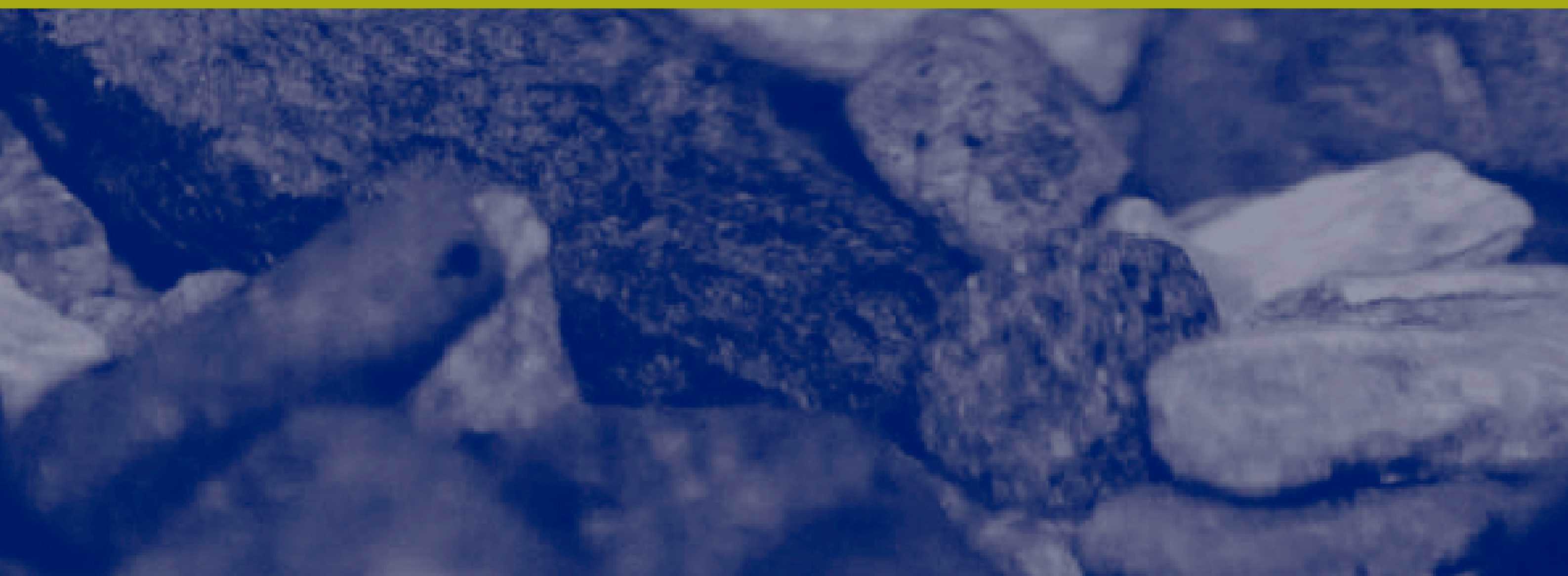
Ministry for the Environment
Manatū Mō Te Taiao

LAKE MANAGERS' HANDBOOK

# Alien Invaders



*Prepared for the Ministry for the Environment by:*

Paul Champion, John Clayton and David Rowe
National Institute of Water and Atmospheric Research Ltd
PO Box 11 115
Hamilton
New Zealand

Published in June 2002 by the
Ministry for the Environment
PO Box 10-362, Wellington, New Zealand

ISBN: 0-478-24068-6
ME number: 444

This document is available on the Ministry for the Environment's
website: www.mfe.govt.nz

Other publications in this series include:
*Land-Water Interactions*
*Lake Level Management*
*Fish in New Zealand Lakes*
*Lake Ngaroto Restoration: A Case Study*

Cover photo: Koi carp
Photo supplied by: National Institute of Water and Atmospheric
Research Ltd

Ministry for the
Environment
Manatū Mō Te Taiao

# Contents

SECTION 1

# Introduction

'Biosecurity' has become part of the vocabulary of most New Zealanders over the past few years. The media have widely reported incursions of various overseas pests, including varroa bee mites, Mediterranean fruit flies, Argentine and fire ants, painted apple moths, snakes, and scorpions into this country, and there is the ever-present risk to our economy posed by outbreaks of diseases like foot and mouth, as occurred in Britain in 2001. Biosecurity extends beyond the management of new organisms entering the country, however, to the naturalisation and spread of invasive alien (introduced) species once they have entered New Zealand. As well as economic threats, invasive aliens pose huge threats to our indigenous biodiversity and recreational activities.

Biosecurity is an international issue, especially with the global economy and movement to free trade, and the increasing movement of people and products between countries. Although New Zealanders are familiar with being on the receiving end of alien biota, we also need to be aware that our indigenous biota may pose a threat to other countries. An example is the native snail *Potamopyrgus antipodarum*, which is spreading throughout Europe and North America (Claudi and Leach 1999).

New Zealand is an isolated country with a relatively recent history of human occupation. Since European settlement in the 1840s approximately 1,500 alien species have become naturalised. In fact there are now almost as many naturalised species here as there are indigenous species. A large number of animals and plants have been introduced as ornamental garden/aquarium specimens, but also as part of a deliberate acclimatisation policy. Consequently, New Zealand is noted as having one of the highest percentages (about 50%) of introduced floras in the world (Williamson 1996).

Freshwater systems in New Zealand, including lakes, have been highly invaded, with large numbers of alien species present. Forty five percent of aquatic plant (Johnson and Brooke 1998) and 38% of freshwater fish species are alien (McDowall 2000). Unlike fish and plants, few aquatic alien invertebrates have established in our lakes. They will not be considered further, but this is an area that requires more investigation.

> Alien invertebrates include several mollusc species, along with a few crustaceans, annelids, coelenterates and even one microinvertebrate – the North American rotifer *Conochilus exiguus* from Lake Rotomanuka in the Waikato (Duggan et al. 2002). Few studies on their distribution and even fewer on their impacts have been undertaken. One evaluation of impacts undertaken by Boothroyd et al. (in press) estimated a removal of 3–4% of the zooplankton population by the alien freshwater jellyfish *Craspedacusta sowerbyi*. They conclude that this organism is unlikely to have a significant effect on zooplankton mortality.

Most of our aquatic habitats have been extensively modified by a large number of alien invaders, to the extent that totally indigenous lakes are now rare. Some alien species are regarded as pests because of the problems they create, but others are regarded as valuable biological resources (for example, salmon and trout – *Oncorhynchus* and *Salmo* spp.), or as having neutral (neither detrimental or beneficial) impact, including various low-stature plants such as starwort (*Callitriche stagnalis*).

For management purposes, the alien species causing problems need to be distinguished from those that are not, and this decision can depend on the type of lake, its uses, and its flora and fauna. Defining which species are pests and which are not can therefore be problematic. Even native species can be pests when they are translocated to environments where they have never occurred and displace other natives. For example, when smelt were introduced into Lake Rotopounamu they displaced the native koaro population (Rowe 1993). However, in this report, we consider only alien pest species.

In *Alien Invaders* we investigate entry pathways into this country and the way pests spread once introduced. We will also provide an updated record of the introduction and distribution of new invasive aliens and the problems they cause, and will discuss endangered species and the habitats that are threatened. We identify future pest species and review biosecurity legislation. Finally, we discuss options for the management of alien invaders, including separate sections on eradication and control.

SECTION 2

# Entry pathways

The majority of freshwater alien species present in New Zealand were introduced here deliberately. Legislation in 1861 encouraged the importation of (non-native) animals and birds that would contribute to the pleasure and profit of the inhabitants. Further Acts set up the acclimatisation societies whose intent was to procure, liberate and establish these species (Wodzicki 1950). Introductions of fish, especially game fish (predominantly salmonids such as trout), were carried out through the latter part of the 19th and early 20th centuries, the rationale being that there was a lack of native fish that could be caught by anglers (McDowall 1978). A number of fish introductions failed to establish, including whitefish (*Coregonus albus*), Australian bass (*Macquaria novemaculeata*) and cutthroat trout (*Oncorhynchus clarkii*). Many did, however, and these are listed in Table 1 (see section 4).

The first known submerged aquatic weed to be introduced into New Zealand was the common oxygen weed elodea (*Elodea canadensis*), which was imported in 1868 with trout ova and subsequently with shipments of perch, tench and goldfish species (Thomson 1922), presumably with the intention of oxygenating the waters supporting these fish. Along with fish and other wildlife, aquatic plant introductions were also encouraged, with the eminent plant ecologist Leonard Cockayne stating:

> *New Zealand possesses plants which do not yield in beauty or interest to those of any other land. With her seaweeds, too, she is well able to hold her own. But when it comes to her freshwater plants she must take a lower place. Rivers, lakes and, smaller sheets of water there are in plenty which offer first class inducements for occupation by aquatic plants, but none of the more beautiful kinds, except for the advent of the European, have accepted the offer: in vain do we look for indigenous water lilies like those of the neighbouring island continent* (Cockayne 1927).

So the introduction of fish species and aquatic plants and associated invertebrates continued unchecked until the latter part of the 20th century.

Objections to the introduction of new fish species began to increase, however, mainly because of the perceived threat to existing fisheries of the introduced trout and salmon species. An attempt to introduce largemouth bass (*Micropterus salmoides*) species to northern waters, where trout did not flourish, was made, but after an evaluation by McDowall (1968) this did not proceed. Grass carp (*Ctenopharyngodon idella*) were introduced in 1971 and after extensive evaluations and trials (Rowe & Hill 1989) were released in 1990 for weed control purposes. Later evaluations prevented aquaculture ventures with marron crayfish (*Cherax tenuimanus*) and channel catfish (*Ictalurus punctatus*), which were deemed to pose a threat to existing aquatic resources. The deliberate introduction of coarse fish and aquarium fish and their spread are ongoing issues, and are discussed later.

The flow of deliberate pond and aquarium plant introductions into New Zealand was unabated until the late 1970s, when legislation (the Plants Act 1970) was introduced to prohibit the entry of undesirable species. Figure 1 summarises the rate of introduction of naturalised fish and aquatic plant species since 1840.

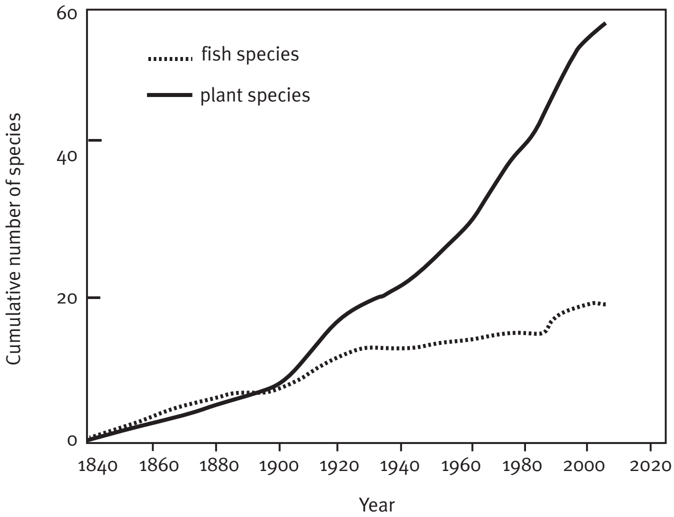



**Figure 1: Dates of first records for successfully established fish and aquatic plant species**
*Note: grass carp and silver carp are excluded, because they do not reproduce in New Zealand.*

The vast majority of alien aquatic plants arrived here through deliberate introduction as ornamental species, with others deliberately introduced for other purposes, including pasture species for animal grazing. The best-known example is reed sweet grass (*Glyceria maxima*), which was imported as a coarse grass to provide feed for cattle in wet areas. Another forage species that has proven problematic in wet areas is Mercer grass (*Paspalum distichum*). One of the earliest plant imports was watercress (*Nasturtium officinale*), which was introduced as a vegetable. Water net (*Hydrodictyon reticulatum*) was first introduced in the 1940s by universities for laboratory teaching purposes to demonstrate its unique anatomy and reproduction. Although it was maintained under culture at various centres and was imported on more than one occasion, it is clear that awareness of its potential weed impact was inconsistent. As a result, disposal of unwanted samples was not always appropriate, and it was merely fortuitous that no discarded samples became naturalised (Hawes et al. 1991). Subsequent naturalisation of water net in the 1980s appears to have been associated with escape from outdoor fish and plant culture ponds from a property in Tauranga involved with importing fish and plants from Singapore, where water net was probably an accidental contaminant of import consignments.



