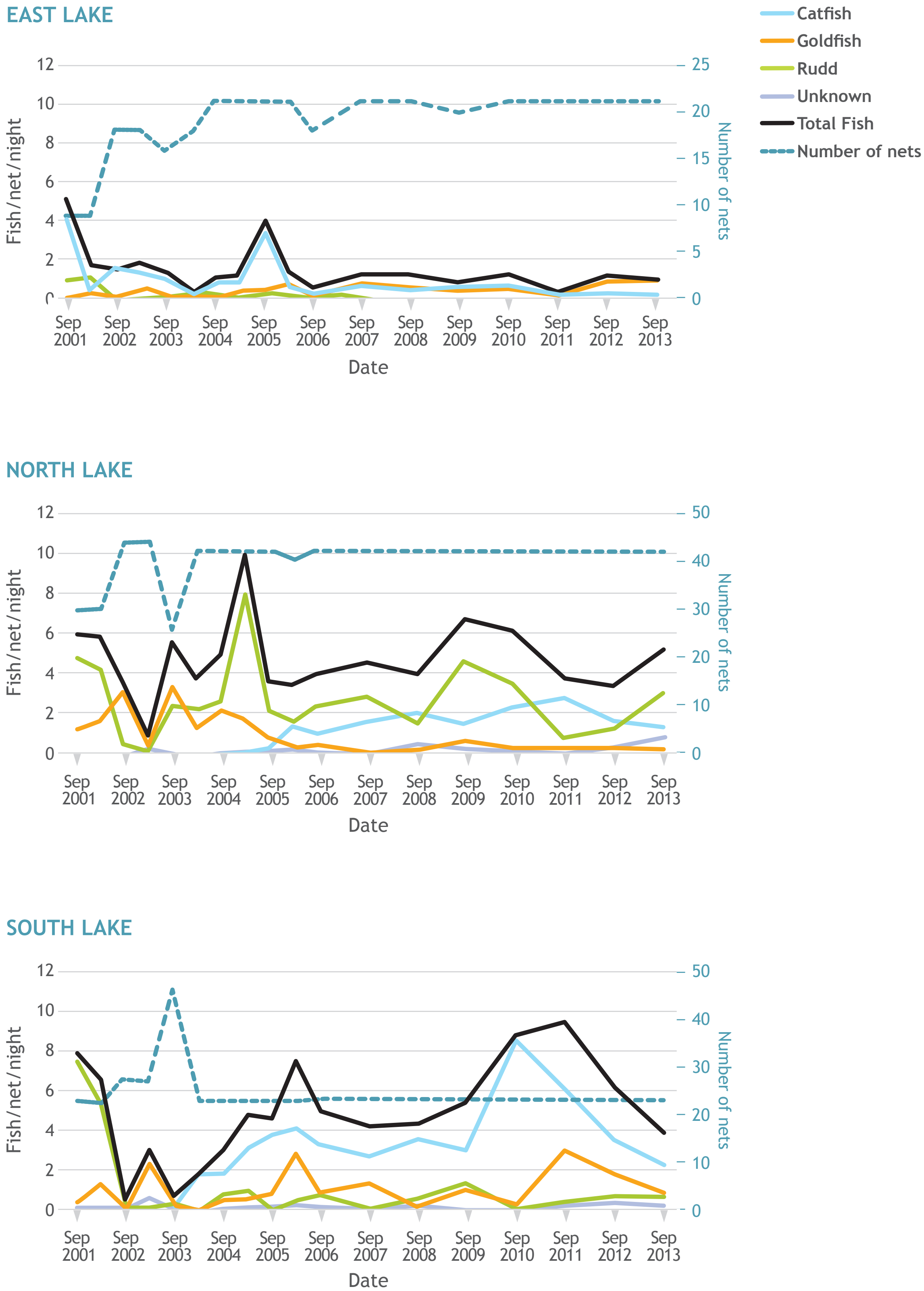

FIGURE 5.3 Changes in first-night catch per unit effort (CPUE) in East, North and South Rotopiko (Serpentine) lakes over 2001-13, with number of nets used on the first night.

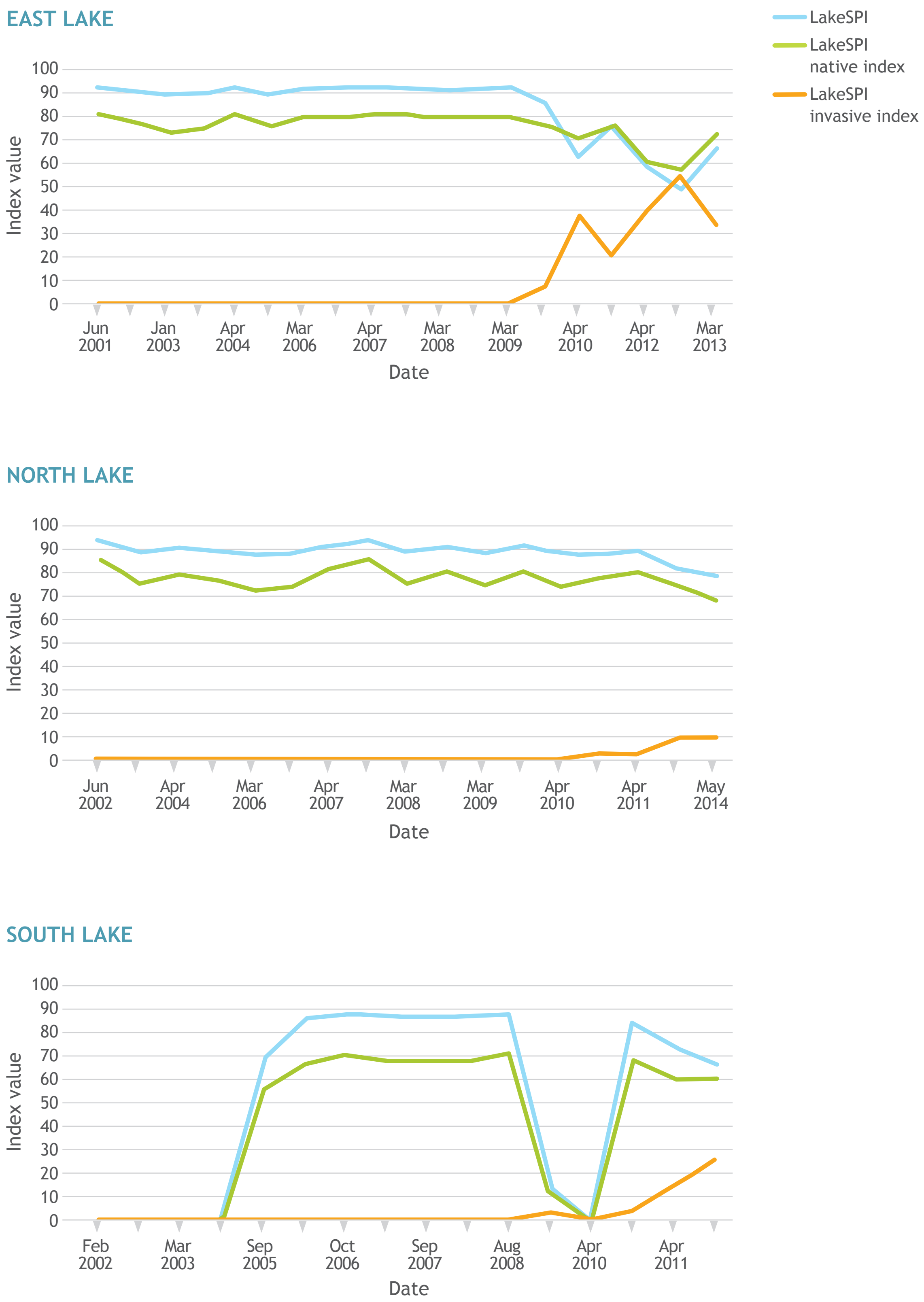

FIGURE 5.4 Changes in Lake Submerged Plant Indicators (LakeSPI) indices over time in Rotopiko (Serpentine) lakes.

Lessons Learned

The current monitoring programme provides a good overview of the general ecological condition of the lakes and how they are changing over time. However, currently the programme is unable to determine causal relationships between plant density and fish density because of confounding variables. For example, turbidity and microscopic algae in lake water will influence the amount of light available for aquatic macrophyte growth. Under favourable growing conditions, density of macrophytes may cause self-shading, eventually reducing macrophyte density. Under this situation, fish grazing may help to reduce self-shading and would not necessarily be detrimental. However, under less favourable growth conditions the same grazing level might lead to collapse of vegetation. Exclosure experiments would provide a more definitive way of clarifying the plant-fish relationship.

The effect of the netting programme on indigenous fish populations is similarly difficult to define with current data due to the lack of observations before netting started. However, the indigenous fish populations of the Rotopiko (Serpentine) lakes are relatively large compared to the non-indigenous invasive fish (Wu *et al*. 2013), pointing towards a positive effect of the netting programme. Gill netting appears to be effective for suppressing rudd numbers, as shown by the consistently low catches since netting began. Catfish and goldfish may also pose a threat to macrophyte populations, but their effects are as yet unknown as their feeding ecology and behaviour in vegetated peat lakes have not been studied. Catfish would be more effectively targeted by fyke nets than by gill nets, but eel by-catch would be an issue.

Continuing the current netting and plant surveillance programmes would be useful for monitoring changes in fish abundance and plant community health over time. If rudd abundance increases or macrophyte populations decline significantly, an intensive gill netting programme can be initiated to reduce pest fish numbers. Monitoring of plant populations on a yearly basis is necessary for detecting any detrimental trends early enough to take remedial action. However, netting once every two years may be adequate to determine trends in pest fish numbers.

5.5 Control of Perch in Lake Wainamu

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Management Issues

Lake Wainamu is a freshwater dune lake of approximately 14.5 ha in size and 12 m in depth located near Bethells Beach/Te Henga on Auckland's west coast. The majority of the lake's catchment is in regenerating native bush, with a small amount of low-intensity cattle grazing present at the north-western end of the lake. The lake has three inflow streams (Houghton, Plum Pudding and Wainamu) and one outflow (Waiti Stream). The water quality of the lake is regularly monitored by Auckland Council as part of its long-term State of the Environment programme (Hamill & Lockie 2014).

Lake Wainamu is one of 11 high conservation value waterbodies designated in the Auckland Regional Pest Management Strategy (Auckland Regional Council 2007). This status prohibits any fishing activity within the lake in an effort to eliminate any incentive to introduce further non-indigenous species for sport. Unusually, perch is designated as a pest species in these 11 lakes and can be controlled, whereas elsewhere in New Zealand perch is considered a sports fish (Auckland Regional Council 2007; Sabetian *et al*. 2015).

Native fish recorded within the lake include īnanga, banded kōkopu, grey mullet, common bully, shortfin eel, common smelt and longfin eel (Auckland Council catch data; New Zealand Freshwater Fish Database; Rowe & Smith 2001). Six non-indigenous invasive fish species have been recorded in Lake Wainamu—perch, goldfish, rudd, tench, gambusia and catfish (Rowe & Smith 2001; Rowe 2007). Most of these species were illegally introduced to the lake in an attempt to create new recreational fisheries. Perch were likely introduced between 1991 and 1995 (Rowe 2007) and, based on Auckland Council catch data, are the dominant species in the lake (Table 5.8), which accords with the findings of Rowe & Smith (2001).

The introduced aquatic weed *Egeria densa* was also introduced to the lake sometime prior to 1991, and by 1995 it completely dominated the littoral margins of the lake (de Winton & Edwards 2012). Prior to this period, the lake's aquatic flora consisted mainly of native charophyte meadows and *Potomageton ochreatus*, all of which largely disappeared due to competition from the invasive egeria. Water clarity in Lake Wainamu decreased substantially from 1995, followed by a collapse in the macrophyte community in 1999, both of which were linked to the introduction of perch between 1991 and 1995 (Rowe 2007).

These changes in lake condition raised concerns with the local community, and in 2004 the former Auckland Regional Council responded by commencing an invasive fish removal programme. This action was taken because the presence of non-indigenous fish in the lake was considered to be having negative effects on the native fish community and potentially influencing water clarity through predation on zooplankton (Rowe & Smith 2001).

SUGGESTED CITATION FOR SECTION 5.5: Surrey G, Neale M 2015. Control of Perch in Lake Wainamu. Section 5.5 in Collier KJ & Grainger NPJ eds. New Zealand Invasive Fish Management Handbook. Lake Ecosystem Restoration New Zealand (LERNZ; The University of Waikato) and Department of Conservation, Hamilton, New Zealand. Pp 105-109.

TABLE 5.8 The fishing effort and numbers of different non-indigenous fish species caught each year in the programme in Lake Wainamu.

	FISHING EFFORT (net nights)	NUMBER OF PERCH	NUMBER OF GOLDFISH	NUMBER OF RUDD	NUMBER OF TENCH	NUMBER OF CATFISH
2004	448	1,767	502	64	6	3
2005	528	3,181	208	149	9	5
2006	456	2,525	62	126	5	7
2007	208	305	35	23	2	0
2008	192	762	31	66	15	5
2009	192	521	53	84	42	52
2010	192	3,598	184	130	72	29
2011	192	457	171	43	25	53
2012	192	648	74	68	7	28
2013	192	2,745	110	33	6	24
2014	192	1,103	102	15	2	11
TOTAL	2,984	17,722	1,532	801	191	217

Control Approach

The methodology originally used for the fish removal programme in 2004 involved setting 40 gill nets around the littoral margin of the lake and 24 gill nets in the mid-water area. In 2007, the use of mid-water nets was abandoned due to low catch rates, and a total of 52 littoral nets were deployed. In 2008, this number was reduced to 48 littoral nets and this approach has been consistently used in every subsequent year. The nets used are monofilament gill nets, 30 m long and with a 1.8-m drop. Three different mesh sizes are used, 14 mm (small), 25 mm (medium) and 43 mm (large), in order to capture the full size range of fish present. A total of 24 small-, 12 medium- and 12 large-mesh nets were set approximately every 50 m around the perimeter of the lake in an alternating order of mesh size (small, medium, small, large etc.).

Up until 2006 the programme was carried out biannually in summer and autumn, but this was changed to annually in 2007. The programme is currently carried out over a period of one week in early March. Nets are set on a Monday, cleared and reset on Tuesday and Wednesday, and cleared and packed down on Friday. All fish captured are identified to species and counted, as well as being weighed and measured where practical. Many of the smaller perch caught in the nets are scavenged by eels, making accurate weighing and measuring difficult. In addition, there were often hundreds of young-of-year perch caught that were around 100 mm in length; these fish were typically enumerated rather than being individually measured. The programme is logistically demanding, with two small powered boats crewed by three people each used to set and retrieve the nets, while a larger shore crew of around 10 people removed fish from the nets, counted, measured and weighed the catch, and prepared the nets to be redeployed.

Monitoring

Over 20,000 non-indigenous fish, including nearly 18,000 perch, have been removed from the lake between 2004 and 2014, with sampling effort equating to 2,984 net nights. The fishing effort has varied from year to year, peaking in 2005 (528 net nights), but has remained constant since 2008 (192 net nights; Table 5.8). Although perch were by far the most common fish species caught within the lake, comprising 87% of the total catch, numbers varied by year (Table 5.8). The catch per unit effort (CPUE), here defined as the number of perch captured per net per night, has varied over the course of the programme (Figure 5.5).

The peak in CPUE in 2010 can be linked to the introduction of grass carp to the lake by Auckland Council in 2009 to eradicate the dense swards of egeria that had occupied all littoral habitat to around 5 m depth within the lake. Within a year of the introduction of grass carp, the majority of the weed beds within the lake had been significantly reduced. We hypothesise that the reduction in egeria is likely to have affected the CPUE by reducing the amount of refuge habitat available for fish and by increasing the effectiveness of the nets. In previous years the dense surface-reaching swards of egeria had resulted in nets becoming tangled, and reduced the area of nets that could be set properly.

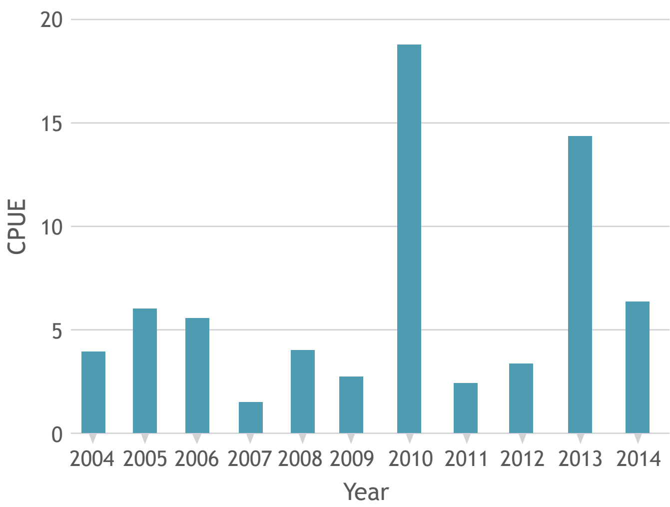

FIGURE 5.5 Catch per unit effort (CPUE; number of fish/net/night) by year for perch catch in Lake Wainamu.

The size class of the perch caught in the programme shows a bimodal distribution (Figure 5.6). Young-of-the-year fish (<150 mm long; Sabetian *et al*. 2015) are numerically dominant, representing 87% of the total catch. The second peak is centred around 180 mm which, based on Lake Wainamu perch growth curves (Sabetian *et al*. 2015), likely represent two-, three- and four-year-old fish. Larger specimens (i.e. greater than 250 mm), representing fish older than four years, are rare.

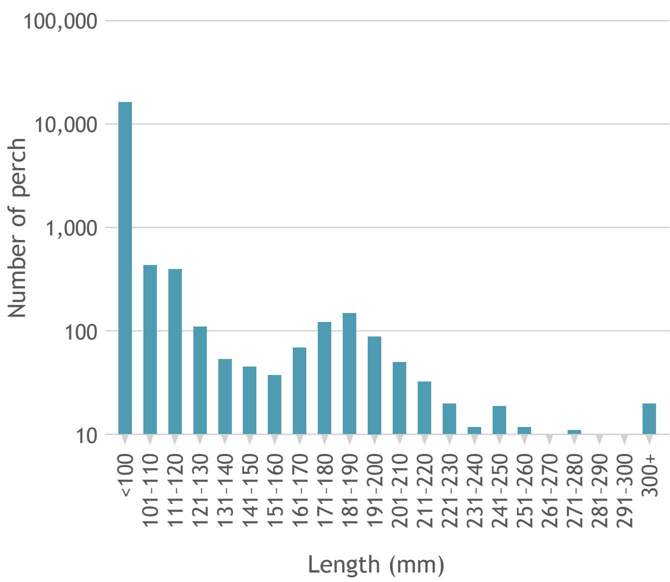

FIGURE 5.6 Size-class distribution for perch caught during the Lake Wainamu control programme (all fish caught over 2004-14).

Outcomes

The size structure of the perch caught during the removal programme within Lake Wainamu is shown in Figure 5.7. Whilst there is inter-annual variation in number of fish caught and population size structure, young-of-the-year fish (<150 mm) are numerically dominant in all years except 2007. This is particularly evident in the years of high catch (i.e. >2000 perch caught) when high numbers of young-of-the-year fish are present. Whilst the removal of large perch can result in high abundances of small fish due to

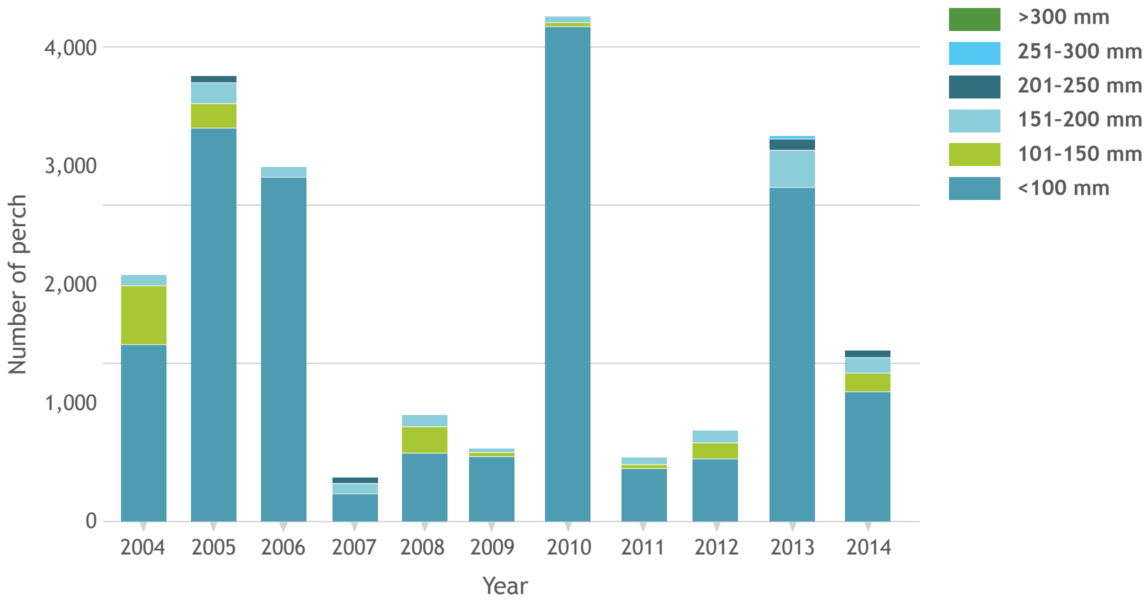

FIGURE 5.7 **Size structure of perch caught in Lake Wainamu over 2004-14.**

their cannibalistic nature (Ludgate & Closs 2003), it is impossible to determine if these changes are an outcome of the programme. However, we hypothesise that the large catch of young-of-the-year fish in 2010 may be due to removal of large fish over the previous years (i.e. reduced cannibalism pressure), in conjunction with the increased effectiveness of nets associated with the removal of egeria.

Since 2010, the percentage of large perch caught has shown a small, but steadily increasing trend (the percentage of fish >180 mm has increased from 1% in 2010, to 4% in 2011, 8% in 2012, 10% in 2013 and 12% in 2014). The reasons for this change are not immediately apparent, but may be related to the reduced frequency of netting since 2007. The perch in Wainamu have a life span of 5-6 years (Sabetian *et al*. 2015), hence the reduction in fishing pressure from 2007 onwards may be resulting in more fish surviving to maturity. However, this increased survival may not represent a negative outcome for Lake Wainamu, as the presence of these larger fish may provide a significant regulating factor on the perch population through the cannibalism of young-of-the-year fish (Ludgate & Closs 2003).

The invasive fish removal programme was initiated in response to community concerns about water quality in the lake, and there has been an improvement in water quality recorded between 2005 and 2010, particularly in water clarity measures (Hamill & Lockie 2014). However, associating such a change with the removal of invasive fish is difficult, particularly given the concurrent introduction of grass carp and subsequent eradication of egeria.

Lessons Learned

Whilst the programme has removed nearly 20,000 perch from Wainamu over the last decade, there is no compelling evidence that the programme has reduced the size or changed the size structure of the perch population within the lake. Indeed, based on CPUE data, there is a suggestion that the perch population has continued to increase during the course of the programme, although there is a large caveat associated with the concurrent removal of egeria from the lake. Nevertheless, it is somewhat concerning that, despite a sustained, logistically-demanding effort to remove perch, there does not appear to have been an overall decrease in the size of the perch population within the lake.

Hence, the key lesson learnt through this case study is the difficulty of effectively controlling perch populations through netting alone in a lake the size of Lake Wainamu. The tendency for large fish to cannibalise smaller conspecifics means that food does not tend to be a limiting resource and the highly fecund nature of this species makes it very difficult to ensure long-term control of the population by using only nets. In order to eradicate invasive fish from Lake Wainamu it would likely require the large-scale application of a piscicide such as rotenone, although given the size of the lake this option is likely to be impractical.

While the CPUE can be used as a performance measure of the programme, there was no specific assessment of the effects on lake water quality or ecology of the invasive fish removal programme. It was assumed that reducing the number of perch would, inter alia, have a positive effect on native fish populations in the lake. However, the absence of monitoring to document such positive effects is problematic as it is difficult to sustain the programme based on the invasive fish catch data alone. A targeted water quality monitoring programme and some native biodiversity monitoring would have been useful to understand the effects and potential benefits of the fish removal programme.

Collaboration with other organisations in projects such as this may provide additional research opportunities. Auckland University of Technology assisted with fieldwork in 2012 and 2013, and performed analyses on a sample of the perch caught during that period to determine their size and age structure, as well as looking at their reproductive development (Sabetian *et al*. 2015). Information from this study contributes to a better understanding of perch population dynamics and may offer insight into how the species may be managed elsewhere in New Zealand.

GOLDFISH (ORANGE VARIANT)
Photo: Helen McCaughan (DOC)


GOLDFISH
Photo: Brendan Hicks (UoW)


PERCH
Photo: Bruno David (WRC)

6

Surveillance, Inventory and Monitoring

Standardised invasive fish sampling methods are essential to ensure that information collected is consistent and comparable between survey periods, and that there can be confidence in the results of surveillance and monitoring operations. Confirming the presence or absence of fish species in freshwater environments is challenging. A range of survey methods therefore needs to be employed to ensure there is an adequate chance of encountering the species of interest, balanced with knowledge of the cost-effectiveness of the different methods employed. This section outlines some of the tools that can be used for invasive fish surveillance and monitoring, including the developing technology of environmental DNA.

6.1 Department of Conservation Invasive Fish Monitoring Tools

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Background

In New Zealand, Joy *et al.* (2013) give guidance on how to survey wadeable rivers and streams for assessing and monitoring their state, but there is no published protocol on how to design or carry out surveillance monitoring programmes for invasive fish species. This section gives an overview of the Department of Conservation's Inventory and Monitoring Toolbox and Invasive Fish Inventory and Monitoring Best Practice Guidance that go some way to addressing the requirements of practitioners trying to maximise the chances of detecting non-indigenous invasive fish species.

Inventory and Monitoring Toolbox

The Inventory and Monitoring Toolbox (Greene & McNutt 2012) defines 'inventory' as a one-off survey or assessment with no intention to re-measure, and 'monitoring' as an assessment of change or trend over time that requires re-measurement of parameters at some pre-determined frequency. The introductory section of the freshwater fish part of the toolbox (Grainger *et al.* 2013) presents a series of decision trees to identify the most suitable and cost-effective way to survey the type of fish or habitat of interest; it covers all freshwater fish species in New Zealand and does not focus just on invasive species. The toolbox recognises that there is no single method that can be applied to all species in all habitats, and that the design of an inventory and/or monitoring programme will depend on target species, habitat and project objectives. Decision trees cover:

- Clarifying objectives—do you need to know what species are present (inventory) or do you need to know about population size (monitoring)?
- Appropriate inventory and monitoring methods for functional groups of fish (Figure 6.1).
- Appropriate inventory and monitoring methods for particular habitats.

Method specifications include spotlighting (fixed reach, multi-pass), land-based electrofishing (fixed reach, mutli-pass) and passive nets (Gee minnow, fyke, gill and trammel). Boat electrofishing is described in detail in Section 4.4. Each method specification outlines assumptions, advantages and disadvantages, suitability for inventory and/or monitoring, skills and resources required, and advice on data collection, management and storage. The passive net methodologies section of the toolbox are of most relevance to invasive fish inventory and monitoring and are available at:

- Gee minnow traps
  www.doc.govt.nz/Documents/science-and-technical/inventory-monitoring/im-toolbox-freshwater-fish/im-toolbox-freshwater-fish-passive-nets-minnow-traps.pdf

SUGGESTED CITATION FOR SECTION 6.1: Grainger N 2015. Department of Conservation Invasive Fish Monitoring Tools. Section 6.1 in Collier KJ & Grainger NPJ eds. New Zealand Invasive Fish Management Handbook. Lake Ecosystem Restoration New Zealand (LERNZ; The University of Waikato) and Department of Conservation, Hamilton, New Zealand. Pp 112–115.

- Fyke nets
  www.doc.govt.nz/Documents/science-and-technical/inventory-monitoring/im-toolbox-freshwater-fish/im-toolbox-freshwater-fish-passive-nets-fyke nets.pdf
- Gill and trammel nets
  www.doc.govt.nz/Documents/science-and-technical/inventory-monitoring/im-toolbox-freshwater-fish/im-toolbox-freshwater-fish-passive%20nets-gill-and-trammel-nets.pdf

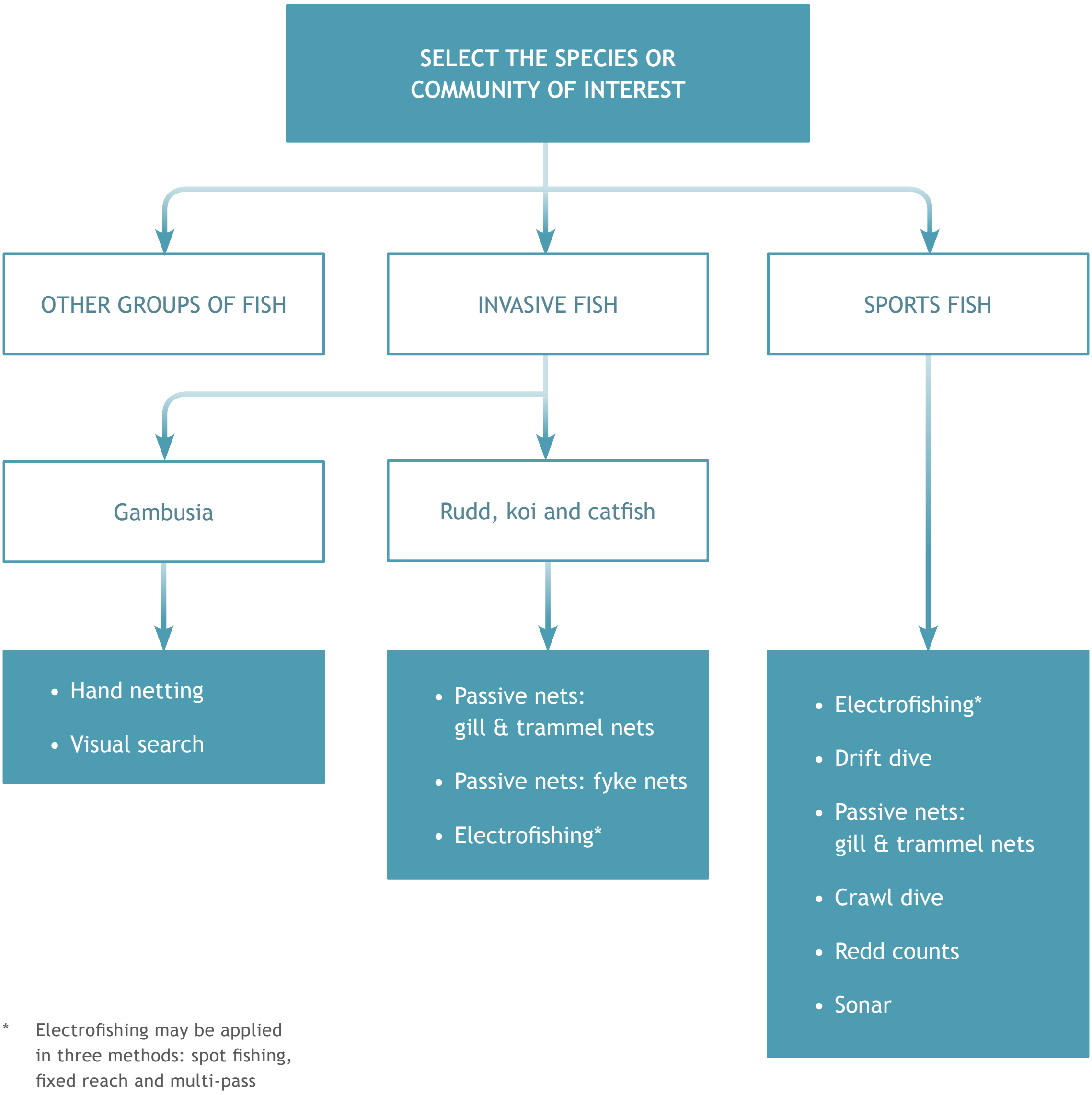

FIGURE 6.1 Methodologies recommended for inventory and monitoring of some invasive fish and sports fish.

Inventory and Monitoring Best Practice Guidance

The Invasive Fish Inventory and Monitoring: Best Practice Guidance (Grainger *et al*. 2014), reproduced in Appendix 2, is more specific than the method specifications provided in the toolbox. It aims to provide practical information and suggestions to maximise the chances of detecting invasive fish as part of inventory and monitoring activities. The best practice guidance recognises that methods for inventory and monitoring surveys will be similar, but the intensity and frequency of effort needs to vary depending on the survey objective. For surveillance or inventory work, a range of methods will need to be deployed to ensure a range of species could be encountered (Table 6.1), whereas if post-eradication monitoring is being undertaken it is likely the methodology will specifically target the species of interest.

A **minimum** sampling effort for a multi-species inventory of a 0.5 ha waterbody is:

- visual observation—50 m length of shoreline or 25% of waterbody edge;
- active netting—one each of dip net, seine net or push net;
- set nets—one panel gill net and/or one trammel net; and
- set traps—1–2 fyke nets and/or 3–5 Gee minnow traps.

This effort must be scaled up for larger sites. The document gives guidance on when and where to survey for invasive fish species as well as a brief overview of the methodologies (Table 6.1). The best practice guidance also sets standards for declaring freshwater fish populations to have been eradicated. Surveys need to be undertaken at the best time of year to survey and use at least double the minimum number of nets/traps per 0.5 ha. Table 6.2 is derived from the best practice guidance of the eradication monitoring standards for designating freshwater fish populations as ‘eradicated’. These standards are intended as guides only and need to be tailored to the species and site of interest.

Supporting Documents

Best practice guidance is also available to decontaminate freshwater gear (Grainger & McCaughan 2014a; Appendix 3), and prevent the unintentional capture of diving birds (Grainger & McCaughan 2014b; Appendix 4). The decontamination protocols (Grainger & McCaughan 2014a) are based on work done by Dugdale & Wells (2002) and Matheson *et al*. (2007); these protocols are effective against a suite of introduced fish, plant, invertebrate and algal species.

TABLE 6.1 Suggested sampling methods for invasive fish, and when and where to survey (see Appendix 2 for full details).

MAIN HABITAT	SAMPLING METHODS	WHEN TO SURVEY	WHERE TO SURVEY
GAMBUSIA			
Fish clusters occupying very shallow, calm waters around edges of lakes, ponds and drains	**All life stages:** Gee minnow trap; fyke net (fine mesh); seine net; visual observation; dip net; bottle traps	**Best:** Summer months (Dec-Mar) **Satisfactory in northern areas:** Sep-May	Shallow shelving shorelines (<1 m deep) with aquatic vegetation present Sheltered shorelines
RUDD, PERCH			
Schooling fish found in surface waters around the edges, and near edges of lakes and ponds	**Adults:** Gill net; trammel net; visual observation; electrofishing **Juveniles:** Seine net; Gee minnow trap; dip net; visual observation	**Best:** Summer months (Dec-Mar) **Satisfactory in northern areas:** Sep-May	Lake edge, beyond and over aquatic vegetation
KOI CARP, GOLDFISH			
Often solitary fish found throughout water column and near edges, particularly around vegetated lake edges	**Adults:** Trammel net; gill net; fyke net; visual observation; electrofishing **Juveniles:** Seine net; Gee minnow trap; visual observation; dip net	**Best:** Summer months (Dec-Mar) **Satisfactory in northern areas:** Sep-May	Near shoreline, at outer edge of tall aquatic vegetation and out into waterbody a short way
CATFISH, TENCH			
Often solitary fish found near the lake bottom and edges, including around vegetated lake edges	**Adults:** Trammel net; fyke net; gill net; electrofishing **Juveniles:** Gee minnow trap; dip net	**Best:** Spring/ summer months (Oct-Mar) **Satisfactory in northern areas:** Sep-May	Near shoreline, at outer edge of tall aquatic vegetation and out into waterbody a short way

TABLE 6.2 Monitoring standards for designating freshwater fish populations 'eradicated'.

