Pages 53-65 in Collier, K.J. (Ed), 1994. Restoration of Aquatic Habitats. Selected papers from the second day of the New Zealand Limnological Society 1993 Annual Conference. Department of Conservation.

BIOMANIPULATION OF PLANTS AND FISH TO RESTORE LAKE PARKINSON: A CASE STUDY AND ITS IMPLICATIONS

D. K. Rowe and P. D. Champion

NIWA, P.O. Box 11-115, Hamilton

ABSTRACT

The biomanipulation of aquatic plants and fish was successfully used to restore recreational uses of Lake Parkinson, a small (1.9 ha) dune lake, southwest of Auckland, after it had been degraded by introductions of exotic plant and fish species. The oxygen weed *Egeria densa* was eradicated by stocking a herbivorous fish, the grass carp, *Ctenopharyngodon idella*. Complete removal of all plants in this lake enabled the subsequent restructuring of its fish fauna. All fish species including the stocked grass carp, rudd (*Scardinius erythrophthalmus)*, tench (*Tinca tinca*), the native smelt (*Retropinna retropinna)* and the common bully (*Gobiomorphus cotidianus*) were removed following application of the piscicide, rotenone. After removal of the grass carp, communities of native macrophytes regenerated from senescent seeds in the lake-bed sediment. The common bully was re-established in the lake by stocking to provide a forage fish for trout. Lake Parkinson now supports a valuable put-and-take trout fishery and is free from problems caused by exotic macrophytes. The combination of biomanipulation techniques used in Lake Parkinson has the potential to restore recreational values of other small lakes, to help protect rare native macrophyte and fish species threatened by invasions of exotic species, to restructure fish populations, and to minimise the spread of unwanted exotic plant and fish species.

INTRODUCTION

New Zealand has an abundance of freshwater, but the geographical distribution of this resource is not even. In Auckland and Northland, rivers are comparatively small and there are few of the large lakes or reservoirs that occur in the south of the country. The northern half of the North Island is also the most populous part of the country and is currently experiencing growth in horticulture and forestry. Such development can be expected to place extra demands on the already scarce freshwater resources. The numerous small dune lakes on the west-coast of the North Island, north of Hamilton (Group W3 in Appendix A, Viner 1987) therefore constitute a major water resource for northern New Zealand and have special ecological significance.

The future uses of this aquatic resource are being steadily reduced by a deterioration in water quality and by invasions of exotic species of plants and fish (Table 1). The consequences of such invasions to lakes include reduced aesthetic appeal, reduced use for recreation, fishing, and boating, and problems for water abstraction as well as for stock watering and potable water supply. This reduction in the use of aquatic resources can be expected to increase in the future as the species of plant and fish causing problems spread to previously unaffected lakes. The spread of such plants and fish has increased recently

(Table 1), and this spread can be expected to accelerate as development of Northland increases.

Table 1 Lakes in Northland and Auckland Regions impacted by introduced plants and/or fish. (* = Not established as a breeding population. # = Land-locked populations.)

Lake	Introduced plants	Introduced fish
Ngakeketa	*Ceratophyllum*	unsurveyed
Waiperera	*Lagarosiphon, Egeria*	*Gambusia*, both eel spp#.
Rotokawau (Waipapakauri)		*Gambusia*
Ngatu	*Lagarosiphon*	*Gambusia*, rudd*, goldfish, trout*
Rotoroa	*Egeria, Potamogeton crispus*	smelt, both eel spp#.
Owhareiti	*Egeria*	short finned eel#
Waikere		*Gambusia*, trout*, short finned eel#
Kai-iwi		*Gambusia*, trout*, rudd*
Parawanui		rudd, koi carp*
Rototuna		rudd
Roto otuauru	*Egeria*	unsurveyed
Rotokawau	*Egeria*	short finned eel#, smelt
Tuanui		perch
Tomarata		rudd
Ototoa		trout, rudd*, goldfish, tench*, koi carp*
Kereta	*Zizania latifolia, Ranunculus trichophyllus*	rudd, tench
Pupuke	*Vallisneria, Egeria, Myriophyllum aquaticum*	rudd, tench, catfish, goldfish, trout
Whatihua	*Egeria*	trout*
Otamarearoa	*Elodea, Egeria, Ceratophyllum*	rudd
Parkinson	*Egeria*	rudd, tench, trout, smelt, short finned eel#, koi carp*

Figure 1 Flow chart illustrating how the effects of cattle, exotic plants, and fish combined to reduce the uses of Lake Parkinson in 1976.