Other accidental introductions account for a range of other species entering New Zealand. Manchurian wild rice (*Zizania latifolia*), alligator weed (*Alternanthera philoxeroides*) and Californian bulrush (*Schoenoplectus californicus*) were probably introduced in the heydays of kauri logging as solid ballast in the holds of ships, which were subsequently discarded onto riverbanks near the port of Dargaville (Cumberland 1966; de Lange et al 1998). Other accidental pathways of introduction include contaminants of other water plants, for example, the duckweed (*Spirodela punctata*), or seed-contaminated soil, for example, starwort. Hitchhiking on ships, either in ballast water or by hull-fouling, is a well-documented pathway for the accidental introduction of alien species such as the European zebra mussel to the North American Great lakes. A newly recognised fish to New Zealand, the dart goby (*Parioglossus marginalis*), was recently found in the brackish waters of streams on Great Barrier Island and in Northland (McDowall 2000). This species is native to the east coast of Australia and may have spread to New Zealand via ballast water.

Legislation now in place prevents the legal importation of potential pest species (see section 8), but there is still the problem of illegal entry. The illegal importation of fish eggs could prove difficult to detect, as eggs are much easier to transport (and hide) and there is no easy way to distinguish species at this stage. Close inspection of all legal imports of juvenile tropical fish is now required, as illegal species are difficult to distinguish from legal species and can be hidden within a legal import. Alternative methods of entry of aquatic plants to New Zealand appear to be as diverse as the imagination and the determination of interested persons – so much so that the term 'pocket plants' has been coined for such illegal imports. Csurhes and Edwards (1998) have reported on the ease with which people can smuggle the seeds of new plant species into Australia via the mail system. Improperly labelled plants may also be imported alongside permitted species, especially as seed or bulbs. Permissible plant species contaminated with propagules of illegal species may provide another route of introduction.

SECTION 3

# Spread within New Zealand

The spread of fish and introduced plants is limited by the nature of the available dispersal mechanisms, and a range of species remain restricted to the water bodies they were first introduced into (see section 4).

Alien fish species currently in New Zealand are mostly unable to spread between catchments naturally, unless they are tolerant of saltwater (for example, chinook salmon *Oncorhynchus tshawytscha* and brown trout *Salmo trutta*). The main mechanism of spread has therefore been by deliberate stocking to create new fisheries (either of salmonids or coarse fish) or food resources, and this is why brown and rainbow trout are now widespread throughout the country. Other fish, such as goldfish (*Carrasius auratus*), may simply have been introduced to new water bodies as liberated aquarium contents. Gambusia (*Gambusia affinis*) have been widely spread under the misconception that this species would control mosquitoes, with their common name of mosquitofish alluding to this. Catfish (*Amieurus nebulosus*), although deliberately introduced to New Zealand to provide a food for early settlers, may have subsequently been spread by accidental transfer in eel nets, trailers or the bilge water of boats, as this species is hardy and capable of withstanding long periods out of water.

Many plants – including the submerged oxygen weeds, alligator weed, water poppy (*Hydrocleys nymphoides*) and parrot's feather (*Myriophyllum aquaticum*) – do not reproduce sexually in New Zealand. These species are spread from catchment to catchment by human activities, including deliberate aquarium liberation or ornamental plantings, contaminated water-craft and trailers, fishing nets, or drainage equipment. These mechanisms are sufficient to allow the continued spread of these species to new water bodies.

Some introduced aquatic plants reproduce sexually and have more efficient dispersal mechanisms. For example, fringed waterlily (*Nymphoides peltata*) has floating seed with bristly margins adapted to adhere to ducks' feet and beaks (Cook 1990). Bladderwort (*Utricularia gibba*) is a prolific flowerer and seeder and is rapidly spreading in the northern Auckland region. Other examples of prolific seeders new to the introduced invasive flora include the *Sagittaria* species *S. montevidensis, S. platyphylla* and *S. subulata*. The algal filaments of water net can be spread by aquatic birds, and quite possibly even by large insects such as dragonflies.

SECTION 4

# Distribution of pest plants and fish

Few pest species are widely distributed throughout New Zealand. Their reliance on human-mediated transfer is a key factor in their restricted distribution. Of the 21 introduced fish, 11 (52%) are restricted to only a few water bodies. The introduced species and their geographical distributions are listed in Table 1.

**Table 1: Freshwater exotic fish species and their geographic distribution in New Zealand lakes and reservoirs**

| Common name (scientific name) | Distribution and status of reproducing populations |
|---|---|
| **Salmonidae (salmon, trout and char)** | |
| Rainbow trout (*Oncorhynchus mykiss*) | Most large NI and SI lakes; dominant in NI lakes |
| Chinook salmon (*Oncorhynchus tshawytscha*) | Lake stocks in SI lakes east and west of Alps |
| Sockeye salmon (*Oncorhynchus nerka*) | Waitaki River reservoirs, but stocks declining |
| Brown trout (*Salmo trutta*) | Most large NI and SI lakes; dominant in SI lakes |
| Atlantic salmon (*Salmo salar*) | Lake Te Anau; rare |
| Lake trout (*Salvelinus namaycush*) | Lake Pearson; rare |
| Brook trout (*Salvelinus fontinalis*) | Headwater streams of many small SI lakes south of Banks Peninsula; plus Lakes Taupo and Rotorua in NI |
| **Cyprinidae (carps and coarse fish)** | |
| Goldfish (*Carassius auratus*) | Widespread in NI; isolated populations in SI, mostly around Banks Peninsula |
| Tench (*Tinca tinca*) | Mainly in northern NI, with isolated populations in Bay of Plenty, Wellington and Oamaru in SI |
| Rudd (*Scardinius erythrophthalmus*) | Small northern NI lakes, plus Waikato reservoirs and isolated populations near Wellington, New Plymouth and Canterbury |
| Koi carp (*Cyprinus carpio*) | Small northern NI lakes, plus isolated populations near Wellington, New Plymouth, and Nelson in SI |
| Orfe (*Leuciscus idus*) | Few lakes north of Auckland |
| Grass carp (*Ctenopharyngodon idella*) | Few water bodies, mostly NI but doesn't breed in NZ |
| Silver carp (*Hypophthalmichthys molitrix*) | Few NI water bodies, but doesn't breed in NZ |
| **Poeciliidae (live bearers)** | |
| Mosquitofish (*Gambusia affinis*) | Lakes and ponds in northern NI, Hawke's Bay, Nelson |
| Sailfin molly (*Poecilia latipinna*) | Geothermal waters draining into swamps of Lake Taupo |
| Guppy (*Poecilia reticulata*) | Geothermal waters draining into Lake Ohakuri (NI) |
| Swordtail (*Xiphophorus helleri*) | Waipahihi Stm, Lake Taupo; probably extinct |
| Caudo (*Phallocerus caudimaculatus*) | Whangarei |

| | |
|---|---|
| **Percidae (perch)** | |
| Perch (*Perca fluviatilis*) | Many small lakes throughout NI and SI |
| **Ictaluridae (catfish)** | |
| Catfish (*Ameiurus nebulosus*) | Taupo, Waikato, and northern NI lakes, Lake Wairarapa, Lake Mahinapua and Lake Ellesmere in SI |

*Note: NI = North Island; SI = South Island.*

Descriptions of the distributions and biology of these fish are given by McDowall (1990b), with a synopsis provided in the atlas of freshwater fish at the NIWA website:

**www.niwa.cri.nz/rc/freshwater/fishatlas/index.htm**

An almost identical proportion of introduced aquatic plants, 31 of the 58 species (53%), are restricted to only a few water bodies. These species and their distributions are shown in Table 2.

**Table 2: Species of introduced aquatic plants and their distribution in New Zealand**

| Common name (scientific name) | Distribution and status of populations |
|---|---|
| **Chlorophyta (green algae)** | |
| **Hydrodictyaceae** | |
| Water net (*Hydrodictyon reticulatum*) | Scattered in Bay of Plenty and Waikato (formerly abundant in BOP); presently common in central Hawke's Bay |
| **Charophyta (charophytes)** | |
| Chara vulgaris | Pond in Hawke's Bay; probably extinct |
| **Filicales (ferns)** | |
| **Marsileaceae (nardoos)** | |
| Nardoo (*Marsilea mutica*) | Cultivated; two naturalised sites in Auckland |
| **Salviniaceae (floating ferns)** | |
| Ferny Azolla (*Azolla pinnata*) | Common in northern NI |
| Salvinia (*Salvinia molesta*) | Mostly northern NI; most sites eradicated |
| **Monocotyledones** | |
| **Alismataceae (water plantains)** | |
| Arrowhead (*Sagittaria montevidensis*) | Cultivated; two naturalised sites in Auckland |
| Arrowhead (*Sagittaria* sp. probably *sagittifolia*) | Cultivated; one known site on Coromandel Peninsula |
| Sagittaria (*Sagittaria platyphylla*) | Cultivated; few naturalised sites in Auckland and Waikato |
| (*Sagittaria subulata*) | Cultivated; few naturalised sites in Auckland and Waikato |

| Common name (scientific name) | Distribution and status of populations |
|---|---|
| **Aponogetonaceae** | |
| Cape pondweed (*Aponogeton distachyus*) | Scattered throughout NI and SI |
| **Limnocharitaceae** | |
| Water poppy (*Hydrocleys nymphoides*) | Few sites from Northland, Auckland, Waikato, Bay of Plenty; most sites eradicated |
| **Hydrocharitaceae (oxygenweeds)** | |
| Egeria (*Egeria densa*) | Common throughout most of NI; also common in Marlborough; few sites in Canterbury |
| Elodea (*Elodea canadensis*) | Common throughout NZ |
| Hydrilla (*Hydrilla verticillata*) | Few sites in Hawke's Bay |
| Lagarosiphon (*Lagarosiphon major*) | Common throughout most of NI; more restricted in SI; absent in Fiordland |
| Swamp lily (*Ottelia ovalifolia*) | Common in NI and northern SI |
| Eelgrass (*Vallisneria gigantea*) | Lake Pupuke in Auckland |
| Eelgrass (*Vallisneria spiralis*) | Few sites in Auckland, Wanganui, Wairarapa and probably Marlborough |
| **Potamogetonaceae (pondweeds)** | |
| Curled pondweed (*Potamogeton crispus*) | Common throughout NZ, apart from Westland |
| Clasped pondweed (*Potamogeton perfoliatus*) | One site near Lake Hayes, Otago; eradicated |
| **Pontederiaceae** | |
| Water hyacinth (*Eichhornia crassipes*) | Mostly northern NI; most sites eradicated |
| **Araceae (arums)** | |
| Water lettuce (*Pistia stratiotes*) | Two known sites in Northland and Bay of Plenty; eradicated |
| **Lemnaceae (duckweed)** | |
| Purple-backed duckweed (*Spirodela punctata*) | Common in NI; scattered through much of SI |
| **Juncaceae (rushes)** | |
| Bulbous rush (*Juncus bulbosus*) | Throughout NZ in peaty waters |
| **Iridaceae (irises)** | |
| Yellow flag iris (*Iris pseudacorus*) | Locally common south of Auckland |
| **Cyperaceae (sedges)** | |
| Californian bulrush (*Schoenoplectus californicus*) | Common on northern Wairoa River and Waikato delta; planted elsewhere in NI |
| **Poaceae (grasses)** | |
| Floating sweet grass (*Glyceria declinata*) | Locally common throughout NZ |
| Floating sweet grass (*Glyceria fluitans*) | Locally common throughout NZ |
| Reed sweet grass (*Glyceria maxima*) | Locally common throughout NZ |
| Mercer grass (*Paspalum distichum*) | Locally common in NI, Marlborough and Nelson |

| Common name (scientific name) | Distribution and status of populations |
|---|---|
| Phragmites (*Phragmites australis*) | Few sites in Napier, Murchison and Christchurch |
| Manchurian wild rice (*Zizania latifolia*) | Abundant around Dargaville; few sites elsewhere in Northland, Auckland, Waikato and Kapiti Coast |
| **Dicotyledones** | |
| **Ranunculaceae (buttercups)** | |
| Water buttercup (*Ranunculus trichophyllus*) | Locally common throughout NZ; absent from Northland to northern Waikato |
| **Nymphaeaceae (water lilies)** | |
| Yellow water lily (*Nuphar lutea*) | One site in Central Hawke's Bay; nearly eradicated |
| Water lily (*Nymphaea alba*) | Cultivated; planted throughout NZ |
| Mexican water lily (*Nymphaea mexicana*) | Few known sites in Auckland and Waikato |
| **Ceratophyllaceae** | |
| Hornwort (*Ceratophyllum demersum*) | Common and rapidly spreading through most NI regions; recently found near Motueka, SI |
| **Brassicaceae (cresses)** | |
| Watercress (*Nasturtium officinale*) | Common throughout NZ |
| Watercress (*Nasturtium microphyllum*) | Common throughout NZ |
| **Amaranthaceae** | |
| Alligator weed (*Alternanthera philoxeroides*) | Common in Northland and Auckland; scattered sites in Waikato, Bay of Plenty, Taumarunui and Christchurch |
| **Haloragaceae** | |
| Parrot's feather (*Myriophyllum aquaticum*) | Cultivated; locally common in NI, although absent from many areas; scattered sites in northern SI and Westland |
| **Onagraceae** | |
| Primrose willow (*Ludwigia peploides*) | Common in Waikato, with scattered sites north and a few localities in southern NI |
| Water purslane (*Ludwigia palustris*) | Common throughout NZ |
| **Callitrichaceae (starworts)** | |
| (*Callitriche hamulata*) | Few sites in Kaipara, NI, and Marlborough, SI |
| (*Callitriche heterophylla*) | Waikato River |
| (*Callitriche platycarpa*) | Drains in Palmerston North, NI |
| (Starwort (*Callitriche stagnalis*) | Common throughout NZ |
| **Apiaceae (carrots)** | |
| Water celery (*Apium nodiflorum*) | Scattered throughout NI; a few localities in SI |
| Horsebane (*Oenanthe aquatica*) | A few sites in Marlborough |
| (*Hydrocotyle verticillata*) | One site near Hastings, NI |