SPECIES	MINIMUM ERADICATION MONITORING STANDARD	CRITERIA (DO ALL)
Gambusia	No capture/sighting of target species from at least three separate valid monitoring surveys over a three-or-more year period following treatment, with time between surveys of at least one month.	1. Survey at best time in season 2. Use full range of applicable methods 3. At least double number of nets/ traps per 0.5 ha
Rudd, koi carp, catfish, goldfish, perch, tench	No capture of target species from at least three separate valid monitoring surveys over a three-year period following treatment.	

6.2 Biomass Estimation of Invasive Fish

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Introduction

Invasive fish have a variety of effects on indigenous fish communities and freshwater ecosystems generally, and the magnitude of these effects is partly dependent on invasive fish biomass. For example, a koi carp biomass of 120–130 kg/ha was sufficient to depress macroinvertebrate and plant biomass, and to elevate chlorophyll *a* concentrations (Haas *et al*. 2007; Bajer *et al*. 2009; Hicks *et al*. 2011). The purpose of this section is to provide (i) estimates of the relative biomasses of invasive fish that have been established by boat electrofishing in a range of lake and riverine habitats in the North Island; and (ii) some estimates of absolute biomass derived from mark-recapture studies in shallow lakes. Collectively, these data provide a basis for future comparisons of invasive fish monitoring information in a region where coarse fish have proliferated.

Relative Biomass Estimates of Invasive Fish in Waikato Lakes

Reliable data on fish abundance are difficult to collect. The reasons for this are varied, but the principle impediments are the selective nature of sampling gear, patchy distribution of the fish themselves, and behaviour of the fish. Boat electrofishing offers a rapid and quantitative sampling tool in non-wadeable freshwater habitats (see Section 4.4), and a number of quantitative surveys have been conducted of shallow lakes in the Waikato region using this method (Table 6.3, Figure 6.2). Between March 2007 and February 2014, this involved 10-minute shots in 16 lakes, with 9–11 shots in each lake, fishing primarily in the littoral zone but also in open water at depths less than 3 m. Two lakes were fished twice (Kimihia and Waahi).

The total weight of each species caught was divided by four times the length of the fishing track, as determined by a Garmin GPSMAP 60Cx global positioning unit, to give a biomass for each species per hectare, with the electrofishing pulsator setting as described in Section 4.4. This approach should be considered as providing a minimum biomass estimate for each species because single-pass boat electrofishing catches on average 48% of the total population, and does not take into account the bias of boat electrofishing against eels and catfish (see sections 4.4 and 6.3).

We caught nine species of non-indigenous fish, mostly koi carp, goldfish, brown bullhead catfish and rudd, and six species of indigenous fish of which shortfin eel, common bully and common smelt were the most widespread (Table 6.3). In most lakes with koi carp, their biomass was the highest of any species, with a maximum of 189 kg/ha in Lake Kimihia in 2012. Koi carp biomasses in lakes Kimihia, Whangape and Hakanoa (Table 6.3), once corrected for the proportion of the total population caught by boat electrofishing, exceeded the biomass threshold of 50–100 kg/ha for impaired water quality and

SUGGESTED CITATION FOR SECTION 6.2: Hicks BJ, Brijs J, Daniel A, Morgan D, Ling N 2015. Biomass Estimation of Invasive Fish. Section 6.2 in Collier KJ & Grainger NPJ eds. New Zealand Invasive Fish Management Handbook. Lake Ecosystem Restoration New Zealand (LERNZ; The University of Waikato) and Department of Conservation, Hamilton, New Zealand. Pp 116-122.

TABLE 6.3 Original fish biomass estimates from boat electrofishing in water <3 m deep for 16 Waikato lakes before fish removal. Note: Oranga is a pond on The University of Waikato campus; three adult koi weighing a total of 9.55 kg (13.8 kg/ha) were removed by bow fishing before boat electrofishing.

LAKE	SURVEY DATE	AREA (ha)	MAX. DEPTH (m)	*n*	MEAN FISH BIOMASS (kg/ha)																	
					INDIGENOUS SPECIES						NON-INDIGENOUS SPECIES											
					Shortfin eel	Longfin eel	Common bully	Common smelt	Grey mullet	Īnanga	Koi carp	Goldfish	Catfish	Rudd	Perch	Koi/goldfish hybrid	Tench	Rainbow trout	Gambusia	TOTAL (non-indigenous)	TOTAL (all species)	PERCENT (non-indigenous)
Hakanoa	16 Oct 09	56	2.5	10	8.7	0	0.04	0.010	1.6	0	90.6	4.5	5.6	0	0	0	0	0	0.020	101	111	91
Kainui	18 Sep 09	25	6.7	9	72.0	1.4	0.08	0	0	0	0	3.0	5.9	0.1	0	0	0	0	0.100	9	82	11
Kaituna	14 May 09	15	1.3	10	56.8	0	0.59	0	0	0.052	37.7	77.1	4.8	1.5	0	0	0	0	0.020	121	179	68
Kimihia	21 May 09	58	1.0	10	5.9	0	0.03	0.060	0	0.010	13.9	27.1	1.4	1.0	0	0	0	0	0.100	43	49	88
Kimihia	6 Sep 12	58	1.0	11	7.3	0	0	0	0.1	0	189.4	93.3	11.1	0.9	0	0	0	0	0.100	295	302	98
Koromatua	4 Jun 09	7	0.8	9	31.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	31	0
Mangahia	4 Feb 09	10	1.5	10	24.9	7.6	0	0	0	0	0	78.8	17.6	0	0	0	0	0	0.004	96	129	75
Ngaroto	2 Feb 09	130	3.5	11	6.1	0	0.02	0	0	0	22.2	0	1.7	2.4	0	4.4	0	0	0.012	31	37	83
Ohinewai	28 May 09	16	4.5	8	24.6	1.5	0.03	0	0	0	21.5	0.01	0.6	0	0	9.3	0	0	0.005	31	58	55
Oranga	22 Jan 14	0.69	0.8	10	19.1	0	1.64	0	0	0	0.8	18.4	3.0	0	0	5.3	0	0	0.477	28	49	57
Otamataeroa	28 Apr 09	5	3.0	10	75.9	0	0.11	0	0	0	0	11.4	1.0	0	0	0	0	1.0	0	13	90	15
Puketirini	10 Feb 14	54	64.0	9	1.2	0	0	0	0	0	55.1	0	0	2.4	0.9	0	0	0	0.020	58	60	98
Rotokaeo	12 Dec 08	3.7	1.8	9	26.4	0	0	0	0	0	0	8.6	3.0	0	0	0	0	0	0.020	12	38	31
Rotokauri	29 Sep 09	77	4.0	9	15.2	0	0.22	0.013	0	0	21.6	5.4	0.8	0	0	2.9	0	0	0.020	31	46	66
Rotoroa	9 Jan 12	54	6.0	10	4.5	0	0	0	0	0	0	0	3.1	0.1	6.7	0	8.0	0	0.100	18	23	80
Waahi	8 Mar 07	522	5.0	11	10.2	0	0.01	0.056	0	0.002	29.1	43.0	7.2	1.6	5.9	0	0	0	0.007	87	97	89
Waahi	23 Mar 11	522	5.0	9	5.1	0	0	0.020	0	0	22.2	22.3	2.2	2.3	7.5	0	0	0	0.020	56	62	92
Whangape	24 Aug 10	1450	3.5	9	11.7	0	0.04	0	1.3	0.030	98.8	72.7	4.4	0.5	0	0	0	0	0.020	176	189	93
MEAN					23	1	<1	<1	<1	<1	33	26	4	1	1	1	<1	<1	23	67	91	66

destruction of macrophytes (Bajer *et al*. 2009; Hicks & Ling 2015). Koi carp were not caught in Lake Mangahia during the fishing in February 2009, but 25 carp were caught by boat electrofishing during an intensive fish removal in 2010 (see Mark-recapture biomass estimates later in this section).

In over half of the lakes, non-indigenous fish comprised ≥80% of the total fish biomass caught. At a maximum biomass of up to 93 kg/ha, goldfish were the next most abundant non-indigenous species behind koi carp, sometimes exceeding their biomass (e.g. in lakes Waahi and Kimihia in 2009). A severe drought in the summer of 2008 probably reduced the number of koi carp while affecting the goldfish population less because of their extreme tolerance to hypoxia. Tench and rainbow trout were each found in only one Waikato lake (rainbow trout in Lake Otamataeroa where they are stocked; tench in Lake Rotoroa). Gambusia were extremely widespread but comprised only a small biomass relative to other invasive fish species.

Relative Biomass Estimates of Invasive Fish in a Large River

The first electrofishing boat survey of the lower Waikato River and its tributaries was conducted between 8–15 February 2005 (Hicks *et al*. 2005). In total, 2,915 fish were caught in the river, comprising seven introduced and six native fish species in 5.63 km of fished length from a total of 27 sites (Figure 6.3). Again, assuming that the fishing track was 4 m wide, the total area fished was 22,520 m² or 2.252 ha.

Koi carp comprised 285 kg, or 69% (range 0–97% per site) of the 410 kg of fish caught. The majority of koi carp were caught in zones 2–4 (Table 6.4), where they occurred in all habitats except mid-channel sand bars. The greatest koi carp biomasses (up to 1,240 kg/ha) were associated with willow (*Salix*) fringes and macrophyte beds. The Waikato River is relatively narrow throughout most of Zone 1, with few beaches or gently shelving littoral areas. These habitats increase in number and extent in Zone 2,

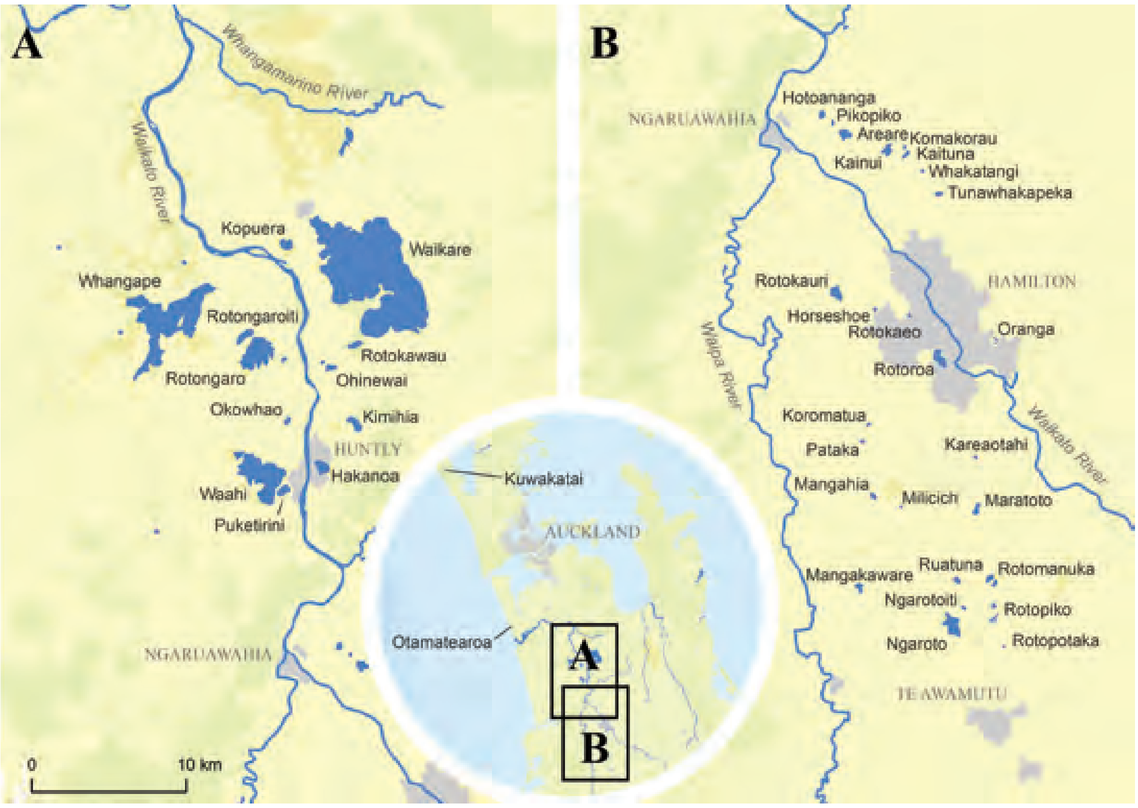

FIGURE 6.2 Peat and riverine lakes of the Waikato region.

and the floodplain is most developed in Zone 3 where extensive flat, off-channel areas are lined by willows and extensive macrophytes beds. The lower end of Zone 4 is influenced by tidal water level fluctuations, and habitat is less usable by koi carp overall. Koi carp abundance reflected these habitat changes, and was highest in Zone 3. Goldfish and rudd, however, were most abundant around macrophyte beds in Zone 2. Abundance of the indigenous grey mullet, a large, benthivorous fish, was lowest where koi carp abundance was greatest, possibly suggesting competitive exclusion of grey mullet by koi carp.

In the Whangamarino River, which flows into the Waikato River from the Whangamarino Wetland, mean biomass of koi carp at 20 sites (326 kg/ha) was higher than in the Waikato River (Hicks *et al*. 2008; Table 6.4). Mean biomasses of goldfish (79 kg/ha) and catfish (5.9 kg/ha) were also higher in the Whangamarino River than in any site fished in the Waikato River, highlighting the importance of wetland tributaries for koi carp.

FIGURE 6.3 Sites fished in the lower Waikato River between 8-15 February 2005. Green circles = fished sites; red circles = locations of zones breaks. Source: Hicks *et al*. (2005).

Mark-recapture Biomass Estimates

To quantify the biomass of invasive fish at representative sites and provide a basis for interpreting single-pass electrofishing estimates, mark-recapture techniques were used between 2010 and 2014 in shallow lakes ranging in area from 0.69 to 36 ha (Table 6.5). In these mark-recapture population estimates, fish were captured by boat electrofishing, fyke netting and pod trapping, marked with a fin clip and released back into the lake. Marked fish were allowed to mix with unmarked fish for a period of 2–6 weeks, and then the lake was re-sampled using the same methods. Non-indigenous fish were removed and humanely destroyed and native species were returned to the lake. Population estimates (N) were made based on the adjusted Petersen method (Ricker 1975), which uses the total number of fish originally marked (M), the total number recaptured (C), and the number of those fish that were marked (R), as follows:

$$N = \frac{(M+1)(C+1)}{R+1} \quad \text{(Equation 2)}$$

TABLE 6.4 Fish biomass estimates from boat electrofishing over 8-15 February 2005 at 27 sites in the Waikato River (separated into zones 1-4; Figure 6.3), and at 20 sites in the Whangamarino River and its tributaries on 3-6 March 2008.

SPECIES	MEAN BIOMASS (kg/ha)				
	WAIKATO RIVER				WHANGAMARINO RIVER
	ZONE 1	ZONE 2	ZONE 3	ZONE 4	
Number of sites	8	6	6	7	20
NON-INDIGENOUS SPECIES					
Koi carp	39.6	147.6	307.8	183.5	325.8
Goldfish	0.2	19.5	16.2	18.7	78.9
Rudd	0.4	7.7	4.2	1.4	2.5
Catfish	0	0	0.7	2.9	5.9
Brown trout	73.2	0	0	0	0
Rainbow trout	6.3	0	0	0	0
Koi-goldfish hybrid	0	0	2.6	0.6	0
Gambusia	0.001	0.010	0.013	0.009	-
INDIGENOUS SPECIES					
Shortfin eel	26.4	11.9	8.0	9.5	13.9
Grey mullet	22.5	16.6	5.3	29.9	9.5
Common smelt	2.8	1.1	0.6	1.4	0.70
Common bully	0.05	0.25	0.05	0.09	0.04
Īnanga	0.08	0.20	0.06	0.03	0.10
Longfin eel	0	0	0	0.19	0.40
Torrentfish	0	0	0	0.001	0
TOTAL SPECIES	172	205	346	248	438
TOTAL NON-INDIGENOUS SPECIES	120	175	331	207	413
% NON-INDIGENOUS SPECIES	70	85	96	83	94

- gambusia widely present but not enumerated

The greatest biomass of invasive fish was found in Lake Mangahia, which yielded 625 (out of a total of 670) kg/ha, comprising predominantly goldfish and catfish; there were also 37 kg/ha of shortfin eels and 8 kg/ha of longfin eels (Table 6.5A). The lowest invasive fish biomass was in the Rotopiko (Serpentine) lakes, from which rudd have been removed repeatedly by the Department of Conservation since 2001 (e.g. Neilson *et al*. 2004; see Section 5.4). No rudd were caught in these lakes during extensive netting between March and June 2012, and there were only low biomasses of catfish and goldfish (0.4–2.2 kg/ha); shortfin eels dominated the fish communities and ranged from 27–45 kg/ha (Table 6.5E). Lake Kuwakatai, a 36 ha dune lake on northern Auckland's west coast, had only a modest biomass of invasive fish (140 kg/ha) but a large number of rudd, mostly juveniles. Of the lakes surveyed, perch were caught only in Lake Kuwakatai (Table 6.5B). A lower biomass of invasive fish (123 kg/ha) was estimated in Lake Kaituna where koi carp dominated biomass but goldfish and eel were most abundant numerically (Table 6.5C).

TABLE 6.5 Population estimates of non-indigenous and indigenous fish species in shallow lakes (see Figure 6.2) calculated from the adjusted Petersen method (Ricker 1975).

SPECIES	POP. ESTIMATE	BIOMASS (kg/ha)
A. Lake Mangahia: 25 Mar-23 Apr 2010 (area 10 ha)		
NON-INDIGENOUS FISH		
Catfish	4,875	66
Goldfish	24,245	556
Koi carp*	25	1.4
Rudd*	63	0.69
INDIGENOUS FISH		
Shortfin eel	822	37
Longfin eel	48	7.7
TOTAL	30,078	670
TOTAL NON-INDIGENOUS (%)	29,208	625 (93)
B. Lake Kuwakatai: Nov 2011-Jan 2012 (area 36 ha)		
NON-INDIGENOUS FISH		
Goldfish	9,324	26
Koi carp	780	33
Perch	2,513	7.6
Rudd	28,934	28
Tench	12,676	43
INDIGENOUS FISH		
Shortfin eel	1	0.08
Kōura (crayfish)	2,400	2.1
TOTAL	56,629	140
TOTAL NON-INDIGENOUS (%)	54,228	138 (98)
C. Lake Kaituna: 9 Sep-4 Nov 2010 (area 15 ha)		
NON-INDIGENOUS FISH		
Catfish	923	12
Goldfish	2,727	46
Koi carp	619	77
Rudd	302	3.3
INDIGENOUS FISH		
Shortfin eel	4,760	56
Longfin eel	45	1.1
TOTAL	9,376	193
TOTAL NON-INDIGENOUS (%)	4,571	123 (71)
D. Lake Ohinewai: 17-28 Jan 2011 (area 16 ha)		
NON-INDIGENOUS FISH		
Catfish	1,559	15
Goldfish	878	8.3
Koi carp	8,549	374
Rudd	102	0.92
INDIGENOUS FISH		
Shortfin eel*	792	9.4
Longfin eel*	18	0.36
TOTAL	11,897	424
TOTAL NON-INDIGENOUS (%)	11,087	414 (98)

SPECIES	POP. ESTIMATE	BIOMASS (kg/ha)
E. Rotopiko (Serpentine) lakes: 28 Mar-22 Jun 2012		
South Lake (area 8.3 ha)		
NON-INDIGENOUS FISH		
Catfish	15	0.40
Gambusia*	1	-
Goldfish	20	0.62
INDIGENOUS FISH		
Shortfin eel	638	27
Longfin eel	13	1.4
Common bully*	819	-
Common smelt*	2	-
TOTAL	1,508	29
TOTAL NON-INDIGENOUS (%)	36	1.0 (3)
North Lake (area 5.3 ha)		
NON-INDIGENOUS FISH		
Catfish	48	2.2
Gambusia*	1	-
INDIGENOUS FISH		
Shortfin eel	546	43
Longfin eel*	6	-
Common smelt*	21	-
TOTAL	622	46
TOTAL NON-INDIGENOUS (%)	49	2.2 (5)
East Lake (area 1.6 ha)		
NON-INDIGENOUS FISH		
Catfish	8	0.7
INDIGENOUS FISH		
Shortfin eel	269	45
Longfin eel*	3	0.17
Common bully*	819	-
TOTAL	1,099	46
TOTAL NON-INDIGENOUS (%)	8	0.7 (2)
F. Oranga Lake: 22 Jan-14 Mar 2014 (area 0.69 ha)		
NON-INDIGENOUS FISH		
Catfish	91	51
Goldfish >100 mm	231	126
Goldfish <100 mm*	1,327	8
Koi carp	120	26
Koi carp*†	3	14
Koi-goldfish hybrids	18	27
Gambusia*	4,658	1
INDIGENOUS FISH		
Shortfin eel	299	148
Common bully*	1,433	2
TOTAL	8,179	402
TOTAL NON-INDIGENOUS (%)	6,447	252 (63)

* this is the actual number of fish caught because there were no marked fish

† removed by bow fishing

\- missing data

In the smallest of the lakes surveyed, Lake Oranga, which was constructed as a storm-water detention pond on the campus of The University of Waikato, only goldfish >100 mm fork length were marked, so juveniles were estimated from the numbers removed during 38 10-minute boat electrofishing shots. This small lake had a goldfish biomass of at least 134 kg/ha (Table 6.5F), which is second only behind the estimate for Lake Mangahia (Table 6.5A). Koi carp were discovered in Lake Oranga about three years ago, and have yet to reach carrying capacity. To the biomass of 26 kg/ha determined by mark-recapture must be added three adults weighing 9.55 kg in total, equivalent to 14 kg/ha, that were removed by bow fishing before the mark-recapture fishing started. This lake therefore had an invasive fish biomass of at least 252 kg/ha, above the threshold considered to contribute to impaired water quality. Lake Ohinewai had the highest biomass of koi carp (374 kg/ha) of any lake for which mark-recapture biomass estimates were made (Table 6.5D).

Summary

In the lakes where invasive fish had not been controlled, biomass ranged from 123 to 625 kg/ha based on mark-recapture population estimates. High biomass of koi carp, which are highly migratory (Daniel *et al*. 2011), reflected ease of access to lakes, highlighting the importance of barriers to exclude koi carp. Lake Ohinewai had 374 kg/ha of koi carp and only 10 kg/ha of eels, but eel biomass seems to be increasing following koi carp removal (see Section 5.2). The rudd removal programme was clearly effective in the Rotopiko (Serpentine) lakes where eel biomass is within the range for most other Waikato lakes sampled (27–57 kg/ha).

Fish biomass estimates from boat electrofishing gave indicative information about the relative abundance and biomass of each species, but this was not always in accordance with the results of mark-recapture studies. For instance, in Lake Kaituna boat electrofishing caught about half of the koi carp population estimated by mark-recapture, whereas in Lake Ohinewai boat electrofishing caught about 6% of the mark-recapture estimate. The relative maximum depths of these lakes (1.3 m for Kaituna and 4.5 m for Ohinewai) suggests that in the deeper lake, many koi carp were out of range of the electrofishing field and evaded capture. In support of this conclusion, the depth sounder on the electrofishing boat did locate large fish at 2–4 m depth that were not caught during the Lake Ohinewai electrofishing.

At riverine sites, koi carp biomass was as high as in most lakes, especially in the Whangamarino River, a known hotspot for koi carp. Shortfin eels and grey mullet showed a somewhat inverse relationship with koi carp biomass between the four zones of the Waikato River, suggesting that competitive exclusion may be taking place and that reduction of carp biomass may help improve eel abundance. The most reliable recent information suggests that koi carp biomass should be <50–100 kg/ha to avoid environmental damage (Bajer *et al*. 2009, Baidou & Goldsborough 2010). Biomass exceeds this level in most sites around the Waikato River, and in its lakes and tributaries, often by a large margin. Goldfish are even more widespread than koi carp, and they are frequently the second most abundant invasive fish. The poor water clarity in Lake Mangahia, where goldfish biomass exceeded 500 kg/ha, suggests that they could be just as problematic as koi carp in terms of water quality impacts.

6.3 Costs and Effectiveness of Different Methods for Capturing Invasive Fish

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Background

Comparisons of the effectiveness of different fishing techniques in non-wadeable habitats give insights into the relative abundance of invasive fish and native fish, which is important to provide evidence for changes in fish abundance over time. Such comparisons can also be used to determine the most effective methods to remove invasive fish. The objective of this section is to examine methods that yield the most fish for the least cost (i.e. maximise the catch per unit effort). Because comparisons are most effective when applied in a single habitat, they are best considered as case histories at one location. All costs of removal in this chapter are in $NZ. Rotenone has been applied successfully in New Zealand in small waterbodies (e.g. the 0.7 ha Lake Parkinson near Auckland—Tanner *et al*. 1990; Rowe & Champion 1994) and routinely by the Department of Conservation; use of rotenone to control invasive fish is not considered in this section because it is dealt with in Section 4.1.

Boat electrofishing is a technique that has been applied widely in the North Island of New Zealand since 2003 (e.g. Hicks & Bell 2003; Hicks & Tempero 2013; Section 4.4), and provides a useful basis for comparing other methods as it is highly effective at capturing some fish species in non-wadeable habitats. For instance, while boat electrofishing 700 m^2 of the Lake Whangape littoral margin (0.4–0.7 m deep) during the spawning season in September 2003, 24 koi carp were caught in 11 minutes, weighing 87.4 kg, with a mean fish mass of 3.64 kg and a catch rate of 349 fish/person-day or 1,271 kg/person-day. The calculated population estimate of 68 carp from the single removal (24 carp), applying Equation 1 in Section 4.4, implies a biomass of 3,541 kg/ha. The electrofishing boat normally has a crew of three, so assuming a cost of $480/person-day and a time of 0.07 person-day, the capture cost was $0.38/kg. The average catch rate for koi carp across our entire data set for locations with koi carp (205 capture occasions) by boat electrofishing is 62 fish/person-day and 99 kg/person-day, suggesting an average capture cost of $4.85/kg for labour for fishing time. These costs do not take into account consumables, travel, capital costs, depreciation or maintenance.

SUGGESTED CITATION FOR SECTION 6.3: Hicks, BJ, Daniel A, Ling N, Morgan D, Gautier S 2015. Costs and Effectiveness of Different Methods for Capturing Invasive Fish. Section 6.3 in Collier KJ & Grainger NPJ eds. New Zealand Invasive Fish Management Handbook. Lake Ecosystem Restoration New Zealand (LERNZ; The University of Waikato) and Department of Conservation, Hamilton, New Zealand. Pp 123–132.

Trap Netting

There have been few comparisons of the effectiveness of different fishing techniques in a single waterbody in New Zealand, but Hayes (1989) compared trap nets, similar in design to those described by Beamish (1973), to five other fishing techniques in shallow lakes in the Waikato River basin (Gee minnow traps, single-leader fyke nets, gills nets, and beach and purse seine nets; Table 6.6). In that comparison, the large, fine mesh (1 mm) trap nets with two 1 m^3 pots and a single 15 m x 1 m leader were the most effective for a wide range of fish species, except for goldfish, catfish and rudd, three of the most important invasive fish. Koi carp, which are now abundant in the lakes sampled, were not caught in 1986 and 1987 when Hayes (1989) sampled. No estimates of costs are available for that study.

TABLE 6.6 Number of each species and their length ranges (mm) caught by six gear types in lakes Whangape and Waahi, Waikato River basin, in January 1986 and February 1987; *n* = numbers of net nights or hauls. Adapted from Hayes (1989).

	GEE MINNOW (*n* = 12)		FYKE NET (*n* = 3)		TRAP NET (*n* = 4)		GILL NET (*n* = 6)		BEACH SEINE (*n* = 8)		PURSE SEINE (*n* = 6)	
	NO.	LENGTH	NO.	LENGTH	NO.	LENGTH	NO.	LENGTH	NO.	LENGTH	NO.	LENGTH
NON-INDIGENOUS SPECIES												
Gambusia					848	15-55			378	16-45	10	7-44
Goldfish					15	10-190	16	140-275	24	23-95	4	12-45
Catfish			3		13	65-280	40	160-500	43	30-50		
Rudd							5	134-200				
INDIGENOUS SPECIES												
Shortfin eel	52	120-450	139	>120	1,378	>70			2			
Common bully	2	47-49	240	30-66	3,688	15-80			351	15-57	100	9-63
Common smelt					105	20-110			82	44-75	10	21-81
Īnanga					162	45-135			128	55-65	1	70-95
Grey mullet							184	220-425				

GAMBUSIA TRAPPING: Gambusia live in the shallow margins of waterbodies in summer and are not vulnerable to most capture methods because of their small size and the shallowness of their habitats (commonly 0.1-0.3 m deep). However, Gee minnow traps are moderately effective. To investigate trap efficiency of Gee minnow traps for catching gambusia, one to four 3-mm mesh traps were set in each of six circular concrete tanks that were 0.55 m deep and 1.50 m in diameter (2.72 m^2 in area) with about 1,000 L of water. At the start of each trial 50 or 100 gambusia were placed in each tank, a fish density of 18 or 37 fish/m^2, with 1-4 unbaited Gee minnow traps in each tank. Traps were set at approximately 08:30 hrs and 13:00 hrs and left to fish for three hours before being removed in the same order they were set. Catch rate per trap declined with increasing numbers of traps per tank, but the total proportion of fish caught increased with increasing numbers of traps (Figure 6.4). At a maximum, minnow traps were able to catch a mean of 70% of the fish present. Gambusia tended to aggregate in traps, possibly regarding them as habitat. The presence of dried blood worms in the traps approximately doubled the catch rate compared to traps without blood worms.

In another experiment, 40 collapsible Promar 1-mm mesh unbaited bait traps (Plate 6.1) were set in Chapel Lake, 0.44 ha in area with a maximum depth 1.8 m on The University of Waikato campus. Traps were set starting at 09:00 hrs and retrieved starting at 10:30 hrs on three consecutive days, twice over two weeks (3–5 and 10–12 February 2009), to give a total of six removals. A total of 5,781 gambusia were removed weighing a total of 1.14 kg (Figure 6.5). Fish caught declined from 1,734 to 509 per day, and catch rates for the same days declined from 43 to 13 fish/trap. Maximum likelihood methods (CAPTURE; Otis *et al.* 1978) to estimate the total population ± 95% confidence interval from the daily removal totals (Figure 6.5A) indicated 7,444 ± 491 fish. This estimate suggests that 78% of the gambusia were removed from Chapel Lake, which required three person-days, equating to 1,927 fish/person-day at a total labour cost of $1,440, or $1,263/kg.

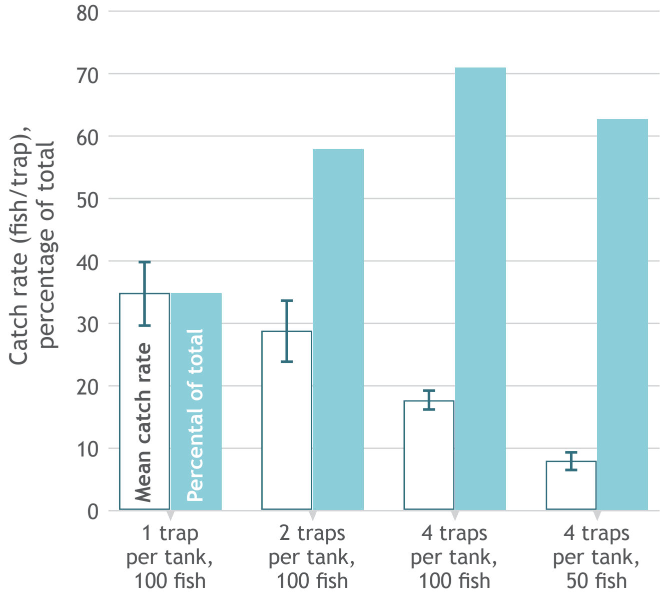

FIGURE 6.4 Catch rate of gambusia caught in fine-mesh Gee minnow traps set for three hours in circular concrete tanks with 50 or 100 fish in each tank. Error bars are 95% confidence intervals.

PLATE 6.1 Collapsible Promar fine-mesh bait trap used to catch gambusia.

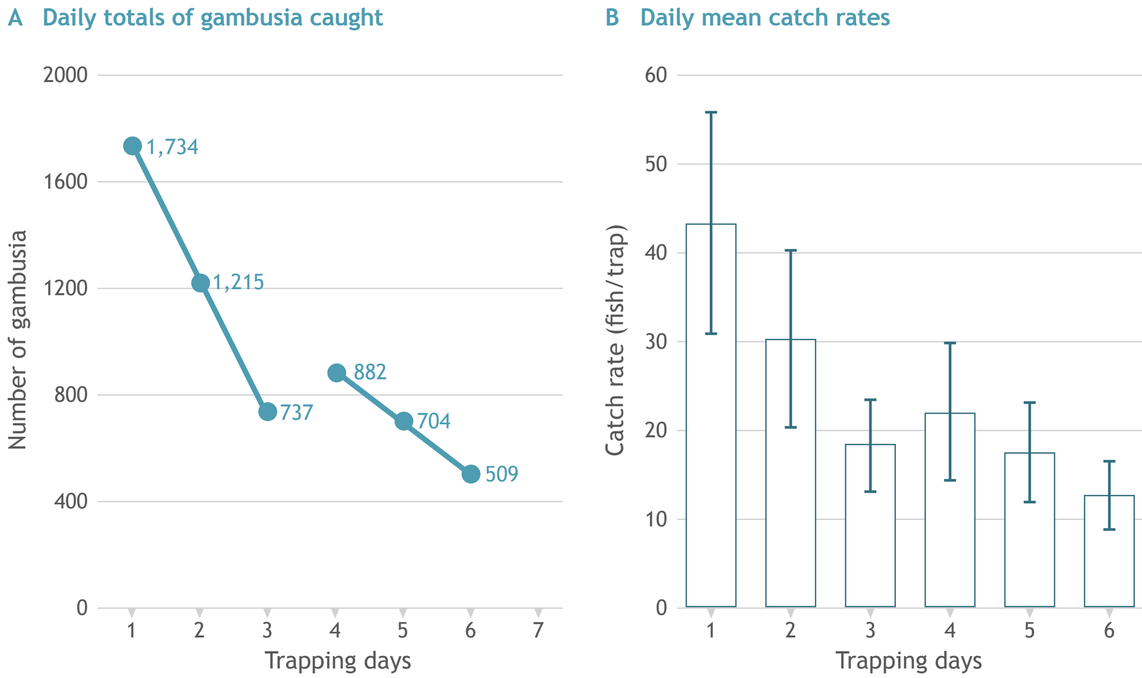

FIGURE 6.5 Gambusia caught in Chapel Lake, The University of Waikato, during six 1.5 hour sets on separate days (3-5 and 10-12 February 2009) with 40 unbaited collapsible Promar fine-mesh bait traps; (A) daily totals of gambusia caught; (B) daily mean catch rates. Error bars are 95% confidence limits.

Netting and Boat Electrofishing Comparisons

LAKE KAITUNA: A combination of conventional fish methods such as fyke nets, boat electrofishing and coarse-mesh trap nets were used in Lake Kaituna, a shallow, hypertrophic peat lake in the Waikato region with a surface area of 15 ha and a maximum depth of 1.3 m. Because of its isolation from other waterbodies, and restoration of its riparian margin through stock exclusion and re-establishment of native vegetation, the lake was considered a candidate for in-lake ecological restoration through removal of invasive fish. Preliminary studies found shortfin and longfin eels, and the invasive fish species koi carp, catfish, goldfish and rudd. Boat electrofishing, fyke nets and trap nets were used to estimate total fish abundance by mark-recapture (see Section 6.2). Marking was carried out over 10 consecutive days in September and October 2010, and marked and unmarked fish were caught on 10 fishing days and nights in October and November 2010 (20 days after the marking phase).

During the 14-day recapture and removal phase, 40 fyke nets were set over six nights, 36 20-minute shots of boat electrofishing (720 minutes in total) were administered over four days, and two double-winged 40 mm mesh trap nets were set for 28 trap nights. A total of 1,777 invasive fish were caught totalling 736 kg of biomass, including 410 kg of invasive fish that were removed, comprising 20% of the estimated 2,070 kg total of invasive fish biomass. The number of invasive fish initially marked, as a proportion of total population estimates, ranged from 10 to 24% (Table 6.7). Boat electrofishing caught 1,220 fish, with a catch rate of 271 fish/person-day and 136.3 kg/person-day. Fyke netting caught 557 invasive fish (56 fish/person-day and 12.3 kg/person-day).