| Common name (scientific name) | Distribution and status of populations |
|---|---|
| **Asteraceae (daisies)** | |
| Senegal tea (*Gymnocoronis spilanthoides*) | Cultivated; naturalised sites in Auckland and Waikato; mostly eradicated |
| **Menyanthaceae** | |
| Bogbean (*Menyanthes trifoliata*) | One naturalised site near Darfield, Canterbury; eradicated |
| Marshwort (*Nymphoides geminata*) | Several naturalised sites in Auckland, Waikato, Bay of Plenty, Wellington, Nelson and Canterbury; most sites eradicated |
| Fringed water lily (*Nymphoides peltata*) | One naturalised site on Whangaparoa Peninsula, Auckland |
| **Boraginaceae** | |
| Water forget-me-not (*Myosotis laxa*) | Common throughout NZ |
| Water forget-me-not (*Myosotis scorpioides*) | Common throughout NZ |
| **Scrophulariaceae (foxgloves)** | |
| Monkey musk (*Mimulus guttatus*) | Common throughout NZ, apart from northern NI |
| Water speedwell (*Veronica anagallis-aquatica*) | Common throughout NZ |
| **Lentibulariaceae** | |
| Bladderwort (*Utricularia gibba*) | Common in Waitakere and Rodney districts, Auckland, and a few sites in Northland and Waikato |

Descriptions of the distributions and biology of these plants are given by Johnson and Brooke (1998). Information on the more problematic species is provided at the NIWA website:

**www.niwa.cri.nz/rc/prog/aquaticplants/species**

# Problems with pest plants and fish invasions

## Environmental problems

### Fish

Environmental impacts caused by pest fish include:

- reduction in the abundance of indigenous fish through predation and competition
- changes in the distribution of resident fish species through interactive segregation
- hybridisation
- the introduction or spread of parasites and diseases
- a decline in water transparency related to changes in plankton communities by zooplanktivorous species
- habitat degradation from de-vegetation or bio-perturbation of sediments.

Predation by alien fish species on native fish is a major issue for New Zealand lakes. Populations of koaro declined in many central North Island lakes (for example, Taupo and Rotorua) following the introduction of trout (McDowall 1990a; Rowe 1990), and this was undoubtedly due to predation on the schooling juveniles by adult trout. Similarly, dwarf inanga populations in some northern dune lakes were reduced by introductions of rainbow trout (Rowe and Chisnall 1997). Perch are also carnivorous, and have been associated with a reduction in bullies in some South Island tarns (Closs and Ludgate 2001) and in a North Island perch lake (Rowe & Smith 2002).

Changes in the distributions of native fish in lakes have been caused by gambusia. In several northern dune lakes where this species now occurs, common bullies are rarely seen in the shallow littoral zone during summer, particularly where rushes are present and gambusia abound (Rowe, personal observation). However, bullies are common in the same habitats in nearby lakes where gambusia are absent. Gambusia were observed killing (but not eating) dwarf inanga in Lake Waikere by nipping their fins and eyes (Rowe 1998). Such aggressive attacks no doubt exclude native fish species such as dwarf inanga and bullies from the littoral zone.

No parasites and diseases have been associated with the introduction of exotic fish to New Zealand. Some diseases and parasites have come in by other routes, such as the whirling disease, a protozoan thought to be introduced by anglers from North America, and the tapeworm (*Ligula intestinalis*), present in several northern, west coast, dune lakes in New Zealand, where it afflicts common bullies (Weekes and Penlington 1986). New Zealand freshwater fish have largely escaped the disease and parasite problems that have plagued some fish species in other countries, mainly due to the lack of these organisms in New Zealand. If they were introduced, the New Zealand fish fauna may prove highly vulnerable.

The potential risk associated with introductions of new fish species (including live aquarium fish) is illustrated by the introduction of grass carp to New Zealand. The imported stock contained six species of foreign parasite, and these were only eliminated after the stocks had been held in quarantine and treated (Edwards and Hine 1974). Kahn et al. (1999) have undertaken a survey and risk assessment of diseases carried by imported aquarium fish in Australia. Based on this evaluation, they propose risk management measures for these fish, including methods for verifying the health certification provided by exporting countries.

A number of overseas studies have indicated that in some lakes planktivorous fish can reduce zooplankton populations to a point where algal densities increase, and there is a corresponding decline in water transparency (Power 1992). Similarly, some predatory fish may exert control over planktivores in lakes, and therefore maintain water transparency (Power 1992). This top-down effect in lake ecology is yet to be demonstrated in New Zealand lakes. However, overstocking of Lake Okareka (Rotorua) with rainbow trout produced some of the symptoms of top-down control (increased water clarity and more *Daphnia*) (R. Pitkethely, personal communication); and removal of all fish in Lake Parkinson – particularly all planktivores – increased its water clarity (Rowe and Champion 1994).

As the main planktivorous fish in most New Zealand lakes are larval bullies, Rowe (1999a) and Jeppeson et al. (1997) have suggested that they may influence plankton community structure. However, juvenile smelt and galaxiids are also planktivorous and occur in some of the larger lakes. Smelt were introduced to many North Island lakes as a forage fish for trout, and so may also influence plankton communities in these lakes. In this context it is worth noting that *Daphnia* (water fleas) are generally rare in most central North Island trout lakes containing smelt, but are abundant in at least two lakes that lack smelt (Rotoaira and Otamangakau).

Herbivorous fish can degrade fish habitats in lakes. The potential impacts of koi carp were suggested by experiences with common carp in North American and many Australian lakes and ponds. It is clear that these fish are prolific breeders, and large populations of fish build up quickly in lakes and ponds. They feed by pulling plants out, which results in a decline in macrophytes. The greater area of exposed littoral zone is then subject to erosion and increased re-suspension of silt by wave action. As a consequence, turbidity increases and the reduced light penetration can compound heavy browsing pressure on plants by reducing the depth to which light penetrates and reducing the lower depth limit for macrophytes. The end result is that macrophytes become scarce and water quality declines.

Habitat impacts of coarse fish in New Zealand have not been documented, but this may reflect lack of research as much as lack of impact (Hanchet 1990). The type and extent of impact may vary between lakes depending on their morphology and geology, and may also be related to the densities of fish that develop. Clayton and Wells (2001) reported that the bottom of some de-vegetated Waikato lakes 'was like a moonscape' and attributed the numerous depressions and holes on the bottom to the impact of the diverse range of pest fish found there. Carp and other large benthic (bottom)-feeding fish, catfish and tench have the potential to disturb or uproot plants. Rudd are also herbivorous and have been implicated as a factor in the decline of submerged vegetation in some lakes (for example, the loss of vegetation in Lake Rotoroa [Clayton and de Winton 1994], and of charophyte-dominated vegetation from Lake Tomorata [Gibbs et al.

1999]). They, too, are prolific breeders, and large populations of stunted fish quickly develop in shallow, weedy lakes. They may influence the species composition of submerged vegetation and prevent the regeneration of aquatic plants (Wells 1999; Dugdale 2000). Other species such as goldfish have been reported to create similar problems in Canadian ponds (Richardson and Whoriskey 1992; Richardson et al. 1995).

### Plants

The low stature and vigour of most native aquatic species compared to many of the introduced species has led to either a complete elimination of native species from a water body, or (more commonly) exclusion from more favourable sites (to either the deeper more light-limited or shallower more exposed sites). Many alien plants represent life forms not found – or with very few native equivalents – in New Zealand. These include bottom-rooted, floating or emergent-leaved plants (water lily type) and sprawling, emergent, floating or mat-forming plants (watercress type). Displacement of native plant species represents a loss in habitat and genetic diversity due to replacement (usually by a single introduced species), loss of habitat for native animals, and degradation of seed banks due to the isolation of sediments from seed sources and changes in burial rate.

Currently the most problematic submerged aquatic weed plants belong to the families Hydrocharitaceae (genera: *Elodea, Egeria* and *Lagarosiphon*) and Ceratophyllaceae (genus: *Ceratophyllum*). These plant families are not represented in the native flora. All the species are much taller than native vegetation, often growing to the water surface, and they spread by fragmentation of stems, enabling rapid spread within a water body. Initial invasion tends to be by establishment in holes within existing vegetation or in un-vegetated or low-density areas. Their subsequent growth habit can then result in overtopping of adjacent vegetation and exclusion by shading. After establishment, these species usually form a dense monoculture, often exceeding 5 m in height and to depths of up to 10 m or, in the case of hornwort (*Ceratophyllum demersum*), even deeper.

The maximum depth attained by such plants is dependent on water clarity (light penetration). Establishment of these dense beds has a profound effect on the other biota, often altering the substrate beneath the beds by increasing organic material and decreasing density, and replacing native species to which many invertebrates are adapted. Surface-reaching beds have a dampening effect on wave action and affect erosion and deposition processes. These species do provide habitat for epiphyton (attached algae) and the invertebrates that feed on these, refuges for various biota, and food for several birds, including the introduced black swan (*Cygnus atratus*). In several cases, shallow lakes dominated by one introduced species, especially egeria (*Egeria densa*), have undergone a decline and subsequent loss of all vegetation, with a resulting turbid, planktonic algal-dominated state, with major impacts on all other lake biota. Examples of lakes with vegetation declines include Omapere, Waahi and Waikare (Champion, in press).

Sprawling marginal mats of some plants, such as parrot's feather, alligator weed and Mercer grass, can potentially displace all aquatic life in shallow, sheltered water bodies by forming a thick floating mass, eliminating light from the water and reducing oxygenation through root respiration and litter production. In larger, more exposed water bodies these species can displace the diverse native turf communities by shading. The tall, emergent species Manchurian wild rice and yellow flag iris (*Iris pseudacorus*) are both capable of displacing all other emergent vegetation due to their taller and denser growth, or, in the case of yellow flag, due to the production of a dense floating mat of rhizomes.

High-density weed beds affect water quality and weed bed fauna, which in turn affect the nature of wildlife and fisheries values. Benthic fauna may be particularly affected by periodic reductions in dissolved oxygen, as well as accumulation of flocculant organic detritus beneath weed beds. Weed beds may provide a refuge for small prey, which can be beneficial, provided areas of open water still remain. For example, one of the unexpected benefits of recreational problems arising from dense growths of water net has been the increased refuge for small fauna, which in turn has contributed to record catches of large, well-conditioned trout (Wells and Clayton 2001).

Native aquatic plants all produce seed, and recruitment from seed is an important part of population recovery following disturbance. All of the most troublesome submerged weed species in New Zealand rely on asexual reproduction. The displacement of submerged native species by these weeds has led to a significant decline in the seed-bank densities of invaded sites, and a reduction in biodiversity on account of reduced seed rain and accelerated burial (de Winton and Clayton 1996). This may have important implications for the ability of degraded water bodies to recover from disturbances such as storms, or whether restoration will succeed where there has been more extreme degradation arising from vegetation decline.

## Economic problems

Alien aquatic weeds have a number of economic impacts, including:

- obstructing hydroelectric generation
- promoting flooding
- causing a decline in tourism and waterfront property values
- indirect economic impacts from lake restoration costs after contributing to declining water quality values.

Approximately 80% of New Zealand's electricity is produced from hydroelectric lakes. The longest river (the Waikato) has eight such lakes, and many other rivers have also been dammed for power. Regular removal of weed accumulations from screen intakes is required, particularly during autumn when weed senescence is most pronounced. Submerged weed species invariably pose the greatest management challenge, with hornwort causing widespread problems in the North Island. This plant does not produce roots, and stems readily fragment, especially during autumn. Hornwort has caused shut-downs at several stations, which can cost the power-generation companies millions of dollars in repairs and lost generation.