Comparing actual catches to population estimates, different methods showed clear species bias (Table 6.7). Fyke nets were 21-52% efficient for catfish and eels, but only 2% efficient for goldfish and caught no koi carp. Boat electrofishing was 13-22% efficient for goldfish and koi carp, but only 2-6% efficient for catfish and eels. Unbaited trap nets were 1-2% efficient for goldfish and koi carp.

TABLE 6.7 Capture efficiency of boat electrofishing, fyke nets and unbaited trap nets during mark-recapture and fish removal in Lake Kaituna, Waikato region.

SPECIES	POPULATION ESTIMATE	MARKED FISH (% of total)	CAPTURE EFFICIENCY (%)		
			BOAT ELECTROFISHING	FYKE NETTING	TRAP NETTING
NON-INDIGENOUS SPECIES					
Catfish	973	23.7	5	21	0
Goldfish	2,727	19.7	13	2	2
Koi carp	619	14.7	22	0	1
Rudd	302	10.3	3	19	0
INDIGENOUS SPECIES					
Longfin eel	45	49.2	2	72	0
Shortfin eel	4,760	29.3	6	53	0
TOTAL	9,376				

Catch rates of koi carp can be improved by baiting traps with chicken feed (6.1 kg/day for unbaited traps compared to 43.8 kg/day when the same traps were baited in Lake Ohinewai; Daniel & Morgan 2011).

LOWER KARORI RESERVOIR: The lower Karori Reservoir, Wellington, is a small lake with an area of 2.34 ha, an average depth of 8.2 m, and a maximum depth of about 20 m (Smith & Lester 2007). It was created behind a 21-m earth dam built in 1874 that was part of the Wellington City water supply until 1992. A population of perch was established in 1878 for recreational angling and these fish are presumed to induce cyanobacterial blooms in the reservoir through a trophic cascade (Smith & Lester 2006; Hicks *et al*. 2007).

During fishing in February 2007, we found that gill netting was an effective way to remove large perch from the lower Karori Reservoir but was less effective than boat electrofishing at night in the littoral zone to catch young-of-the-year (YOY, age 0) perch (Figure 6.6). Boat electrofishing for 527 minutes resulted in a catch rate of 693 fish/person-day (n = 2,282 fish), compared to day-time gill netting with a total fished length of 1,728 m of 1 m long 25–100 mm mesh mist nets with a catch rate of 1.5 fish/m (n = 1,666 fish).

In February 2009, we conducted a comparison of nocturnal boat electrofishing and diurnal gill netting techniques. We caught 4,671 perch in 617 minutes of boat electrofishing (catch rate 1,211 fish/person-day), and 773 perch in six 3-h sets of 60 m (360 m of net in total; catch rate 2.1 fish/m) of 25 mm mesh gill netting to give a total of 5,158 perch ≥35 mm fork length. Boat electrofishing caught 4,281 YOY perch <100 mm and 390 perch ≥100 mm; all perch caught by gill netting were ≥100 mm.

Our initial estimates of the number of perch in the lower Karori Reservoir were 20,000 to 22,000 fish. In 2007, we removed 3,948 perch totalling 78 kg. The steep sides of the reservoir made fyke netting inappropriate for much of the shoreline. Fish removal in the first year was estimated to be 18–20% of the total number of fish present, or 8–10% of the estimated total biomass. This took 7.3 person-days of effort, implying a capture efficiency of 541 fish/person-day or 10.7 kg/person-day. Using an estimate of $480/person-day, the cost of removal in labour alone was $3,501, or $41/kg. From our estimates, boat electrofishing was 11–22% efficient and gill netting 4–8% efficient.

As an aside, a population estimate before fish removal in 2009 was obtained using a hydroacoustic method, which indicated 2,877 perch >30 mm (acoustic target strength ≥-56 dB) and 1,333 perch after removal (Figure 6.7). This result suggests that the hydroacoustic methods were 30% efficient, detecting 1,544 of the 5,158 perch that we removed. The most likely cause of the relatively low efficiency of

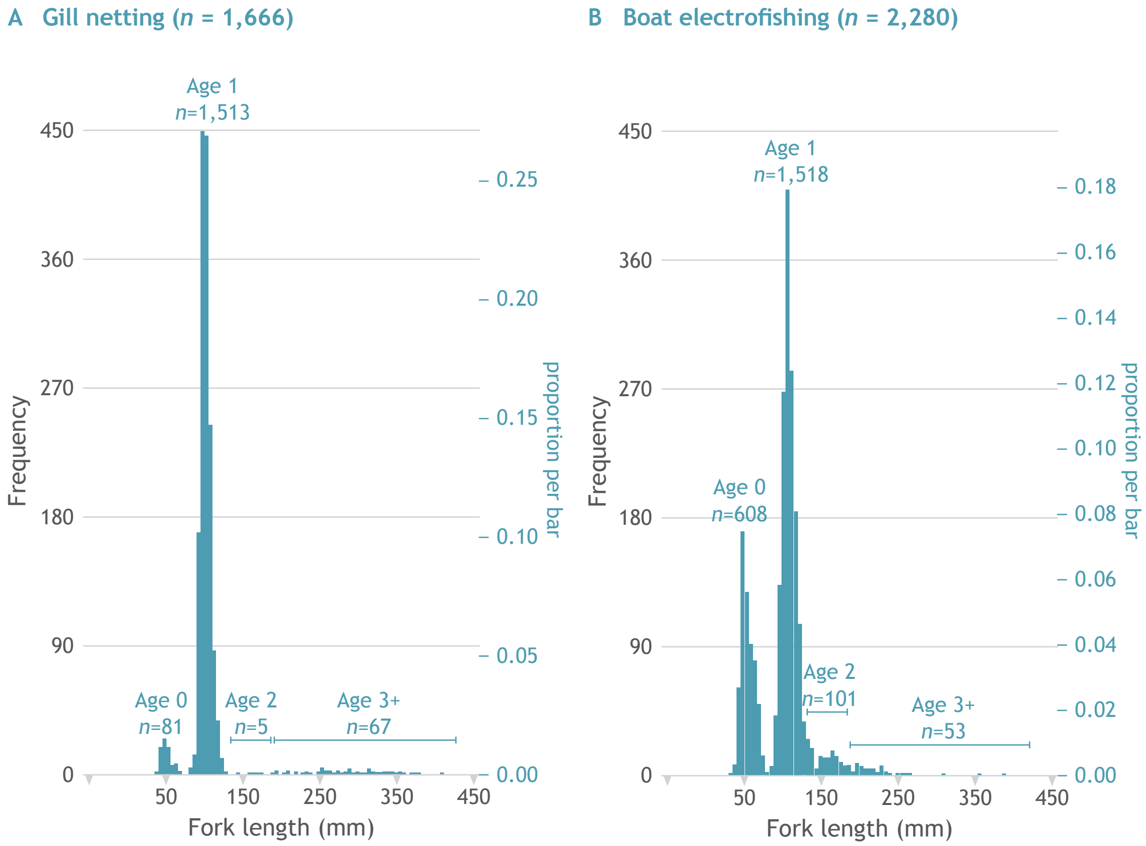

FIGURE 6.6 Size frequency of perch caught in the lower Karori Reservoir, Wellington, from 12–15 February 2007 by (A) gill netting; (B) boat electrofishing. Source: Hicks *et al*. (2007).

hydroacoustic estimates was the concentration of small fish close to the bed in littoral zones where the hydroacoustic signal could not detect them.

ROTOPIKO (SERPENTINE) LAKE COMPLEX: Fine-mesh monofilament gill nets set overnight were used in the three shallow Waikato lakes (the Rotopiko (Serpentine) lakes—East, North and South) to assess the potential of this method as a tool for controlling or eradicating rudd (Neilson *et al*. 2004). Between 2001 and 2003, gill nets 15 m long and 1.8–3.0 m deep with several stretched mesh sizes between 10 and 38 mm were set at a density of 16–30 nets depending on lake size. Boat electrofishing was undertaken once in September 2003 during the post-removal sampling period in North and East lakes.

Between September 2001 and March 2003, 1,740 rudd were removed from the lakes. In September 2003, after the intensive removal, boat electrofishing in North Lake for 106 minutes caught 10 rudd and 109 goldfish. Shortfin eels and common smelt were abundant but were not enumerated. In East Lake, electrofishing for 58 minutes caught three goldfish and one catfish, but no rudd. Common smelt were abundant but were not caught. Gill netting in North for 16 net nights caught 17 rudd and 25 goldfish, and three weeks of netting in East Lake caught four rudd.

A total of 640 and 570 person hours in September 2002 and March 2003, respectively, were spent carrying out intensive removal over the three Rotopiko (Serpentine) lakes. The most labour-intensive part of the fishing effort was undoing knots in nets that had been created by eels scavenging captured fish. This was particularly so in North Lake where large numbers of goldfish were captured in addition to rudd. Using the Department of Conservation standard operating procedure charge-out rate for field staff of $60 per hour, the labour component of the two intensive removal periods came to $72,600. In comparison the cost of the nets was just $4,720, or 6% of the total cost (Neilson *et al*. 2004).

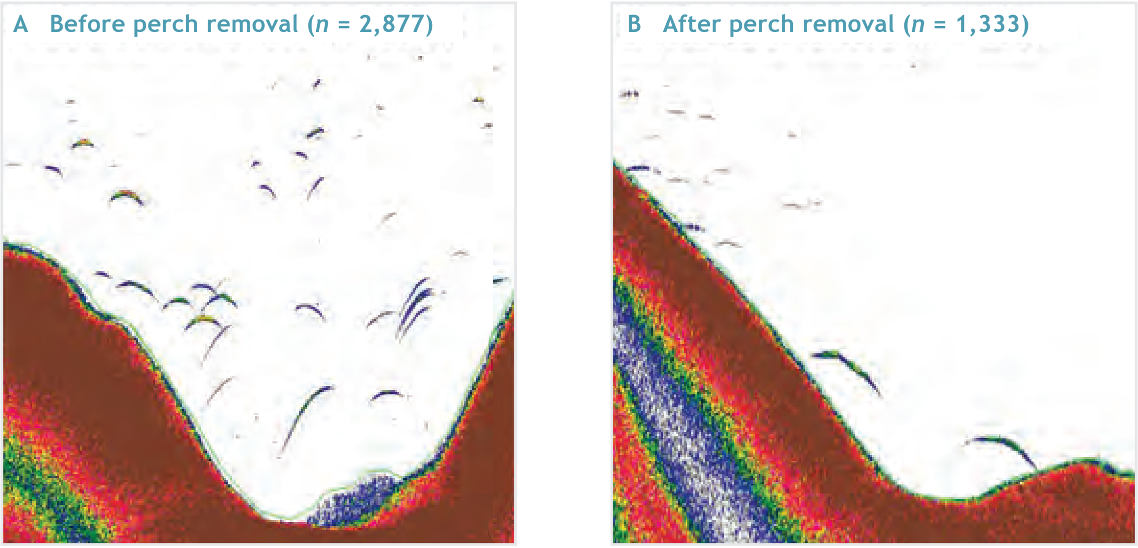

FIGURE 6.7 Representative hydroacoustic scans of lower Karori Reservoir, Wellington, in February 2009 showing the echo traces of fish in the water column (A) before and (B) after removal of 5,158 perch ≥35 mm. Source: S. Gautier, NIWA, Wellington, unpubl. data.

These authors concluded that it was more cost-effective to set nets for one or two nights, retrieve and discard the nets, and then set new nets for another one or two nights as most of the fish were caught in the first 3–4 days of fishing. This level of control effort has continued (see Section 5.4).

Pod (Feeder) Traps

Pod traps are pyramid-shaped nets equipped with an automated wildlife feeder that frequently adds fresh bait to the trap to attract fish (Plate 6.2). Baits lose most of their attraction properties within an hour in the water, so by adding fresh bait, trapping rates are greatly improved. Once inside the pod trap, one-way doors keep fish within the trap until emptied. Pod traps are particularly effective at trapping koi carp and also rudd, and have been shown to improve catch rates compared with other types

PLATE 6.2 Pod trap (left) developed by Adam Daniel (shown right) to catch koi carp, and (right) installed in Lake Ohinewai with automatic bait dispenser.

of nets. Baited traps, such as the pod trap, lose their effectiveness after the bulk of the population has been removed because food becomes more plentiful, making bait less attractive to fish. Baits laced with toxins have been used elsewhere to control carp numbers, but flavouring is often necessary to mask the unpleasant taste of some piscicides.

The effectiveness of floating baits made mainly from brewer's yeast and grain laced with 'bold' flavours, such as vanilla or strawberry essence has been investigated (Morgan *et al*. 2013). All flavours were readily consumed by koi carp indicating that any of the formulations could be used with equal success. One advantage of using floating baits is that unconsumed pellets can be removed from the water surface before they sink and toxins become available to native species feeding at night or on the bottom, such as eels. Pod traps and baits may form part of a range of methods used to trap fish and monitor population change as part of integrated pest fish management.

An invasive fish removal project in Lake Kuwakatai, north Auckland, showed that pod traps set overnight had a higher catch rate overall than either fyke nets or 10-minute boat electrofishing shots. In this comparison, which was a mark-recapture study, pod traps baited with chicken feed delivered from a wildlife feeder were by far the most effective method to catch rudd, the most numerous species in the marking phase (13–16 November 2012) when 1,655 fish (176 kg) were caught, marked, and released back into the lake. During the subsequent recapture and removal phase (27 November 2012 to 17 January 2013), when 20,566 fish (912 kg) were caught, baited pod trapping was the most effective way to catch large numbers of rudd. The addition of fyke nets to the sampling tools showed their effectiveness at catching large numbers of rudd and juvenile perch (Table 6.8). Boat electrofishing was the best method to catch adult koi carp, which were present at low abundance in Lake Kuwakatai (33 kg/ha; Section 6.2).

Cost-effectiveness can be calculated from the known personnel effort, which was 1.3 person-days for boat electrofishing, 24 person-days for fyke netting, and 27 person-days for pod trapping. This means that catch rates for the different methods were 47.1, 11.6 and 21.3 kg/person-day for boat electrofishing, fyke netting and pod trapping, respectively, equating to $10/kg, $42/kg and $23/kg. Baited pod traps were the cheapest of the three methods to remove rudd at high densities because boat electrofishing and fyke netting caught only 4% and 23% of the total number of rudd, whereas pod trapping caught 71%. Pod traps caught 576 kg of fish, almost 10 times the total biomass from boat electrofishing (59 kg), mostly because pod trapping was used more as it requires cheaper equipment and less training.

Summary

Catch rates of invasive fish in this comparison are highly variable, depending on water depth and morphology of littoral habitat, and methods need to be highly targeted to different species. The fine-mesh trap net described by Hayes (1989) is very effective for gambusia (as well as native bullies and eels), but is expensive and cumbersome for normal use. In addition, its efficiency for species such as koi carp and rudd is unknown. Fyke netting is the best method to catch catfish (and eels), whereas boat electrofishing is more efficient for goldfish and koi carp in shallow water than other methods. Baiting improves catch rates of traps, in this case for catches of gambusia in minnow traps and koi carp, goldfish and rudd in pod traps. Baited pod traps worked well for rudd in Lake Kuwakatai where the population was estimated by mark-recapture at 28,934 (Section 6.2), almost half of which were removed by pod trapping.

A preliminary survey to estimate population size is important to establish a target biomass for removal, but fishing alone will not necessarily achieve a given target. Personnel costs of capture can vary from $0.38 to $50/kg for boat electrofishing, $39–42/kg for fyke netting, and $29–41/kg for gill netting, depending on species, and $22/kg for pod trapping (Table 6.9). One minnow trapping trial for gambusia cost $1440/kg because of their extremely small size; nearly 6,000 fish weighed just over 1 kg. The capture efficiencies and costs of conventional methods of fish capture (fyke nets, trap nets, gill nets, pod traps and electrofishing) mean that control of fish populations by the capture methods summarised in this section is not generally realistic within limited budgets.

TABLE 6.8 Comparative catches from 10-minute boat electrofishing shots, fyke nets and pod traps set overnight in Lake Kuwakatai, as (A) numbers and (B) biomass, from the removal phase over 27 November 2012 to 17 January 2013. Juveniles are fish <100 mm fork length.

A Number

SPECIES	TOTAL NUMBER	MEAN NUMBER PER SHOT OR TRAP NIGHT		
		ELECTROFISHING	FYKE NET	POD TRAP
	(*n* = 434)	(*n* = 20)	(*n* = 197)	(*n* = 206)
NON-INDIGENOUS SPECIES				
Koi carp	75	0.60	0.15	0.16
Koi-goldfish hybrid	1	0.00	0.01	0.00
Juvenile goldfish	114	0.65	0.28	0.22
Goldfish	712	6.35	1.66	1.03
Juvenile perch	3,289	3.20	14.41	1.85
Perch	1,050	2.05	4.54	0.29
Rudd	14,284	31.15	16.55	49.42
Tench	841	3.95	2.38	1.32
INDIGENOUS SPECIES				
Common bully	184	0.00	0.92	0.01
Shortfin eel	1	0.00	0.01	0.00
Kōura (crayfish)	358	0.00	1.79	0.03
TOTAL NUMBER	20,909	959	8,413	189

B Biomass

SPECIES	TOTAL WEIGHT (kg)	MEAN WEIGHT PER SHOT OR TRAP NIGHT (g)		
		ELECTROFISHING	FYKE NET	POD TRAP
NON-INDIGENOUS SPECIES				
Koi carp	113.6	1000	182	276
Koi-goldfish hybrid	0.3	0	2	0
Juvenile goldfish	0.1	1	0	0
Goldfish	75.3	565	169	133
Juvenile perch	5.7	19	25	1
Perch	114.9	288	434	59
Rudd	510.1	625	327	2068
Tench	108.1	308	223	271
INDIGENOUS SPECIES				
Common bully	0.2	0	1	0
Shortfin eel	2.8	0	14	0

TABLE 6.9 Comparative catch rates of invasive fish and personnel costs of capture for boat electrofishing, fyke netting, gill netting, minnow trapping, and pod trapping in North Island lakes. Costs calculated assuming $NZ480/person-day. ND = no data.

LOCATION	FISHING METHOD	SPECIES	PERSON-DAYS	BIOMASS (kg)	NO. OF FISH	TOTAL LABOUR COST ($)	FISH/ PERSON-DAY	WEIGHT (kg/ person-day)	COST ($/fish)	COST (kg)
Average, all North Island sites (*n* = 205)	Boat electrofishing	Koi carp	47.1	4,658	2,939	22,596	62	98.9	7.69	4.85
Lake Whangape	Boat electrofishing	Koi carp	0.07	87	24	33	349	1,270.7	1.38	0.38
Lake Kaituna, marking and removal	Boat electrofishing	Catfish, goldfish, koi carp, rudd	4.5	613	1,220	2,160	271	136.3	1.77	3.52
	Fyke netting		10.0	123	557	4,800	56	12.3	8.62	39.15
Lower Karori Reservoir	Boat electrofishing 2007	Perch	3.3	32	2,282	1,581	693	9.6	0.69	50.19
	Gill netting 2007		4.0	46	1,666	1,920	417	11.6	1.15	41.47
	Boat electrofishing 2009		3.9	45	4,671	1,851	1,211	11.7	0.40	40.95
	Gill netting 2009		4.0	67	773	1,920	193	16.7	2.48	28.79
Chapel Lake	Minnow trapping	Gambusia	3.0	1.1	5,781	1,440	1,927	0.4	0.25	1,263.16
Lake Kuwakatai, removal phase only	Boat electrofishing	Rudd, perch, goldfish, koi carp, tench	1.3	59	959	600	767	47.1	0.63	10.19
	Fyke netting		24.0	278	8,413	11,520	351	11.6	1.37	41.50
	Pod trapping		27.0	576	11,194	12,960	415	21.3	1.16	22.50
Serpentine (Rotopiko) lakes	Gill netting (DOC) 2001-03	Rudd	151.3	ND	1,740	72,600	12	ND	41.72	ND

6.4 Molecular Genetic Techniques for Detecting Invasive Fish

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Background

Molecular tools can improve biosecurity by ensuring the accurate identification of imported fish, especially larval fish, without distinguishing morphological characters, eliminating the need for specialist taxonomic knowledge. DNA sequences can be obtained from specimens of any age, mutilated specimens and even from carcasses that are several months old (Banks *et al*. 2010; Collins *et al*. 2012). In addition, there is increasing use of DNA isolated from environmental samples, such as water, to monitor the presence of invasive species. It is relatively simple to sequence a reference gene, such as the widely accepted 'barcode gene' cytochrome C oxidase subunit 1 (Hebert *et al*. 2003). The sequence obtained can be compared to the sequence on file for a voucher specimen in genetic databases such as GenBank (Benson *et al*. 2009) and the Barcode of Life Database (BOLD; Ratnasingham & Hebert 2007).

Genetic Methods to Detect Invasive Fish

DNA is usually extracted from tissue or blood. It can take as little as 30 minutes to obtain DNA using commercially prepared extraction kits such as prepGem tissue extraction kit (ZyGem, Hamilton). Once the DNA is extracted, short segments of genes that identify the species are amplified using polymerase chain reactions (PCR) containing synthetic nucleotides and the DNA polymerase (i.e. DNA replicating) Taq enzyme. The reactions are made species-specific by adding primers (short sequences of DNA referred to as oligonucleotides that are complementary to a portion of the species' genome). Taq-mediated replication starts once the primers bind to the template DNA; if the primers do not bind, replication cannot start. Thus the identity of a species is confirmed by successful amplification of DNA that is detected by visualising amplicons after electrophoresis on an agarose gel, or by detecting fluorescence in response to DNA synthesis (see Wood *et al*. (2013) for further description).

Although DNA has traditionally been isolated from tissue, methods to isolate DNA from environmental samples such as water or sediments are being developed. The isolation of DNA from material other than that taken directly from a specimen has become known as environmental DNA or 'eDNA'. Environmental DNA is a promising method to detect the presence of introduced aquatic species (Ficetola *et al*. 2008; Jerde *et al*. 2011), or to characterise aquatic biological communities (Thomsen *et al*. 2012; Kelly *et al*. 2014). It is thought the DNA from the target species is obtained from material such as skin cells or gut epithelium sloughed into the environment.

SUGGESTED CITATION FOR SECTION 6.4: Banks JC, Hogg ID 2015. Molecular Genetic Techniques for Detecting Invasive Fish. Section 6.4 in Collier KJ & Grainger NPJ eds. New Zealand Invasive Fish Management Handbook. Lake Ecosystem Restoration New Zealand (LERNZ; The University of Waikato) and Department of Conservation, Hamilton, New Zealand. Pp 133-135.

Environmental DNA has been used for border control. Collins *et al*. (2012) found that DNA could be isolated from the water that was used to transport ornamental fish being imported in to New Zealand as part of the aquarium trade. They also found that a single *Danio rerio* mixed with 19 closely related *D*. aff. *kyathit* could be detected from the DNA shed into the water, showing that eDNA could be used to detect the 'contamination' of imports.

Detection of Invasive Fish in Habitats Using Genetic Methods

Environmental DNA has also been used to detect fish in wild habitats. Traditionally, fish distributions have been determined using visual methods such as spotlight surveys, and/or capture-based methods such as electrofishing, gill nets and traps (see Section 6.1). The efficacy of survey methods is affected by the behaviour and habitat of the target species; for example, electrofishing is relatively ineffective in deeper water where alternative monitoring techniques would be useful. DNA-based methods are now being used to detect invasive fish in their environments and to characterise fish communities.

Environmental DNA has been used to infer the range of frogs and salamanders (Goldberg *et al*. 2011), silver carp, bighead carp (*Hypophthalmichthys nobilis*) (Jerde *et al*. 2011), and other species of fish (e.g. Minamoto *et al*. 2012). Molecular tools have also been applied overseas to the containment and eradication of unwanted fish species. Eradication is made easier by early detection and accurate data on the extent of an introduced species' range (Myers *et al*. 2000; Wittenberg & Cock 2001). Detecting surviving pockets of individuals allows the targeting of eradication efforts. Determining the distribution of introduced fish and assessing the effectiveness of management remain significant challenges to removing fish from waterways.

Use of eDNA in New Zealand

Molecular techniques are also being developed to detect the presence of invasive fish in New Zealand. For example, assays have been developed to detect koi carp through the analysis of DNA shed into water in aquaria and artificial ponds (Knox *et al*. 2009; Banks *et al*. 2014). Although these studies have demonstrated the applicability of the methods, they are not currently being used for routine biosecurity surveillance. Environmental DNA has also been used in projects restoring habitats. The utility of eDNA methods for the detection of the introduced brown trout was tested during their eradication from the Zealandia Sanctuary in Wellington (J Banks *et al*. unpubl. data), as part of a project to restore the fauna in the sanctuary to a pre-European state. Water (2 L) was filtered through glass fibre filters, the DNA extracted from the filter, and PCR assays run using primers specific to brown trout. PCR amplicons were obtained from water samples taken immediately before the application of rotenone (the poison used to kill the brown trout) to some of the sanctuary's streams, but not in samples collected three months after the dosing. This suggests that eDNA will be a useful tool for monitoring the success of remedial actions.

Future Developments

There are a large number of potential uses for eDNA from biosecurity at the border through to assessing the effectiveness of projects to remove introduced fish from different ecosystems. A particular advantage of eDNA over traditional methods is the removal of risks to non-target species that occur with netting and electrofishing. Future work includes assessing the rates of false positives (a positive PCR but the target species is not present) and false negatives (failure to detect the target species when it is present), the minimum detectable biomass in a waterbody, and the effect of differences in physical parameters such as water chemistry and turbidity on the detectability of introduced fish.

One area of eDNA that requires further research is the 'capture' of DNA from environmental samples. Techniques for obtaining DNA include concentration from water samples by centrifugation or by filtration (see Rees *et al*. 2014 for a review). Filtration methods are a trade-off between using filters with small pore sizes that are more likely to capture cells or DNA bound to sediments but clog easily, versus using filters with larger pores that can filter larger volumes of water but may fail to capture the DNA. The plethora of techniques used to isolate eDNA suggest that some methods are better at isolating DNA from particular conditions than others, and that the optimisation of extraction methods and defining the best DNA capture technique for the conditions would increase the uptake of this technique.

CATFISH
Photo: David West (DOC)

KOI SPAWNING
Photo: Kevin Collier (UoW)

RUDD
Photo: Helen McCaughan (DOC)

7

Determining and Managing Invasion Risk

Factors influencing future incursions of invasive fish, whether they be new arrivals or range expansion of species currently in New Zealand, need to be understood to identify locations at risk and develop management priorities. This section explores factors associated with invasion risk, including attitudes of coarse fishers who consider many invasive species as valued fisheries, and awareness of waterway users who move between high value waterbodies. Approaches to raise public awareness of invasive non-indigenous fish and avoid human-mediated spread are also described.

7.1 Determining Invasion Risk for Non-indigenous Fish

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Background

Introduction of invasive fish is mediated by connectivity among habitats, and by the deliberate or accidental transfer of species among sites. As New Zealand is an island nation, transfer between larger catchments is limited by salinity for most freshwater fish, and human vectors are required for spread. Risks associated with establishment and impact are mediated by environmental factors that enable self-sustaining populations to develop and the sensitivity of sites to degradation from invasive fish impacts. Invasiveness does not predict impact and therefore key considerations for assessing the vulnerability of sites include (Vander Zanden & Olden 2008):

- Introduction—which sites will be colonised?
- Establishment—which sites will support a self-sustaining population?
- Impact—which sites will be affected?

Not all incursions of non-indigenous fish result in ecological damage. Therefore assessments of invasion risk need to provide a rapid and objective method for identifying potential ecosystem harm to assist with developing a management response. In New Zealand an assessment based on invasive fish traits reflecting likelihood of establishment and ecological impact has been conducted by Rowe & Wilding (2012) who produced the Fish Risk Assessment Model (FRAM). Additionally, recent numerical modelling work has explored environmental and demographic factors associated with the occurrence of invasive fish in New Zealand, and this has been used to predict future establishment risk in lake catchments. This section summarises this work and links it to information on fish thermal tolerances to provide tools for assessing invasion risk.

Fish Risk Assessment

FRAM was developed from a customised questionnaire addressing the risks of non-indigenous fish becoming established and spreading ('establishment risk'), and the risk of an ecological impact occurring ('ecological impact risk'), so that these two types of risk could be assessed independently (Rowe & Wilding 2012; see www.niwa.co.nz/sites/niwa.co.nz/files/fram_questionaire_0.pdf for questionnaire). A scoring system that provided higher scores for greater risk was applied to all non-indigenous fish in New Zealand (see Table 7.1). This analysis highlighted that the greatest overall risk came from koi carp, perch, catfish and gambusia, with the eight fish species dealt with in this handbook

SUGGESTED CITATION FOR SECTION 7.1: Collier KJ, Leathwick J, Ling N, Rowe D 2015. Determining Invasion Risk for Non-indigenous Fish. Section 7.1 in Collier KJ & Grainger NPJ eds. New Zealand Invasive Fish Management Handbook. Lake Ecosystem Restoration New Zealand (LERNZ; The University of Waikato) and Department of Conservation, Hamilton, New Zealand. Pp 138-148.

among the top 11 of the 21 non-indigenous species ranked. Other species that ranked highly were brown trout, rainbow trout and silver carp, although the latter species had a low risk of establishment (Table 7.1).

Threshold scores were applied to define 'high', 'medium', and 'low' risks of establishment and impact, based on distributional information and existing literature on ecological impacts (e.g. reduction in endemic species, decrease in water quality, decline in macrophytes; Rowe & Wilding 2012). The resulting decision support system (Figure 7.1) provides a tool for defining management responses to introductions. For example, under this framework a species with high establishment risk and high ecological impact risk would be denied entry if it was not already present in New Zealand, or would demand a rapid management response if spread within the country was detected, whereas those species with low risk might be allowed entry. However, a range of factors is likely to influence the final decisions made, including the statutory responsibilities of management agencies and the outcomes of consultative processes (see Section 3). Nevertheless, the FRAM does provide an objective and rapid desk-top assessment to assist with such decisions (see Rowe & Wilding 2012 and references therein for further details).

TABLE 7.1 List of non-indigenous fish species present in New Zealand with scores indicating their overall risk, risk of establishment and ecological impact risk from the Fish Risk Assessment Model of Rowe & Wilding (2012). Grey = species dealt with in this publication.

COMMON NAME	SCIENTIFIC NAME	ESTABLISHMENT RISK (#/16)	ECOLOGICAL IMPACT RISK (#/61)	OVERALL RISK (#/77)
Koi carp	*Cyprinus carpio*	14	32	46
Perch	*Perca fluviatilis*	14	31	45
Catfish	*Ameiurus nebulosus*	15	26	41
Gambusia	*Gambusia affinis*	13	28	41
Brown trout	*Salmo trutta*	13	26	39
Orfe	*Leuciscus idus*	13	24	37
Rudd	*Scardinius erythrophthalmus*	14	22	36
Rainbow trout	*Oncorhynchus mykiss*	13	23	36
Silver carp	*Hypophthalmichthys molitrix*	7	26	33
Tench	*Tinca tinca*	14	17	31
Goldfish	*Carassius auratus*	14	17	31
Sockeye salmon	*Oncorhynchus nerka*	11	17	28
Brook char	*Salvelinus fontinalis*	13	14	27
Chinook salmon	*Oncorhynchus tshawytscha*	9	18	27
Atlantic salmon	*Salmo salar*	8	18	26
Mackinaw	*Salvelinus namaycush*	6	18	24
Caudo	*Phalloceros caudimaculatus*	5	17	22
Grass carp	*Ctenopharyngodon idella*	3	15	18
Swordtail	*Xiphophorus helleri*	2	13	15
Sailfin molly	*Poecilia latipinna*	2	13	15
Guppy	*Poecilia reticulata*	2	12	14

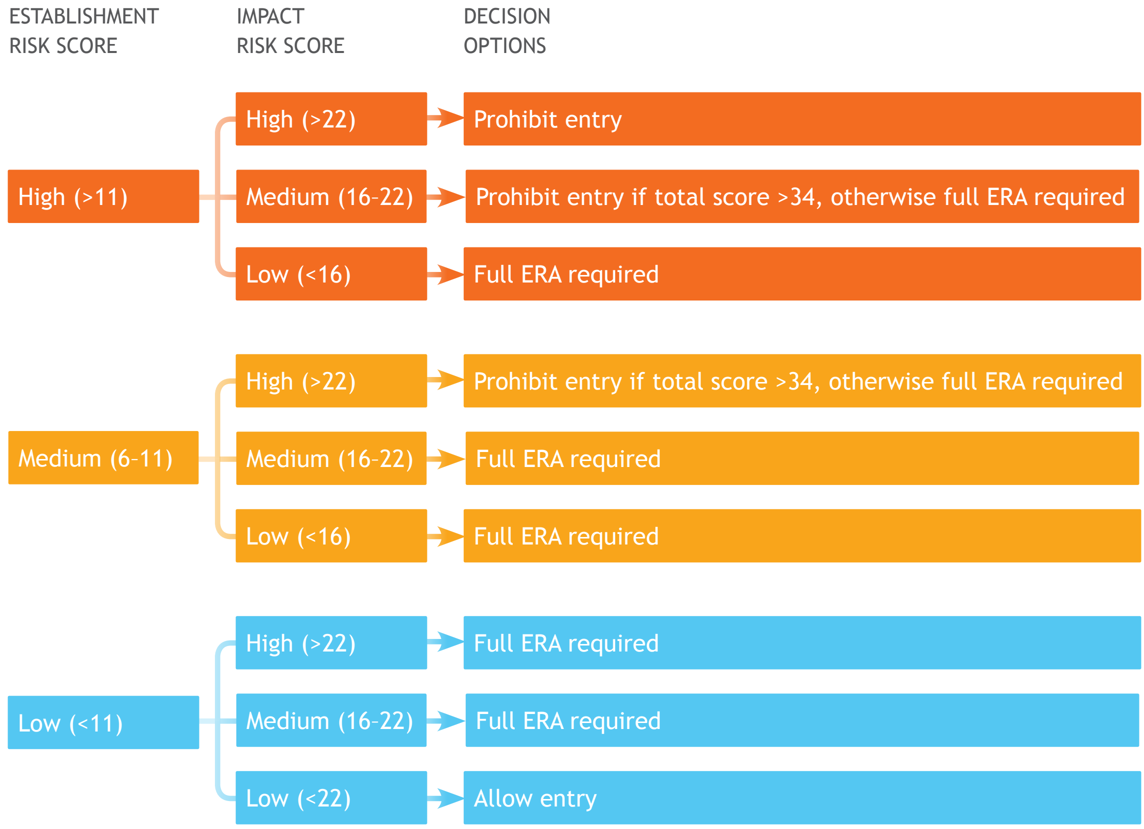


FIGURE 7.1 Decision pathway for the Fish Risk Assessment Model (FRAM; www.niwa.co.nz/freshwater/management-tools/fish-risk-assessment-model), based on Rowe & Wilding (2012). ERA = environmental risk assessment.

Use of Thermal Tolerance to Assess Invasion Risk

Water temperature is a key environmental factor influencing the ability of aquatic species to survive and proliferate in waterbodies. An understanding of responses of non-indigenous fish to temperature regimes in the habitats they invade is therefore key to predicting likely impacts. Temperature tolerance in fishes can be influenced by a variety of biological or environmental variables including developmental stage, salinity, dissolved oxygen and additional stressors including environmental toxins. By far the most important variable affecting both maximum and minimum temperature tolerance is prior acclimation to high or low temperatures, respectively. Upper and lower tolerance temperatures for fish have typically been measured in one of three different ways as follows:

- Incipient lethal temperature (ILT)—fish are acclimated to a range of temperatures and then plunged into water with a temperature close to the estimated thermal maximum or minimum; the time taken to a specified endpoint, usually loss of equilibrium for 50% of individuals, is determined.
- Critical thermal maximum or minimum (CTM)—fish are acclimated to a range of temperatures and then the water temperature is gradually increased or decreased at a specified rate until a specified endpoint is reached, usually loss of equilibrium.
- Chronic lethal maximum or minimum (CLM)—this technique is similar to that of the CTM method except that, following acclimation, the rate of temperature increase or decrease is much slower (typically 1°C per day or less) and death is the usual measured endpoint.