Some alien water plants tolerate a wide range of habitats, with the result that productive farmland may be invaded by troublesome species such as Manchurian wild rice and alligator weed. In some regions these species have displaced palatable grasses and interfered with crop production, with alligator weed and reed sweet grass also becoming a nuisance in pastures due to their toxic effects on cattle.

Economic problems caused by pest fish are also significant, but they have not been quantified, mainly because restoration is expensive. Following the collapse of a trout fishery in an Auckland lake through interference from rudd, a relatively expensive restoration programme was instigated. This involved applying the piscicide rotenone to eradicate rudd, followed by re-stocking with trout and native fish. The ongoing expense of controlling pest fish species that cannot be eliminated from lakes will present a major challenge to management authorities, and underscores the need for research into low-cost but effective control options (see section 9).

## Recreational problems

Small water bodies can be overgrown or difficult to access due to the prolific growth of marginal plant species. More often it is surface-reaching weed beds of submerged species that cause the greatest recreational problems. This group of species can reach the water surface from water depths of 4 to 5 m. The effect this has on swimming, boating and fishing will mainly depend on the aspect of the lake bed, as well as wave fetch (the distance travelled by wind across open water). For example, surface-reaching weed beds are only likely where the perpendicular fetch to the shoreline is less than 0.5 km (Howard-Williams and Davies 1980).

Another problem associated with dense, submerged weed beds is their periodic detachment, after which they are washed up on the shore. This can interfere with the use of beaches, as well as creating unpleasant odours for local residents and tourists. Water net forms dense, free-floating rafts on the surface of reservoirs and ponds, as well as loosely attached surface-reaching covers above submerged weed beds. Lake Rotorua, a lake renowned for its weed problems, has had significant interference from about 200 ha of floating rafts of water net. Tourist boat operators have had to replace outboard motors which have over-heated because of blocked engine intakes.

The rainbow trout in Lake Taupo and the Rotorua lakes are valuable fishery resources which could potentially be threatened by introductions of certain coarse fish species. For example, the decline of trout growth rates in Lake Pupuke (Auckland) may have been due to the multiple introductions of coarse fish species (perch, tench, catfish, rudd and gambusia). Other changes, such as a reduction in water quality or changes in littoral zone habitats (Rowe 1983), cannot explain the decline in this fishery. However, knowledge of the biology of coarse fish species in New Zealand waters and of their interactions with trout is rudimentary (Rowe 1984), so there is little basis on which to predict their impacts. Coarse fish species are generally dependent on lake littoral zones, and it could be argued that the Rotorua and Taupo trout fisheries would not be greatly affected by introductions of such fish because these fisheries are largely based on pelagic (open-water) rather than littoral food chains. However, the pelagic forage fish in these lakes (such as smelt) lay eggs in the littoral zone, and these could be vulnerable to predation by some coarse fish species. Also, an unknown proportion of juvenile trout rear in the littoral zones of lakes (as opposed to streams) and may be vulnerable to displacement by, or competition for food from, some coarse fish species.

In the South Island, trout populations are more dependent on the littoral zone so would theoretically be more vulnerable to coarse fish species. However, the generally colder water temperatures may prevent the development of large coarse fish populations, and any impacts on fisheries may therefore be reduced.

Rudd do not affect other fish species directly, but large stunted populations have degraded trout fisheries. Rudd take the lures of anglers much more readily than target species such as trout. In at least one New Zealand lake trout angling was spoilt to such an extent that anglers would not fish it and stocking was no longer viable. The fishery was abandoned until the rudd were eliminated (Rowe and Champion 1994). However, such problems have not occurred in all lakes containing rudd, and may be limited to lakes where the rudd population is large and stunted. Orfe may create a similar problem if introduced to other New Zealand lakes; they are now present in just one lake.

Differences in the distributions of catfish and eels have been observed by commercial fishermen in parts of the lower Waikato River (McDowall 1987), suggesting that catfish may exclude eels from certain habitats. However, over-harvesting of eels could also allow catfish to colonise habitats formerly occupied by the eels. Some evidence supporting the view that eels exclude catfish until the eels are removed was provided by the observation that eels prey on the yolk-sac stage of catfish fry (J. Bannerman, personal communication).

SECTION 6

# Endangered species, habitats and communities

Experience with alien fish species in New Zealand lakes has indicated that the galaxiids (koaro and dwarf inanga) are the most endangered indigenous species. Eels, bullies and smelt appear to be less affected by introduced species. Unfortunately, few galaxiid-dominated lakes remain, particularly in the North Island. The most endangered populations of galaxiidae are probably those of the land-locked giant kokopu, the banded kokopu, lacustrine (lake-dwelling) inanga, koaro and dwarf inanga. Of the seven indigenous fish regarded as endangered by Hilton-Taylor (2000), only the giant kokopu (*Galaxias argenteus*), dwarf inanga and Tarndale bully (*Gobiomorphus alpinus*) inhabit lakes. Although the koaro is not a rare species, land-locked populations in lakes are now scarce in both the North and South Islands. It is likely that many land-locked koaro populations have diverged genetically from diadromous[1] stocks. These evolutionarily significant units (ESU) of fish populations contribute to biodiversity, and the general reduction in koaro means that many such populations can now be regarded as threatened. Similarly, some ESUs for dwarf inanga and land-locked inanga are threatened.

Lakes supporting totally indigenous vegetation are now rare, and are usually situated in areas far from human habitation, with difficult access for the main dispersal vectors – boats and fishing nets. A recent survey of Northland lakes (Champion et al. 2002) found that 19 of 33 lakes still contained totally native vegetation. This is certainly the largest concentration of such lakes in the North Island, and possibly in New Zealand. However, 12 of the 33 lakes have been impacted by alien plants, with one or more of these species now dominating the vegetation of six lakes. This represents a significant decline in native status compared with a survey of these lakes in the 1980s (Tanner et al 1986), which found that only five of 26 lakes surveyed were impacted by alien submerged plants.

Only a few aquatic plant species are considered endangered. The following species (Table 3) are recognised by de Lange et al. (1999).

**Table 3: Conservation status of endangered aquatic plants (de Lange et al. 1999) and their growth form and habitat**

| Conservation status | Species | Growth form/habitat |
|---|---|---|
| Critically endangered | *Amphibromus fluitans* | Erect; emergent in ephemeral pools |
| Endangered | *Crassula hunua*<br>*Triglochin palustris* | Amphibious submerged<br>Amphibious submerged |
| Vulnerable | *Utricularia protrusa* | Free-floating |
| Declining | *Hydatella inconspicua*<br>*Myriophyllum robustum* | Obligate submerged<br>Obligate emergent submerged/ sprawling |

[1] Migrating between the sea and freshwater.

All of these species are currently under threat from various alien plants (Reid 1998), and most are now restricted to habitats where weeds are not well established.

The grass *Amphibromus fluitans* is regarded as critically endangered, with extinction considered inevitable within 10 years unless conservation intervention is carried out (de Lange et al. 1999). This species has been recorded from the margins of several lakes (Edgar and Connor 2000; Champion et al. 2001), with its decline linked to invasion by Mercer grass and water purslane (*Ludwigia palustris*) at some locations (Rebergen 1998).

The endangered species *Crassula hunua* and *Triglochin palustris* do not occur in lake habitats.

*Utricularia protrusa* is an endemic bladderwort now regarded as vulnerable, and the species is likely to move into a more endangered category unless factors causing decline are reduced (de Lange et al. 1999). This species is common in the lakes of the Aupouri Peninsula in Northland, but is mainly restricted to pools in peat bogs in other parts of the country. It has disappeared from many previously known sites (for example, the Waipa peat lakes), possibly due to nutrient enrichment of lake waters rather than invasive alien plants (de Winton and Champion 1993).

*Hydatella inconspicua* is an endemic turf species regarded by de Lange et al. (1999) as declining. Before its discovery in Fiordland (Wells et al. 1993) and more recently in Central Otago, this species was only known from 13 of the Northland west coast lakes (Tanner et al. 1988). Weed invasion is seen as one of the major threats to this species (Champion et al. 1993). *Myriophyllum robustum* does not occur in lake habitats.

A large number of indigenous species have been eliminated from former locations through alien weed invasion; for example, the submerged fern ally[2] *Isoetes kirkii* is apparently extinct from all formerly reported sites north of the Rotorua lakes, and even there this species is now rare in lakes dominated by the alien species lagarosiphon (*Lagarosiphon major*), egeria or hornwort.

In summary, relatively few species are threatened with extinction as a result of alien species invasions, but very few of our lakes are not affected in a major way by introduced fish or plants, and therefore all aquatic habitats still free from alien plants or fish can be regarded as endangered. Methods for protecting these water bodies are discussed in section 9.



[2] Plant division which is not a fern, but is a close relative.

# Predicting future problem species and their risk

## Plants

The potential for newly introduced plant species to impact on indigenous freshwater biodiversity is limited in comparison to what we have experienced from past introductions of weed species (Champion and Clayton 2000). The spread of already naturalised weed species represents the most immediate threat to the ecological values and biodiversity of the remaining non-impacted or minimally impacted habitats. Yet the threat from invasion remains. Several of the worst weeds internationally are not known to be present in New Zealand, including Eurasian milfoil (*Myriophyllum spicatum*), *Ludwigia peruviana* and water chestnut (*Trapa natans*).

Of the 58 naturalised alien aquatic plant species currently recognised in New Zealand, 25 are considered to be a severe enough threat to be included in plant pest management strategies, or declared as Unwanted Organisms under the Biosecurity Act (1993). Many are actively controlled to prevent further range extension (see Section 9). There is also a group of plants cultivated in ornamental ponds and aquaria that are not naturalised. Champion and Clayton (2001b) found a total of 179 aquatic and 25 bog plant species (marginal species adapted to waterlogged, but not aquatic, conditions) introduced, but not naturalised, in a recent survey. The majority of these are unlikely to establish as naturalised populations, and even fewer have weed potential, but the potential for future weeds to emerge from this group still exists; for example, one species yet to naturalise here, *Cabomba caroliniana* is now classified as a weed species of national importance in Australia (Edwards 2000).

## A model for predicting aquatic plant weed risk

An aquatic plant weed risk assessment model to determine which aquatic plant species pose the greatest risk to New Zealand has been designed by Champion and Clayton (2000; 2001a). Aquatic plants are a relatively small group of species within a wide number of families, but most have a similar range of adaptive characteristics to enable them to survive in the aquatic environment. Many aquatic species only spread clonally[3] in New Zealand, and their spread is constrained by a lack of natural dispersal pathways from one water body to another (see discussion in section 2). Water plants have a range of attributes and management requirements significantly different from terrestrial species. General weed risk assessment models (Esler et al. 1993; Pheloung 1996) fail to adequately separate aquatic plants with different levels of impact, although the predominance of introduced aquatic species becoming weedy is recognised.

The key variables evaluated in the aquatic plant weed risk assessment model are:

- invasiveness, or ability to establish and displace other plants
- potential geographic distribution
- extent of potential impacts.

[3] Asexual plant division e.g. fragmentation, rhizome extension, production of 'daughter plants'.

Invasive attributes include habitat versatility (tolerance of ranges of temperature, salinity, substrate, flow and water depth), competitive ability compared with other species (see, for example, Hofstra et al. 1999), and effective dispersal measured as a combination of reproductive output and mechanisms of spread. Potential distribution is dependent on the availability of suitable habitat. Impacts include damage to natural ecosystems, obstruction of water uses and resistance to management activities.

An assessment of the plant's weedy behaviour overseas gives an indication of all the above, but this information is not always available in the case of novel weeds (Tanner and Clayton 1985), or applicable to the assessment made for that country if, for example, there is no climate match.

Table 4 presents the highest-ranked weed species using the Aquatic Weed Risk Assessment Model (Champion and Clayton 2000; 2001a). The model ranks highly the worst aquatic weed species identified by managers, and therefore provides a decision support system for managers and a predictive tool to compare the potential weed behaviour of new species with existing aquatic weeds.