These three laboratory techniques all measure absolute temperature tolerance but yield slightly different values varying by a few degrees, with the CLM temperature typically intermediate between the values obtained by the other two methods (Beitinger *et al*. 2000). Although seasonal temperature acclimation is much slower than acclimation rates and times typically used in these experiments, and rapid changes in environmental water temperatures do not normally occur, fish are unlikely to tolerate environmental temperatures close to the CLM or CTM values which should be viewed as potentially extreme conditions. Alternative field-based methods have been used to match environmental temperature records with fish distribution and thereby provide environmental temperature tolerance limits for a variety of species (Eaton *et al*. 1995).

Thermal maxima and minima determined for a range of acclimation temperatures can be used to construct a thermal tolerance polygon for species of interest, as shown in Figure 7.2 for goldfish. Thermal maxima are more commonly determined than thermal minima and available for a much greater number of species. While thermal maxima and minima may set absolute thermal limits for a species, they do not predict whether a species will establish a viable population because minimum temperatures required for spawning, and successful egg and larval development, are typically much higher than the thermal minimum for the species.

The water temperature ranges given in figures 7.2–7.8 are indicative of lake surface water temperatures produced by hydrodynamic modelling for sites in southern (Waituna Lagoon, Southland; Hamilton *et al*. 2012) and northern (Lake Waahi, Waikato; Jones & Hamilton 2014) New Zealand. If lake or river temperatures did not exceed the minimum spawning temperature of approximately 16°C for goldfish, for example, then the species would be unlikely to successfully establish due to reproductive failure. Conversely, if the seasonal water temperature range fell wholly within the polygon bounded by the temperature maxima and minima, and the minimum spawning temperature, then the species could potentially spawn at any time of the year assuming that spawning was not also critically dependent on factors such as photoperiod. Clearly the closer the match between environmental temperature and the optimal temperatures for spawning, growth and behavioural preference, the more likely it is that a non-indigenous species will successfully establish and potentially reach nuisance levels. However, water temperature is not the only key driver of gonadal development and spawning in fish, with photoperiod also critically important for most species.

The major non-indigenous invasive fish species in New Zealand all show a very broad range of temperature tolerance. The area bounded by the thermal tolerance polygon, measured as $°C^2$, gives a comparison of thermal tolerance between species. This value is around 1,220$°C^2$ for the extremely thermally-tolerant goldfish compared with only 583$°C^2$ for the heat-intolerant brown trout. A summary of temperature preferences and tolerances for the warm-water invasive fish species is given in Table 7.2 with comparative values also provided for the more cold-adapted brown trout.

Figure 7.3 illustrates the thermal tolerance polygon of gambusia. The environmental temperature ranges indicate that the critical reproductive temperature for this species would not normally occur in the far south of New Zealand. Gambusia are live-bearing fishes, not egg layers, and therefore embryo development only occurs in this species at temperatures above 16°C. Under this southern climatic regime, reproduction in this species is therefore likely to be restricted to shallow littoral margins where solar heating can warm surface waters to temperatures far exceeding those expected from daily average air temperatures. This is exactly the preferred habitat of gambusia in temperate regions.

Thermal tolerance has been more thoroughly studied in goldfish and gambusia than many other species. The values represented in figures 7.4–7.8 for other New Zealand invasive fish species have been summarised, and in some cases extrapolated, from a variety of literature sources. Differences in the thermal tolerances of catfish and perch illustrate large differences in critical spawning temperatures for these two species. Catfish require warmer water whereas perch are able to spawn in much colder conditions and apparently require some period of chilling to stimulate gonadal development (Migaud *et al*. 2002) even though the preferred and optimum growth temperatures for perch are in the mid-20s°C.

TABLE 7.2 Critical thermal preferences and tolerances (°C) for some non-indigenous fish in New Zealand (ordered by critical thermal maximum). Details for the brown trout are given for comparison with warm-water species.

SPECIES	OPTIMAL GROWTH	PREFERRED TEMPERATURE	CRITICAL THERMAL MAXIMUM*	MINIMUM SPAWNING†	OPTIMAL SPAWNING	OPTIMAL EGG DEVELOPMENT
Gambusia	30 (6)	27.7 (6), 31 (25)	43.7 (13)	>16 (15)	ND	ND
Goldfish	26.6 (6)	27.4 (6), 28 (17), 30 (18)	43.6 (5)	15.6 (20)	21 (6)	17 (6)
Koi carp	27.3 (6), 32 (14)	27.7 (6), 29 (16), 31.5 (12), 32 (14)	42.9 (3)	17 (20)	24 (6)	21 (6)
Tench	ND	ND	39.3 (8)	18 (11)	ND	ND
Rudd	ND	ND	38.3 (8)	18 (24)	ND	ND
Catfish	30.0 (6), 29 (4)	26.2 (6), 29-31 (4)	37.9 (6)	14 (9)	21.1 (6)	22.8 (6)
Perch	23 (23), 26 (7)	23.9 (21), 26.8 (1)	35.9 (8)	7.5 (22)	14 (10)	13 (19)
Brown trout	12.6 (6)	15.7 (6)	29.8 (2)	7 (9)	10 (9)	7.5 (6)

* = maximum reported temperature; † = minimum reported temperature; ND = not determined

Numbers in parentheses refer to references below:

(1) Alabaster & Downing 1966; (2) Beitinger *et al.* 2000; (3) Chetterjee *et al.* 2004; (4) Crawshaw 1975; (5) Ford & Beitinger 2005; (6) Hasnain 2012; (7) Hokanson 1977; (8) Horoszewicz 1973; (9) Lane *et al.* 1996; (10) Migaud *et al.* 2002; (11) Mills 1991; (12) Neill & Magnuson 1974; (13) Otto 1974; (14) Pitt *et al.* 1956; (15) Pyke 2005; (16) Reynolds & Casterlin 1977; (17) Reynolds *et al.* 1978; (18) Roy & Johansen 1970; (19) Saat & Veersalu 1996; (20) Scott & Crossman 1973; (21) Smirnov & Smirnova 2013; (22) Snickars *et al.* 2010; (23) Strand *et al.* 2011; (24) Wheeler 1969; (25) Winkler 1979

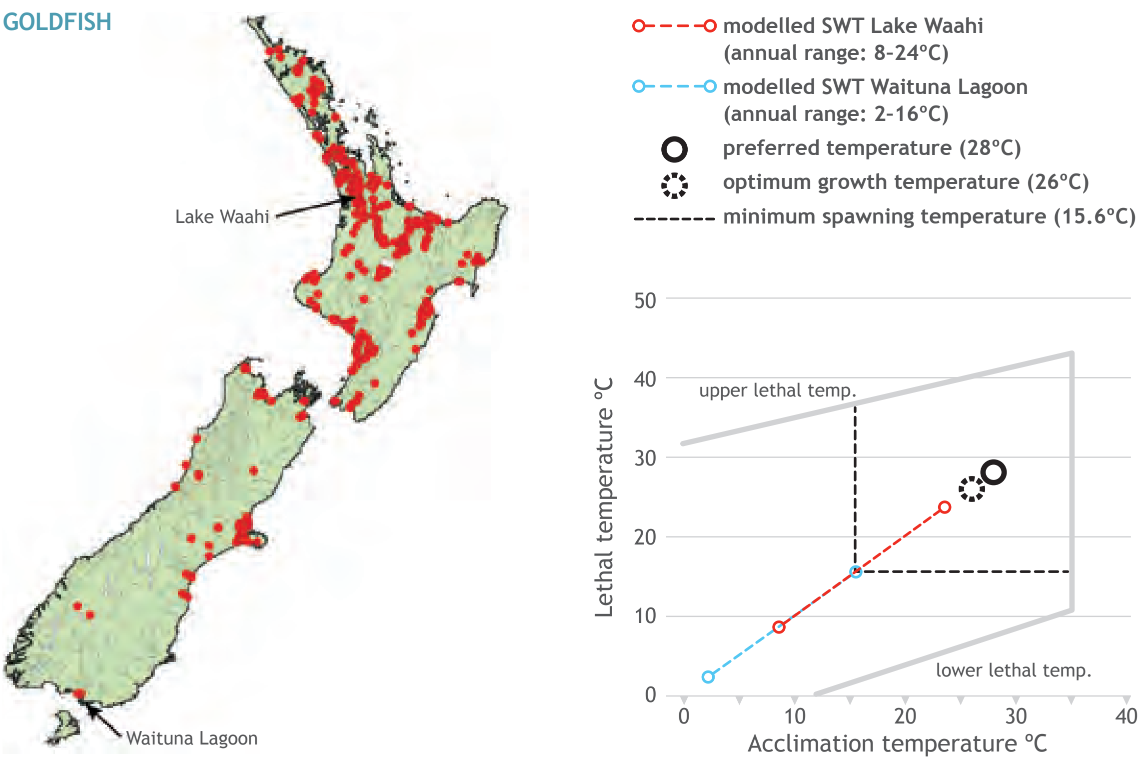


FIGURE 7.2 Thermal tolerance polygon and New Zealand distribution for goldfish, *Carassius auratus*. SWT = surface water temperature.

GAMBUSIA

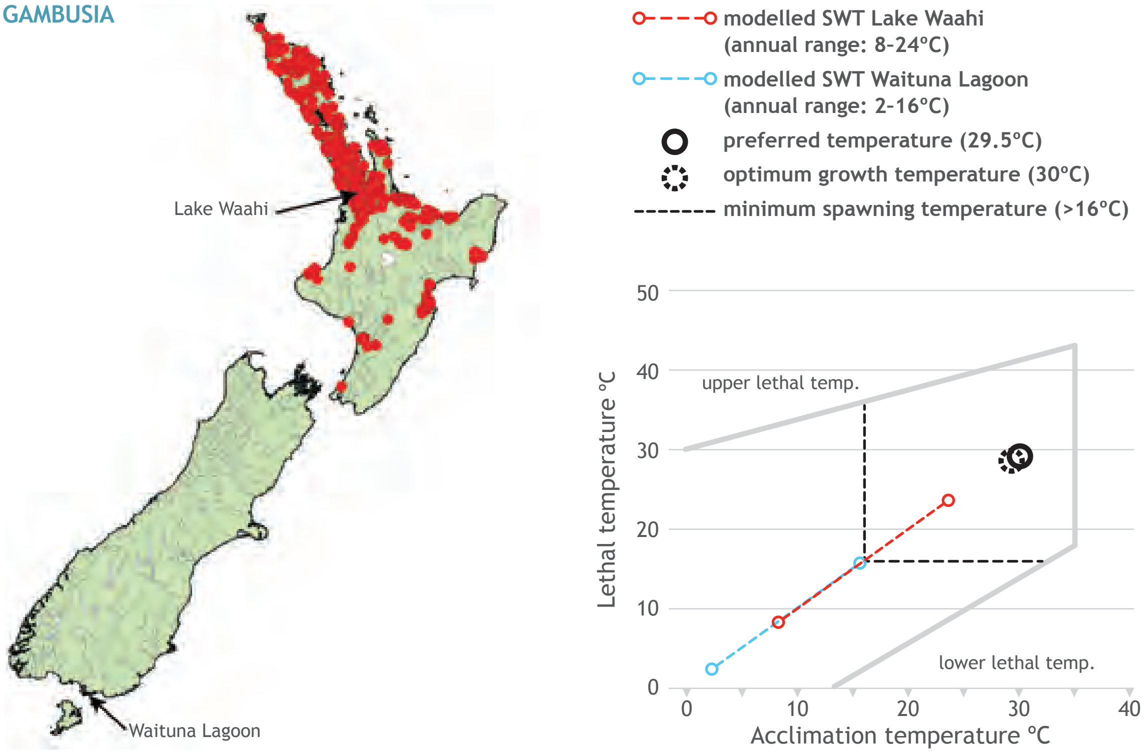


FIGURE 7.3 Thermal tolerance polygon and New Zealand distribution for gambusia, *Gambusia affinis*. SWT = surface water temperature.

KOI CARP

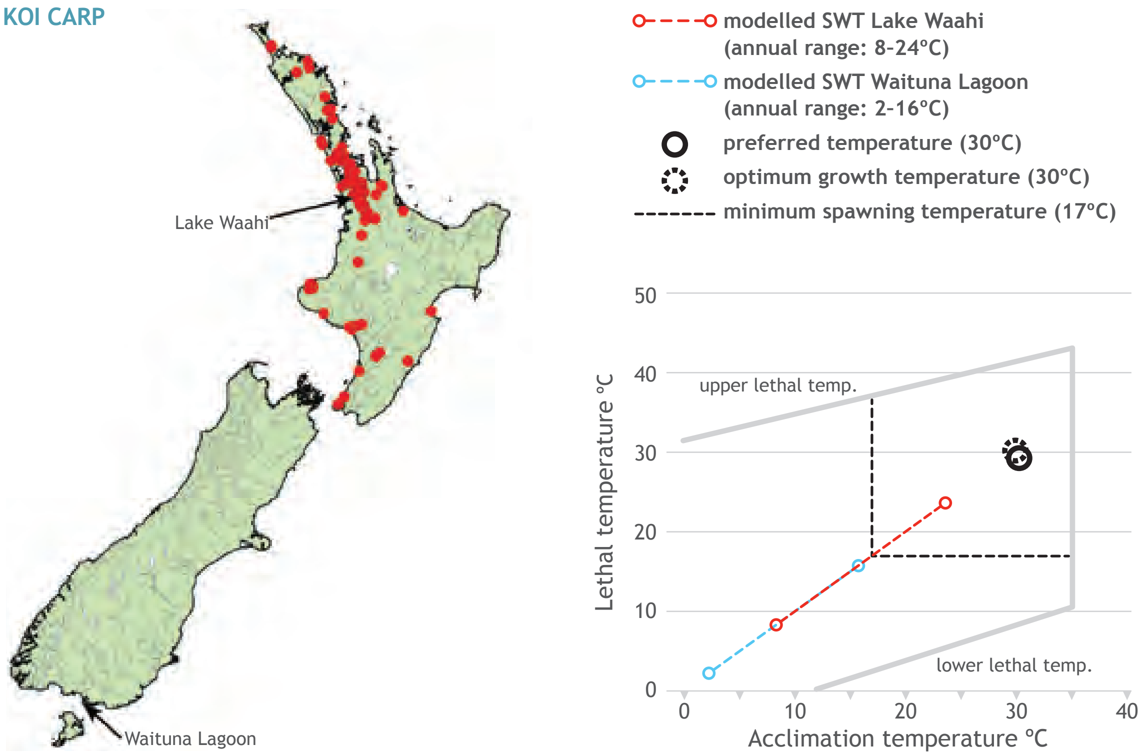


FIGURE 7.4 Thermal tolerance polygon and New Zealand distribution for koi carp, *Cyprinus carpio*. SWT = surface water temperature.

CATFISH

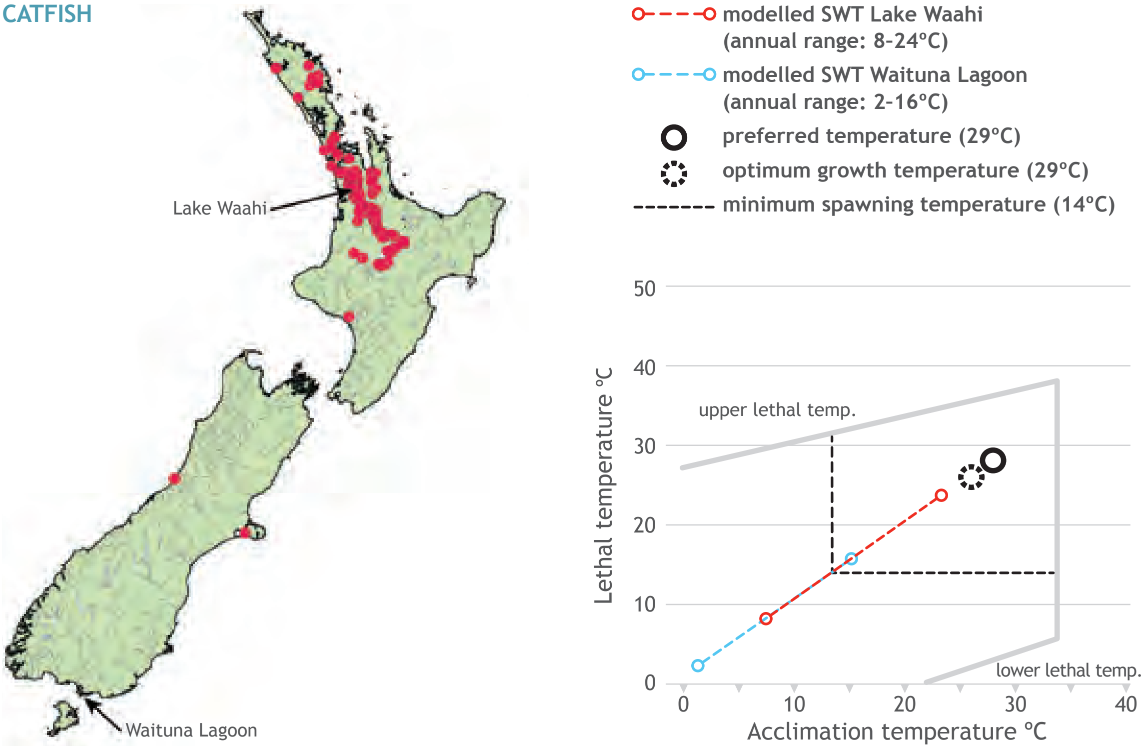


FIGURE 7.5 Thermal tolerance polygon and New Zealand distribution for catfish, *Ameiurus nebulosus*. SWT = surface water temperature.

PERCH

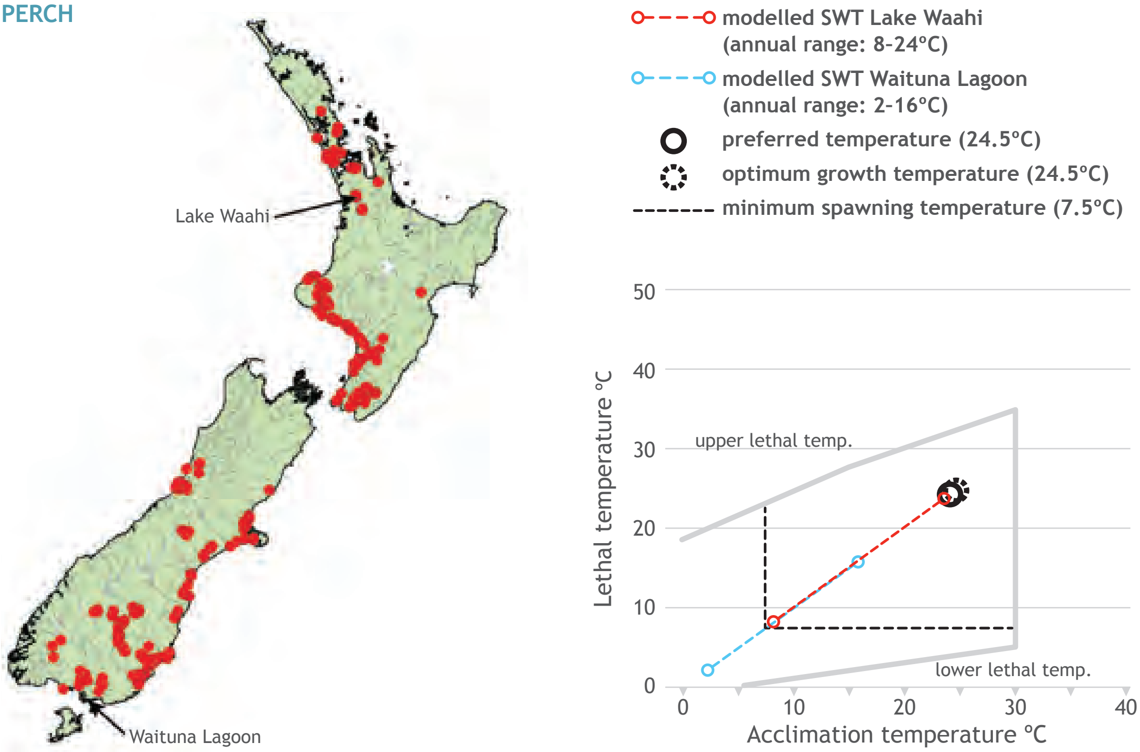


FIGURE 7.6 Thermal tolerance polygon and New Zealand distribution for perch, *Perca fluviatilis*. Maxima and minima values of the thermal tolerance polygon are for the closely related *Perca flavescens* which is not present in New Zealand. SWT = surface water temperature.

RUDD

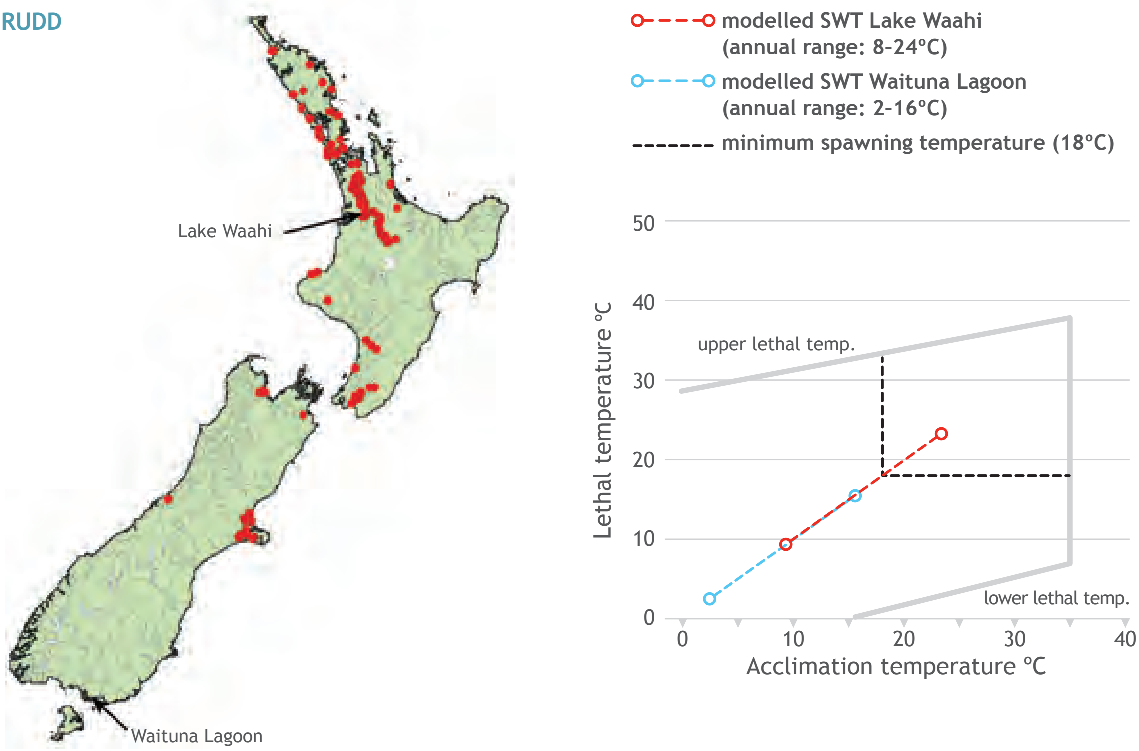


FIGURE 7.7 Thermal tolerance polygon and New Zealand distribution for rudd, *Scardinius erythrophthalmus*. Due to an absence of published data on this species, values of the thermal polygon are estimated based on the tolerances of other warm-water tolerant cyprinids. SWT = surface water temperature.

TENCH

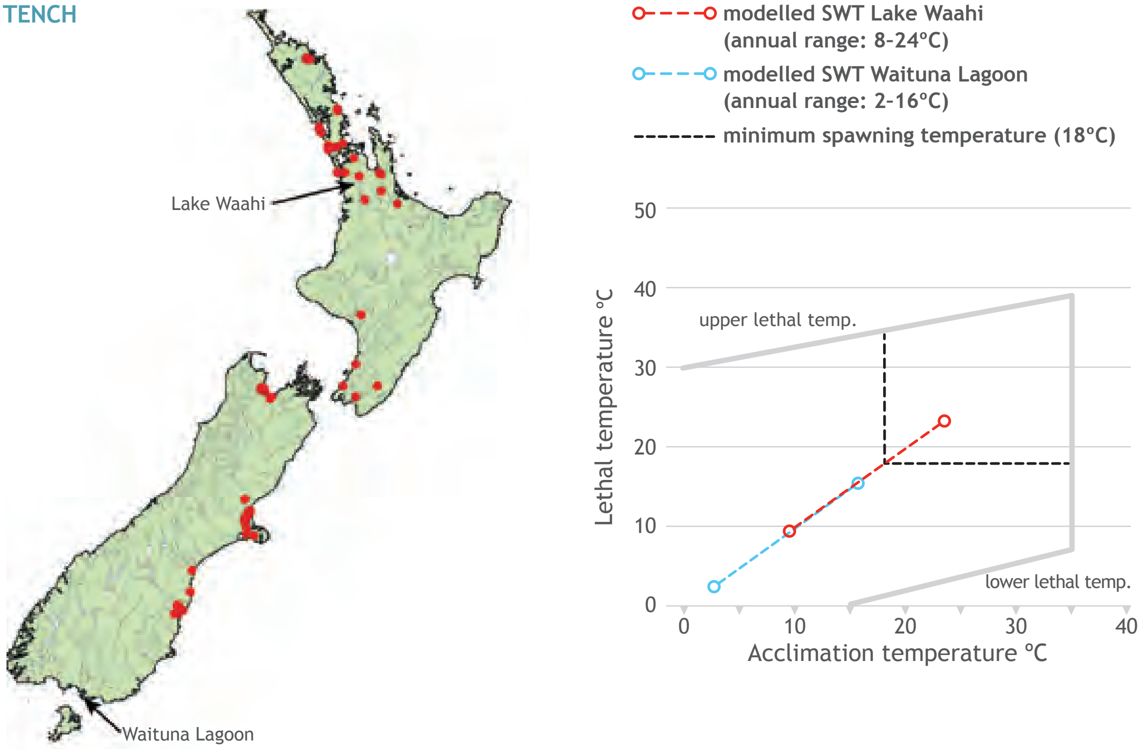


FIGURE 7.8 Thermal tolerance polygon and New Zealand distribution for tench, *Tinca tinca*. Due to an absence of published data on this species, values of the thermal polygon are estimated based on the tolerances of other warm-water tolerant cyprinids. SWT = surface water temperature.

Predicting Invasion Risk

The availability of large scale environmental data layers for river networks and lakes >1 ha throughout mainland New Zealand has provided the opportunity to develop predictions of invasion risk for seven widespread non-indigenous fish. Data from 470 New Zealand lakes with available distribution records were used to build multiple regression models relating species occurrence to predictor variables describing different aspects of the physical environment and human population density (J Leathwick, unpubl. data). Six of the seven invasive species modelled were associated predominantly with lowland lakes with gently sloping catchments, often with high pasture cover, and where summer air temperatures were warmer than average.

Perch was the only species to occur more frequently in lakes with average temperature and solar radiation, indicating an association with cooler conditions compared to the other species. Koi carp and gambusia showed the strongest association with percentage of peat in the catchment. The significance of peatlands may partly reflect (i) the extensive peat areas present in the lower Waikato River catchment where koi carp were originally introduced and are now very widely distributed; (ii) attraction to peat-stained waters, possibly indicating availability of spawning habitat; and (iii) a dense network of drainage channels facilitating much greater hydrological connectivity in the lower Waikato River system.

Goldfish, koi carp and rudd occurred most frequently in larger lakes (>1,000 ha) while gambusia, perch and tench were recorded more frequently in moderate- to small-sized lakes (c.500 ha or less), based on available records. All seven species occurred in lakes with above average human population density in their surrounds, with koi carp and tench occurring in lakes close to the highest average human population density, followed by rudd and catfish. Tench, and to a lesser extent perch, rudd and goldfish, occurred in lakes with above average extents of urban environments in their vicinity. Six of the seven modelled species occurred in lakes that are closer than average to highways and/or have a higher than average density of roads within their vicinity. These relationships underscore the importance of human vectors in the spread of invasive fish and the consequent risks to lakes close to urban centres.

The models were used to make predictions of invasion risk for 3,595 lakes with extents >1 ha to indicate the potential for establishment by each of the seven invasive species, including for more than 3,000 lakes that had no fish distribution records currently available (Figure 7.9 A-G). Thus, where a lake is situated in a catchment for which available evidence indicates that the target species is currently absent, the predictions indicate future likelihood of occurrence, conditional on that species being introduced into the broader catchment within which the lake is located. These models are developed based on data from existing records in lake catchments and therefore predictions reflect environmental and human drivers of current distribution. When comparing with current distributional records (e.g. figures 7.2–7.8) it is important to recognise that these predictions pertain only to lakes >1 ha and their catchments, and exclude catchments without lakes or with smaller lentic waterbodies.

The predictions suggest that South Island lakes most at risk of koi carp establishment occur predominantly along the southern coast (Figure 7.9 A). In contrast, much of the country appears to be at high risk of perch and catfish invasion into lakes (Figure 7.9 B and C). Gambusia appear to have limited establishment potential in South Island lakes under current climatic conditions based on predictions from existing models (Figure 7.9 D). However, there appears much greater risk of rudd invasion, particularly in lakes along the east coast of the North Island, and at scattered coastal and inland locations in the South Island (Figure 7.9 E). The risk of tench invasion appears more limited (Figure 7.9 F), while areas at risk of goldfish establishment are predicted to occur mostly within the current range of this species (Figure 7.9 G).

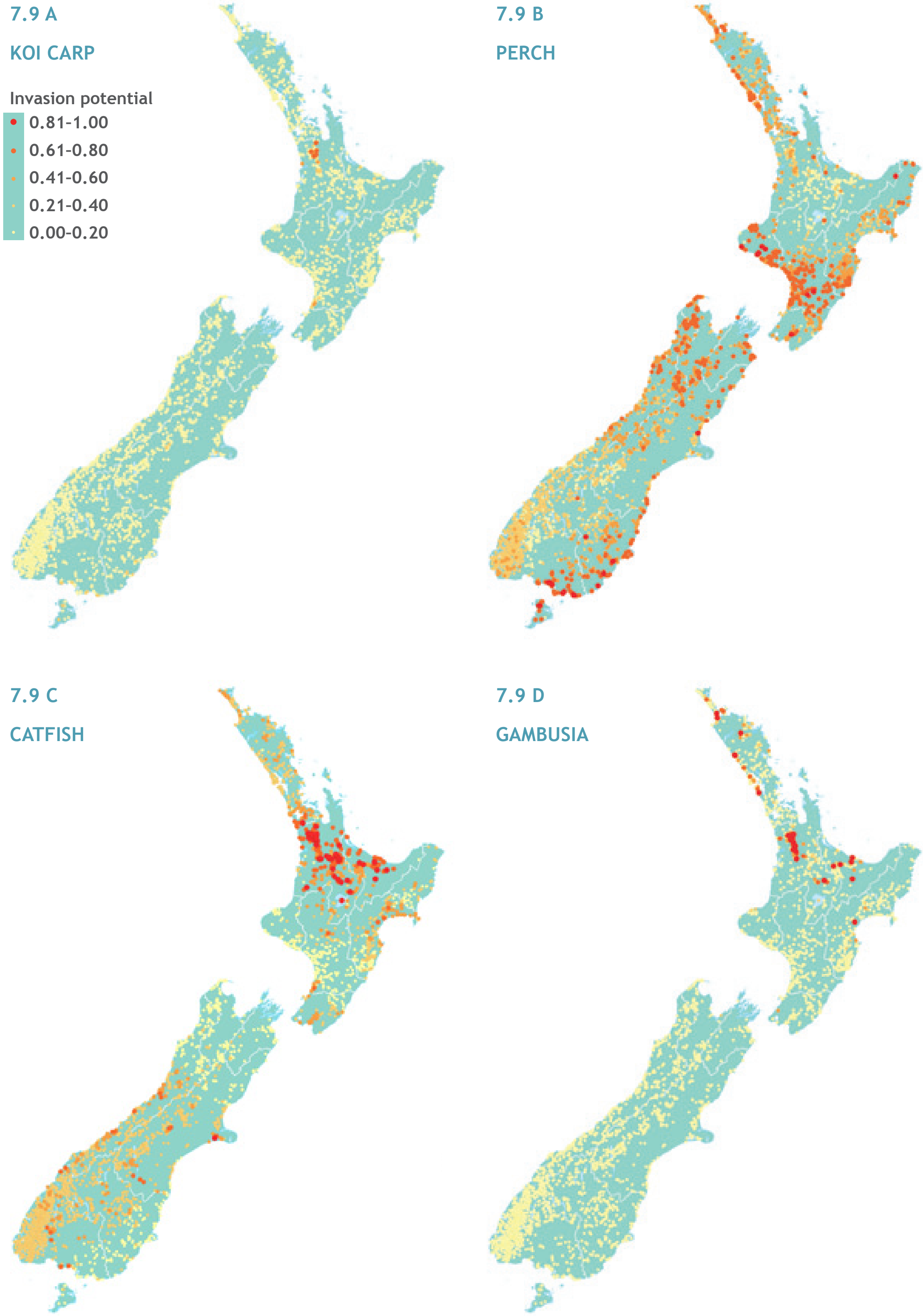
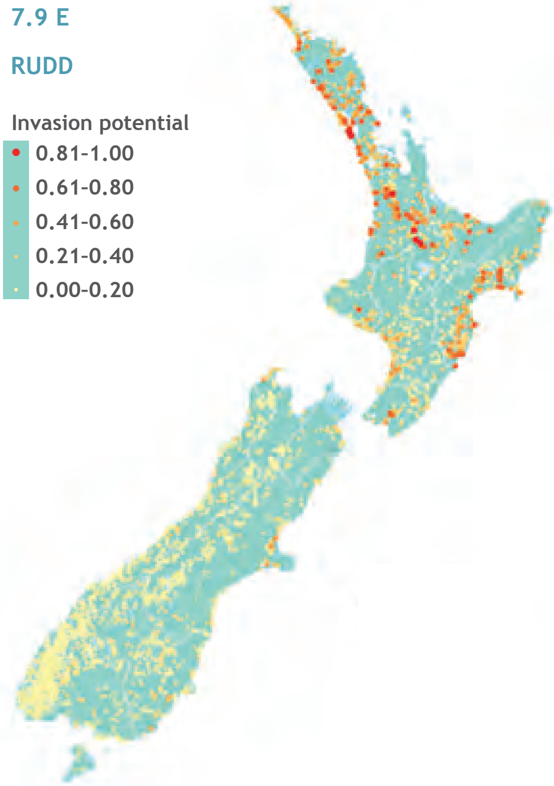


FIGURE 7.9 Probabilities of establishment for seven non-indigenous invasive fish species in New Zealand lakes based on predictive models. The catfish, rudd and perch maps include a spatial factor in the models which accounts for the influence of occurrences in the broader river catchment within which each lake is located; maps for gambusia, tench, koi carp and goldfish do not account for this effect. (Continued over page.)

7.9 E

RUDD



7.9 F

TENCH

7.9 G

GOLDFISH

FIGURE 7.9 Continued.

Summary

The combination of (i) 'ecological impact risk' scores from the FRAM (Table 7.1); (ii) thermal preference polygons (figures 7.2–7.8) placed in the context of temperature profiles for lakes of interest; and (iii) predictions of species establishment in lakes based on statistical models (Figure 7.9), provides a set of tools that can be used to evaluate lakes at risk of non-indigenous fish establishment, species proliferation and adverse ecological effects should invasive fish be released in the lake catchment. This analysis has highlighted particular species (e.g. rudd, perch) that have the potential to spread to lakes well beyond their current range. Future spread of invasive fish may also be influenced by climate change which is predicted to lead to altered water temperatures and hydrological regimes in some parts of New Zealand.

7.2 Perceptions of Recreational Fishers (Coarse Anglers) and Freshwater Managers

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Background

In New Zealand, coarse fishing usually means angling for perch, tench, rudd and koi carp. Other coarse fish species include catfish and wild goldfish, although these are not usually popular with coarse anglers. Understanding coarse angler attitudes and behaviour is important to determine the reasons for, and develop incentives to successfully discourage, deliberate spread of these 'pest' fish species. In addition, it is also important to understand the perceptions of freshwater managers and the ways in which these human perceptions influence management of non-indigenous invasive fish.

To address these issues, semi-structured interviews were conducted with representatives from freshwater management agencies, research providers and iwi, the New Zealand Federation of Coarse Anglers (NZFOCA) and individual coarse anglers. An internet survey was also conducted with individual coarse anglers distributed through club contacts. The internet survey provided results that increase understanding of 'traditional' coarse anglers in New Zealand. However, other angling groups such as those from Asian and eastern European communities have not been captured by this research.

Coarse Angler Perceptions

Although commonly considered pests by freshwater managers, to some anglers coarse fish are valuable species and an important part of their way of life. The fish themselves are not inherently pests, nor are they inherently valuable; their classification is socially constructed and derived from the way they, and their impacts, are interpreted by diverse groups of people at different times and at different locations. Many coarse anglers consider their fishing a fundamental part of their way of life, and many actually consider that they are looking after the environment rather than harming it. Additionally, they hold a strong ethic against killing fish; indeed this is a key factor influencing their relationship with freshwater managers. The anglers recognise that coarse fish are not considered valuable by most New Zealanders, but they also dispute this (de)valuation, recognising the diversity of values that exist. In terms of fishing, coarse anglers recognise that their ethic of returning fish to the water unharmed is unusual in New Zealand.

There are some regional differences in the way specific coarse fish species are valued by coarse anglers, reflecting the regional variation in distribution. In the Auckland/Waikato Fish & Game region, koi carp is generally the favoured fish; the main motivation of most anglers is to catch the biggest koi carp they

SUGGESTED CITATION FOR SECTION 7.2: Duggan KS 2015. Perceptions of Recreational Fishers (Coarse Anglers) and Freshwater Managers. Section 7.2 in Collier KJ & Grainger NPJ eds. New Zealand Invasive Fish Management Handbook. Lake Ecosystem Restoration New Zealand (LERNZ; The University of Waikato) and Department of Conservation, Hamilton, New Zealand. Pp 149–153.

can find. Anglers from other regions typically enjoy fishing for tench, describing them as a beautiful shoaling fish, and also favour perch due to their '*fighting qualities*'. It is interesting to note that many anglers outside of the Auckland/Waikato region mentioned fishing for rudd, although they are only classified as sports fish in the Auckland/Waikato region. Generally, most anglers disliked catfish.

The importance of coarse fishing to anglers' lives emerged from the internet survey where the overwhelming majority (75%) of the 53 respondents indicated that they considered coarse angling to be '*very important*'. Anglers are willing to travel large distances to engage in coarse fishing. When asked approximately how far they usually travelled by car to access coarse fisheries, 30% reported travelling less than 20 km and 40% indicated they usually travel over 50 km, including 16% who regularly travelled further than 100 km.

Coarse anglers appear to have developed a strong ethic against killing fish. Asked in the internet survey what they usually do with the fish after they have caught them, the overwhelming majority (91%) reported that they '*keep them alive and re-release them into the same waterway*'. Nine respondents declared that they '*kill them and take them home*'. However, three of these selected this option only, while a further six indicated they also re-release fish. Worryingly, one person replied that they '*keep them alive and transport them to a waterway they aren't already in*'. It is likely that this was a sarcastic response from a particular member of the coarse fishing forum who is known for expressing similarly provocative views to the chagrin of other forum members, but the response highlights the fact that some risk may remain.

In terms of opportunities for coarse fishing, interviewed coarse anglers reported feeling '*spoilt for choice*' in New Zealand. However, about two-thirds of survey respondents indicated that there are not enough opportunities for coarse angling in New Zealand. Angler dissatisfaction with fishing opportunities is one of the reasons coarse fishers are considered a risk factor in the spread of fish, and there is some evidence that spread is continuing, with koi carp, perch, tench and rudd appearing in various South Island localities over the last few years.

Coarse Angler and Management Agencies Perceptions of Each Other

There appears to be a mutual distrust between coarse anglers and management agencies based on historic grievances, such as the deliberate release of coarse fish (e.g. Winters 2012), and the reduced attention coarse fishing received after Acclimatisation Societies changed to Fish & Game councils. In general, coarse anglers consider Department of Conservation (DOC) and regional councils to be unrealistic in their focus on recreating native ecosystems, and they believe that the effects of coarse fish are exaggerated.

Freshwater managers identified a range of threats to the freshwater environment, including coarse fish and other non-indigenous invasive fish, although the degree to which each was a threat varied between organisations. To DOC and the regional councils, invasive fish management was considered a high priority as it was an area where they felt they had the potential to make a difference. It was recognised in interviews with DOC, regional councils, Ministry for Primary Industries and a freshwater scientist that responsibility for coarse anglers falls under the mandate of Fish & Game councils under the Conservation Act 1987. Fish & Game were primarily concerned with the impact of invasive fish on trout, and considered habitat issues and management of their users to be higher priority than fish management (see also Section 3.3).

The perception by freshwater managers that coarse fishing is not a valuable pursuit has the effect that coarse anglers feel marginalised by management agencies, in addition to the belief that coarse fisheries are not adequately managed. This has the impact of continuing a culture of mistrust and secrecy amongst coarse anglers. However, conflict between coarse anglers and freshwater managers is not inherent. For example, both DOC and the North Canterbury Fish & Game Council are working well with coarse anglers in Christchurch (H McCaughan, DOC, pers. comm.). In this case, coarse anglers have voluntarily implemented local regulations, for example, not allowing coarse fish that are also considered pest fish to count towards competition points.

Discouraging Spread of Coarse Fish

Several possibilities for discouraging the spread of coarse fish species exist, including angler education, a review of the current legislation, improved communication between anglers and management agencies (and among the agencies themselves), and investigating the possibility of creating specific, designated coarse fisheries. However, the typical coarse angler, particularly in the Auckland/Waikato region, does not appear to be interested in spreading fish and therefore needs little discouragement. Instead, an opportunity may exist to negotiate agreements considered legitimate and feasible by coarse anglers and freshwater managers alike (Brechin *et al.* 2002), and to utilise the interests of coarse anglers in favour of biodiversity protection.

ANGLER EDUCATION: Management agencies all viewed education as an important tool for freshwater restoration, and already employ a wide range of educational methods to increase knowledge (see also Section 7.4). Managers highlighted the importance of making education meaningful for people, recognising the need to find a way for the public to decide they care about the freshwater environment. The importance of targeting information at the appropriate level to specific audiences was also recognised. To help freshwater managers design their educational approach, coarse anglers were asked about their interest in learning more about the freshwater environment and coarse angling. They were also asked to specify the tools they currently use to obtain information. An impressive 96% of survey respondents indicated interest in learning about the freshwater environment in general, as well as learning more about their sport. The internet and coarse angling clubs could be key areas for environmental education campaigns to be targeted. However, freshwater managers expressed frustration that, despite their best efforts, education often does not lead to behaviour change.

It is often overlooked that coarse anglers care about, and know more about, freshwater biodiversity than most of the general New Zealand public. In addition, coarse anglers showed a sophisticated understanding of the underlying reasons freshwater management agencies promoted certain messages. The distance that exists between coarse anglers and management agencies is partly due to the anglers' distrust of 'misinformation', and their emotional response to feeling that their perspective is ignored and their personal experiences with the freshwater environment marginalised.

The possibility of integrating the practical knowledge already held by anglers with conservation management and/or scientific research has been investigated in other studies. For example, Granek *et al.* (2008) highlighted some of the ways in which anglers can be employed to help conservation efforts (Table 7.3). Several of the areas for engagement posed by Granek *et al.* (2008) were also suggested by coarse anglers in this research, in particular monitoring (data collection), enforcement (self- and peer-monitoring), promoting conservation through a user fee, involvement in protected area design, and supporting conservation in terrestrial systems.

COMMUNICATION: There appears to be genuine interest from both coarse anglers and freshwater management agencies to engage in productive communication and to negotiate mutually legitimate agreements. There is certainly a large amount of common ground between management agencies and coarse anglers, including a similar appreciation of the value of the freshwater environment. Most freshwater managers indicated a willingness to engage in communication with coarse anglers, and in some cases even to consider setting up specific coarse fishing areas.

Most managers considered a forum or network would be valuable in improving inter-agency communication and collaboration, as well as relationships with coarse anglers. It was noted that if a network were to be set up it would need to be as inclusive as possible and include, for example, aquarists. Suggestions included modelling a network on the National Aquatic Pest Awareness Group (NAPAG, then the Aquatic Pest Technical Advisory Group) of the eastern regions in the North Island, with monthly meetings, or setting up a common database accessible to all organisations to facilitate the fast and efficient transfer of information.

DESIGNATED COARSE FISHERIES: One possible solution, suggested by some freshwater managers and the scientist, as well as coarse anglers, involves establishing a designated, well-managed coarse fishery. This could be done in existing freshwater areas of low conservation value, such as quarry pits and other constructed habitats, or degraded lakes already containing coarse fish. Anglers noted the contribution that attributes of an area provide to the way the sites are valued in the internet survey (Figure 7.10). These characteristics may be just as important as specific valued sites and are important factors to consider if a new fishery was specifically created.

TABLE 7.3 Potential areas for angler engagement in freshwater management and conservation (adapted from Granek *et al*. 2008).

TYPE OF PARTICIPATION	ACTIVITY BY FISHERS
Monitoring	Collect standard suite of quantitative and qualitative data on fish caught—species, location, size, sex, condition
Involvement in fisheries research	Direct support—train scientists in efficient catch methods; catch fish for scientists Indirect support—in-kind support (e.g. boat or equipment use); financial support (e.g. via angling associations)
Enforcement	Self- and peer-monitoring
Promoting conservation	Pay user fee; join conservation group(s); engage in conservation-based approach to resource use
Involvement in protected area design	Give input into design process; identify prime fishing areas; assist with quota determination
Advocacy across systems/education	Support conservation in other systems

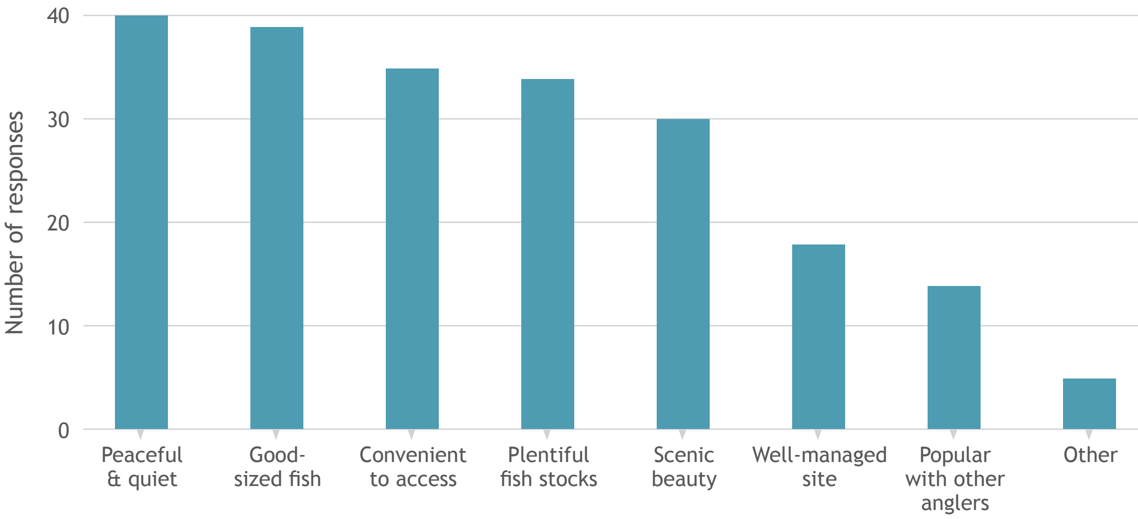

FIGURE 7.10 Aspects of fishing sites most valued by coarse anglers.

Coarse anglers view the construction of a designated fishery very favourably, as it would go some way towards legitimising their sport and relieving their concerns that their favourite coarse fisheries might be subject to fish eradication at any moment. However, it is likely that anglers would expect to be able to return koi carp, for example, live to a designated fishery. That freshwater managers and the one scientist interviewed also see value in keeping coarse anglers satisfied by confining the sport to specific areas reflects the increasing realisation that, once established, fish are very difficult to eradicate. It also recognises that providing for coarse angling is likely to (i) reduce the risk of illegal spread, to which its previous marginalisation may have contributed; and (ii) increase the legitimacy (from the coarse anglers' perspective) of fish control operations in areas outside of these designated fisheries.

Conclusions

Coarse anglers and freshwater managers hold very different perceptions of coarse fish. However, there appears to be scope for reconciliation of these diverse perspectives to negotiate agreements considered legitimate by all participants. Pathways to achieve this include undertaking legislation review, including genuine communication and engagement alongside education campaigns, and investigating the feasibility of establishing a designated coarse fishery.

Anglers are eager to learn about the aspects of fish and the freshwater environment of interest to them, and there is scope for freshwater managers to address coarse angler knowledge with educational material targeted appropriately using existing popular information pathways. However, it is recognised that it is attitude and behaviour change that is required more than increasing coarse angler knowledge. This is more likely to be achieved by recognising the skills and knowledge already held by anglers, and using these as a foundation to negotiate a workable relationship. All participants indicated interest in engaging in communication and it is possible that, as well as reducing the risk of deliberate spread of fish, coarse anglers could provide valuable assistance to generally under-resourced conservation programmes.

A further possibility involves the creation of designated coarse fisheries. Legitimising coarse angling in defined areas has the potential to improve relationships between anglers and managers, and encourage peer-monitoring among the coarse angling fraternity. In addition, legitimising coarse angling in defined areas could support freshwater management outcomes by making the control of fish for conservation purposes in areas outside of these fisheries a less conflict-ridden process. It is possible that the effectiveness of a coarse fishery could be investigated through a case-study trial.

7.3 Invasive Fish Advocacy

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Background

Invasive species management in aquatic environments faces a range of challenges and difficulties, including the detection, eradication and management of invasive species. The 2014 Royal Society of New Zealand report on the Challenges for Pest Management in New Zealand* noted that part of this issue is a lack of political and public awareness. The importance of public awareness and engagement in biosecurity has been recognised for some time, and behaviour change and public awareness approaches are often viewed as a very beneficial course of action to achieve management outcomes. Improving awareness and participation of all New Zealanders is one of the key intermediate outcomes in the Pest Management National Plan of Action and the Royal Society report notes that citizen science should play a much stronger role in the monitoring and surveillance of pests in New Zealand.

Awareness and behaviour change activities are recognised by the Ministry for Primary Industries (MPI) as key components to invasive species management. As the agency responsible for the end-to-end management of the biosecurity system, MPI is focused on biosecurity system improvements to reduce risks at a range of intervention points across the system. This includes using awareness and behaviour-change approaches as part of surveillance, response and long-term management activities.

Aquatic Advocacy

In 2004, the invasive freshwater alga didymo, or ‘rock snot’, was identified in the lower South Island of New Zealand. Didymo was aesthetically shocking and posed unknown threats to the environment. With no known control tools, the only viable option was to put in place measures to slow the spread of the alga and protect high value areas through raising awareness and behaviour change. This was achieved through a campaign that uses a simple call to action, ‘Check, Clean, Dry’, based on decontamination guidance developed to mitigate the risk of didymo transfer. The campaign encouraged high-risk users to take personal responsibility for reducing the accidental spread of didymo between waterways.

It was recognised from the outset that the campaign and measures taken for didymo could be transferred to other aquatic invasive species, and that initiatives should be aligned or incorporated with programmes such as the National Aquatic Pest Awareness Group (NAPAG). NAPAG was formed in 2004 to raise awareness of aquatic pests and share resources and collateral amongst organisations with an interest in controlling the spread of aquatic invasives. The group identified many of the hurdles and opportunities in raising awareness and changing behaviour. By 2008, NAPAG had ceased, with the intention that the ‘Check, Clean, Dry’ advisory group would expand to encompass its scope.

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* www.royalsociety.org.nz/media/2014/03/Challenges-for-pest-management-in-NZ.pdf

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Some efforts have been made to broaden the ‘Check, Clean, Dry’ campaign to help prevent the spread of other invasive aquatic species, but this has not been achieved as successfully as initially planned, especially with regards to invasive fish. While the ‘Check, Clean, Dry’ campaign has delivered limited invasive fish advocacy, regular research has been conducted to identify freshwater user audiences, and to understand their behaviours and beliefs, and barriers to changing behaviour. This research has shown interesting insights into the awareness of, and behaviour relating to, the spread of invasive fish. Understanding the factors that influence decisions and the behaviour of different audiences is important in determining how best to engage with them.

Awareness and Behaviour Change Drivers

The most recent audience research conducted by Colmar Brunton for MPI in 2013 included 1,521 high-risk waterway users who completed an online questionnaire. For the ‘Check, Clean, Dry’ campaign, the high-risk waterway users were defined as freshwater anglers, kayakers, boaties, multisport trainers/racers, mountain bikers and hunters. Research has shown that knowledge, awareness and perceived seriousness of other aquatic pests is lower than for didymo; for example 61% see other aquatic pests as a serious threat to New Zealand, in comparison to 78% who view didymo as a serious risk.

Interestingly, over the last three years, the research has shown a high awareness of koi carp, with 36% of high-risk waterway users being able to name the fish unprompted. Catfish, rudd and gambusia also made it into the top 10 invasive aquatic species that could be named unprompted. The waterway users most likely to name koi carp come from the upper North Island and West Coast/Buller regions, whereas Southland, Otago and Christchurch residents are more likely to recall didymo.

The audience research has shown that the majority of high-risk waterway users maintain a personal responsibility for protecting the environment, with 87–91% of respondents reporting that they have a personal duty to care for and protect rivers, lakes and streams because they are precious and worth fighting for. Conversely, only 1–2% report that they believe it is not their problem if the quality of rivers, lakes or streams is ruined by weeds and algae, and that it is the responsibility of the government. The results consistently show that awareness leads to a higher level of responsibility.

According to the research, stopping the spread of invasive aquatic species and keeping equipment in good order are the main reasons why action is taken, with each motive getting 21% of respondents citing them as incentive for using ‘Check, Clean, Dry’. Eight percent of the high-risk waterway users say they do it out of habit and 1% because they are expected to by peers or their clubs. Other reasons to take action include signage and some indication that a pest is present in the waterway.

In recent years, the research has shown that a potential barrier to some audiences undertaking the appropriate behaviour has been the sense that, as individuals, they cannot make a difference. In addition, we are starting to see the degree of apathy increase amongst high-risk waterway users, which could be linked to how long the awareness campaign has been running.

Key Lessons Learned and the Future of Invasive Fish Advocacy

The ‘Check, Clean, Dry’ campaign has been beneficial in understanding perspectives and behavioural drivers around aquatic pest spread, and it is hoped that its broader principles may be utilised in reducing the spread of other invasive aquatic species, including fish. While there will be differences in the target audience and in understanding what drives awareness and behaviour change in managing the spread of invasive fish, the ‘Check, Clean, Dry’ campaign provides a good starting point. For example, the research has shown that it is possible to manage the unintentional spread of invasive aquatic species by focussing on high-risk waterway users’ sense of personal responsibility for protecting the environment, the high-level of awareness of the seriousness of aquatic pests, and the effective use of well-placed signage to prompt action.

7.4 Raising Public Awareness of Invasive Fish

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Background

A key part of reducing threats to freshwater environments and indigenous species is to raise public awareness. This is particularly relevant for invasive fish and their impacts because they are mainly spread by humans and are often not widely distributed. The existence and impacts of invasive fish are also not that well understood by the public.

In 1999, Department of Conservation (DOC) technical staff identified that increasing public awareness was a key priority in the future management of invasive fish. In 2000, The New Zealand Biodiversity Strategy (NZBS) was launched, and stated that agencies needed to prevent and manage pests that posed a threat to native freshwater biodiversity. This same year, koi carp and gambusia were found in the South Island for the first time (see Section 5.3). Funding from the NZBS was used to carry out national delimitation surveys for pest fish and to start a national pest fish awareness programme. A significant number of fact sheets, posters and other material were produced to be used during this survey work, and an interactive programme to be run in primary schools was instigated.

Interagency work was seen as important to get consistent messages, generate a high profile for the issues, and increase credibility of the programme. In response to this need, a National Aquatic Pest Awareness Group (NAPAG) was established in 2004. This group included representatives from central and local government agencies, researchers and interest groups (including hydropower producers and aquatic societies). A national public awareness strategy was developed to provide a common pathway for this work and a standard set of symbols to be used on publication and signage. In 2006, the Ministry of Agriculture and Forestry (now the Ministry for Primary Industries) took over some of the NAPAG roles and the group was disestablished.

In 2007, DOC worked on an internal national invasive freshwater fish management strategy that included raising public awareness. DOC continues to be involved in public awareness work, particularly in regions where there are active invasive fish management programmes. Currently the most active regions are Northland, Waikato, Taranaki, Nelson/Marlborough, West Coast and Canterbury. The following sections outline the key messages and lessons used to raise public awareness of invasive fish issues.

Making Good Material

Public awareness material needs to be factual, but also interesting and eye-catching. The focus needs to be on key messages that are accurate, brief and clear, with engaging pictures. It is important to talk about the fish, but also mention what it is you are trying to protect and why. People need to know that there are amazing species hidden in our beautiful rivers, lakes and wetlands, because many of these species are not commonly seen or known about.

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Material should say what the invasive species are called (common and scientific names when appropriate), what they look like, why they are considered a problem (i.e. what their impacts are), where they live (preferred habitats), how they are spread, and actions that every person can take to help stop the spread. Often people will want to know when/why the introduced species were brought to New Zealand and this can add some interest. It is also a good idea to mention the legislative status of the invasive species, for example unwanted organism, and if there are any associated penalties with spreading it.

Brochures and factsheets should be informative, brief and attractive with many pictures and few words. This is the same for posters (Plate 7.1 A) and display banners (Plate 7.1 B). To help people know what to do, factsheets can incorporate brief tick lists. Involvement of other agencies/groups, with all their logos on the material, helps send a stronger message. Sometimes signage can be useful along roadsides or at selected waterbodies. Signage can be useful to alert people to be on the lookout for invasive fish and/or to remind them to take precautions not to spread them (Plate 7.2). When erecting a sign, it is important to check with the landowner, local councils and/or the New Zealand Transport Agency (NZTA) first as they may have strict rules that need to be taken into account. It is not a good idea to put up a sign if there are already many other signs at that site.

7.1 A

7.1 B

PLATE 7.1 (A) Poster and (B) display banner featuring New Zealand's most unwanted invasive freshwater fish.

Spreading the Message

To effectively raise public awareness, the material and its messages need to appeal to as many different people and groups as possible and give them a motivating reason to get involved. This can be achieved by getting involved with public events, interest groups and school activities, and promoting messages in the media and to people who work in and around water, as well as those who use it for recreation. To do this, it is important to think about why people would be interested in what the material is saying —'*What is in it for them?*', '*Why should they care and what can they do to help?*' For example, when talking to a fishing group, focus more on the impacts to the fishing resource rather than entirely on native biodiversity; highlight how cleaning gear and not spreading pests will help to protect the waters that people like to play in and enjoy.

It is helpful to find out what public events are coming up in the region each year, focussing on events that will have the most people involved in related activities, such as outdoor activity shows (four-wheel drive vehicles, boats, camping) and A&P shows. Sometimes, all that is needed is to put up some eye-catching banners with informative factsheets, but there may be events where a live fish display and/or some demonstrations are possible. Incorporating life-size models of invasive fish gives a realistic idea of what they look like (Plate 7.3). It is important not to go overboard at a display because it becomes confusing for people to look at if there are too many posters. Making the display look good will help attract people to it, for example by placing some rocks and plants around it, or some old fishing nets. It can be really engaging to have some fun activities and games such as a treasure hunt, an invasive fish pot-shot game with fish to knock off (Plate 7.4), some sheets to colour in (Plate 7.5), stickers, and useful giveaways (such as key ring floats—Plate 7.6).

Many interest groups have regular meetings and are keen on guest speakers, for example fishing clubs, tramping clubs, Forest & Bird and aquarium clubs. Having live fish in a tank really engages people. Local schools may also want a classroom guest, or involvement on a field trip or school camp. Children engage really well with hands-on activities and love being asked questions and listened to. Cushions or puppets that look like invasive fish (life-size) help children engage and be hands-on (Plate 7.7). Fun activities like gear cleaning competitions or 'spot the pest' can also be used to engage children.

Articles in newspapers, magazines or local newsletters can reach a wide range of people, but they should be brief, visual and get the key messages in at the beginning. These articles could be seasonal, in response to an incursion, or in response to work that is occurring in that area (control or surveillance). Pet shops and outdoor activity places may be happy to display information on your behalf.

PLATE 7.2 Lakeside sign highlights pests present in the waterbody and how people can help to stop their spread.

PLATE 7.3 Life-size fibreglass models of rudd, koi carp and goldfish.

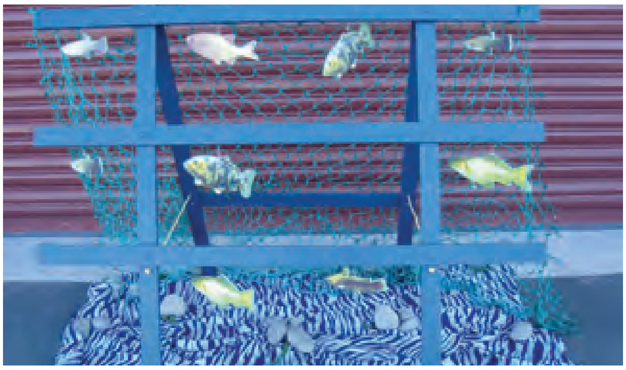


PLATE 7.4 Invasive fish pot-shot game; the aim is to knock the fish down and leave the natives.

PLATE 7.5 Colouring in sheet highlighting the sensitivity of streams. (Drawing by S Asplin, DOC)

Other groups, such as local Fish & Game councils, not just the staff but council members and honorary rangers, may be able to help with surveillance and compliance as they spend a lot of time around waterbodies. Local restoration and community groups may have special sites they are looking after, and people who work in and around water, such as city/district council staff and drainage workers, may also help with surveillance by reporting sightings. Such workers also need to be reminded about cleaning the gear they use on the job.

PLATE 7.6 Key ring floats with a simple message and some memory prompts.

PLATE 7.7 Cushions with life-size images on both sides of rudd (top) and koi carp (bottom).

Conclusions

The following key points should be considered to effectively raise public awareness of invasive fish:

- Key messages—keep these simple and clear.
- Use local examples and pictures—people can relate to places they know; use visual examples of healthy places or of an invasive species and its impacts.
- Highlight what you are trying to protect—our special places and species.
- Target the theme to the audience—what's in it for them? Why they should help?
- Have active as well as passive displays and events.
- Use people who know their stuff and show genuine enthusiasm.
- Join in with others and send a stronger message—run combined displays and activities, and get everyone's logo on the material.
- Get everyone involved early—people involved in similar work (inside and outside your agency/group), other interest groups, your publishing team (set formats).
- Check you can put up a sign before you invest in it (landowners, NZTA, councils).
- You won't convince everybody—keep to the facts (don't get drawn into emotive arguments).

References

Adámek Z, Maršálek B 2013. Bioturbation of sediments by benthic macroinvertebrates and fish and its implication for pond ecosystems: a review. Aquaculture International 21: 1–17.

Alabaster JS, Downing AL 1966. A field and laboratory investigation of the effect of heated effluents on fish. Fishery Investigation 6(4). HMSO, London, United Kingdom. 42 p.

Alas A, Solak K 2004. The reproductive biology of tench (*Tinca tinca* L. 1758) in Kayabogazi (Kutahya, Yurkey) dam lake. Turkish Journal of Veterinary and Animal Science 28: 879–885.

Auckland Regional Council 2007. Auckland regional pest management strategy 2007–2012. Auckland Regional Council, Auckland, New Zealand. 225 p.

Badiou PHJ, Goldsborough LG 2010. Ecological impacts of an exotic benthivorous fish in large experimental wetlands, Delta Marsh, Canada. Wetlands 30: 657–667.

Bajer PG, Sullivan GS, Sorensen PW 2009. Effects of a rapidly increasing population of common carp on vegetative cover and waterfowl in a recently restored Midwestern shallow lake. Hydrobiologia 632: 235–245.

Banks JC, Hicks BJ, Lobb R, Blair J 2010. Genetic identification of fish. CBER report 109. Centre for Biodiversity and Ecology Research, The University of Waikato, Hamilton, New Zealand. 17 p.

Banks, JC, Watson NTN, Hogg ID 2014. Comparison of the efficiency of three methods of isolating fish DNA from environmental samples. Environmental Research Institute report 45. The University of Waikato, Hamilton, New Zealand. 17 p.

Bannon HJ 2001. Biological responses to grass carp (*Ctenopharyngodon idella*) in Waikato drains. Hamilton, New Zealand. Unpubl. MSc thesis, The University of Waikato, Hamilton, New Zealand. 74 p.

Barnes GE 1996. The biology and general ecology of the brown bullhead catfish (*Ameiurus nebulosus*) in Lake Taupo. Unpubl. MSc thesis, The University of Waikato, Hamilton, New Zealand. 114 p.

Barrier RFG, Hicks BJ 1994. Behavioural interactions between black mudfish (*Neochanna diversus*, Stokell, 1949: Galaxiidae) and mosquitofish (*Gambusia affinis* Baird & Girard, 1854). Ecology of Freshwater Fish 3: 93–99.

Bayley PB, Austen DJ 2002. Capture efficiency of a boat-electrofisher. Transactions of the American Fisheries Society 131: 435–451.

Beamish RJ 1973. Design of a trap net with interchangeable parts for the capture of large and small fishes from varying depths. Journal of the Fisheries Research Board of Canada 30: 587–590.

Beitinger TL, Bennett WA, McAuley RW 2000. Temperature tolerances of North American freshwater fishes exposed to dynamic changes in temperature. Environmental Biology of Fishes 58: 237–275.

Beklioglu M, Moss B 1998. The effects of tench (*Tinca tinca* (L.)) and sticklebacks (*Gasterosteus aculeatus* L.) on planktonic and benthic communities in mesocosms in a shallow lake. Aquatic Ecology 32: 229–240.

Benson D, Karsch-Mizrachi I, Lipman D, Ostell J, Sayers E 2009. GenBank. Nucleic Acids Research 37 (Database issue): D26–31.

Blumer LS 1985. Reproductive natural history of the brown bullhead *Ictalurus nebulosus* in Michigan. The American Midland Naturalist 114: 318–330.

Bomford M, O'Brien P 1995. Eradication of Australia's vertebrate pests: a feasibility study. In: Grigg GC, Hale PT, Lunney D eds, Conservation through sustainable use of wildlife. University of Queensland, Centre for Conservation Biology, Brisbane, Australia. Pp 243–250.

Brabrand Å 1985. Food of roach (*Rutilus rutilus*) and ide (*Leuciscus idus*): significance of diet shift for interspecific competition in omnivorous fishes. Oecologia 66: 461–467.

Brammeier J, Polls I, Mackey S 2008. Preliminary feasibility of ecological separation of the Mississippi River and the Great Lakes to prevent the transfer of aquatic invasive species. Great Lakes Fisheries Commission, Chicago, Illinois, USA. 106 p.

Brechin SR, Wilshusen PR, Fortwangler CL, West PC 2002. Beyond the square wheel: toward a more comprehensive understanding of biodiversity conservation as social and political process. Society and Natural Resources 15: 41–64.

Breukelaar AW, Lammens EHRR, Klein Breteler JGP, Tátrai I 1994. Effects of benthivorous bream (*Abramis brama)* and carp (*Cyprinus carpio*) on sediment resuspension and concentrations of nutrients and chlorophyll *a*. Freshwater Biology 32: 113–121.

Bronmark C 1994. Effects of tench and perch on interactions in a freshwater, benthic food chain. Ecology 75: 1818–1828.

Brousseau CM, Randall RG, Clark MG 2005. Protocol for boat electrofishing in nearshore areas of the lower Great Lakes: transect and point survey methods for collecting fish and habitat data, 1988 to 2002. Canadian manuscript report of fisheries and aquatic sciences 2702. Great Lakes Laboratory for Fisheries and Aquatic Sciences, Burlington, Ontario, Canada. 106 p.

Burns NM, Rutherford JC, Clayton JS 1999. A monitoring and classification system for New Zealand lakes and reservoirs. Lake and Reservoir Management 15: 255–271.

Cadwallader PL 1977. Introduction of rudd *Scardinius erythrophthalmus* into New Zealand. Part 1. Review of the ecology of rudd and the implications of its introduction into New Zealand. Fisheries technical report 147. New Zealand Ministry of Agriculture and Fisheries, Wellington, New Zealand. Pp 1–18.

Cadwallader PL 1978. Acclimatisation of rudd *Scardinius erythrophthalmus* (Pisces: Cyprinidae) in the North Island of New Zealand. New Zealand Journal of Marine and Freshwater Research 12: 81–82.

Cadwallader PL, Backhouse GN 1983. A guide to the freshwater fish of Victoria. Victorian Government Printing Office, Melbourne, Australia. 249 p.

Canagaratnam P 1959. Growth of fishes in different salinities. Journal of the Fisheries Research Board of Canada 16: 121–130.

Canfield DE, Langeland KA, Linda SB, Haller WT 1985. Relations between water transparency and maximum depth of macrophyte colonization in lakes. Journal of Aquatic Plant Management 23: 25–28.

Champion P, Rowe D, Smith B, Wells R, Kilroy C, de Winton M 2013. Freshwater pests of New Zealand. National Institute of Water and Atmospheric Research, Hamilton, New Zealand. 64 p.

Chetterjee N, Pal AK, Manush SM, Das T, Mukherjee SC 2004. Thermal tolerance and oxygen consumption of *Labeo rohita* and *Cyprinus carpio* early fingerlings acclimated to three different temperatures. Journal of Thermal Biology 29: 265–270.

Clayton J, Edwards T 2006. LakeSPI: a method for monitoring ecological condition in New Zealand lakes. Technical Report. Version 2. National Institute of Water and Atmospheric Research, Hamilton, New Zealand. 67 p.

Clearwater SJ (compiler) 2005. Lime application for aquatic pest eradication: A compilation of current knowledge. Department of Conservation pesticide information reviews. National Institute of Water and Atmospheric Research, Hamilton, New Zealand. 37 p.

Clearwater SJ, Hickey CW Martin ML 2008. Overview of potential piscicides and molluscicides for controlling aquatic pest species in New Zealand. Science for Conservation 283. Department of Conservation, Wellington, New Zealand. 74 p.

Clearwater SJ, Kusabs IA, Budd R, Bowman E 2014. Strategic evaluation of kōura populations in the upper Waikato River. NIWA client report HAM2014-086. National Institute of Water and Atmospheric Research, Hamilton, New Zealand. 77 p.

Cline JM, East TL Threlkeld ST 1994. Fish interactions with the sediment-water interface. Hydrobiologia 275/276: 301–311.

Closs GP, Ludgate V, Goldsmith RJ 2003. Controlling European perch (*Perca fluviatilis*): Lessons from an experimental removal. In: Munro R ed, Managing invasive freshwater fish in New Zealand. Proceedings of a workshop hosted by Department of Conservation, 10–12 May 2001, Hamilton. Department of Conservation, Wellington, New Zealand. Pp 37–47.

Collins R, Armstrong K, Holyoake A, Keeling S 2012. Something in the water: biosecurity monitoring of ornamental fish imports using environmental DNA. Biological Invasions: 1–7.

Conallin A, Stuart I, Higham J 2008. Commercial application of the Williams' carp separation cage at Lock 1. Final report to Murray-Darling Basin Commission. Murray-Darling Basin Commission, Canberra, Australia. 40 p.

Congdon BC 1994. Characteristics of dispersal in the eastern mosquitofish *Gambusia affinis*. Journal of Fish Biology 45: 943–952.

Copp GH 1997. Microhabitat use of fish larvae and 0+ juveniles in a highly regulated section of the River Great Ouse. Regulated Rivers: Research and Management 13: 267–276.

Crawshaw LI 1975. Attainment of the final thermal preferendum in brown bullheads acclimated to different temperatures. Comparative Biochemistry and Physiology 52A: 171–173.