**Table 4: Aquatic plant species ranked using the Aquatic Weed Risk Assessment Model (Champion and Clayton 2000; 2001a)**

| Aquatic weed species | Aquatic weed risk assessment ranking |
|---|---|
| *Phragmites australis*[1] | 75 |
| *Hydrilla verticillata*[1] | 74 |
| *Myriophyllum spicatum*[4] | 73 |
| *Zizania latifolia*[1] | 68 |
| *Ceratophyllum demersum*[1] | 67 |
| *Eichhornia crassipes*[1] | 67 |
| *Egeria densa* [1] | 64 |
| *Ludwigia peruviana* [4] | 64 |
| *Alternanthera philoxeroides*[1] | 63 |
| *Trapa natans*[4] | 63 |
| *Lagarosiphon major*[1] | 60 |
| *Cabomba caroliniana*[2] | 58 |
| *Nymphoides peltata*[1] | 58 |
| *Typha latifolia*[2] | 58 |
| *Gymnocoronis spilanthoides*[1] | 57 |
| *Salvinia molesta*[1] | 57 |
| *Myriophyllum aquaticum*[1] | 56 |
| *Azolla pinnata*[1] | 54 |
| *Lythrum salicaria*[1] | 54 |
| *Potamogeton perfoliatus*[3] | 54 |
| *Utricularia gibba*[1] | 54 |
| *Sagittaria sagittifolia*[1] | 53 |
| *Iris pseudacorus*[1] | 52 |
| *Sagittaria platyphylla*[1] | 52 |

| | |
|---|---|
| *Glyceria maxima*[1] | 51 |
| *Ludwigia peploides*[1] | 51 |
| *Mimulus guttatus*[1] | 51 |
| *Vallisneria gigantea*[1] | 51 |
| *Vallisneria spiralis*[1] | 51 |
| *Hydrocotyle verticillata*[1] | 48 |
| *Nymphaea mexicana*[1] | 47 |
| *Elodea canadensis*[1] | 46 |
| *Nymphoides geminata*[1] | 46 |
| *Sagittaria montevidensis*[1] | 46 |
| *Hydrocleys nymphoides*[1] | 45 |
| *Menyanthes trifoliata*[3] | 45 |

*Notes:*
*1 Naturalised in New Zealand.*
*2 Cultivated in New Zealand but not growing in the wild.*
*3 All known sites of the plant are eradicated.*
*4 Not known in New Zealand.*

## Fish

Actual or potential problems with koi carp, rudd and gambusia have resulted in action to halt their spread. Both koi carp and gambusia have been declared Unwanted Organisms. Rudd remains an acclimatised fish in the Auckland–Waikato region, but is classified as noxious elsewhere. The current status of introduced fish species in New Zealand is shown in Table 5.

**Table 5: Current status of exotic fish in New Zealand**

| ACCLIMATISED SPECIES | NOXIOUS SPECIES (FRESHWATER FISH REGULATIONS) ACT) | UNWANTED ORGANISM (BIO-SECURITY ACT) | PROHIBITED ORGANISM (HSNO ACT) | RESTRICTED SPECIES (CONSERVATION ACT) | UNCLASSIFIED SPECIES |
|---|---|---|---|---|---|
| Brown trout | Koi carp | Koi carp | Sticklebacks | Silver carp[3] | Orfe |
| Rainbow trout | Rudd[2] | Gambusia | | Grass carp[3] | Sailfin molly |
| Chinook salmon | | | | | Guppy |
| Sockeye salmon | | | | | Swordtail |
| Brook trout | | | | | Caudo |
| Atlantic salmon | | | | | Goldfish |
| Lake trout | | | | | Catfish |
| Tench | | | | | |
| Perch | | | | | |
| Rudd[1] | | | | | |

*Notes:*
*1. Only in Auckland and Waikato.*
*2. Except in Auckland and Waikato.*
*3. Only non-reproducing populations present.*

The introduction of aquarium fish also poses a danger. Arthington et al. (1999) reviewed the current status of aquarium fish and the risks they pose in Australia. Forty-three alien fish are recorded outside of culture in Australia, with a number of these species originating from aquarium escapes/liberations. There is a similar situation in the US, with 41 species established following liberation (Claudi and Leach 1999). Examples include Asian eels (*Monopterus albus*), which have recently been introduced and spread to waters in Florida, and the weather loach (*Misgurnus anguillacaudatus*), which is naturalised in the US and recently in Australia. In New Zealand a population of caudo was recently found in ponds in Northland. Such introductions are possibly accidental rather than deliberate. Nevertheless, they indicate that ornamental or aquarium species that can breed in the wild in New Zealand waters can also be expected to be liberated and establish wild populations.

## Predicting the risk from fish species

Arthington et al. (1999) have taken a conservative approach to the assessment of risks posed by aquarium fish in Australia. They regard species that have been recorded as naturalised as having a very high probability of establishing, other members of those genera as having a high probability, and other members of the same family as having a moderate to high probability of establishing a feral population in Australia. Representative species from other families with a history of successful establishment in other countries are regarded as having a moderate probability of establishment. All remaining non-native fish have a residual probability of establishment. (This assumes that any naturalised fish would have a deleterious impact.)

In New Zealand, fish species that pose little risk include those whose reproduction is either unlikely (grass carp, silver carp), or that are restricted to extreme environments such as geothermal waters (guppy, sailfin molly). However, species that can reproduce in New Zealand freshwaters all pose a potential risk, either to other fish or to lake environments. Mathematical models of fish species extinctions predict that they will occur when simultaneous predation and competition (for food) occur within the same food chain of a food web. This model explains the elimination of koaro by smelt in Lake Rotopounamu, and the near extinction of dwarf inanga in lakes containing gambusia. However, it is apparent that other environmental factors, particularly the presence of refuges from predators, need to be taken into account.

# Legislation

## Border control

Two recent acts of Parliament now cover the importation of animals and plants into New Zealand. The Hazardous Substances and New Organisms Act 1996 (HSNO Act) covers the importation of any new organism not present in the country before 29 July 1998, and the Biosecurity Act (1993) covers species already present here.

The HSNO Act lists the procedures for approving new introductions. An application to introduce a new plant or animal can be submitted to the Environmental Risk Management Authority (ERMA), a body set up by the HSNO Act. The options are as follows:

- An application can undergo *rapid assessment* (Sections 34 and 35), provided the organism is not an unwanted species under the Biosecurity Act 1993 (see below) and it meets certain conditions. These conditions are that the organism will not form a self-reproducing population in New Zealand (taking into account the ease of eradication), or displace a valued species, or cause a deterioration of natural habitats, or result in a disease or parasite problem, or adversely affect human health or the environment.
- Where any of these conditions are not completely met, a *full application* may be processed (Section 38), but an important clause allows applications to be declined if there is insufficient information to make an informed decision on the liabilities versus the benefits of the introduction.
- The third type of approval can be made by the Minister under Section 68. This is where the Minister considers that the decision has significant economic, environmental, international or health implications for the country. Once evaluated, a species is either permitted entry into New Zealand or it becomes an Unwanted Organism. With this status no application for import of that species would be permitted.

The Biosecurity Act 1993 included legislation to deal with the importation of risk goods, including living organisms that may carry diseases or pests (Part 3), surveillance and prevention of pests, and Unwanted Organisms establishing within New Zealand (Part 4). This Act provides for screening of imported plants and fish to ensure that no pests or diseases are introduced with the import, but also plays a role in preventing illegal introductions or further introductions of the pest species already present.

Section 22 of the Biosecurity Act defines health standards set for the importation of new organisms (such as aquarium fish). These were prepared by the Ministry of Agriculture and Fisheries (MAF) and include both a list of fish (mainly aquarium species) that are approved imports, and a list of 92 species that are prohibited imports (MAF 1996).

MAF has initiated an online database for plants (including aquatic plants), import requirements and permitted/prohibited species. It is called the MAF Biosecurity Authority Plants Biosecurity Index, and is available at:

**www.maf.govt.nz/biosecurity/imports/plants/index.htm**

Species that are current or potential pests can be designated as unwanted organisms under this Act. These are species that a chief technical officer (CTO), a position defined under the Act, believes are capable, or potentially capable, of causing unwanted harm to any natural resources. Currently the Ministry of Agriculture and Forestry (MAF), the Department of Conservation (DOC) and the Ministry of Fisheries (MFish) have nominated CTOs that have declared as unwanted 36 aquatic plant species, plus three species, one genus and two groups of fish (Esocidae or pikes, and venomous fish). These species are not permitted entry into New Zealand. Other ramifications of this classification are discussed in the next section.

Currently, assessments for new introductions are user-pays, and all costs associated with information-gathering and evaluation are borne by the applicant. This is invariably an expensive exercise, but if the organism is accepted for entry then there is no requirement for evaluation of subsequent introductions of that species – potentially by a business competitor of the original importer. Thus there is no incentive to import, and in the case of aquatic plants no imports have been assessed by the Environmental Risk Management Authority (ERMA) since its foundation in 1998.

Another problem with the implementation of the HSNO Act is the lack of information regarding the plant and fish species currently present in New Zealand, particularly ornamental species. A survey of importers indicates that at least 27% of the species present within the aquatic plant trade were not previously known to be present in New Zealand (Champion and Clayton 2001b). It is highly likely that many of these species have been imported without screening by border control. Unless all species present in this country are recorded, it will be difficult to determine if an importation is a new organism.

Any potential weed species already present within New Zealand without a control programme (for example, not yet naturalised or of limited distribution) cannot be refused entry to the country. Although the rationale is to prevent trade barriers, this situation could increase the risk from undesirable species already in the country but not yet naturalised. It also constitutes an entry pathway for different genetic stock of naturalised species.

Despite these limitations, the current combination of HSNO and Biosecurity Acts provides a high level of border control, with any legal import of either fish or aquatic plant requiring an in-depth assessment of potential impact, meaning there is a minimal chance of problem species entering the country. However, smuggling will always provide the potential for new pest species to enter. People in the nursery and ornamental fish industries and hobby groups need to be fully involved with projects such as identification of species currently within New Zealand and policing any new illegal entries.

## Post-border control

Once a plant species has been permitted entry and released from quarantine conditions there are currently no regulations monitoring the fate of such introductions. The situation is very different for fish.

Controls on the introduction of fish to new water bodies are provided by the Freshwater Fisheries Regulations of the Conservation Act 1987. A number of government departments and resource managers (e.g. DOC, fish and game councils and MFish) are involved in decision-making related to this Act. DOC is concerned mainly with the protection of native fish species, whereas fish and game councils are concerned more with the effects of fish introductions on sports fisheries. Where a species of fish is already present in a particular lake, and further stocking is required, MFish has an interest in the control of fish diseases and parasites.

The main limit on the spread of exotic species is provided by Section 26ZM of the Freshwater Fisheries Regulations. This requires a permit from the Minister of Conservation for the introduction of any aquatic life into a water body where it is not already present. In practice, this requires a thorough and comprehensive assessment of the pros and cons of any introduction to be provided to DOC. In addition, Section 59 specifies that no person shall liberate any fish (or ova) into any water without a permit from the appropriate fish and game council. This means that a permit to release any species of fish (already in New Zealand) into a new location is required from both the Minister of Conservation and the appropriate fish and game council. Other regulations make it an offence to keep live sportsfish (those listed as acclimatised) or gambusia in captivity. In a recent addition to the Conservation Act, it is now an offence to keep restricted fish without authorisation from the Minister of Conservation. At present, the only fish listed as restricted are grass carp and silver carp.

Part 5 of the Biosecurity Act (1993) provides for the effective management of pests already established in New Zealand. Pest Management Strategies (PMS) can be developed by central government (National Pest Management Strategies – NPMS) or by regional councils or unitary authorities (Regional Pest Management Strategies – RPMS).

Of the five NPMS developed for weeds by MAF, three are for aquatic plants – salvinia (*Salvinia molesta*), water hyacinth (*Eichhornia crassipes*) and water lettuce (*Pistia stratiotes*). All costs associated with the control and inspection of sites containing these species are borne by MAF. A much larger number of aquatic plants are controlled by RPMS, the species targeted depending on which plants are problematic within each region and whether control is practicable and acceptable. A total of 16 alien aquatic plant species are actively controlled under RPMS, with koi carp also included in the RPMS of some regions.

A total of 36 aquatic plant species and three species, one genus and two groups of fish are currently declared unwanted organisms. This status allows access to a range of biosecurity management options, which can be divided into two main types.

- *Small-scale management programmes for recent incursions of an unwanted organism without the requirement for inclusion in a pest management strategy*, (Section 100 of the Act) if the organism can be effectively controlled within three years, and the cost of management is less than a prescribed amount. The occurrences of koi carp and gambusia in Nelson and alligator weed infestations in the Bay of Plenty were dealt with in this way. DOC has recently declared hornwort an unwanted organism and will be seeking measures for its eradication in the South Island.

- *Restriction on the sale, propagation, breeding, release and commercial display of unwanted organisms* (Sections 52 and 53 of the Act). Warranted officers under the Act (regional council staff) have the authority to inspect premises for the presence of such organisms.

In summary, the legislation provides an adequate framework for the management of aquatic alien species in New Zealand. Unfortunately, once a fish or aquatic plant – especially a submerged species – becomes fully established within a water body, eradication is often either impossible or requires intrusive whole-of-lake management techniques, which are very disruptive ecologically. However, any short-term damage resulting from control must be weighed against potential future disruption as a result of the establishment and spread of that alien species. Surveillance and early recognition of problem alien incursions are essential techniques for the management of these problems (section 9).

Neither the illegal introduction and distribution of aquatic aliens nor the inadvertent spread of alien species will be completely halted by regulations and permits. A more vigorous and targeted public education programme, such as that advocated by McDowall (1987) and Rowe (2001), is required to work in tandem with legislation to create a widespread sense of public opposition to illegal introductions.

SECTION 9

# Management options for pest plants and fish

## Protection and prevention

The probability and risk of spread of an alien species to New Zealand or a new part of the country is dependent on:

- the methods of spread, including dispersal by natural agents (wind or wildlife), accidental spread by humans (boat trailers or anchor wells, fishing nets, contaminated machinery), or deliberate introduction (ornamental plantings, liberation of fish)
- the distance from the nearest known locality
- the area of infested sites (how many sites and the size of these).

The potential impacts are also important to consider and, in the case of plants, can be assessed using the Aquatic Weed Risk Assessment Model (Champion and Clayton 2000; 2001a).

From the steps outlined above, a list of priority species can be identified and the species managed to prevent spread, either by direct control of the organism and/or, where human-mediated spread leads to dispersal, control of boat-use, fishing etc. in contaminated water bodies. This approach has so far restricted the spread of hydrilla (*Hydrilla verticillata*), potentially our worst submerged weed, to two lakes in the immediate vicinity of the original source within New Zealand, Lake Tutira.

The floras of lakes in most, if not all, regions are now dominated by alien plant species, but many of the worst potential pest species are still relatively localised. There are relatively few South Island lakes containing pest fish compared with North Island lakes, so there is a high priority on keeping such species out of the South Island. As well as knowing which pests are a priority, it is also important to prioritise the lakes and other water bodies within a region and allocate protection measures accordingly.

Once a problem alien fish population has established in a water body, whole-of-lake control may be required for eradication. This may not be necessary for species with restricted spawning habitats (for example, species spawning in streams), because they could be eradicated from some lakes by blocking access to the streams where spawning occurs. Plants spread much more slowly than fish, often being reliant on clonal spread such as stem fragmentation. This offers the possibility of early eradication provided that new weed incursions are detected soon enough. Regular surveillance that targets vector entry points (such as areas for boat access) can provide early detection.

An example of a site where an eradication attempt has a reasonable chance of success is in Rosie Bay, Lake Waikaremoana, where lagarosiphon was discovered during annual inspections by DOC. Plants of this species were easily identified in clear water among low-growing native species, and the site is an isolated bay surrounded by rocky, exposed shores unsuitable for plant growth. In this case weed mat was laid over all areas occupied by lagarosiphon (see next section).

Eradication is unlikely if the introduction occurs within dense vegetation, as was the case with the incursion of egeria into lagarosiphon beds at the outlet of Lake Taupo (Wells and Champion 2001).

## Eradication methods

In theory, eradication of a new incursion of a problematic alien species is the ideal outcome of a management programme. Unfortunately, this can rarely be achieved because:

- there are problems treating a contiguous aquatic environment
- the growth characteristics and behaviours of the organism may make it difficult to target
- there is often a very limited number of eradication techniques available.

This may lead lake managers to think more in terms of control rather than eradication.

In this section we look at methods aimed at eradication, then at those aimed at control. In each case the methods include physical removal, habitat manipulation, and chemical or biological control.

### Physical removal

Hand removal of free-floating alien weeds like water hyacinth and salvinia using nets has successfully eradicated these species from a number of small sites, the largest being the Western Springs lakes in Auckland. This method could also be used to remove other plants that emerge above the water surface, provided they do not have easily fragmented stems/rhizomes. Submerged species are almost impossible to clear by this method, although these weeds can be removed using a suction dredge or diver-operated venturi suction pump. This method is slow and only suited to small areas with good underwater visibility. It is also relatively expensive (estimated at NZ$10,000–15,000/ha, including collection, removal and disposal) (Clayton 1996).

### Habitat manipulation

Eradication of fish and aquatic weeds may be possible in very small lakes and ponds if they can be drained. This method is more suitable for larger fish species such as koi, rudd, tench and perch, and floating weeds like salvinia. It has not proved successful with small, hardy fish such as gambusia, and it has also failed for submerged aquatic weeds like egeria and lagarosiphon. Care needs to be taken to ensure that during draining the plant fragments or larval and juvenile fish are not transported to some other downstream water body. Disposal of water by spraying over land and/or filtration may be required. Total drainage is rarely possible, so the remaining water still needs to be treated with a piscicide to kill any remaining larval and juvenile fish.

Removal of spawning habitat (or access to it) may also eradicate some species in certain lakes. Trout could potentially be excluded from small streams draining into lakes by installing barriers that prevent upstream migrations. This already occurs inadvertently where road culverts are installed which block upstream movements of trout. In lakes where there are few spawning tributaries and no lakeshore spawning grounds, this approach could also be used to remove trout from the lake, if required.

Small plant infestations have been eradicated by light exclusion using a variety of materials, with prices ranging from NZ$10,000–50,000/ha, depending on whether heavy-grade polythene, weed mat or more durable woven PVC materials are used (Clayton 1996). For example, marshwort (*Nymphoides geminata*), first recorded in Lake Okareka as a field population in 1981 after escaping from a nearby ornamental pond (Tanner and Clayton 1985), was covered with polythene and the weed was subsequently eradicated. This technique using weed mat has been used to cover all known areas of lagarosiphon in Rosie Bay, Lake Waikaremoana.

### Chemical control

If a lake is small, and has minimal inlets and/or outlets so that the species is confined, it is possible to eradicate alien fish using piscicides such as rotenone or antimycin. Rotenone was successfully used to remove all grass carp, rudd and tench from Lake Parkinson, a 2 ha lake near Auckland (Rowe and Champion 1994). This is a radical management option, though, as all other fish are killed along with the target species. It should therefore only be contemplated where a number of individuals of the desirable or native species can be temporarily removed for later restocking, or where restocking from other sources is possible. Rotenone breaks down quickly and is non-toxic to birds or mammals using the lake.

Lime was used to increase the pH and eliminate a population of koi carp in an ornamental pond in Tauranga, which was subsequently restocked with native fish. This, too, is a radical approach, and although relatively cheap it is potentially more dangerous than using rotenone, because the strongly alkaline water can burn birds or mammals using the pond during treatment. Also, if lake depth, dense weed beds, bouldery shorelines or dilution from inflows prevent good mixing, then some fish may survive in the pockets of untreated water and subsequently repopulate the lake. Obviously, eradication of exotic species would not be feasible in lakes where re-population can occur from upstream or downstream populations.

Research into the use of fish baits impregnated with rotenone is being trialed. This has been used in the US and in one New Zealand lake (Rowe 1999b) for removing large numbers of grass carp after they had removed exotic weed species, and it has the potential to be adapted to other species such as koi carp if species-specific baits can be developed. However, trials in both New Zealand and the US have shown that fish quickly learn to detect toxic baits from their taste and avoid them. This results in a low rate of success for repeat treatments, so treatment of such baits to mask these cues is needed before this method will be more useful.

Herbicides have been used successfully to eradicate a number of field infestations of alien aquatic plants, including water hyacinth, salvinia, Senegal tea (*Gymnocoronis spilanthoides*) and water poppy. In all these cases, the herbicides used are not registered for aquatic use and discharge consents were required from the appropriate regional council or unitary authority. The only herbicide currently registered for use to control submerged alien weeds is diquat, and this controls many of these species (see section 9.3), but it has not led to successful eradication due to regrowth from stems or shoots buried in bottom sediments.

### Biological control

Biological control can be used to eradicate those species of alien aquatic plants that are dependent on vegetative reproduction and where re-infestation from an upstream source is unlikely. For example, lake restoration was achieved in Lake Parkinson, where the oxygen weed *Egeria* was eradicated by stocking grass carp to browse down the plants. All fish (including unwanted coarse fish) were subsequently removed by treating the whole lake with rotenone (see 'Chemical control' above). Native plants then re-established naturally and native fish were re-introduced (Rowe and Champion 1994). A similar eradication programme for elodea in Lake Waingata was also successful (Rowe et al. 1999).

Grass carp can be very cost-effective. For example, total vegetation control used in Lake Parkinson cost approximately $1,500/ha for the stocked fish, with 60 fish (over 250 mm long) per vegetated hectare. (Note that this indicative figure excludes costs related to site-security measures, environmental impact assessments, consultation and application costs.)

The use of these fish results in almost total vegetation removal (including marginal habitat). This can happen very rapidly (over one to two years) provided that water temperatures exceed 15°C, with the fish consuming 100% of their body weight per day at 20–23°C. Native low-growing turf communities have developed in shallow water at two of the lakes where these fish have been introduced (Clayton et al. 1995; Rowe et al. 1999), and this vegetation may stabilise the wave-washed littoral zone.

Getting rid of the fish after they have done their job can be a problem. Fish re-capture by netting is not feasible, and is costly if a piscicide is used. The use of a species-specific rotenone pellet (Prentox®) is under evaluation for use in this country and may in time provide a solution to this. Otherwise, grass carp may take 10 or more years to die out.

## Control methods

In the previous section we looked at a range of methods aimed at eradicating an unwanted species. Sometimes eradication may not be feasible (or desirable), in which case methods for more limited forms of control can be considered. However, before embarking on a weed control programme for a problem aquatic species, it is first important to determine if in fact it is necessary.

### Is control actually necessary?

A common perception held by water body managers and the general public is that any weed growth is undesirable. However, aquatic plants provide many advantages to an aquatic ecosystem and their control and removal may be unnecessary. To assess this, it is important first to:

- define the nature of the problem that is claimed to be caused by the presence of any weed beds
- identify the purpose and likely effectiveness of any control measure
- ensure that any proposed control measure will not in fact cause even greater problems.

Weed beds can often be left alone, even when there is a perceived threat to power generation or to recreational users. For example, control of large weed beds immediately upstream of a dam can result in greater weed fragment generation and blockage of nearby screen intakes. Disturbance of such weed beds is often unnecessary if the risk of their dislodgement is low and water flows are not significantly impeded.

Another reason for adopting a leave-alone strategy is that regular control of weed beds has been shown to encourage regrowth and extend the duration and commitment required for satisfactory control (Barko et al. 1994). On the other hand, no control can lead to reduced plant biomass after a number of years, which may not happen if regular control is practised. The leave-alone strategy has the added benefit of minimising ongoing costs – and possibly long-term costs as well – with control restricted to intermittent but essential removal costs, if and when detachment leads to health and safety threats, or stranding occurs in an unacceptable location.

However, if the management needs of a water body are being adversely impacted by alien aquatic plant or fish species, then there are a range of control options available, and we discuss these now.

**Physical control**

Where the lake is large and eradication is too expensive, or not possible, then limited physical control of fish may be possible. Such control has been demonstrated for trout, rudd, gambusia and perch populations in lakes.

If the undesirable fish species has a commercial market, it is theoretically possible to keep numbers low by developing the market and creating high fishing pressure. This approach was fostered for both koi carp and catfish in New Zealand (Waikato River lakes), but has not proved viable, mainly because of problems with marketing and/or product development. In this respect, market research to produce a commercially viable product may be a prerequisite to control by harvesting.

Attempts to control alien fish, including rudd and catfish, using intensive netting in Hamilton Lake in the Waikato have allowed the re-establishment of submerged vegetation in the area that has been fished. Present evidence suggests that vegetation decline can result from large populations of herbivorous rudd, so a temporary reduction in pest fish numbers may allow plant regeneration. Similarly, intensive netting is presently being applied to the Serpentine lakes in the Waikato to help protect the last known site in the area that still has native submerged vegetation.

Many mechanical devices have been used to control submerged weed, including cargo nets, suction pumps, suction dredges, pulverisers, harvesters, rota-tillers, boats fitted with rakes, and wire cables mounted to bulldozers. A variety of locally designed cutting machines and imported harvesters are operated around the country, mostly purpose-built for use in small water bodies, canals and drainage systems. Locally built cutters tend to rely on cutting without removal, particularly where cut weed can be removed by flowing water. Harvesters are generally considered a high-cost control option, with an initial capital outlay of around NZ$150,000 for a full-sized imported machine. Operating costs are typically

NZ$1,000–3,000/ha or more, depending on the speed of weed regrowth, the frequency of repeat cuts required in a year, and the efficiency of harvester and operator. One harvester can control 1–2 ha/day, or about 100 ha/yr, or proportionally less if weed beds require cutting more than once a year, or if the harvester must transport collected weed to the shore. These estimates are based on harvesting records that include down-time due to repairs, maintenance and unfavourable weather.