Daniel AJ 2009. Detecting exploitable stages in the life history of koi carp (*Cyprinus carpio*) in New Zealand. Unpubl. PhD thesis, The University of Waikato, Hamilton, New Zealand. 149 p.

Daniel AJ Morgan DKJ 2011. Lake Ohinewai pest fish removal. Centre for Biodiversity and Ecology Research contract report 120. Centre for Biodiversity and Ecology Research, The University of Waikato, Hamilton, New Zealand. 30 p.

Daniel AJ, Hicks BJ, Ling N, David BO 2011. Movements of radio- and acoustic-tagged adult koi carp in the Waikato River, New Zealand. North American Journal of Fisheries Management 31: 352–362.

David B, Hamer M, Collier KJ 2009. Mussel spat ropes provide passage for banded kokopu in laboratory trials. New Zealand Journal of Marine and Freshwater Research 43: 883–888.

Davies-Colley RJ 1988. Measuring water clarity with a black disk. Limnology and Oceanography 33: 616–623.

de Villiers JE 2013. Assessment of injury to New Zealand native fish by boat electrofishing. Unpubl. MSc thesis, The University of Waikato, Hamilton, New Zealand. 97 p.

de Winton M 2014. Serpentine Lakes 2014 macrophyte assessment. NIWA client report HAM2014-054. National Institute of Water and Atmospheric Research, Hamilton, New Zealand. 16 p.

de Winton M, Champion P 1993. The vegetation of the lower Waikato lakes. Volume 1. Factors affecting the vegetation of lakes in the Lower Waikato. NIWA Ecosystems publication 7. National Institute of Water and Atmospheric Research, Hamilton, New Zealand. 89 p.

de Winton MD, Dugdale TM 2003. Coarse fish: the demise of plants and malaise of lakes. In: Munro R ed, Managing invasive freshwater fish in New Zealand. Proceedings of a workshop hosted by Department of Conservation, 10–12 May 2001, Hamilton. Department of Conservation, Wellington, New Zealand. Pp 59–69.

de Winton M, Edwards T 2012. Assessment of Auckland lakes using LakeSPI. Auckland Council technical report 2012/034. Auckland Council, Auckland, New Zealand. 100 p.

de Winton MD, Taumoepeau A, Wells R 2006. Submerged vegetation in the Serpentine Lakes 2005/06: Current condition and weed threat. NIWA client report HAM2006-045. National Institute of Water and Atmospheric Research, Hamilton, New Zealand.

Dean T 2003. Invasive freshwater fish in New Zealand: DOC's present and future management. In: Munro R ed, Managing invasive freshwater fish in New Zealand. Proceedings of a workshop hosted by Department of Conservation, 10–12 May 2001, Hamilton. Department of Conservation, Wellington, New Zealand. Pp 1–9.

Dedual M 2002. Vertical distribution and movements of brown bullhead (*Ameiurus nebulosus* Lesueur 1819) in Motuoapa Bay, southern Lake Taupo, New Zealand. Hydrobiologia 483: 129–135.

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. Department of Conservation, Wellington, New Zealand. 174 p.

Dokulil MT, Teubner K 2003. Eutrophication and restoration of shallow lakes—the concept of stable equilibria revisited. Hydrobiologia 506–509: 29–35.

Donkers P, Patil JG, Wisniewski C, Diggle J 2011. Validation of mark-recapture population estimates for invasive common carp, *Cyprinus carpio* in Lake Crescent, Tasmania. Journal of Applied Ichthyology 28: 7–14.

Downing JA, Watson SB, McCauley E 2001. Predicting cyanobacteria dominance in lakes. Canadian Journal of Fisheries and Aquatic Sciences 58: 1905–1908.

Drake DC, Kelly DJ, Schallenberg M 2010. Shallow coastal lakes in New Zealand: current conditions, catchment-scale human disturbance, and determination of ecological integrity. Hydrobiologia 658: 87–101.

Driver PD, Closs GP, Koen T 2005. The effects of size and density of carp (C*yprinus carpio* L.) on water quallity in an experimental pond. Archiv fur Hydrobiologie 163: 117–131.

Dugdale T, Wells R 2002. Decontamination of fishing nets to prevent transfer of freshwater pest organisms. National Institute of Water and Atmospheric Research client report HAM2002-015. National Institute of Water and Atmospheric Research, Hamilton, New Zealand.

Dudgeon D, Arthington AH, Gessner MO, Kawabata Z-I, Knowler DJ, Leveque C, Naiman RJ, Prieur-Richard AH, Soto D, Stiassny MLJ, Sullivan CA 2010. Freshwater biodiversity: importance, threats, status and conservation challenges. Biological Reviews 81: 163–182.

Eaton JG, McCormick JH, Goodno BE, O'Brien DG, Stefany HG, Hondzo M, Scheller RM 1995. A field-information based system for estimating fish temperature tolerances. Fisheries 20: 10–18.

Edwards T, Clayton J, de Winton M 2005. The condition of lakes in the Waikato region using LakeSPI. NIWA client report HAM2005-125 prepared for Environment Waikato. National Institute of Water and Atmospheric Research, Hamilton, New Zealand. 38 p.

Environment Waikato 1998. Waikato state of the environment report. Waikato Regional Council, Hamilton, New Zealand.

Fairweather AAC, Dean-Speirs TL 2012. Using rotenone to eradicate freshwater invasive fish pesticide information review. Version 2012/1. Unpubl. report docdm-243513. Department of Conservation, Hamilton, New Zealand. 50 p.

Ficetola GF, Miaud C, Pompanon F, Taberlet P 2008. Species detection using environmental DNA from water samples. Biology Letters 4: 423–425.

Ford T, Beitinger TL 2005. Temperature tolerance in the goldfish, *Carassius auratus*. Journal of Thermal Biology 30: 147–152.

Gallegos C 2001. Quality targets to restore and protect submersed aquatic vegetation: overcoming problems in partitioning the diffuse attenuation coefficient for photosynthetically active. Estuaries 24: 381–397.

Garrett-Walker J 2014. The ecology of constructed ponds on the lower Waikato River floodplain: implications for waterfowl management. Unpubl. MSc thesis, The University of Waikato, Hamilton, New Zealand. 160 p.

Gehrke PC, Brown P, Schiller CB, Moffat DB, Bruce AM 1995. River regulation and fish communities in the Murray-Darling River System, Australia. Regulated Rivers: Research and Management 11: 363–375.

Giles N, Street M, Wright RM 1990. Diet composition and prey preference of tench, *Tinca tinca* (L.), common bream, *Abramis brama* (L.), perch, *Perca fluviatilis* L. and roach *Rutilis rutilis* (L.) in two contrasting gravel pit lakes: potential trophic overlap with wildfowl. Journal of Fish Biology 37: 945–957.

Goldberg CS, Pilliod DS, Arkle RS, Waits LP 2011. Molecular detection of vertebrates in stream water: a demonstration using Rocky Mountain tailed frogs and Idaho giant salamanders. PLoS ONE 6: e22746.

Goodman JM, Dunn NR, Ravenscroft PJ, Allibone RM, Boubee JAT, David BO, Griffiths M, Ling N, Hitchmough RA, Rolfe JR 2013. Conservation status of New Zealand freshwater fish. New Zealand threat classification series 7. Department of Conservation, Wellington, New Zealand. 12 p.

Grainger N 2013. Pest fish eradication–handlaying or aerial application of rotenone. Animal pests best practice—rotenone. Version 1.4. Department of Conservation, Wellington, New Zealand. 32 p.

Grainger N, McCaughan H 2014a. Decontamination of freshwater gear: best practice guidance. Version 2. Department of Conservation Wellington, New Zealand. 5 p. (Reproduced in Appendix 3)

Grainger N, McCaughan H 2014b. Set nets and diving birds: best practice guidance. Amendment 1. Department of Conservation, Wellington, New Zealand. 3 p. (Reproduced in Appendix 4)

Grainger N, Goodman J, West D 2013. Introduction to monitoring freshwater fish. Version 1.1. In: Greene T, McNutt K eds, Biodiversity inventory and monitoring toolbox. Department of Conservation, Wellington, New Zealand. 13 p.

Grainger N, West D, McCaughan H 2014. Invasive fish inventory and monitoring: best practice guidance. Version 2.0. Department of Conservation, Wellington, New Zealand. 17 p. (Reproduced in Appendix 2.)

Granek EF, Madin EMP, Brown MA, Figueira W, Cameron DS, Hogan Z, Kristianson G, Villiers PD, Williams JE, Post J, Zahn S, Arlinghaus R 2008. Engaging recreational fishers in management and conservation: global case studies. Conservation Biology 22: 1125–1134.

Greene T, McNutt K eds 2012. Biodiversity inventory and monitoring toolbox. Department of Conservation, Wellington, New Zealand. www.doc.govt.nz/getting-involved/run-a-project/our-procedures-and-sops/biodiversity-inventory-and-monitoring/freshwater-fish/.

Gumbley J 2010. Stephen O'Dea study grant report - invasive fish management. Unpubl. report docdm-638339. Department of Conservation, Hamilton, New Zealand. 50 p.

Haas K, Köhler U, Diehl S, Köhler P, Dietrich S, Holler S, Jaensch A, Niedermaier M, Vilsmeier J 2007. Influence of fish on habitat choice of water birds: a whole system experiment. Ecology 88: 2915–2925.

Hamill KD, Lockie SE 2014. Auckland lake water quality: state and trends. Auckland Council technical report. Auckland Council, Auckland, New Zealand.

Hamilton DP Jones HFE, Özkundacki D, McBride C, Allan MG, Faber J, Pilditch CA 2012. Waituna Lagoon modelling: Developing quantitative assessments to assist with lagoon management. Environmental Research Institute report 004, prepared for Environment Southland. The University of Waikato, Hamilton, New Zealand. 92 p.

Hanchet S 1990. The effects of koi carp on New Zealand's aquatic ecosytems. New Zealand freshwater fisheries report 11. MAF Fisheries, Rotorua, New Zealand. 41 p.

Hansson LA, Johansson L, Persson L 1987. Effects of fish grazing on nutrient release and succession of primary producers. Limnology and Oceanography 32: 723–729.

Haq S, Prasad RN, Shukla RP, Sharma VP 1992. *Gambusia affinis*: dispersal due to floods and its failure to colonise new water bodies in Shahjahanpur District (U.P.). Indian Journal of Malariology 29: 113–118.

Harvey G, Fortin R 1982. Reproduction et dynamique de population de la barbotte brune *Ictalurus nebulosus* (Le Sueur) dans la frayère de la rivière aux Pins, fleuve Saint-Laurent, près de Montréal (Québec). Canadian Journal of Zoology 60: 31–39.

Hasnain S 2012. Thermal response of North American freshwater fishes. Unpubl. MSc thesis, The University of Toronto, Canada. 55 p.

Havens KE, James RT, East TL, Smith VH 2003. N:P ratios, light limitation, and cyanobacterial dominance in a subtropical lake impacted by non-point source nutrient pollution. Environmental Pollution 122: 379–390.

Hayes JW 1989. Comparison between a fine mesh trap net and five other fishing gears for sampling shallow-lake fish communities in New Zealand. New Zealand Journal of Marine and Freshwater Research 23: 321–324.

Hebert PDN, Cywinska A, Ball SL, deWaard JR 2003. Biological identification through DNA barcodes. Proceedings of the Royal Society of London B 270: 313–321.

Heffer DK 2003. Wetlands of lakes Sorell and Crescent: Conservation and management. Inland Fisheries Service Hobart, Tasmania, Australia.

Hicks BJ, Bell DG 2003. Electrofishing survey of the Manawatu, Whanganui, and Mokau rivers, and Lake Rotorangi, Patea River. Centre for Biodiversity and Ecology Research contract report 30. Centre for Biodiversity and Ecology Research, The University of Waikato, Hamilton, New Zealand. 14 p.

Hicks BJ, Tempero G 2013. Boat electrofishing survey of Lake Puketirini, Waikato. Environmental Research Institute report 40, prepared for Genesis Energy Ltd. Environmental Research Institute, The University of Waikato, Hamilton, New Zealand. 14 p.

Hicks BJ, Ling, N 2015. Common carp as an invasive species. In: Pietsch C, Hirsch P eds, Biology and ecology of carp. CRC Press, Boca Raton, Florida, USA. Pp 244–279.

Hicks BJ, Reynolds GB, Jamieson PM, Laboyrie JL 2001. Fish populations of Lake Ngaroto, Waikato, and fish passage at the outlet weir. Centre for Biodiversity and Ecology Research contract report 14, prepared for the Waipa District Council. Centre for Biodiversity and Ecology Research, The University of Waikato, Hamilton, New Zealand. 22 p.

Hicks BJ, Ling N, Osborne MW, Bell DG, Ring CA 2005. Boat electrofishing survey of the lower Waikato River and its tributaries. Centre for Biodiversity and Ecology Research contract report 39, prepared for Environment Waikato. Centre for Biodiversity and Ecology Research, The University of Waikato, Hamilton, New Zealand. 17 p.

Hicks BJ, Osborne MW, Ling N 2006. Quantitative estimates of fish abundance from boat electrofishing. In: Phelan MJ, Bajhau H eds, A guide to monitoring fish stocks and aquatic ecosystems. Australian Society for Fish Biology workshop proceedings, Darwin, Northern Territory, 11–15 July 2005. Fisheries incidental publication 25. Northern Territory Department of Primary Industry, Fisheries, and Mines, Darwin, Australia. Pp 104–111.

Hicks BJ, Hamilton DP, Ling N, Wood S 2007. Top down or bottom up? Feasibility of water clarity restoration in the lower Karori Reservoir by fish removal. Centre for Biodiversity and Ecology Research contract report 54, prepared for the Karori Wildlife Sanctuary Trust. Centre for Biodiversity and Ecology Research, The University of Waikato, Hamilton, New Zealand. 21 p.

Hicks BJ, Brijs J, Bell DG 2008. Electrofishing survey of the fish community in the Whangamarino Wetland. CBER contract report 67. Centre for Biodiversity and Ecology Research, Department of Biological Sciences, School of Science and Engineering, The University of Waikato, Hamilton, New Zealand.

Hicks BJ, Ling N, Wilson BJ 2010. Introduced fish. In: Collier KJ, Hamilton DP, Vant WN, Howard-Williams C eds, Waters of the Waikato: Ecology of New Zealand’s longest rivers. Environment Waikato and Centre for Biodiversity and Ecology Research, The University of Waikato, Hamilton, New Zealand. Pp 209–228.

Hicks BJ, Ling N, Daniel AJ 2011. Common carp (*Cyprinus carpio*). In: Francis RA ed, A handbook of global freshwater invasive species. Earthscan, London. Pp 247–260.

Hokanson KEF 1977. Temperature requirements of some percids and adaptations to the seasonal temperature cycle. Journal of the Fisheries Research Board of Canada 34: 1524–1550.

Holcík J 1967. Life history of the rudd *Scardinius erythrophthalmus* (Linnaeus, 1758) in the Klícava Reservoir. Vestnik Ceskoslovenské Spolecnosti Zoologické Acta Societatis Zoologicae Bohemoslovenicae 31: 335–348.

Horoszewicz L 1973. Lethal and disturbing temperatures in some fish species from lakes with normal and artificially elevated temperature. Journal of Fish Biology 5: 165–181.

Inland Fisheries Commission 1995. European carp. Inland Fisheries Commission Newsletter 24: 6–7.

Jackman G 2009. American eel passage enhancement plan for the Bronx River, recommendations and protocols. Technical report. City of New York Parks and Recreation, New York, USA.

Jackson ZJ, Quist MC, Downing JA, Larscheid JG 2010. Common carp (*Cyprinus carpio*), sports fishes, and water quality: Ecological thresholds in agriculturally eutrophic lakes. Lake and Reservoir Management 26: 14–22.

Jeppesen E, Lauridsen TL, Mitchell SF, Christoffersen K, Burns CW 2000. Trophic structure in the pelagial of 25 shallow New Zealand lakes: changes along nutrient and fish gradients. Journal of Plankton Research 22: 951–968.

Jerde CL, Mahon AR, Chadderton WL, Lodge DM 2011. “Sight-unseen” detection of rare aquatic species using environmental DNA. Conservation Letters 4: 150–157.

Jones MH 2010. Simulations of electrical fields around the Hiko Hi Ika electrofishing boat. Unpubl. report, School of Engineering, The University of Waikato, Hamilton, New Zealand. 50 p.

Jones HFE, Hamilton DP 2014. Assessment of the Waikato River estuary and delta for whitebait habitat management: field survey, GIS modelling and hydrodynamic modelling. Environmental Research Institute report 27, prepared for Waikato Regional Council. The University of Waikato, Hamilton, New Zealand. 79 p.

Joy M, David B, Lake M 2013. New Zealand freshwater fish sampling protocols. Part 1 – Wadeable rivers and streams. Massey University, Palmerston North, New Zealand. 51 p.

Kane DS 1995. The status of fish in Hamilton Lake (Lake Rotoroa). Unpubl. MSc thesis, The University of Waikato, Hamilton, New Zealand. 121 p.

Kapuscinski KL, Farrell JM, Stehman SV, Boyer GL, Fernando DD, Teece MA, Tschaplinski TJ 2014. Selective herbivory by an invasive cyprinid, the rudd *Scardinius erythrophthalmus*. Freshwater Biology 59: 2315–2327.

Keast A 1985. Growth responses of the brown bullhead (*Ictalurus nebulosus*) to temperature. Canadian Journal of Zoology 63: 1510–1515.

Kelly RP, Port JA, Yamahara KM, Crowder LB 2014. Using environmental DNA to census marine fishes in a large mesocosm. PLoS ONE 9: e86175.

Kennedy M, Fitzmaurice P 1974. Biology of the rudd *Scardinius erythrophthalmus* (L) in Irish waters. Proceedings of the Royal Irish Academy 74 section B 18: 245–303.

Keys L, Studholme B, Brow A, Gibbs J 2003. Koi carp and gambusia: The North Island pest fish survey 2001–2002. Occasional publication 57. Department of Conservation, Wellington, New Zealand. 32 p.

Kirkpatrick JB, Tyler PA 1988. Tasmanian wetlands and their conservation. In: McComb AJ, Lake PS eds, The conservation of Australian wetlands. Surrey Beaty and Sons Pty Ltd, Sydney, Australia. Pp 1–16.

Kline JL Wood BM 1996. Food habits and diet selectivity of the brown bullhead. Journal of Freshwater Ecology 11: 145–151.

Kloskowski J 2011. Impact of common carp *Cyprinus carpio* on aquatic communities: direct trophic effects versus habitat deterioration. Fundamental and Applied Limnology / Archiv Hydrobiologie 178: 245–255.

Knox MA, Hicks BJ, Banks JC, Hogg ID 2009. Fish biosurveillance by genetic methods: a feasibility study. Centre for Biodiversity and Ecology Research contract report 90. Centre for Biodiversity and Ecology Research, The University of Waikato, Hamilton, New Zealand. 26 p.

Koli L 1984. Suomen Eläimet. Kalat, sammakkoeläimet ja matelijat. Animals of Finland. Fish, frogs and reptiles). Finland, Weilin + Göös. 343 p.

Kolmakov VI, Gladyshev MI 2003. Growth and potential photosynthesis of cyanobacteria are stimulated by viable gut passage in crucian carp. Aquatic Ecology 37: 237–242.

Lake MD 1998. The feeding ecology of rudd (*Scardinius erythrophthalmus*) in New Zealand. Unpubl. MSc thesis, The University of Waikato, Hamilton, New Zealand. 63 p.

Lake M 2010. Review of Rotopiko (Serpentine) lakes exotic fish control programme. Unpubl. report docdm-455123. Department of Conservation, Hamilton, New Zealand. 25 p.

Lake MD, Hicks BJ, Wells RDS, Dugdale TM 2002. Consumption of submerged aquatic macrophytes by rudd (*Scardinius erythrophthalmus* L.) in New Zealand. Hydrobiologia 470: 13–22.

Lake M, Brijs J, Hicks B 2009. Fish survey of the Whangamarino Wetland. Unpubl. report. Department of Conservation, Hamilton, New Zealand. 28 p.

Lamarque P 1967. Electrophysiology of fish subject to the action of an electric field. In: Vibert R ed, Fishing with electricity: Its application to biology and management. Fishing News Books, London, U.K. Pp 65–92.

Lane JA, Portt CB, Minns CK 1996. Spawning habitat characteristics of Great Lakes fishes. Canadian Manuscript report of fisheries and aquatic sciences 2368. 48 p.

Lane W 1979. Rudd likely to spread further. Freshwater Catch 3: 12.

Lane WL 1983. The population dynamics, food and reproductive habits of rudd (*Scardinius erythrophthalmus* L.) in New Zealand. Unpubl. PhD thesis, University of Auckland, Auckland, New Zealand. 119 p.

Leprieur F, Beauchard O, Blanchet S, Oberdorff T, Brosse S 2008. Fish invasions in the world's river systems: when natural processes are blurred by human activities. PLoS Biol 6(2): e28.

Lesko LT, Smith SB, Blouin MA 1996. The effect of contaminated sediments on fecundity of the brown bullhead in three Lake Erie tributaries. Journal of Great Lakes Research 22: 830–837.

Ling N 2003. Rotenone – a review of its toxicity and use for fisheries management. Science for Conservation 211. Department of Conservation, Hamilton, New Zealand. 40 p.

Ling N 2004. Gambusia in New Zealand: really bad or just misunderstood. New Zealand Journal of Marine and Freshwater Research 38: 473–480.

Ling N 2013. Sensitivity of Rotopiko Lakes fish and charophytes to rotenone. Unpubl. client report prepared for Department of Conservation. The University of Waikato, Hamilton, New Zealand. 18 p.

Ling N, Willis K 2005. Impacts of mosquitofish, *Gambusia affinis*, on black mudfish, *Neochanna diversus*. New Zealand Journal of Marine and Freshwater Research 39: 1215–1223.

Lloyd LN, Arthington AH, Milton DA 1986. The mosquitofish: a valuable mosquito control agent or a pest? In: Kitching RL ed, The ecology of exotic animals and plants: Some Australian case histories. John Wiley and Sons, Brisbane, Australia. Pp 7–25.

Lockley AS 1957. Adrenal cortical hormones and osmotic stress in three species of fishes. Copeia 1957: 241–242.

Lorenzoni M, Ghetti L, Pedicillo G, Carosi A 2010a. Analysis of the biological features of the goldfish *Carassius auratus auratus* in Lake Trasimeno (Umbria, Italy) with a view to drawing up plans for population control. Folia Zoologica 59: 142–156.

Lorenzoni M, Dolciami R, Ghetti L, Pedicillo G, Carosi A 2010b. Fishery biology of the goldfish *Carassius auratus* (Linnaeus, 1758) in Lake Trasimeno (Umbria, Italy). Knowledge and Management of Aquatic Ecosystems 396: 1–13.

Loughnan A, Williams R, Keeling S 2007. Fluorescent fish spark GM response. Biosecurity 78: 4–5.

Ludgate BG, Closs GP 2003. Responses of fish communities to sustained removals of perch (*Perca fluviatilis*). Science for conservation 210. Department of Conservation, Wellington, New Zealand. 38 p.

Matheson FE, Dugdale AM, Wells RDS, Taumoepeau A, Smith JP 2007. Efficacy of saltwater solutions to kill introduced freshwater species and sterilise freshwater fishing nets. DOC research and development series 261. Department of Conservation, Wellington, New Zealand. 24 p.

Matsuzaki SS, Usio N, Takamura N, Washitani I 2007. Effects of common carp on nutrient dynamics and littoral community composition: Roles of excretion and bioturbation. Fundamental and Applied Limnology 168: 27–38.

McDonald A, Lake MD 2006. Rotopiko Lakes fish surveys, February 2006. Waikato Conservancy Unpubl. internal report. Department of Conservation, Hamilton, New Zealand. 14 p.

McDowall RM 1990. New Zealand freshwater fishes. A natural history guide. Heinemann Reed, Auckland, New Zealand. 553 p.

McDowall RM 1996. Freshwater perches. In: McDowall RM ed, Freshwater fishes of south-eastern Australia. Reed Books, Chatswood, Sydney, Australia. Pp 52–77.

McDowall RM 2000. The Reed field guide to New Zealand freshwater fishes. Reed Books, Auckland, New Zealand. 224 p.

McKinnon LJ 1997. Monitoring of fish aspects of the flooding of Barmah Forest. Final report to the Murray-Darling Basin Commission. Project V1014. Marine and Freshwater Resources Institute, Australia. 184 p.

Meador MR 2005. Single-pass versus two-pass boat electrofishing for characterizing river fish assemblages: species richness estimates and sampling distance. Transactions of the American Fisheries Society 134: 59–67.

Migaud H, Fontaine P, Sulistyoa I, Kestemont P, Gardeur J 2002. Induction of out-of-season spawning in Eurasian perch *Perca fluviatilis*: Effects of rates of cooling and cooling durations on female gametogenesis and spawning. Aquaculture International 12: 87–102.

Miller SA, Crowl TA 2006. Effects of common carp (*Cyprinus carpio*) on macrophytes and invertebrate communities in a shallow lake. Freshwater Biology 51: 85–94.

Mills CA 1991. Reproduction and life history: Chapter 17 in: Winfield I, Nelson J eds, Cyprinid fishes. Fish and Fisheries Series Volume 3. Springer, Netherlands. Pp 483–508.

Minamoto T, Yamanaka H, Takahara T, Honjo M, Kawabata Z 2012. Surveillance of fish species composition using environmental DNA. Limnology 13: 193–197.

Ministry of Agriculture and Forestry 2011. Import health standard for ornamental fish and marine invertebrates from all countries. Ministry of Agriculture and Forestry, Wellington, New Zealand. 72 p. www.mpi.govt.nz/importing/live-animals/aquatic-animals/requirements.

Mitchell CP 1986. Effects of introduced grass carp on populations of two species of small native fishes in a small lake. New Zealand Journal of Marine and Freshwater Research 20: 219–230.

Mitro MG, Zale AV 2000. Predicting fish abundance using single pass removal sampling. Canadian Journal of Fisheries and Aquatic Sciences 57: 951–961.

Moore A 1988. Golden orfe in New Zealand, an illegal introduction. Unpubl. internal report. Department of Conservation, Wellington, New Zealand. 13 p.

Morgan DK, Hicks BJ 2013. A metabolic theory of ecology applied to temperature and mass dependence of N and P excretion by common carp. Hydrobiologia 705: 135–145.

Morgan DK, Kumar H, Ling N, Hicks BJ 2013. The palatability of flavoured novel floating pellets made with brewer's spent grain to captive carp. New Zealand Journal of Zoology 40: 170–174.

Morgan DK, Verbeek CJR, Rosentrater KA, Hicks BJ 2014. Toxicity effects of oral gavage of aqueous solutions of cube-root powder and sodium nitrite in common carp. Wildlife Research 40: 647–653.

Morgan DL, Beatty SJ 2007. Feral goldfish (*Carassius auratus*) in Western Australia: a case study from Vasse River. Journal of the Royal Society of Western Australia 90: 151–156.

Morgan DL, Hambleton SJ, Gill HS, Beatty SJ 2002. Distribution, biology and likely impacts of the introduced redfin perch (*Perca fluviatilis*) in Western Australia. Marine and Freshwater Research 53: 1211–1221.

Mulholland M 2010. Lake Serpentine fish barrier investigation. Environment Waikato technical report 2010. Environment Waikato, Hamilton, New Zealand. 19 p.

Mutenia A 1978. Säyneen biologiasta Lokan tekojärvessä. On the biology of the ide *Leuciscus idus* L. in Lokka reservoir, Finnish Lapland. Luonnon Tutkija 82: 135–137.

Myers JH, Simberloff D, Kuris AM, Carey JR 2000. Eradication revisited: dealing with exotic species. Trends in Ecology and Evolution 15: 316–320.

Nagdali SS, Gupta PK 2002. Impact of mass mortality of a mosquito fish, *Gambusia affinis* on the ecology of a fresh water eutrophic lake (Lake Naini Tal, India). Hydrobiologia 468: 45–52.

Neill WH, Magnuson JJ 1974. Distributional ecology and behavioral thermoregulation of fishes in relation to heated effluent from a power plant at Lake Monona, Wisconsin. Transactions of the American Fisheries Society 103: 663–710.

Neilson K, Kelleher R, Barnes G, Speirs D, Kelly J 2004. Use of fine-meshed monofilament gill nets for the removal of rudd from a small lake complex in Waikato, New Zealand. New Zealand Journal of Marine and Freshwater Research 38: 525–539.

Neitzel DA, Abernaethy CS, Lusty EW 1991. Evaluation of rotating drum screen facilities in the Yakima River basin, south-central Washington State. American Fisheries Society Symposium 10: 325–334.

Otis DL, Burnham KP, White GC, Anderson DR 1978. Statistical inference from capture data on closed animal populations. Wildlife Monographs 62: 1–135.

Otto RG 1974. The effects of acclimation to cyclic thermal regimes on heat tolerance of the western mosquitofish. Transactions of the American Fisheries Society 103: 331–335.

Patchell GJ 1977. Studies on the biology of the catfish *Ictalurus nebulosus* Le Sueur in the Waikato region. Unpubl. MSc thesis, The University of Waikato, Hamilton, New Zealand. 144 p.

Patil JG, Wisniewski CD 2006 (revised 2011). Hypophysation: a technique for deployment of odour donor fish for control of the common carp (*Cyprinus carpio*). Technical report 5, Inland Fisheries Service, Hobart. Tasmania, Australia. 8 p.

Patil JG, Purser GJ, Nicholson A 2014. Development and deployment of sterile 'Judas fish' to assist carp eradication in Lake Sorell, Tasmania—surgical and chemical sterilization. Final report, FRDC project 2012/039, May 2014. Fisheries Research and Development Corporation, Tasmania, Australia. 45 p.

Pen LJ, Potter IC 1992. Seasonal and size-related changes in the diet of perch, *Perca fluviatilus* L. in the shallows of an Australian river, and their implications for the conservation of indigenous teleosts. Aquatic Conservation: Marine and Freshwater Ecosystems 2: 243–253.

Peňáz M, Wohlgemuth E, Hamackova J, Kouril J 1981. Early ontogeny of the tench, *Tinca tinca* 1. Embryonic period. Folla Zoologica Brno 30: 165–176.

Perez Regadera JJ, Gallardo JM, Ceballos EG, Garcia JCE 1994. Model development for the determination of final preferenda in freshwater species application in tench (*Tinca tinca* L.). Polish Archives of Hydrobiology 42: 27–34.

Persson A 1997. Phosphorus release by fish in relation to external and internal load in a eutrophic lake. Limnology and Oceanography 42: 577–583.

Peters M 2008. Guidelines for landowners in peat lake catchments. New Zealand Landcare Trust Hamilton, New Zealand. 21 p.

Pham L, West D, Closs GP 2013. Reintroduction of a native galaxiid (*Galaxias fasciatus*) following piscicide treatment in two streams: response and recovery of the fish population. Ecology of Freshwater Fish 22: 361–373.

Pingram MA 2005. Ecology of freshwater fish in the littoral zone of Lake Waikere, Kai Iwi Lakes, Northland, New Zealand: for the conservation of the dune lakes galaxias (*Galaxias* sp.). Unpubl. MSc thesis, University of Otago, Dunedin, New Zealand. 100 p.

Pitt T, Garside ET, Hepbum RL 1956. Temperature selection of the carp (*Cyprinus carpio* Linn.). Canadian Journal of Zoology 34: 555–557.

Prejs A 1984. Herbivory by temperate freshwater fishes and its consequences. Environmental Biology of Fishes 10: 281–296.

Preisendorfer RW 1986. Secchi disk science: Visual optics of natural waters. Limnology and Oceanography 31: 909–926.

Pyke GH 2005. A review of the biology of *Gambusia affinis* and *G. holbrooki*. Reviews in Fish Biology and Fisheries 15: 339–365.

Quinn JM, Cooper AB, Colley RJD, Rutherford JC, Williamson RB 1997. Land use effects on habitat, water quality, periphyton, and benthic invertebrates in Waikato, New Zealand, hill-country streams. New Zealand Journal of Marine and Freshwater Research 31: 579–597.

Rahel FJ, Olden JD 2008. Assessing the effects of climate change on aquatic invasive species. Conservation Biology 22: 521–533.

Ratnasingham NS, Hebert PDN 2007. The barcode of life data system (www.barcodinglife.co.org). Molecular Ecology Notes 7: 355–364.

Ravera O, Jamet JL 1991. The diet of the rudd (*Scardinius erythrophthalmus*, L.) in relation to the possible consequences for the removal of this species from an eutrophic lake. Archiv für Hydrobiologie 123: 99–109.

Rees HC, Maddison BC, Middleditch DJ, Patmore JRM, Gough KC 2014. The detection of aquatic animal species using environmental DNA—a review of eDNA as a survey tool in ecology. Journal of Applied Ecology 51: 1450–1459.

Reynolds JB, Holliman FM 2004. Injury of American eels captured by electrofishing and trap netting. North American Journal of Fisheries Management 24: 686–689.

Reynolds WW, Casterlin ME 1977. Temperature preferences of four fish species in an electronic thermoregulatory shuttlebox. The Progressive Fish Culturist 39: 123–125.

Reynolds WW, Casterlin ME, Matthey JK, Millington ST, Ostrowski AC 1978. Diel patterns of preferred temperature and locomotor activity in the goldfish, *Carassius auratus*. Comparative Biochemistry and Physiology 59A: 225–227.

Ricker WE 1975. Computation and interpretation of biological statistics of fish populations. Bulletin 191. Fisheries Research Board of Canada, Ottawa, Canada. 382 p.

Robbins LW, Hartman GD, Smith MH 1987. Dispersal, reproductive strategies and the maintenance of genetic variability in mosquitofish (*Gambusia affinis*) Copeia 1987: 156–164.

Romare P, Bergman E, Hansson L-A 1999. The impact of larval and juvenile fish on zooplankton and algal dynamics. Limnology and Oceanography 44: 1655–1666.

Rowe DK 1984. Some effects of eutrophication and the removal of aquatic plants by grass carp (*Ctenopharyngodon idella*) on rainbow trout (*Salmo gairdnerii*) in Lake Parkinson, New Zealand. New Zealand Journal of Marine and Freshwater Research 18: 115–127.

Rowe DK 1998. Management trials to restore dwarf inanga show mosquitofish threat to native fish. Water and Atmosphere 6: 10–12.

Rowe DK 2004. Potential effects of tench (*Tinca tinca*) in New Zealand freshwater ecosystems. NIWA client report HAM2004-005. National Institute of Water and Atmospheric Research, Hamilton, New Zealand. 28 p.

Rowe DK 2007. Exotic fish introductions and the decline of water clarity in small North Island, New Zealand lakes: a multi-species problem. Hydrobiologia 583: 345–358.

Rowe DK 2014. Biosecurity status of non-native freshwater fish species in Northland. NIWA client report HAM2014-008, prepared for Northland Regional Council. National Institute of Water and Atmospheric Research, Hamilton, New Zealand. 26 p.

Rowe DK, Champion PD 1994. Biomanipulation of plants and fish to restore Lake Parkinson: A case study and its implications. In: Collier KJ ed, Restoration of aquatic habitats. Selected papers from the second day of the New Zealand Limnological Society 1993 annual conference. Department of Conservation, Wellington, New Zealand. Pp 53–65.

Rowe DK, Graynoth E 2000. Fish populations in New Zealand lakes. NIWA client report MfE00223, prepared for Ministry for the Environment. National Institute of Water and Atmospheric Research, Hamilton, New Zealand.

Rowe DK, Smith JP 2001. The role of exotic fish in the loss of macrophytes and increased turbidity of Lake Wainamu, Auckland. Auckland Regional Council technical report 2008/003. National Institute of Water and Atmospheric Research, Hamilton, New Zealand. 21 p.

Rowe DK, Wilding T 2012. Risk assessment model for the introduction of non-native freshwater fish into New Zealand. Journal of Applied Ichthyology 28: 582–589.

Rowe DK, Moore A, Giorgetti A, Maclean C, Grace P, Wadhwa S, Cooke J 2008. Review of the impacts of gambusia, redfin perch, tench, roach, yellowfin goby and streaked goby in Australia. NIWA client report, prepared for the Australian Government Department of the Environment, Water, Heritage and the Arts. National Institute of Water and Atmospheric Research, Australia. 241 p.

Roy AW, Johansen PH 1970. The temperature selection of small hypophysectomized goldfish (*Carassius auratus* L.). Canadian Journal of Zoology 48: 323–326.

Saat T, Veersalu A 1996. Rate of early development of perch *Perca fluviatilis* L. and ruff *Gynocephalus cernuus* (L.) at different temperatures. Annales Zoologici Fennici 33: 693–698.

Sabetian A, Trip EDL, Wheeler P, Wakefield S, Visconti V, Banda F 2015. Biological plasticity of non-native European perch (*Perca fluviatilis*) populations and the implications for management in northern New Zealand. New Zealand Journal of Marine and Freshwater Research 49: 119–131.

Schaus MH, Vanni MJ, Wissing TE, Bremigan MT, Garvey JE, Stein RA 1997. Nitrogen and phosphorus excretion by detritivorous gizzard shad in a reservoir ecosystem. Limnology and Oceanography 42: 1386–1397.

Scheffer M, Carpenter SR 2003. Catastrophic regime shifts in ecosystems: linking theory to observation. Trends in Ecology and Evolution 18: 648–656.

Scheffer M 1998. Ecology of shallow lakes. Chapman and Hall, London, United Kingdom. 358 p.

Schwartz FJ 1964. Natural salinity tolerances of some freshwater fishes. Underwater Naturalist 2: 13–15.

Scott WB, Crossman EJ 1973. Freshwater fishes of Canada. Bulletin 184. Fisheries Research Board of Canada, Ottawa, Canada. 966 p.

Shaw T, Studholme B 2001. Koi carp and gambusia. Survey for eradication of gambusia (*Gambusia affinis*) koi carp (*Cyprinis* (sic) *carpio*) populations in the Nelson region 2000–2001. Occasional publication 32. Department of Conservation, Wellington, New Zealand. 61 p.

Shields JT 1957. Experimental control of carp reproduction through water drawdowns in Fort Randall reservoir, South Dakota. Transactions of the American Fisheries Society 87: 23–33.

Sinnott TJ, Ringler NH 1987. Population biology of the brown bullhead (*Ictalurus nebulosus* LeSueur). Journal of Freshwater Ecology 4: 225–234.

Smirnov AK, Smirnova ES 2013. Dependence of young perch (*Perca fluviatilis* L.) preferred temperature from presence of covers in the experimental environment. Fundamental Research 10: 2882–2886.

Smith B 2005. The state of the art: a synopsis of information on common carp (*Cyprinus carpio*) in Australia. Final technical report, SARDI Aquatic Sciences publication RDO4/0064-2, SARDI aquatic sciences research report 77. South Australian Research and Development Institute (Aquatic Sciences), Adelaide, Australia. 68 p.

Smith BB, Thwaites L, Fleer D 2009. Guidelines for the selection and implementation of carp management options at wetland inlets: a test case for South Australia. Final report for project 4.F.12. SARDI Aquatic Sciences for the Invasive Animals Cooperative Research Centre, Canberra, Australia. 29 p.

Smith KF, Lester PJ 2007. Trophic interactions promote dominance by cyanobacteria (*Anabaena* spp.) in the pelagic zone of Lower Karori Reservoir, Wellington, New Zealand. New Zealand Journal of Marine and Freshwater Research 41: 143–155.

Snickars M, Sunbalod G, Sandström A, Ljunggren L, Bergström U, Johansson G, Mattile J 2010. Habitat selectivity of substrate-spawning fish: modelling requirements of the Eurasian perch *Perca fluviatilis*. Marine Ecology Progress Series 398: 235–243.

Strand A, Magnhagen C, Alanärä A 2011. Growth and energy expenditures of Eurasian perch *Perca fluviatilis* (Linnaeus) in different temperatures and of different body sizes. Journal of Aquaculture Research and Development 2: 114.

Strayer DL 2010. Alien species in freshwaters: ecological effects, interactions with other stressors, and prospects for the future. Freshwater Biology 55: 152–174.

Strickland RR 1980. Fisheries aspects of the Whangamarino Swamp. Fisheries Research Division, Fisheries environmental report 7. New Zealand Ministry of Agriculture and Fisheries, Turangi, New Zealand. 37 p.

Stuart IG, Williams A, McKenzie J Holt T 2003. Separation cages for removal of carp from Murray-Darling Basin fishways. Final report of project R2104 to the Murray-Darling Basin Commission. Arthur Rylah Institute for Environmental Research, Department of Sustainability and Environment, Heidelberg, Victoria, Australia. 20 p.

Stuart IG, Williams A, McKenzie J, Holt T 2006. Managing a migratory pest species: a selective trap for common carp. North American Journal of Fisheries Management 26: 888–893.

Studholme B 2002. Koi carp and gambusia: The South Island pest fish survey 2001–2002. Occasional publication 56. Department of Conservation, Wellington, New Zealand. 37 p.

Studholme B 2003. Koi carp and gambusia: The South Island pest fish survey 2002–2003. Occasional publication 58. Department of Conservation, Wellington, New Zealand. 27 p.

Szczerbowski JA 2001. *Carassius auratus* (Linneaus, 1758). In: Bănărescu PM, Paepke H-J eds, The freshwater fishes of Europe. Volume 5/III; Cyprinidae 2/III and Gasterosteidae. Wiebelsheim, AULA-Verlag GmbH. Pp 5–41.

Tanner CC, Wells RDS, Mitchell CP 1990. Re-establishment of native macrophytes in Lake Parkinson following weed control by grass carp. New Zealand Journal of Marine and Freshwater Research 24: 181–186.

Taylor AH, Tracey SR, Hartmann K, Patil JG 2012. Exploiting seasonal habitat use of the common carp, *Cyprinus carpio* in a lacustrine system for management and eradication. Marine and Freshwater Research 63: 587–597.

Tempero GW, Ling N,Hicks BJ, Osborne MW 2006. Age composition, growth, and reproduction of koi carp (*Cyprinus carpio* L.) in the lower Waikato, New Zealand. New Zealand Journal of Marine and Freshwater Research 40: 571–583.

The New Zealand Biodiversity Strategy 2000. Department of Conservation and Ministry for the Environment, Wellington, New Zealand. 146 p.

The Vision and Strategy for the Waikato River 2008. Waikato River Authority, Hamilton, New Zealand. 9 p.

Thompson ME, Lortie JP, Karwacky K, Topsham ME, Svirsky S 2002. Estimating fish biomass in the Housatonic River, Massachusetts. Society of Environmental Toxicology and Chemistry, 23rd Annual Meeting, 16–20 November 2002, Salt Lake City, Utah, USA.

Thomsen PF, Kielgast J, Iversen LL, Møller PR, Rasmussen M, Willerslev E 2012. Detection of a diverse marine fish fauna using environmental DNA from seawater samples. PLoS ONE 7(8): e41732.

Thwaites L, Fleer D, Smith B 2007. Conceptual development of a 'finger' style pushing trap for the common carp, *Cyprinus carpio*. SARDI aquatic sciences publication F2007/000790-1. SARDI research report series 238. South Australian Research and Development Institute (Aquatic Sciences), Adelaide, Australia. 33 p.

Thwaites LA, Smith BB, Decelis M, Fleer D, Conallin A 2010. A novel push trap element to manage carp (*Cyprinus carpio* L.): A laboratory trial. Marine and Freshwater Research 61: 42–48.

Tyler JE 1968. The Secchi disc. Limnology and Oceanography 13: 1–6.

Vander Zanden J, Olden J 2008. A management framework for preventing the secondary spread of aquatic invasive species. Canadian Journal of Fisheries and Aquatic Sciences 65: 1512–1522.

Vanni MJ 2002. Nutrient cycling by animals in freshwater ecosystems. Annual Review of Ecology and Systematics 33: 341–370.

Verburg P, Hamill K, Unwin M and Abell J 2010. Lake water quality in New Zealand 2010: Status and trends. NIWA client report HAM2010-107, prepared for Ministry of the Environment. National Institute of Water and Atmospheric Research, Hamilton, New Zealand. 48 p.

Verrill DD, Berry CR Jr 1995. Effectiveness of an electrical barrier and lake drawdown for reducing common carp and bigmouth buffalo abundances. North American Journal of Fisheries Management 15: 137–141.

Vibert R 1963. Neurophysiology of electric fishing. Transactions of the American Fisheries Society 92: 265–275.

Vilizzi L, Thwaite LA, Smith BB, Nicol JM, Madden CP 2014. Ecological effects of common carp (*Cyprinus carpio*) in a semi-arid floodplain wetland. Marine and Freshwater Research 65: 802–817.

Villéger S, Grenouillet G, Suc V, Brosse S 2012. Intra- and interspecific differences in nutrient recycling by European freshwater fish. Freshwater Biology 57: 2330–2341.

Wakelin R 1986. The biology of *Gambusia affinis* (Baird & Girard) in Lake Waahi, Huntly. Unpubl. MSc thesis. The University of Waikato, Hamilton, New Zealand. 93 p.

Weatherley AH 1959. Some features of the biology of the tench *Tinca tinca* (Linnaeus) in Tasmania. Journal of Animal Ecology 28: 73–87.

Weber MJ, Brown ML 2009. Effects of common carp on aquatic ecosystems 80 years after “Carp as a dominant”: ecological insights for fisheries management. Reviews in Fisheries Science 17: 524–537.

Wells R 1999. Are rudd a threat to water plants? NIWA Water & Atmosphere 7: 11–13.

West DW, Ling N, Hicks BJ, Tremblay LA, Kim ND, van den Heuvel MR 2006. Cumulative impacts assessment along a large river, using brown bullhead catfish (*Ameiurus nebulosus*) populations. Environmental Toxicology and Chemistry 25: 1868–1880.

Wheeler A 1969. The fishes of the British Isles and North-West Europe. Macmillan, London, United Kingdom. 613 p.

White GC, Anderson DR, Burnham KP, Otis DL 1982. Capture-recapture methods for sampling closed populations. LA-8787-NERP. Los Alamos National Laboratory, Los Alamos, New Mexico, USA. 235 p.

Williams AE, Moss B, Eaton J 2002. Fish induced macrophyte loss in shallow lakes: top-down and bottom-up processes in mesocosm experiments. Freshwater Biology 47: 2216–2232.

Winkler P 1979. Thermal preference of *Gambusia affinis affinis* as determined under field and laboratory conditions. Copeia 1979: 60–64.

Winters B 2012. That Pommie bastard: a roaring true tangle with New Zealand environmental politics. Oceanbooks, Mount Maunganui, New Zealand. 209 p.

Wise G 1990. The biology of three exotic freshwater fish species in Hamilton Lake. Unpubl. MSc thesis. The University of Waikato, Hamilton, New Zealand. 104 p.

Wittenberg R, Cock MJW eds 2001. Invasive alien species: a toolkit of best prevention and management practices. CAB International, Wallingford, United Kingdom. 228 p.

Wood SA, Smith KF, Banks JC, Tremblay LA, Rhodes L, Mountfort D, Cary SC, Pochon X 2013. Molecular tools for environmental monitoring of New Zealand’s aquatic habitats: past, present and the future. New Zealand Journal of Marine and Freshwater Research 47: 90–119.

Wu N, Daniel A, Tempero G 2013. Fish biomass and gonad development in the Rotopiko (Serpentine) lakes. Environmental Research Institute report 20. The University of Waikato, Hamilton, New Zealand. 27 p.

Zielinskia DP, Vollera VR, Svendsenb JC, Hondzoa M, Mensingerc AF, Sorensen P 2014. Laboratory experiments demonstrate that bubble curtains can effectively inhibit movement of common carp. Ecological Engineering 67: 95–103.

Appendices

APPENDIX 1:
Koi Containment Area Boundary Notice 1990

This notice may be cited as the Koi Containment Area Boundary Notice 1990.

Pursuant to regulation 67 (c) (a) of the Freshwater Fisheries Regulations 1983 (as inserted by the Freshwater Fisheries Regulations 1983, Amendment No. 9), the Director-General of Conservation hereby establishes and describes for the purposes of Part VIIIA of the Freshwater Fisheries Regulations, the following containment area (in clockwise order):

From the State Highway (SH) 3 road bridge at Otorohanga in a straight line to the Te Uku road junction, north-east along SH 23 to the junction with SH 22 and north along SH 22 to its junction with Logan Road just south of Pukekawa. The boundary then follows a generally westerly direction along Logan Road, Kauri Road, Wairamarama-Onewhero Road, Klondyke Road, Daff Road and the road to Port Waikato. From Port Waikato, it then follows the south river bank to the mouth of the Waikato River, crosses the river and goes north up the coast to Muriwai Beach and Grid Reference Q10275040. It then goes directly east to the junction of South Head and Springs Roads in Parakai. From Parakai along the main road to Helensville, then north-east along SH 16 and Kaihikatea Flat Road through Waitoki to the junction with SH1 just north of Dairy Flat. It then follows SH 1 north-west to the Weiti River at Silverdale. The boundary continues along the south bank of the Weiti River to Karepiro Bay and then south down the coast to the Auckland Harbour Bridge. It then follows SH 1 south to its junction with SH 2, east along SH 2 to the Kopuku Road junction and southwards along Kopuku Road and Okaeria Road and Stannard Road to Waerenga. It proceeds along Waerenga Road to Waikare Road and then in a generally south-easterly direction along Waikare Road and Waiterimu Road to the Tahuna Road junction. It follows Tahuna Road south-east to the Te Hoe Road junction, and then generally south along Proctor Road to Orini Road and south along Orini Road to the Whitikahu Road junction. It proceeds south-west along Whitikahu Road to the Gordonton Road junction and then south along Gordonton Road to Hamilton. At Hamilton, Gordonton Road joins onto Tramway Road. From Tramway Road, the boundary then turns west into East Street and then south along Peachgrove Road to the SH 1 intersection. It then follows SH 1 in a southerly direction to Hydro Road and the Karapiro Dam. From Karapiro Dam the boundary runs in a straight line to the Allen Road junction with SH 3 just south of Kihikihi, then along SH 3 to the Otorohanga Road Bridge.

The description set out above is shown on a series of New Zealand Map Series 260 topographical maps held by the Department of Conservation, Wellington.

Dated at Wellington this 9th day of October 1990.

Bill Mansfield
DIRECTOR-GENERAL OF CONSERVATION

APPENDIX 2:

Invasive Fish Inventory and Monitoring: BEST PRACTICE GUIDANCE

Contents

SUGGESTED CITATION FOR APPENDIX 2: Grainger NPJ, West D, McCaughan H 2014. Invasive fish inventory and monitoring: best practice guidance. Version 2.0. Department of Conservation, Wellington, New Zealand. Appendix 2 in Collier KJ & Grainger NPJ eds, 2015. New Zealand Invasive Fish Management Handbook. Lake Ecosystem Restoration New Zealand (LERNZ; The University of Waikato) and Department of Conservation, Hamilton, New Zealand. 17p.

1.0 Purpose

The purpose of this document is to provide information and suggestions to help DOC staff maximise their chances of detecting invasive fish when they undertake surveillance work and/or post control/ eradication monitoring.

2.0 Introduction

This document gives a brief explanation of why the Department does invasive fish work, with a list of the pest species. It focuses on the best methods to catch/detect introduced invasive fish, based on experience from the invasive fish survey and monitoring programmes. This document does not give guidance on selection or prioritisation of sites, but the key points are highlighted in Section 3.1.

2.1 The Department's role in invasive fish work

The key reason the Department manages invasive freshwater fish populations is because they pose a threat to our native species and ecosystems. Section 6(ab) of the Conservation Act 1987 states that our role in freshwater conservation is "to preserve so far as is practicable all indigenous freshwater fisheries, and protect recreational freshwater fisheries and freshwater fish habitats". Part 8 and schedule 3 of the Freshwater Fisheries Regulations 1983 set out roles in relation to noxious species and koi carp.

Most of the Department's work is on pest fish species that are listed in Section 2.2, but work is sometimes carried out on fish that are not listed as pests, for example if they are released into a site illegally or if their impacts on an endangered species at a site outweigh their value at that site. These could be sports fish or native fish. Note that this document focuses on controlling exotic invasive fish, it does not cover the control of native invasive fish (where a native fish has established in a site it would not have naturally occurred).

There are three main steps involved in invasive fish work and these are covered in later sections:

- Be clear about why you are doing this work (Section 3)
- Get information about the site (Section 4)
- Decide which methods will be best and how to use them (Section 5).

2.2 Pest fish species

There are four pest fish species that the Department prioritises work on. These are:

- Koi carp (*Cyprinus carpio*); Unwanted Organism[*], Noxious Fish[†]
- Rudd (*Scardinius erythrophthalmus*); Noxious Fish[‡]
- Gambusia (*Gambusia affinis*); Unwanted Organism[1]
- Catfish (*Ameiurus nebulosus*)[§]

* Biosecurity Act 1993

† Freshwater Fisheries Regulations 1983

‡ The Noxious fish designation for rudd only applies outside the Auckland/Waikato Fish & Game region, rudd are sports fish within that region

§ Although not a pest species, it is illegal to have live catfish in your possession (Fisheries Regulations (Amateur Fishing) 2013) and illegal to sell live catfish (Fisheries Regulations (Commercial Fishing) 2001)

3.0 STEP 1: Why are you doing this work?

There are three main reasons to undertake inventory and monitoring of invasive fish populations:

1. Surveillance/inventory;
2. Incursion response;
3. Post-control/eradication monitoring.

Although the basic methods for each of these are the same, the intensity and frequency of effort will vary so it is important to be clear about your objectives. Before you embark on inventory and monitoring of invasive fish it is useful to note down some goals and make a brief plan. It does not have to be a long document, but should include notes on:

1. Why you are going to do the work (surveillance, incursion response, post-control monitoring);
2. How you are going to do it (appropriate methods);
3. How you are going to tell if it's working (monitoring);
4. When you will reassess (is it worth continuing?);
5. What other parties are going to be involved (e.g. council, iwi, Fish & Game);
6. How/where you are going to record and store data.

Note that an important part of any pest management programme is increasing public awareness. This is particularly relevant for invasive fish and their impacts, because they are mainly spread by humans and are often not widely distributed. The existence and impacts of invasive fish on our native species and ecosystems are not that well publicly understood. Raising public awareness also helps us find pest populations by people reporting them.

3.1 Surveillance: first survey/inventory

Every region of New Zealand has some waterways/bodies that could sustain the key invasive fish species (koi carp, rudd, gambusia and catfish). These can all have major impacts on our native species and ecosystems, so it is important that we are out there looking for them — just the same as we do for other animal and plant pests.

When visiting a site for the first time you will want to use a range of different methods to increase your chance of detecting all of the species present. Section 5 has detail on the different methods, which species they are best for and the best time of year to target each species.

This document does not give detail on how to select surveillance sites, but the basic rules are to choose sites that have:

1. Suitable habitat for invasive fish;
2. High risk of incursion (e.g. public access, proximity to other known invasive populations);
3. Good biodiversity values at the site, nearby sites or in the catchment.

3.2 Incursion response: an invasive fish sighting or illegal release

Someone might phone in saying that they have seen what they think is an invasive fish species or someone on staff may have seen something. Make sure you get as much information as you can initially (where/when/what), before you go and check it out. It may not be clear exactly what species has been seen, so using a range of methods is often the most effective (see Section 5).

3.3 Monitoring: post-control, post-eradication

If you have been controlling an invasive fish at a site, or have carried out an eradication operation, you will want to see if it has worked. To do this you need to target your monitoring methods to the species and size classes that are likely to be at the site and Section 5.1 gives detail on methods to use for this. Section 6 has some criteria as to whether you can declare an eradication successful or not, but you are advised to seek advice from the National Freshwater Team or others in DOC that have been involved in this type of work. Note that even if an eradication was declared successful it is ideal to continue carrying out periodic monitoring to detect any new incursions.

You may also want to incorporate some native species monitoring (fish, plant and/or invertebrate) to see if the removal of the pest is having a positive influence on the species/ecosystem you are trying to protect. Refer to the 'Inventory and Monitoring Toolbox' for more information on this (some methods are more developed than others).

3.4 Data collection and storage

It is really important to keep good notes, including photos and GPS records. The main things you need to record are: where you went, when you went there, what you did and what you caught. The datasheets suggested below are shown in Appendices 1–4.

Job sheet: this sheet's main role is to hold the site name and landowner details, and to record things such as when contact was made, what was discussed (brief notes), when the site was visited and suggested follow-up work. It is useful to have this paper a different colour than white, e.g. pale green.

1. Site description form — this records where the site is and has room for a sketch. Make sure you include information such as site access and features that can help you locate and orientate to the site in future (e.g. roads, pylon lines, compass directions (north pointer), nearby waterways). Also mark on the map where in the waterbody effort was focussed (e.g. where nets were set).
2. NZ Freshwater Fish Database form — this has more detail on the habitat at the site, the methods that were used and what was caught. These data can then be entered into the New Zealand Freshwater Fish Database which is used by many groups (inside and outside DOC), when assessing waterways/bodies. Note that this database is administered by NIWA and the forms may change.
3. Plant surveillance form — this form lists various surveillance weeds and native plants. It is really useful to look for these things whilst you are at a site, this helps build a good picture and saves time. It can be useful to have this sheet a different colour than white, e.g. pale yellow. Note that the forms provided here were customised for Canterbury and the West Coast, so you will need to check these for species relevance to your particular region.

Now you've collected it all, don't lose it! Make sure you have somewhere safe to keep your datasheets–you may want to scan them into the computer. It is a good idea to make a simple spreadsheet to record where and when you went, with some brief notes on what was done and what was found.

4.0 STEP 2: Assess the site

Before you visit a site it is a good idea to have some initial discussions with the landowner and/or other staff to collect as much information about this site as you can–this can help you to decide what methods to use and what gear you will need. This information can be recorded on the Job Sheet mentioned in Section 3.4. Try and find out things like: access routes into the site, size/depth of the waterbody, presence of diving birds and weed beds, historical observations such as droughts/floods, and level of public access (include things like duck hunting, boating and fishing).

Sources such as aerial photographs, topographical maps and DOC GIS can also give you more information. Don't forget to find out if you need to contact other parties before you go, such as neighbours, local/regional council, iwi and/or Fish & Game.

5.0 STEP 3: Methods — choosing and using

5.1 General guidance

Your approach will depend on the site and the species you are targeting. All freshwater fish sampling methods have different biases towards the species and size of fish they will most efficiently catch, so a variety of methods are discussed here and you would commonly use more than one at a site. You will maximise the likelihood of catching/detecting fish if the water temperature is above 15°C, when the target fish species tend to be more active.

Most of the methods in this document work best in still or slow-flowing water, and these are the places that pest fish tend to prefer. Large rivers and deep water can be difficult to survey properly. Some general notes on fish monitoring and deciding which method to use are in the 'Introduction to monitoring freshwater fish' document that is part of the 'Inventory and Monitoring Toolbox'.

There are three main ways you can survey for invasive fish and Table 1 gives you suggestions on which methods are best for which species and life stages (adults or juveniles):

- Visual observation (Section 5.2);
- Netting/trapping (Section 5.3);
- Electric fishing (Section 5.4).

The minimum sampling effort, listed below, was developed by a Technical Working Group (TWG) that was established in 2000, in response to the detection of koi carp and gambusia in the northern South Island. This general methodology was aimed at targeting a wide range of invasive species at a large number of sites. What you do will be site-dependent, but remember that the greater the sampling effort the greater the likelihood of fish detection (particularly where the fish may be in low numbers).

Minimum sampling effort for a 0.5 hectare waterbody; this effort must be scaled up for larger sites:

- Visual observation — 50 m length of shoreline or 25% of waterbody edge;
- Active netting — 1 each of dip net, seine net or push net;
- Set nets — 1 panel gill net and/or 1 trammel net;
- Set traps — 1–2 fyke nets and/or 3–5 Gee minnow traps.

0.5 hectare (70 m x 70 m) is approximately the size of one rugby field (70 m x 100 m — 1.0 hectare = 100 m x 100 m). More detail on these early discussions can be found in the early invasive fish survey reports and notes made at the TWG meetings (see Relevant material list in Section 9).

Note that there are various other techniques such as bow hunting, pod traps (developed by Adam Daniel whilst at The University of Waikato), spotlighting etc., which may suit a unique combination of sites and species. These methods have not been validated for this work and so are not discussed in this document.

Information on where to source some of the more specialised equipment needed for the methods mentioned in the following sections is in the Freshwater Equipment Suppliers document. You may be able to borrow some items from others, so emailing the DOC Freshwater Group can be helpful too.

Note that perch and tench are sports fish, so work would only be carried out on them in consultation with Fish & Game. Goldfish have no legal designation, but are often illegally released into waterways.

TABLE 1:
List of invasive fish with suggested sampling methods, and when and where to survey.

Species	Main hang out	Sampling methods (section in this document)	When to survey	Where to survey
Gambusia	Fish clusters occupying very shallow, calm waters around edges of lakes, ponds, drains	**All ages:** Gee minnow trap; fyke net (fine mesh); seine net; visual observation; dip net; bottle traps	**Best:** Summer months (Dec-Mar) Okay in northern areas: Sep-May	Shallow shelving shorelines (<1 m deep), with aquatic vegetation present Sheltered shorelines
Rudd & Perch	Schooling fish found in surface waters around stream edges and near edges of lakes and ponds	**Adults:** Gill net; trammel net; visual observation; electric fishing **Juveniles:** Seine net; Gee minnow trap; dip net; visual observation	**Best:** Summer months (Dec-Mar) Okay in northern areas: Sep-May	Lake edge, beyond and over aquatic vegetation
Koi carp & Goldfish	Often solitary fish found throughout water column, around vegetated lake edges and near edges	**Adults:** Trammel net; gill net; fyke net; visual observation; electric fishing **Juveniles:** Seine net; Gee minnow trap; visual observation; dip net	**Best:** Summer months (Dec-Mar) Okay in northern areas: Sep-May	Near shoreline, at outer edge of tall aquatic vegetation and out into waterbody a short way
Catfish & Tench	Often solitary fish found near the lake bottom around vegetated lake edges and near edges	**Adults:** Trammel net; fyke net; gill net; electric fishing **Juveniles:** Gee minnow trap; dip net	**Best:** Spring/Summer months (Oct-Mar) Okay in northern areas: Sep-May	Near shoreline, at outer edge of tall aquatic vegetation and out into waterbody a short way

5.2 Visual observation

Visually observing a waterbody is best done on a warm calm day, wearing polarising sunglasses. If it is raining or windy visibility into the water will not be very good.

Walk around the edge of the site, creating as little disturbance as possible. This method is most effective when water temperatures are up around 20ºC, when the target fish species are more active. Focus on the surface of the water, especially in shallow margins around patches of aquatic plants. It is useful to take a dip net with you, so if you see a fish nearby you can catch it to confirm identification.

Inspect at least 50 metres of the shoreline in total, or at least 25% of the waterbody edge.

5.3 Netting/trapping

Most nets/traps are set into a waterbody, left for a period of time and then removed. These set net techniques are called passive. Using a net that is pulled through the water, such as a dip net or a seine net, is considered an active technique. You may use one or both of these techniques at the same site. The 'Inventory and Monitoring Toolbox' also contains information on various freshwater methods.

It is best to target the parts of a waterbody/way where the fish are most likely to be–so it helps if you try and think like a fish. Ultimately, the more nets/traps you set the more likely you are to catch species that are present, but survey methods may need to be modified according to site limitations, for example presence of endangered species. Overnight sets are preferable, but day sets or dawn/dusk sets need to be considered when you have large numbers of eels and/or diving birds present. Refer to Section 7.2 and the 'Set nets and diving bird best practice' document for guidance on how to avoid catching birds.

Be aware of possible changes in the weather, particularly if you are working in an area where the waterways/bodies levels can change quickly in response to rain. For example, if you set some nets/traps and it rains heavily overnight you run the risk of some of them getting washed away and/or you being unable to get to the places where you set them. Also, if it has been raining heavily and the water levels are very high, they could drop overnight leaving your nets/traps stranded above the water, possibly causing unnecessary deaths of animals caught in them.

As a general rule, if you are setting nets and leaving them unattended you will need to make sure they are labelled, at least with the Department's name and a contact phone number. An example gear tag is shown in Figure 1.

FIGURE 1:
Example gear tag.

5.3.1 Netting

These are sometimes called hand or scoop nets. They are mesh nets on poles, similar to what whitebaiters use, though the mesh size may vary (recommended to be 1–2 mm) and the nets are much smaller (see Figure 2). The basic technique is it to walk around the edge of the site, creating as little disturbance as possible, using the net to dip in and catch fish as you see them (or you see disturbance that could be caused by fish). This method is usually only effective for smaller bodied or juvenile fish, but it can be useful for species like goldfish if they are in a very small waterbody or a contained area of a larger waterbody.

Target likely habitat areas in shallows and quiet pools (see Table 1) and inspect at least 50 metres of the shoreline in total, or at least 25% of the waterbody edge.

FIGURE 2:
Dip nets being used.

Gill nets

These are a long flat mesh panel that is made of fine nylon (monofilament), similar in appearance to the mist nets that are used to capture birds (see Figure 3). The idea is that the fish cannot see the mesh and as they swim they bump into it and get tangled. The mesh size will determine the size of fish that will get caught, so it is useful to use a range of mesh sizes–one net can have more than one mesh size in it (they are then called panel gill nets). Recommended mesh sizes are 25–50 mm (note that if the site has many inanga, bully or smelt, try to avoid using any smaller mesh as that makes it more likely to catch these natives and they tend to die when caught in gill nets).

Gill nets are usually set near the surface of the water and you may need to attach extra floats along their length to keep them up near the surface (this can be important at public sites so that the nets can be seen and avoided). It is preferred to stake one end securely to, or near, the bank with the other end either staked or held in place by a weight (with a float above it so you can see where the end is). If setting out into a larger waterbody you may find it better to use weights (and floats) at both ends of the net.

Good places to target are: across the entrance way to small bays, along the edge of weed/raupo beds, out from/perpendicular to promontories or large debris, around areas where fish are aggregating, anywhere that you think the fish will be travelling through/past. Because the invasive fish species tend to like warmer water it makes more sense to set nets in sunny areas rather than in the shade.

If you are setting gill nets in an area where there is noticeable water flow, set them on a shallow angle to the flow, so they will not collect a lot of debris and will be less likely to get washed away. Always ensure that the nets are firmly attached so they will not detach during the night and set at least one gill net per 0.5 hectare.

FIGURE 3:
Gill net containing rudd.

Trammel nets

These nets are similar to gill nets (see Figure 3), but in addition to the nylon mesh there is an outer coarse string mesh on both sides. These have a similar catching technique to gill nets, but the extra layer of coarse mesh means they can get very tangled. Recommended inner nylon mesh size 45 mm.

These nets can be set on the bottom of the waterbody, if you are targeting catfish or tench, or set near the surface if you are targeting koi carp or rudd. The basic setting technique is the same as for gill nets, but if you are setting them deep in the water make sure you have a weight and a floating buoy at each end. Set at least one trammel net per 0.5 hectare.

Seine nets

These nets are pulled through the water, similar to floundering or trawling (see Figure 4). A seine net is best in small ponds and wetlands, but is also useful around the shallow margins and little bays of larger ponds, wetlands and rivers. It is easiest in wadeable areas, but can be used in deeper water by using a small boat (for example kayak or dingy) to run out one end of the net. Recommended mesh size is <5 mm.

The method is to have one person on each end of the net. The net is spread out and then dragged, with the two ends moving roughly parallel and coming together to trap the fish within. It is ideal to keep the bottom (weighted) line coming in at the same time as the top (float) line. You may have to clear debris from the site prior to using the seine so it does not get snagged. It is best to do this one to two hours before you seine, or the day before.

If possible, drag the net across an entire pool and then beach it at the top of the pool. Or divide the waterbody up and seine it in sections. If using a seine net on its own, try and cover between one third and one half of the waterbody. Otherwise use this method to target the shallows and bays, and use other methods in the deeper more open areas of the same waterbody.

FIGURE 4:
Seine net being used.

5.3.2 Trapping

Use of bait

It is not generally advised to bait traps set for invasive fish. Baiting tends to attract a higher proportion of eels and these can fill the traps. They can also prey on other animals caught in the traps, causing unnecessary deaths (also if the eels eat other fish before you see them, you won't know they were caught). Both of these things can potentially bias your catch.

Fyke nets/traps

Although these are commonly called fyke nets, they are included in the trapping section because they function as a trap–fish swim in through an opening and are unable to get out. The general design of a fyke net (see Figure 5) is that it has a long straight 'leader' and then a basket containing inverted cones with a tie at the end (called the 'cod end'). Use 5 mm mesh where possible, but if you know there are many small fish at your site and you are not after these then use a larger mesh.

These nets are set on the bottom. Good places to target are: out from/perpendicular to promontories, large debris or weed beds, around areas where fish are aggregating. If setting them in still water, set them perpendicular to the shore with the leader end firmly attached to/near the bank. If the water is flowing, then set the nets on a shallow angle to the flow, with the cod end attached at/near the bank and the leader extending downstream, so they will not collect a lot of debris and will be less likely to get washed away (you may need to put an extra stake in by the mouth of the net, to stop it rolling over in the flow). Make sure you always anchor the two ends of the net well–a stake is best at the leader end, but you can use a stake or a weight (for example: brick, rock, dive weight) at the cod end. Set one to two nets per 0.5 hectare.

Note: Lindeman's fyke nets are not recommended as they are were found to not be effective at catching fish in New Zealand.

FIGURE 5:
Fyke net set in a waterway.

Gee minnow traps

FIGURE 6:
Gee minnow trap set in a waterway.

A Gee minnow trap is a small cage with an inverted cone at each end, so the fish can swim in but not get back out. They can be rigid steel (see Figure 6) or collapsible mesh and usually come in 3 mm or 6 mm mesh size. For invasive fish work the mesh size of the traps is not vital, but coarser mesh may be better in less pristine water.

Place Gee minnow traps parallel to the shore. Commonly near the bank, next to vegetation, debris, structures, blocking inlets, rather than in open water. Setting at a variety of depths will target a wider variety of fish.

Always attach these firmly to/near the bank so they will not detach during the night. If setting these in rivers, only set them in slow flowing and/or weedy areas. If you need to drop a method when surveying for invasive fish this should be the first method to drop. Set three to five traps per 0.5 hectare.

Bottle traps

As the name suggests, they are made from plastic bottles with an inverted end (see Figure 7), so a bit similar to a Gee minnow trap. They are set at the water's surface, tied to vegetation or a stake near the bank. Partly fill with water, so they float near the surface with 10–20 mm out of the water. You can leave them in the waterbody for 1–3 days, but they will need to be checked every day to remove any fish or other animals that have been caught.

Always attach the traps firmly to/near the bank so they will not detach during the night. If setting these in rivers, only set them in slow flowing and/or weedy areas. These may work well in cooler waters because the water inside the bottle will warm in the sun. This warming feature makes them more attractive to gambusia, particularly during cooler times of the year, but you must be careful that they will not get too hot during the warmer months.

FIGURE 7:
Bottle trap.

5.4 Electric fishing

Electric fishing is more suitable for adult fish and in limited habitats. The methods described in sections 5.2 and 5.3 are recommended as being more effective for detecting invasive fish. If you are going to undertake electric fishing work ensure you make yourself familiar with the requirements in the standard operating procedure documents: 'Electric fishing technical document (health and safety)' and 'Electric fishing' one page SOP .

5.4.1 Backpack electric fishing machines

This is the most common form of electric fishing used by the Department in small ponds, drains, streams and small rivers. It involves introducing a pulsed electric current from a machine to water through a hand held electrode that temporarily stuns the fish, enabling them to be scooped up in a net. This method is not effective in water that is deeper than one metre and is best in reasonably clear water that has some flow.

5.4.2 Electric fishing boat

Some DOC offices have contracted The University of Waikato electric fishing boat to survey for koi carp in larger ponds, lakes and rivers. People thinking about using the electric fishing boat should try and talk to someone who may have already done it (for example Tauranga Office or the National Freshwater Team) to see it if is an appropriate method for their situation.