Mechanical harvesters are particularly suited for use in water bodies that are largely free of obstacles. Also, the weed species to be controlled should already occupy all available habitat, to avoid further establishment by spreading fragments. The effects of cutting often tend to be short-lived, particularly where tall-growing, mono-specific weed beds are cut to only 2 m below the surface. In some cases, repetitive harvesting can result in reduced regrowth rates, and when exotic weed beds are cut close to the sediment level a change to a more desirable species can occur. For example, Howard-Williams (1993) reported a change in species dominance from lagarosiphon to native *Nitella* species after trial areas were repeatedly cut in the oligotrophic Lake Aratiatia.

Another option currently being investigated by power authorities is the use of pulversisers at dam intakes, which have the potential to reduce accumulated weed to sufficiently small particles to enable direct passage through station intakes and turbines.

**Habitat manipulation**

Control via habitat manipulation may be possible for fish species dependent on submerged plants and/or discrete spawning habitats. For example, removal of aquatic macrophytes resulted in a measurable decline in rudd in Lake Parkinson because the weed beds provided shelter from shag predation. Their removal resulted in an increase in shag numbers, which reduced the rudd population (Rowe 1984). Similarly, rush beds are an important habitat factor increasing gambusia numbers in lake margins (Rowe et al. 1999), so their removal can be expected to reduce gambusia abundance.

However, a careful assessment of the effects of any habitat manipulation needs to be carried out first. For example, the rush beds removed to reduce gambusia may also provide important habitat for other fish species, and the possible effects on these other species need to be checked. Weed removal in Lake Parkinson also removed a major source of spawning substrate for rudd – but this did not appear to affect the rudd greatly. They and other phytophylls (fish generally spawning on plants) can utilise submerged sticks, stones and logs for spawning when plants are lacking. However, a reduction in macrophytes may reduce spawning success and thus prevent large stunted populations from developing and impacting on lake environments.

Trout are often dependent on streams for spawning, and access to spawning streams can be manipulated to control their population size. The lack of adequate spawning streams for trout in a number of the Rotorua lakes means that trout numbers need to be artificially stocked to maintain a population large enough to provide a fishery. When one of the two major spawning streams for trout in Lake Rotoaira was dammed, the trout population in the lake declined to a point where angler catch rates were more than halved. It is therefore clear that the number of spawning streams and the size of spawning grounds within them is an important factor governing the size of trout populations in lakes.

Removing water to cause plant desiccation is an effective control for aquatic plants, but this is generally only feasible for dammed water bodies and reservoirs. Operating water level ranges for a minority of lakes used for hydropower (for example, Hawea 8 m, Moawhango and Cobb Reservoir 14 m) already exceed the depth range of vascular plant growth, with the result that no nuisance weed beds exist there (Clayton 2001).

Routine lake lowering as a weed control option was discontinued on the Waikato hydro-lakes by around 1976 due to both economic and environmental concerns. To be effective, lowering had to be carried out annually, but the loss of water storage and generation capacity for two weeks was considered cost prohibitive, and the benefits did not justify the expense from the power authority's point of view. There are also environmental concerns with this method because of the extensive disruption of all littoral weed beds, which are important for the biological productivity of most lakes. Draw-downs have been shown to be detrimental to insects and other fauna associated with weed beds and de-watered sediments.

In New Zealand, lake-level lowerings may be deleterious to both brown and rainbow trout fisheries. Conflict over maintaining the benefits of a multi-purpose lake during a period of lake lowering led to the conclusion that the recreational benefits never justified the environmental costs. Any lake lowering for weed control now requires a consent under the Resource Management Act 1991. Difficulties over ownership issues and responsibilities for the beds of hydro-lakes, plus the legal costs in acquiring an inevitably controversial consent, have all contributed to a lack of interest in pursuing lake lowering for weed control.

### Chemical control

Chemical control is the most widely used option in New Zealand for the various types of alien weeds. Many emergent and marginal weeds are controlled using glyphosate, with several formulations registered for this purpose. Chemical options for submerged weeds are limited, because diquat is the only herbicide registered for use in New Zealand for the control of underwater weeds. Diquat is available in two formulations, aqueous or gel, and these have been the primary method of weed control for New Zealand's largest and longest established weed problems, such as those experienced in the Rotorua Lakes District (Clayton 1986). Diquat is a short-lived contact herbicide that controls aquatic weeds by acting specifically on photosynthetic tissues. It is only effective in clear water, since inorganic turbidity or dirty leaves on target plants will deactivate diquat and prevent its uptake. Environmental and plant growing conditions have a critical influence on control, so results are not always consistent. However, excellent results are often achieved.

Chemical methods can enable managers to control extensive areas of nuisance weed quickly and at a low cost. At around NZ$1,000–1,200/ha, with application by means of hovercraft or boat, this method has been the most cost-effective option for controlling oxygen weed beds on a large scale, as experienced in Lake Rotorua. Selective herbicide treatment with gel-formulated diquat has been effective not only for controlling most oxygen weeds, but also for maintaining a desirable characean vegetation comprising Chara and Nitella species, which are resistant to the effects of diquat (Clayton and Tanner 1988). The fate and environmental impact of diquat when applied to aquatic weed beds has been studied both in New Zealand and overseas. The overall nature of these results has been sufficiently favourable to enable continued use for aquatic weed control, although public opposition to pesticides continues to increase.

Chemical control of pest fish species is widely used in the US. Rotenone is the main piscicide, and is applied to lakes at reduced concentrations, or only to certain parts of lakes to reduce pest fish while retaining the more desirable species.

### Biological control

Biological control (the use of predators) may also be a potentially useful method for controlling some coarse fish species. For example, some salmonids and eels are highly piscivorous and feed more on certain types of fish. However, they cannot breed in most lakes and so would need to be stocked and their behaviour exploited to target small coarse fish species. Small schooling fish such as juvenile rudd and gambusia could prove vulnerable to such biological controls, but catfish are unlikely to be controlled in this way because they have spines, which deters predators.

The use of predator control has not been tested in New Zealand waters, so the efficacy of the method, the stocking densities needed, the types of coarse fish that can be controlled, and the predators best suited to them have not been determined. However, large eels prey heavily on gambusia in some waters (Chisnall 1987) and predation by trout and/or eels may have reduced densities of gambusia in Lake Waikare (Rowe et al. 1999). Brown trout are suspected of exerting a controlling influence on some coarse fish species such as rudd in lakes. These are specialised piscivores and likely to be adept at preying on young fish in lake littoral zones. These species may therefore be of some use for biocontrol in some New Zealand lakes. One danger with biocontrol is that the predators may reduce desirable fish species as well as coarse fish, so successful use of such control measures is likely to depend on the species mix in an individual lake.

Only two classical (using species-specific insects) biological control agents are used in New Zealand for controlling aquatic weeds. The flea beetle *Agasicles hygrophila* and moth *Vogtia malloi* were released in 1982 and 1987 respectively to control alligator weed. Self-sustaining populations have now established and a moderate degree of control has been achieved. Alternative biocontrol agents have been used overseas to control various aquatic weeds, but either these weeds are targeted for eradication in New Zealand (for example, salvinia and water hyacinth), which could not be achieved with classical biocontrol, or different species not present in New Zealand are causing a problem (for example, Eurasian milfoil *Myriophyllum spicatum*). Currently there are no classical biocontrol agents identified and evaluated to control most alien weed species that are problematic in this country, especially submerged species.

The use of grass carp as an eradication tool is examined in the discussion above on eradication. This species has also been used to control the submerged aquatic weed hydrilla in Hawke's Bay (Clayton et al. 1995), reducing the biomass of this plant to a level where its spread to new water bodies would be extremely unlikely. However, this species has not been eradicated.

A further type of biological control – applying the spores of fungi in a similar way to herbicides (a myccoherbicide) to selectively attack problem weeds – has not been trialed in New Zealand, but shows some promise internationally (Shearer 1997) and could become a useful management tool for certain aquatic plant species in the future.

SECTION 10

# References


Arthington, AH, Kailola, PJ, Woodland, DJ, Zalucki, JM. 1999. *Baseline Environmental Data Relevant to an Evaluation of Quarantine Risk Potentially Associated with the Importation to Australia of Ornamental Finfish*. Australian Quarantine and Inspection Service, Canberra.

Barko, JW, Smith, CS, Chambers, PA. 1994. Perspectives on submersed macrophyte invasions and declines. *Lake and Reservoir Management* 10(1): 1–3.

Boothroyd, IK, Etheridge, MK, Green, JD. (in press) Spatial distribution, size structure, and prey of *Craspedacusta sowerbyi* Lankester in a shallow New Zealand lake. Submitted to *Hydrobiologia*.

Champion, PD. (in press). *Egeria densa*: an alien invasive responsible for the loss of submerged vegetation from New Zealand shallow lakes. *Proceedings 13th Australian Weeds Conference*, Perth, Australia, 9–11 September 2002.

Champion, PD, Clayton, JS. 2000. Border control for potential aquatic weeds: Stage 1: Weed risk model. *Science for Conservation 141*, Department of Conservation, Wellington.

Champion, PD, Clayton, JS. 2001a. A weed risk assessment for aquatic weeds in New Zealand. In: RH Groves, FD Panetta, JG Virtue (eds.) *Weed Risk Assessment*. CSIRO Publishing, Collingwood, Victoria.

Champion, PD, Clayton, J.S. 2001b. Border control for potential aquatic weeds. Stage 2: Weed risk assessment. *Science for Conservation* 185, Department of Conservation, Wellington.

Champion, PD, Clayton, JS, de Winton, MD. 1993. *Study on* Hydatella inconspicua *Seed Production, Germination and Maintenance of Habitat in the Northland Dune Lakes*. NIWA consultancy report DOC001, NIWA, Hamilton.

Champion, PD, Dugdale, AM, Beadel, SM. 2001. Turf communities of Lake Whangape and experimental assessment of some potential management techniques. *Science for Conservation* 186, Department of Conservation, Wellington.

Champion, PD, Dugdale, AM, Taumoepeau, A. 2002. *The Aquatic Vegetation of 33 Northland lakes*. NIWA consultancy report NRC01203, NIWA, Hamilton.

Chisnall, BL. 1987. Juvenile eel biology in the backwaters of the Waikato River. MSc thesis. University of Waikato, New Zealand.

Claudi, R, Leach, JH. 1999. *Nonindigenous Freshwater Organisms, Vectors, Biology and Impacts*. Lewis Publishers, Boca Raton, Florida.

Clayton, JS. 1986. Review of diquat use in New Zealand for submerged weed control. Proceedings EWRS/AAB Symposium on Aquatic Weeds 7: 73–79.

Clayton, JS. 1996. Aquatic weeds and their control in New Zealand lakes. *Lake and Reservoir Management* 12(4): 477–86.

Clayton, JS. 2001. New Zealand hydroelectric lake weed species and operational features contributing to management problems. *Proceedings of the Third International Weed Science Congress*, 2000 June 6-11, Foz do Iguassu, Brazil. Manuscript number 451. CD-ROM. Available from: International Weed Science Society, Oxford, MS, USA.

Clayton, JS, Champion, PD, McCarter, NH. 1995. Control of *Hydrilla verticillata* in a New Zealand lake using triploid grass carp. In: ES Delfosse, RR Scott (eds.) *Proceedings of the Eighth international Symposium on Biological Control of Weeds*, 2–7 February 1992, Lincoln University, New Zealand.

Clayton, JS, de Winton, MD. 1994. *Lake Rotoroa: Change in an urban lake*. NIWA ecosystems publication No 9, NIWA, Hamilton.

Clayton JS, Tanner, CC. 1988. Selective control of submerged aquatic plants to enhance recreational use of water bodies. *Verhandlungen/International Vereinigung fuer Theoretische und Angewandte Limnologie*. 23: 1518–21.

Clayton, JS, Wells, RDS. 2001. Weed management in the Rotorua Lakes. *Proceedings and Report: Rotorua Lakes: A symposium on research needs in the Rotorua Lakes*. Lakes Water Quality Society, Rotorua.

Closs, G, Ludgate, B. 2001. European perch control: an experimental removal. A paper presented at Just Add Water: New Zealand Hydrological Society and New Zealand Limnological Society Joint Conference, Massey University, Palmerston North, 20–23 November 2001.

Cockayne, L. 1927. *New Zealand Plants and Their Story*. Government Printer, Wellington.

Cook, CDK. 1990. Seed dispersal of *Nymphoides peltata*. *Aquatic Botany* 37: 325–40.

Csurhes, S, Edwards, R. 1998. *Potential Environmental Weeds in Australia*. Environment Australia, Canberra.

Cumberland, GLB. 1966. Manchurian ricegrass research. *Proceedings of 19th New Zealand Weed and Pest Control Conference*: 103–106.

de Lange, PJ, Gardner, RO, Champion, PD, Tanner CC. 1998. *Schoenoplectus californicus* (Cyperaceae) in New Zealand. *NZ Journal of Botany* 36: 319–27.

de Lange, PJ, Heenan, PB, Given, DR, Norton, DA, Ogle, CC, Johnson, PN, Cameron, EK. 1999. Threatened and uncommon plants of New Zealand. *NZ Journal of Botany* 37: 603–28.

de Winton, MD, Champion, PD. 1993. *The Vegetation of the Lower Waikato Lakes. Volume 1: Factors affecting the vegetation of lakes in the Lower Waikato*. NIWA ecosystems publication No. 7, NIWA, Hamilton.

de Winton, MD, Clayton, JS. 1996. The impact of invasive submerged weed species on seed banks in lake sediment. *Aquatic Botany* 53:32-46.

Dugdale, AM. 2000. Rudd and koi carp: underwater possums. *Fish & Game* special issue No. 11, Auckland–Waikato supplement.

Duggan, IC, Green, JD, Shiel, RJ. 2002. Distribution of rotifer assemblages in North Island, New Zealand, lakes: relationships to environmental and historical factors. *Freshwater Biology* 47: 195–206.

Edgar, E, Connor, HE. 2000. *Flora of New Zealand*. Vol. 5. Grasses. Manaaki Whenua Press, Lincoln, Canterbury.

Edwards, R. 2000. *Draft National Strategy for Cabomba Weed Management*. URL: www.weeds.org.au/natsig.htm#list.

Edwards, DJ, Hine, PM. 1974. Introduction, preliminary handling, and diseases of grass carp in New Zealand. *NZ Journal of Marine and Freshwater Research* 8: 441–54.

Esler, AE, Liefting, LW, Champion, PD. 1993. *Biological Success and Weediness of the Noxious Plants of New Zealand*. MAF Quality Management, Lynfield, Auckland, New Zealand.

Gibbs, M, Boothroyd, I, Champion, P, Green, J, Duggan, I. 1999. *ARC Lakes Monitoring Programme Review*. NIWA client report ARC00256, NIWA, Hamilton.

Hanchet, S. 1990. *The Effects of Koi Carp on New Zealand's Aquatic Ecosystems*. Freshwater Fisheries Report No 117. New Zealand Ministry of Agriculture and Fisheries, Rotorua.

Hawes, I, Wells, RDS, Clayton, JS, Howard-Williams, C. 1991. *Report of the Status of Water Net (Hydrodictyon reticulatum) in New Zealand and Options for its Control*. Joint DSIR and MAF report prepared for Water Net Technical Committee, DSIR Taupo and MAF Hamilton.

Hilton-Taylor, C. (compiler) (2000). *2000 IUCN Red List of Threatened Species*. IUCN, Gland, Switzerland and Cambridge, UK.

Hofstra, DE, Clayton, JS, Green, JD, Auger, M. 1999. Competitive performance of *Hydrilla verticillata* in New Zealand. *Aquatic Botany* 63: 305–24.

Howard-Williams, C. 1993. Processes of aquatic weed invasions: the New Zealand example. *Journal of Aquatic Plant Management* 31: 17–23.

Howard-Williams, C, Davies, J. 1980. The invasion of Lake Taupo by the submerged water weed *Lagarosiphon major* and its impact on the native flora. *NZ Journal of Ecology* 11:13–19.

Jeppesen, E, Lauridsen, T, Mitchell, SF, Burns, CW. 1997. Do planktivorous fish structure zooplankton communities in New Zealand lakes. *NZ Journal of Marine and Freshwater Research* 31: 163–73.

Johnson, PN, Brooke, PA. 1998. *Wetland Plants in New Zealand*. Manaaki Whenua Press, Lincoln, Canterbury.

Kahn, SA, Wilson, DW, Perera, RP, Hayder, H, Gerrity, SE. 1999. *Import Analysis on Live Ornamental Fish*. Australian Quarantine and Inspection Service, Canberra.

McDowall, RM. 1968. The proposed introduction of the largemouthed black bass Micropterus salmoides (Lacepidae) into New Zealand. *NZ Journal of Marine and Freshwater Research* 2: 149–61.

McDowall, RM. 1978. *New Zealand Freshwater Fishes: A guide and natural history*. Heinemann Educational Books, Auckland.

McDowall, RM. 1987. Impacts of exotic fishes on the native fauna. In: AB Viner (ed.). *Inland Waters of New Zealand*. DSIR bulletin 241: 333–47.

McDowall, RM. 1990a. Filling in the gaps: the introduction of exotic fishes into New Zealand. *Bureau of Rural Resources Proceedings* 8: 69–82.

McDowall, RM. 1990b. *New Zealand Freshwater Fishes: A natural history and guide*. Auckland, Heinemann Reed.

McDowall, RM. 2000. *The Reed Field Guide to New Zealand Freshwater Fishes*. Reed Books, Auckland.

MAF. 1996. *Import Health Standard for the Importation into New Zealand of Ornamental Fish and Marine Invertebrates from all Countries*. Ministry of Agriculture and Fisheries, Wellington.

Pheloung, PC. 1996. Predicting the weed potential of plant introductions. *Proceedings of Eleventh Australian Weeds Conference*, Weed Science Society of Victoria Inc., Australia.

Power, ME. 1992. Top-down and bottom-up forces in food webs: do plants have primacy? *Ecology* 73: 733–46.

Rebergen, A. 1998. *Status of the Swamp Grass* Amphibromus fluitans *at Boggy Pond in June/July 1998*. Internal report. Department of Conservation, Masterton.

Reid, VA. 1998. The impact of weeds on threatened plants. *Science for Conservation* 164, Department of Conservation, Wellington.

Richardson, MJ, Whoriskey, FG. 1992. Factors influencing the production of turbidity by goldfish (*Carassius auratus*). *Canadian Journal of Zoology* 70: 1585–89.

Richardson, MJ, Whoriskey, FG, Roy, LH. 1995. Turbidity generation and biological impacts of an exotic fish *Carassius auratus*, introduced into shallow seasonally anoxic ponds. *Journal of Fish Biology* 47: 576–85.

Rowe, DK. 1983. *Fisheries Values and Problems of Lake Pupuke, Auckland*. Report to the Takapuna City Council and Auckand Acclimatisation Society, Auckland.

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. *NZ Journal of Marine and Freshwater Research* 18: 115–27.

Rowe, DK. 1990. Who killed the koaro? *Freshwater Catch* 43: 15–18.

Rowe, DK. 1993. Disappearance of koaro, *Galaxias brevipinnis*, from Lake Rotopounamu, New Zealand following the introduction of smelt, *Retropinna retropinna*. *Environmental Biology of Fishes* 36: 329-336.

Rowe, DK. 1998. Management trials to restore dwarf inanga show mosquitofish a threat to native fish. *Water & Atmosphere* 6: 10–12.

Rowe, DK. 1999a. Factors influencing the abundance of the common bully, *Gobiomorphus cotidianus* McDowall, in small North Island New Zealand lakes. *Fisheries Management and Ecology* 6: 377–86.

Rowe, DK. 1999b. Prentox: a method for removing grass carp from lakes. *Water & Atmosphere* 7: 15–17.

Rowe, DK. 2001. Rotenone-based approaches to pest fish control in New Zealand. Paper presented at the Department of Conservation Workshop on Managing Invasive Freshwater Fish in New Zealand, Hamilton Airport, 10–12 May 2001.

Rowe, DK, Hill RL. 1989. Aquatic macrophytes, waterweeds. In Cameron, PJ, Hill, RL, Bain, J, Thomas, WP. Eds. A review of biological control of invertebrate pests and weeds in New Zealand 1874-1987. pp. 331-337, DSIR Technical Communication No. 10.

Rowe, DK, Champion, PD. 1994. Biomanipulation of plants and fish to restore Lake Parkinson: a case study and its implications. In: JJ Collier (ed.). *Restoration of Aquatic Habitats*. Department of Conservation, Wellington.

Rowe, DK, Champion, PD, de Winton, MD. 1999. *Lake Management Trials for Dwarf Inanga* (Galaxias gracilis) *and a Rare Plant* (Hydatella inconspicua) *in Northland Dune Lakes*. NIWA client report DOC90202, NIWA, Hamilton.

Rowe, DK, Chisnall, BL. 1997. Environmental factors associated with the decline of dwarf inanga *Galaxias gracilis* McDowall in New Zealand lakes. *Aquatic Conservation: Marine and Freshwater Ecosystems* 7: 277–86.

Rowe, DK, Smith, JP. 2002. The role of exotic fish in the loss of macrophytes and increased turbidity of Lake Wainamu, Auckland. NIWA client report ARC02286, NIWA, Hamilton.

Shearer, J. 1997. *Endemic Pathogen Biocontrol Research on Submersed Macrophytes: Status report 1996*. Technical Report A-97-3. US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Tanner. CC, Clayton JS. 1985. *Nymphoides geminata* (R. Br.) Kuntze in New Zealand. *NZ Journal of Botany* 23: 187–90.

Tanner, CC, Clayton, JS, Harper, LM. 1986. Observations on aquatic macrophytes in 26 northern New Zealand lakes. *NZ Journal of Botany* 24: 539–51.

Tanner, CC, Clayton, JS, Wells, RDS. 1988. The distribution, biology, habitat and conservation status of the endangered aquatic plants *Hydatella inconspicua* and *Myriophyllum robustum*, with recommendations for future management. Unpublished report. MAF Aquatic Plants Section, NIWA, Hamilton.

Thomson, GM. 1922. *The Naturalisation of Animals and Plants in New Zealand.* Cambridge University Press, Cambridge.

Weekes, PJ, Penlington, PB. 1986. First record of *Ligula intestinalis* (Cestoda) in rainbow trout, *Salmo gairdneri*, and common bully, *Gobiomorphus cotidianus*, in New Zealand. *Journal of Fish Biology* 28: 183–90.

Wells, RDS. 1999. Are rudd a threat to water plants? *Water & Atmosphere* 7: 11–13.

Wells, RDS, Champion, PD. 2001. I*ssues and Options for the Management of Egeria densa in Lake Taupo*. NIWA consultancy report EVW01230, NIWA, Hamilton.

Wells, RDS, Clayton, JS. 2001. Ecological impacts of water net (*Hydrodictyon reticulatum*) in Lake Aniwhenua, New Zealand. *NZ Journal of Marine & Freshwater Research* 25: 55–63.

Wells, RDS, Clayton, JS, de Winton, MD. 1993. *The Submerged Vegetation of Lakes Hauroko, Te Anau, Manapouri and Monowai, Fiordland, New Zealand, and Effects of Water Level Fluctuations*. NIWA consultancy report ELE121, NIWA, Hamilton.

Williams GR, Given, DR. 1981. *The Red Data Book of New Zealand: Rare and endangered species of endemic terrestrial vertebrates and vascular plants*. Nature Conservancy Council, Wellington.

Williamson, M. 1996. *Biological Invasions*. Chapman and Hall, London, UK.

Wodzicki, KA. 1950. *Introduced Mammals of New Zealand.* DSIR bulletin 98, DSIR, Wellington.

## About the Ministry for the Environment

The Ministry for the Environment works with others to identify New Zealand's environmental problems and get action on solutions. Our focus is on the effects people's everyday activities have on the environment, so our work programmes cover both the natural world and the places where people live and work.

We advise the Government on New Zealand's environmental laws, policies, standards and guidelines, monitor how they are working in practice, and take any action needed to improve them. Through reporting on the state of our environment, we help raise community awareness and provide the information needed by decision makers. We also play our part in international action on global environmental issues.

On behalf of the Minister for the Environment, who has duties under various laws, we report on local government performance on environmental matters and on the work of the Environmental Risk Management Authority and the Energy Efficiency and Conservation Authority.

Besides the Environment Act 1986 under which it was set up, the Ministry is responsible for administering the Soil Conservation and Rivers Control Act 1941, the Resource Management Act 1991, the Ozone Layer Protection Act 1996, and the Hazardous Substances and New Organisms Act 1996.

**Head Office**
Grand Annexe Building
84 Boulcott Street
PO Box 10362
Wellington, New Zealand
Phone (04) 917 7400
Fax (04) 917 7523
Internet www.mfe.govt.nz

**Northern Regions Office**
8-10 Whitaker Place
PO Box 8270, Auckland
Phone (09) 913 1640
Fax (09) 913 1649

**South Island Office**
Level 4
Price Waterhouse Centre
119 Armagh Street
PO Box 1345
Christchurch
Phone (03) 963 0940
Fax: (03) 963 2050