6.0 Eradication success criteria

To carry out a monitoring survey that is valid for declaring an eradication successful you will need to invest greater effort over a longer period than you would for surveillance work or an incursion response. The methods to use are the same as those in Section 5 and should be targeted to the species eradicated, but if there is a chance that another species has been illegally introduced to the site you should employ a wider range of methods. If there are any fish present at an eradication site they are likely to be in very low numbers, so the greater the number and variety of methods used the more likely it is that fish will be caught/detected. You will also need to carry out repeat monitoring events for more than one season.

To ensure you have a valid monitoring survey you will need to sample at the best time of the year and use at least **double** the minimum number of nets/traps per 0.5 hectare (refer to Section 5.1), depending on the site. Dr David Rowe, Principal Scientist at NIWA, reviewed DOC's eradication criteria (in 2012) and recommended the minimum eradication standards in Table 2 as appropriate for determining the success of an eradication operation. If you cannot fulfil all of the criteria in the table each time you monitor, then you must invest more effort than that suggested in the table.

This advice is a guide only. Pest fish occur in many different sites, species and life stages so it is highly recommended that you **seek specialist advice** for your set of circumstances (for example from the National Freshwater Team). The main considerations are: the generation time of the species you have tried to eradicate, the risk of re-introductions and the chance of the eradication method failing.

TABLE 2:
Eradication monitoring standards for designating freshwater fish populations eradicated.

Species	Minimum eradication monitoring standard	Criteria (do all)
Gambusia	No capture/sighting of target species from at least three separate valid monitoring surveys over a three or more year period following treatment, with time between surveys of at least one month.	1. Survey at best time in season. 2. Use full range of applicable methods. 3. At least double number per 0.5 ha of nets/traps.
Rudd, koi carp, catfish, goldfish, perch, tench	No capture of target species from at least three separate valid monitoring surveys over a three year period following treatment.	

7.0 Other considerations

7.1 Biosecurity

There are many things that can inadvertently be transferred on gear–algae, weeds, freshwater insects, worms, snails, small fish and eggs (fish, frogs and insects). It is therefore very important that we are stringent with **cleaning/decontaminating all gear that comes into contact with water**. Refer to the 'Decontamination of freshwater gear best practice' document for details on how to clean nets and other gear.

7.2 Presence of diving birds

Fishing nets are generally designed to have low visibility in water, so diving birds may inadvertently get caught in them and drown. This is more likely to happen with fine filament nets, such as gill nets and trammel nets. On rare occasions a bird may dive into a fyke net, presumably because they see fish in there. Gee minnow traps are not considered to be at risk of catching birds. The general rule is to monitor set nets if birds are present, but the 'Set nets and diving birds best practice' document gives more detail on how to reduce the risk of catching diving birds in fishing gear.

8.0 Associated documents

Forms:

Job sheet, Site description, NZ Freshwater Fish Database, Plant surveillance:
Department of Conservation document–docDM-1479763

Best practice:

Decontamination of freshwater gear: best practice guidance:
Department of Conservation document–docDM-428359

Set nets and diving birds: best practice guidance:
Department of Conservation document–docDM-1470778

Standard operating procedures (SOP):

Electric fishing technical document (health and safety):
Department of Conservation document–docDM-752861

Electric fishing one page SOP:
Department of Conservation document–docDM-676678

Other:

Inventory and Monitoring Toolbox:
Department of Conservation document–Biodiversity toolbox on DOC website

Introduction to monitoring freshwater fish:
Department of Conservation document–docDM-1008026

Freshwater equipment suppliers:
Department of Conservation document–docDM-421033

9.0 Relevant material

Department of Conservation 2001. Managing Invasive freshwater fish in New Zealand. Proceedings of a workshop hosted by DOC, 10–12 May 2001. Department of Conservation, Wellington, New Zealand.

Freshwater Fisheries Training Manual olddm-763299

Joy M, David B, Lake M 2013. New Zealand Freshwater Fish Sampling Protocols: Part 1 - Wadeable Rivers and Streams. Massey University, Palmerston North, New Zealand. (docDM-1155639).

Key L, Studholme B, Brow A, Gibbs J 2003. Koi carp and gambusia. The North Island pest fish survey 2001–2002. Occasional Publication no. 57. Department of Conservation, Wellington, New Zealand.

Shaw T, Studholme B 2001. Koi carp and gambusia. Survey for and eradication of gambusia (*Gambusia affinis*) and koi carp (*Cyprinus carpio*) populations in the Nelson region 2000–2001. Occasional Publication no. 52. Department of Conservation, Wellington, New Zealand.

Studholme B 2002. The South Island pest fish survey 2001–2002. Occasional Publication no. 56. Department of Conservation, Wellington, New Zealand.

The following three documents are available at Department of Conservation document–docDM-757337

- Pest Fish Technical Working Group Collated Survey Advice.
- Pest Fish Technical Working Group Meeting Nelson 7th November 2000. Recommendations from the Pest Fish Advisory Group meeting 22/04/2002.
- Nelson/Marlborough Fish & Game Office. Notes on setting nets and traps, gleaned from Rhys Barrier, Gerry Closs and Dave West.

The photographs in this Appendix 2 document were all taken by DOC staff.

Appendix A: Job sheet

A printable version is available in: Department of Conservation document — docDM-1479763.
This is the green sheet.

Department of Conservation *Te Papa Atawhai*	**JOB SHEET**	**Site ID:**	
Name, address, phone:		**Map:**	
		Easting:	
		Northing:	
Date, time:			

Appendix B: Site Description form

A printable version is available in: Department of Conservation document — docDM-1479763.

Date:	Observer/s:	Site ID:

Landowner:

Map:
Easting:
Northing:

Description (waterbody type, size…)**:**

Sketch of site (include - inlets, outlest, fences/gates, O/H wires, vegetation, orientation, scale):

Attach: Job sheet, Pest fish survey form (FW d/base), Weed surveillance sheet, Photos, Cadastral map, etc.

Appendix C: NZ Freshwater Fish Database form

A printable version is available in: Department of Conservation document — docDM-1479763 but you must check it is up-to-date.

NZ FRESHWATER FISH DATABASE FORM
PLEASE RETURN TO: FRESHWATER FISH DATABASE, NIWA, PO BOX 11-115, HAMILTON

Date:	Catchment system:		Catchment number:
Time:	Sampling locality:		
Observer:	Access notes:		Altitude (m):
Organisation:	NZMS260 map:	Coordinates:	Inland distance (km):
Fishing method:	Area fished (m^2) or Number of nets used:	Number of electric fishing passes:	Tidal: yes/no/unknown

HABITAT DATA

Water

Colour: blue / green / tea / uncoloured / other:	Clarity: clear / milky / dirty	Temp.:	pH:
Average width (m):	Average depth (m):	Maximum depth (m):	Conductivity (ms/m) :

Habitat type (%):	Still:	Backwater:	Pool:	Run:	Riffle:	Rapid:	Cascade:
Substrate type (%	Mud:	Sand:	Fine gravel:	Coarse gravel:	Cobble:	Boulder:	Bedrock:

Fish cover (yes/no)	Weed Algae:	Instream debris:	Undercut banks:	Bank vegetation:

Catchment vegetation (%)	Native forest:	Exotic forest:	Farming:	Urban area:	Scrub:	Swamp land:	Other:
Riparian vegetation (%)	Native forest:	Exotic forest:	Grass Tussock:	Exposed bed:	Scrub Willow:	Raupo Flax:	Other:

Type of river/stream/lake

Water level: low / normal / high / unknown	Downstream blockage: yes / no / unknown	Pollution: nil / low / moderate / high

Large invertebrate fauna	Koura: abundant / common / occasional / rare / nil / unknown or numbers observed:	
	Paratya shrimp: abundant / common / occasional / rare / nil / unknown	
	Freshwater mussels: nil / present / unknown	
Small benthic invertebrate fauna	Numbers: low / moderate / high / unknown	Predominant species: mayflies / caddisflies / snails / combination / other

Permanent water: yes / no / unknown

Purpose of work:

FISH DATA

Species and life stage	Abundance *	Length data	Habitat/comments

Comments:

* Use numbers observed or abundant/common/occasional/rare

Appendix D: Plant Surveillance form

A printable version is available in: Department of Conservation document — docDM-1479763
This is the yellow form. Note: This form was customiesd for parts of the South Island, so you will need to check for species relevance to your region.

Aquatic plant surveillance sheet

Location/Owner:	Co-ordinates	Site ID:
	Map:	
	East:	Date:
	Nrth:	

submerged species

	Species name	found
E	*Cabomba caroliniana* (cabomba or fanwort) *	
E	*Callitriche stagnalis* (starwort)	
E	*Ceratophyllum demersum* (hornwort) UO *	
E	*Egeria densa* (egeria) UO *	
E	*Elodea canadensis* (Canadian pondweed)	
E	*Hydrilla verticillata* (hydrilla) UO *	
E	*Juncus bulbosus* *	
E	*Lagarosiphon major* (lagarosiphon) UO *	
E	*Potamogeton crispus* (curly pondweed)	
E	*Potamogeton perfoliatus* (clasped pondweed) UO *	
E	*Ranunculus trichophyllus* (water buttercup)	
E	*Sagittaria subulata* (dwarf sagittaria) *	
E	*Vallisneria* spp. (eelgrass) UO *	
N	*Callitriche petriei* (starwort)	
N	*Chara* spp.	
N	*Myriophyllum propinquum* *	
N	*Myriophyllum triphyllum* *	
N	*Nitella* spp.	
N	*Potamogeton ochreatus*	

free floating species

	Species name	found
E	*Azolla pinnata* (ferny azolla) *	
E	*Eichhornia crassipes* (water hyacinth) UO *	
E	*Salvinia molesta* (salvinia) UO *	
E	*Utricularia gibba* (bladderwort) UO *	
N	*Azolla filiculoides* (native azolla)	
N	*Lemna disperma* (was incorrectly noted as *L. minor*)	
N	*Wolffia australiana* (watermeal)	

waterlily-type species

	Species name	found
E	*Aponogeton distachyus* (Cape pondweed) *	
E	*Hydrocleys nymphoides* (water poppy) UO *	
E	*Nymphoides peltata* (fringed water lily) UO *	
E	*Nuphar lutea* (yellow water lily) UO *	
E	*Nymphaea alba* (common water lily) *	
E	*Nymphaea mexicana* (Mexican water lily) UO *	
E	*Nymphoides geminata* (entire marshwort) UO *	
N	*Potamogeton cheesemanii*	

sprawling emergent species

	Species name	found
E	*Alternanthera philoxeroides* (alligatorweed) UO *	
E	*Glyceria maxima* (reed sweet grass)	
E	*Gymnocoronis spilanthoides* (Senegal tea) UO *	
E	*Ipomoea aquatica* (water spinach)	
E	*Ludwigia peploides* subsp.*Montevidensis* (primrose willow) UO *	
E	*Menyanthes trifoliata* (bogbean) UO *	
E	*Mimulus guttatus* (monkey musk)	
E	*Myosotis laxa* (water forget-me-not)	
E	*Myriophyllum aquaticum* (parrot's feather) UO *	
E	*Myriophyllum variifolium* *	
E	*Paspalum distichum* (Mercer grass) *	
E/N	*Rorippa* spp. (watercress)	
N	*Cotula coronopifolia* (bachelor's button)	
N	*Glyceria fluitans* (floating sweetgrass)	
N	*Mentha pulegium* (penny royal)	

tall emergent species

	Species name	found
E	*Cyperus involucratus* *	
E	*Cyperus papyrus* (papyrus) *	
E	*Glyceria maxima* (reed sweet grass) *	
E	*Iris pseudacorus* (yellow flag iris) UO *	
E	*Lycopus europaeus* (gypsywort) *	
E	*Lythrum salicaria* (purple loosestrife) UO *	
E	*Phalaris arundinacea* (reed canary grass) *	
E	*Phragmites australis* (phragmites)UO *	
E	*Sagittaria montevidensis* (arrowhead) UO *	
E	*Sagittaria platyphylla* (sagittaria) UO *	
E	*Salix cinerea* (grey willow) UO	
E	*Salix fragilis* (crack willow) UO	
E	*Zizania latifolia* (Manchurian wild rice) UO *	
E	*Gunnera* spp.	
N	*Carex* spp.	
N	*Juncus* spp.	
N	*Typha orientalis* (raupo)	

algae

	Species name	found
E	*Didymosphenia geminata* (didymo)	

Notes

E = exotic
N = native
* = collect these species
UO = unwanted organism

APPENDIX 3:

Decontamination of Freshwater Gear: BEST PRACTICE GUIDANCE

Introduction

The purpose of this Best Practice document is to provide suggestions and information to help DOC staff eliminate the risk of spreading freshwater pests (animals and plants) when they undertake their work. This Best Practice document was developed following testing against a wide range of organisms (aquatic plants, fish and snails) and on feedback from DOC staff. The procedures **are more stringent** than the Check, Clean, Dry requirements for didymo that were developed by Biosecurity NZ (now the Ministry for Primary Industries, MPI) and ensure that a much wider range of organism are dealt with.

You must use these protocols when you are visiting multiple sites within a short time period. All gear that comes into contact with the water at a sampling site must be decontaminated before it is used at another site. Leaving gear to thoroughly dry can be effective, but to ensure that organisms are killed it is recommended that gear is soaked or sprayed as detailed in this document.

For more information on didymo decontamination protocols go to the *Didymosphenia geminata* (didymo) decontamination methods for DOC operational work document, or the MPI website: www.biosecurity.govt.nz/pests/didymo/cleaning.

Permit and concession conditions

These protocols have been saved as a separate document so you can attach them as permit/ concession conditions. They are available at Department of Conservation document docdm-441198.

Decontaminating freshwater sampling gear with saltwater

Overview

This method is based on Matheson *et al.* (2007), which was tested on a variety of invasive organisms. It involves soaking gear in a 7% saltwater solution for a minimum of 1 hour. Saltwater solutions are not suitable for all gear, particularly metal items, so an alternative method is detailed in the next section.

SUGGESTED CITATION FOR APPENDIX 3: Grainger NPJ, McCaughan H 2014. Decontamination of freshwater gear: best practice guidance. Version 2. Department of Conservation Wellington, New Zealand. Appendix 3 in Collier KJ & Grainger NPJ eds, 2015. New Zealand Invasive Fish Management Handbook. Lake Ecosystem Restoration New Zealand (LERNZ; The University of Waikato) and Department of Conservation, Hamilton, New Zealand. 5p.

Materials required

1. A drum or water trough large enough to submerse the gear in.
2. A container (e.g. bucket) to measure and add salt and water.
3. Standard agricultural or table salt (sodium chloride, NaCl).
4. Freshwater* (tap water is advised, but you can use pond water to make the soaking solution).

Procedure

1. Put the tub/drum in a suitable place before filling — it will be very heavy once filled with saltwater and gear. Refer to Table 1 for quantities of salt and water for various volumes.
2. Add the salt to the water and stir it until dissolved. It is advisable to use a stick, or other stirrer, and not your hands, as this high concentration of salt is very hard on human skin.
3. Put the nets and other gear into the solution and make sure they are totally submerged. If any of the gear has floats attached it will not stay submerged so you may need to put something heavier on top of it. Alternatively you can push everything under the water, let it refloat, and go back periodically to re-submerge it (if doing this, it is better to leave the gear to soak for longer than the minimum of 1 hour).
4. After a minimum of 1 hour remove all the gear and rinse it in clean freshwater (tap water, not pond water).
5. Gear can be re-used immediately, or dried and stored for later use in the normal way.
6. Note that it is okay to leave the gear soaking overnight. In fact, it is advisable to sometimes leave gear soaking for longer than 1 hour, particularly if the gear has a high quantity of macrophytes entangled amongst it.

TABLE 1:
Amount of salt and water needed to make up a 7% saltwater solution of various volumes.

Salt	Water
700 grams	10 litres
3.5 kilograms	50 litres
7 kilograms	100 litres

Re-use, safety and disposal of saltwater treatment solution

The saltwater solution can be reused indefinitely, as long as the salt concentration is not diluted by rainwater or by putting very wet nets into the solution. If this does occur you will need to periodically top up to the desired level with more salt. Use of a salinity meter is recommended to periodically check that the concentration of the solution is at 7% (70 ppt). Relatively inexpensive salinity/salt concentration meters are available through aquarium shops. Some evaporation of the solution may occur in warmer weather and salt crystals may form on the sides of the drum. These can easily be redissloved into the solution.

The saltwater solution is safe to handle, but it is advisable to wash your skin afterwards. You must exercise caution when disposing of the saltwater solution. If you do not have access to a tradewaste disposal area you will need to dilute the solution with lots of tap water before disposing of it (particularly if it is going into stormwater drains that discharge directly into waterways). Repeated disposal onto the same area of land may result in high salt levels in the soil, which can reduce plant growth and break down soil structure.

* Seawater may be used in place of freshwater. If seawater is collected from the open ocean it is likely to contain 35g/L salt (3.5%) so it will be necessary to add 1 part salt to 28 parts seawater to obtain the required 7% concentration. If brackish water or seawater is collected from an estuary, the salt concentration may be much lower than 3.5%, so it should be treated as if it is freshwater.

Limitations

This method has been shown to be effective on all of the organisms in Table 2. However, this method is not effective against:

1. Alligator weed (*Alternanthera philoxeroides*);
2. Parrot's feather (*Myriophyllum aquaticum*);
3. *Lymnaea* snails (*Lymnaea stagnalis*);
4. Chytrid fungus;
5. Ranavirus;
6. Kauri dieback.

Extra precautions need to be taken if you suspect or confirm that you have these pests where you are working (some of this is covered in sections below).

NOTE: Fish eggs were not tested by Matheson *et al.* (2007) or Dugdale & Wells (2002). If eggs are found on any of the gear, follow the above protocol and then leave everything to thoroughly dry before re-use.

TABLE 2
Organisms the 7% saltwater solution was proven effective on (Matheson *et al.* 2007).

Fish	Plants	Snails	Algae
Catfish (*Ameiurus nebulosus*)	Curly pondweed (*Potamogeton crispus*)	Physa snails (*Physa acuta*)	Didymo (*Didymosphenia geminata*)
Gambusia (*Gambusia affinis*)	Egeria (*Egeria densa*)		
Goldfish (*Carassius auratus*)	Elodea (*Elodea canadensis*)		
Koi carp (*Cyprinus carpio*)	Hornwort (*Ceratophyllum demersum*)		
Perch (*Perca fluviatilis*)	Hydrilla (*Hydrilla verticillata*)		
Rudd (*Scardinius erythrophthalmus*)	Lagarosiphon (*Lagarosiphon major*)		
Tench (*Tinca tinca*)			

Suppliers of salt

Salt is available in 25 kg bags from most farm supply stores, at a relatively low cost. It is available in fine or coarse granules, but the fine granules are easier to dissolve.

If soaking in saltwater is not suitable

Not all items can be effectively soaked in a saltwater solution, due to corrosion risk or practicality. The following list includes some (but not all) items that would be better sprayed than soaked: buckets, measuring boards, Gee minnow traps, waders, gumboots, vehicle, net setting poles, small watercraft (e.g. inflatable boats–including oars and lifejackets), floats, sinkers, net tags. For these items it is recommended that you choose one of the following options:

1. Spray with 2% household bleach solution, leave for 1 minute (double strength of that in Table 3).
2. Follow the DOC operational work protocols.
3. Use the MPI-BNZ didymo protocols www.biosecurity.govt.nz/pests/didymo/cleaning.

When spraying gear make sure it is given a good soaking spray, not just a sprinkle. Items can be rinsed in clean (tap) water after the appropriate contact time. Note that the activity level of household bleach begins to reduce once it is diluted, so this solution must be made fresh each day.

TABLE 3:
Solutions that will kill Chytrid fungus and Ranavirus.

Substance	Concentration	Mix	Contact time
Household bleach	1%	10 ml bleach in 1 litre water	15 minutes
Virkon	0.1%	1 g Virkon in 1 litre water	1 minute
Ethanol	70%		1 minute
TriGene	2%	20 ml TriGene in 1 litre water (1:50)	1 minute
TriGene Advanced	1%	10 ml TriGene Adv. in 1 litre water (1:100)	1 minute
Hot water	60°C		15 minutes

Chytrid fungus and Ranavirus

Salt solution is not effective on either of these organisms, and leaving gear to dry is only effective against Chytrid fungus **not** Ranavirus. If you are working in areas near where there are native frogs, or in sites where Chytrid fungus or Ranavirus are known to be present, you will need to take additional precautions. Table 3 lists effective solutions that can be sprayed on gear, or gear can be soaked in. Ensure that soil and other organic matter is removed from gear, especially footwear, and give everything a good soaking spray, not just a sprinkle. Items can be rinsed in clean (tap) water after the appropriate contact time, but it is important that they are left to dry thoroughly.

NOTE: that the activity level of household bleach begins to reduce once it is diluted, so this solution must be made fresh each day. Other solutions will last longer, refer to the manufacturer's instructions (TriGene solution can last up to 6 months).

See Review of Net Decontamination Protocols for further information and analysis or contact the Lizard Technical Advisory Group for more advice.

Kauri dieback (PTA)

If you are working in areas that may have kauri dieback disease (caused by *Phytophthora taxon Agathis*, PTA) it is important that all soil and other organic matter is removed from footwear and other gear, and everything is then sprayed with a 2% TriGene solution. When spraying gear make sure it is a good soaking spray, not just a sprinkle. Items can be rinsed in clean (tap) water after the appropriate contact time, but it is important that they are left to dry thoroughly.

For amounts of TriGene and water required for the 2% solution refer to Table 3. The approved shelf life of diluted TriGene is 6 months.

More information on kauri dieback can be found on the website: www.kauridieback.co.nz

Alignment of protocols

Ideally, all decontamination protocols (for didymo, fishing nets, kauri dieback disease, Chytrid fungus and Ranavirus) would align so gear could be treated once, but this is not currently possible. An effective protocol or chemical that is efficient, environmentally safe, that does not ruin gear, is easy to handle and cheap, and that kills all pests mentioned does not exist. DOC has engaged with MPI over this to make sure advice is as clear and aligned as it can be.

References

Department of Conservation 2011. *Didymosphenia geminata* (didymo) decontamination methods for DOC operational work. Version 1.7, November 2011. Department of Conservation, Wellington, New Zealand.

Dugdale T, Wells R 2002. Decontamination of fishing nets to prevent transfer of freshwater pest organisms. National Institute of Water and Atmospheric Research Client Report: HAM2002-015. Prepared for Department of Conservation, Wellington, New Zealand.

Kilroy C 2005. Tests to determine the effectiveness of methods for decontaminating materials that have been in contact with *Didymosphenia geminata*. NIWA Client Report CHC2005-005. February 2005 (revised August 2006). Prepared for Biosecurity New Zealand.

Kilroy C, Lagerstedt A, Davey A, Robinson K 2006. Studies on the survivability of the invasive diatom *Didymosphenia geminata* under a range of environmental and chemical conditions. NIWA Client Report CHC2006-0116. December 2006 (revised May 2007). Prepared for Biosecurity New Zealand

Matheson FE, Dugdale AM, Wells RDS, Taumoepeau A, Smith JP 2007. Efficacy of saltwater solutions to kill introduced freshwater species and sterilse freshwater fishing nets. DOC Research and Development Series 291, Department of Conservation, Wellington, New Zealand.

Studholme B 2003. Koi carp and gambusia: the South Island pest fish survey 2002–2003. Occasional Publication no. 58. Nelson/Marlborough Conservancy, Department of Conservation, Nelson, New Zealand. (Appendix Four).

Websites

Kauri dieback website:
www.kauridieback.co.nz

MPI website:
www.biosecurity.govt.nz/pests/didymo/cleaning
The cleaning methods outlined on the MPI website are based on the following two reports:

DOC Resources

The earlier Net Sterilisation Protocol:
Department of Conservation document — olddm-154066.

Review of Net Decontamination Protocols (May 2009):
Department of Conservation document — docdm-425340.
This document summarises and analyses all the reports and methodologies available and was the basis for this document.

APPENDIX 4:

Set Nets and Diving Birds: BEST PRACTICE GUIDANCE

Introduction

The purpose of this Best Practice document is to provide suggestions and information to help DOC staff reduce the risk of catching diving birds in fishing gear. This was developed following experience in the pest fish surveys that started in 2001.

Fishing nets are generally designed to have low visibility in water, because of this diving birds may get inadvertently caught in them and drown. This is particularly likely to happen with fine filament nets, such as gill nets and trammel nets. On rare occasions a bird may dive into a fyke net, presumably because they see fish in there. Gee minnow traps are not considered to be a risk for diving birds.

Birds that are likely to get caught in nets

Birds that dive and swim under the water are at greater risk than those that remain on the surface. Table 1 contains many of the birds that may be seen and they are listed in approximate order of their risk of getting caught in nets. Note that this list does not include all waterfowl; species and numbers will vary between sites.

Adults and juveniles of the same species may have different risk levels, for example paradise shelduck adults usually remain on the surface of the water, but their chicks will swim under the surface when disturbed and are therefore more vulnerable to getting caught.

Assessment

It is important to first assess a site for bird species and presence. Before you go to the site find out as much as you can about bird presence from the landowner or other staff. Once you arrive at the site quietly look around for approximately 30 minutes to assess how many birds you see and what species they are.

Nets at the highest risk of catching birds are gill nets and trammel nets. It therefore may not be appropriate to set these at a site, particularly if there are endangered diving birds present (see Table 1). You will have to decide if it is effective to use a different method or whether you abandon fish survey work at that site. If you are working in a sizeable waterbody you may decide to split the work and set nets in different parts of the waterbody on different days/nights so you can adequately tend them. Make sure you record all of this on your datasheet as this may prove useful when planning future work.

SUGGESTED CITATION FOR APPENDIX 4: Grainger NPJ, McCaughan H 2014. Set nets and diving birds: best practice guidance. Amendment 1. Department of Conservation, Wellington, New Zealand. Appendix 4 in Collier KJ & Grainger NPJ eds, 2015. New Zealand Invasive Fish Management Handbook. Lake Ecosystem Restoration New Zealand (LERNZ; The University of Waikato) and Department of Conservation, Hamilton, New Zealand. 4p.

Refer to the flowchart (Figure 1) to help you decide the best course of action.

NOTE: 300 m refers to a length of river or stream and the 100 x 100 m refers to an area of a lake or pond (approx. 2 rugby fields).

Protocol

If there are many diving birds present and the decision to set nets is made, the most effective method to reduce the chance of catching birds is to tend the nets so you can see when a bird gets caught and be able to release it before it gets entangled and drowns. However, this may reduce fish capture efficiency. The protocol for reducing the chance of catching birds provides two options:

- Nets are set and tended during daylight hours and removed at dusk; or
- Nets are left overnight, but are tended until dark and then removed at dawn.

If there are birds present and you are setting nets, aim to set them in places that you will be able to see and get to easily. You will need to be able to scare birds away from the nets and/or quickly get to the nets to release birds that get caught. Take a pair of binoculars with you so it is easier to watch the nets further away from you (ideally have a pair that enhances low light vision).

It is important not to set nets near obvious nesting sites or public areas, for example picnic tables, seats or where birds are fed. You may want to avoid the nesting season, when adult birds will have chicks with them.

What if a bird gets caught in the nets?

Generally if you get a bird out of the net quickly it will be okay, so just take it some distance from the net and release it (facing away from the net). A bird will not commonly get caught twice in one session, but it can happen. If it is one of the more threatened species that has got caught, for example crested grebe, it may be appropriate to keep the bird in a suitable cage/box until you remove the nets from the water and then let the bird go. This will ensure it does not get caught a second time. It is good practice to record on your datasheet any birds that are caught and released. This can be useful information if that site is visited again in the future.

There may be times when you do not get to a bird quick enough and it dies. This should be recorded on your datasheet and the animal removed from the site. You may have to do one or some of the following with the bird: bury it, take it to a disposal facility, give it to the local iwi for its feathers, freeze it for later taxidermy, send it somewhere for analysis or send photographs and other details of it somewhere. Ensure you are aware of the local procedures before you start setting nets.

If a bird gets caught in a net make sure you check to see if there are any identification bands on its legs. If there are you will need to notify someone (the intranet should have information on species specific procedures for this). You will need to pass on details such as where, when, how and what you caught, plus the details of the bands. The bands may be numbered and/or coloured; you will need to record this and you may need to photograph the bands (or collect them if the bird is dead) — it is important to know which leg each of the bands were on as this is part of the identification process.

TABLE 1.

List of most commonly encountered waterfowl that are at risk of getting caught in fishing nets.

Risk of catch	Common name	Scientific name	Threat ranking (2012)
High	Scaup	*Aythya novaeseelandiae*	Not threatened
	Dabchick	*Poliocephalus rufopectus*	Nationally vulnerable
	Crested grebe	*Podiceps cristatus*	Nationally vulnerable
Medium	Brown teal	*Anas chlorotis*	Recovering
	Mallard	*Anas platyrhynchos*	Naturalised
	Grey teal	*Anas gracilis*	Not threatened
	Paradise shelduck	*Tadorna variegata*	Not threatened
	Grey duck	*Anas superciliosa*	Nationally critical
	Shoveler	*Anas rhynchotis*	Not threatened
Low	Shag/cormorant	*Various*	Various
	Black swan	*Cygnus atratus*	Not threatened
	White/mute swan	*Cygnus olor*	Naturalised

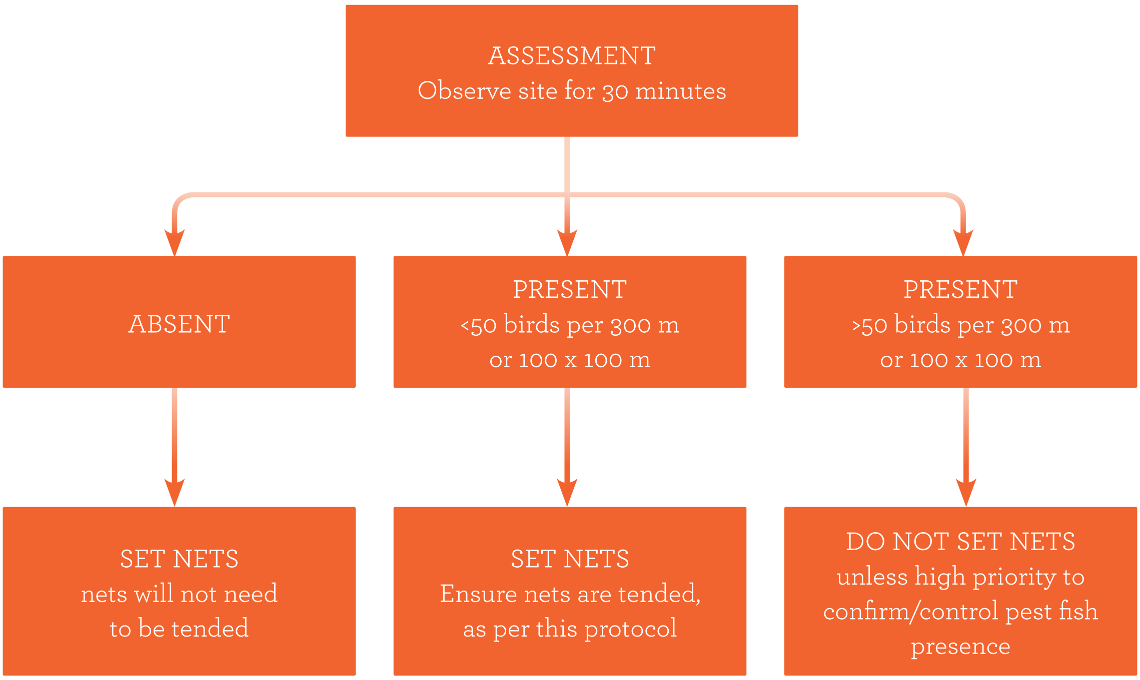


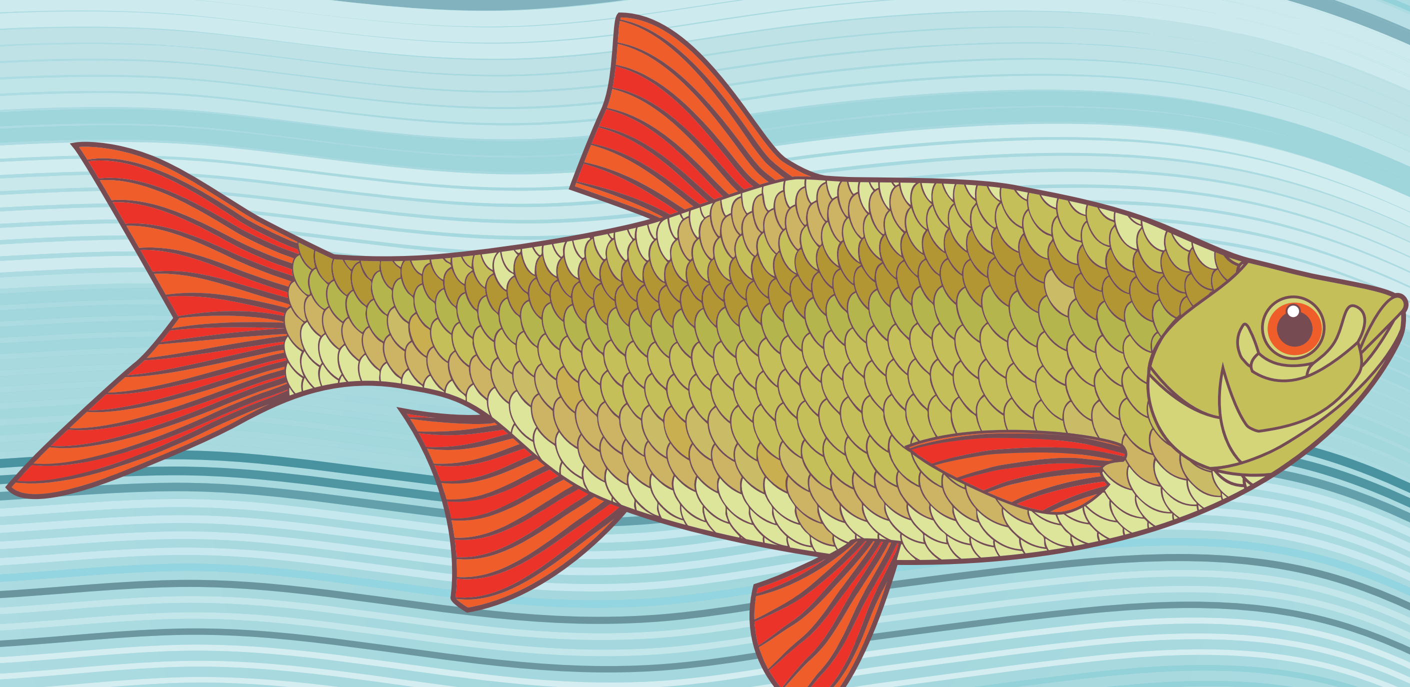
FIGURE 1.

References

New Zealand Birds Online website: www.nzbirdsonline.org.nz

Robertson H, Dowding JE, Elliott GP, Hitchmough RA, Miskelly CM, O'Donnell DFJ, Powlesland RG, Sagar PM, Scofield RP, Taylor GA 2012. Conservation status of New Zealand birds, 2012. Department of Conservation, Wellington, New Zealand.

Invasive fish pose a major threat to the health and integrity of freshwater ecosystems globally. By definition, they reproduce and disperse rapidly, are capable of tolerating a wide range of environmental conditions, and quickly reach very high numbers often dominating the biomass of fish present. Through their feeding and other activities they can adversely affect water quality and native species, contributing to the degraded and depauperate state of freshwater ecosystems. New Zealand has not escaped this plight, with several introduced fish now widespread around the country, particularly in northern New Zealand. Managing and monitoring invasive freshwater fish is a challenge that requires involvement of multiple agencies and use of multiple tools for control, eradication and surveillance. This handbook represents a joint initiative between the Department of Conservation and The University of Waikato's Lake Ecosystem Restoration New Zealand (LERNZ) research programme, part of which focussed on invasive fish management. The handbook provides an up-to-date analysis of the impacts of key invasive fish, statutory responsibilities of different agencies, approaches to control, eradication and surveillance, and ways to assess invasion risk including an analysis of human perceptions and awareness. It will provide a key reference for those involved in invasive fish management, as well as a resource for policy makers, students and the interested public.



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