As the demand for high quality water increases, attention will be increasingly focused on ways of restoring the water quality and of reducing the effects of introduced exotic species in these lakes. In this paper we provide an overview of the biomanipulations used in several small lakes in the North Island. In particular, we focus on the biomanipulations of aquatic plants and fish carried out in Lake Parkinson between 1976 and 1981. Lessons learned from this work are discussed, and we suggest some future directions and applications for these techniques.

PROBLEMS IN LAKE PARKINSON

Lake Parkinson is a small (1.9 ha surface area, maximum depth 9 m) dune lake on the west coast of the North Island, approximately 70 km south of Auckland ($37^{o}19'$S, $174^{o}41'$E). It has no inlet or outlet streams, and water supply is mainly from seepage through underground springs. The catchment has been converted to pasture, and the predominant land use is cattle farming.

By 1975, swimming, the aesthetic values of the lake, water abstraction and trout angling in Lake Parkinson had all been reduced by a deterioration in the lake's environment. Three introductions (nutrients from cattle, an exotic macrophyte, and an exotic fish species) were responsible for this degradation of the lake and several studies of its ecosystem between 1976-1979 (Mitchell and Rowe 1979, Mitchell *et al*. 1984, Rowe 1984a, Mitchell 1986) revealed how these factors interacted to affect the lake's uses (Fig. 1).

Direct access to the lake by cattle (and voidance of faecal material directly into the water) had steadily increased its nutrient load and contributed to its eutrophication (Fig. 1). The main symptoms of its advanced trophic status in 1976 were the minimum Secchi disc depths of 0.5-1.3 m in autumn and deoxygenation of the hypolimnion during periods of calm weather in summer. High levels of phytoplankton (peak chlorophyll *a* levels of 0.10-0.16 $g.m^{-3}$) occurred in autumn and contributed to the reduced water transparency at this time.

The exotic macrophyte *E. densa* had been introduced into the lake in the 1960's. *E. densa* can invade unmodified native vegetation (Tanner *et al*. 1986) displacing native species from much of their previous depth range (Howard-Williams *et al*. 1987). Prior to the introduction of *E. densa*, Lake Parkinson would have supported a native vegetation similar to other northern dune lakes (Tanner *et al*. 1986). However, by 1976, *Egeria* had replaced the comparatively low-growing stands of native plant species around the littoral zone and grew from depths of 5 m up to the lake surface. By 1976 aquatic macrophytes covered 77% of the lake's surface area reducing water circulation and trout access to much of the open water zone of the lake (Fig. 1).

Twenty-six rudd, a species of cyprinid fish, were (illegally) stocked into Lake Parkinson in 1971 for coarse fish angling. A self-recruiting population quickly developed and the beds of *E. densa* provided protection from predators, a food source, and a spawning substrate for the rudd. The weed beds thus contributed to the recruitment and production of a large population of rudd (authors unpublished data). As predators such as rainbow trout and shags (*Phalacrocorax carbo*) were ineffective at reducing rudd numbers, a relatively high density of rudd developed resulting in stunted growth and a preponderance of small fish (modal FL 16 cm) (Fig. 1). Sixty tench *(Tinca tinca*), another cyprinid fish, were also introduced into Lake Parkinson in 1971 and a self-recruiting population of these fish was present in 1976.

These introductions (nutrients from cattle, an exotic plant, and an exotic fish) collectively combined to reduce the use of Lake Parkinson for water abstraction and swimming (Fig. 1). Water intakes had to be positioned high enough in the water column to avoid deoxygenated water in the hypolimnion and the consequent corrosion of metal components by hydrogen sulphide, but low enough to avoid contamination of the water by surface blooms of algae or blockages from strands of aquatic weed. Swimming in the lake was no longer possible because of the surface-reaching growths of weed around the lake littoral zone. In addition, the visual impact of weed beds across much of the lake's surface, together with algal scums and the turbidity of the water in summer months combined to reduce the lake's aesthetic appeal. However, the major impact of the three introductions on lake uses was on the trout fishery.

Prior to 1976, the lake supported a small but productive put-and-take trout fishery but, by 1976, the fishery had completely collapsed. The growth rate of the rainbow trout (*Oncorhynchus mykiss*) present was low relative to that in other North Island lakes and the trout were generally smaller (FL < 40 cm). A reduction in trout habitat rather than food supply was responsible for this (Rowe 1984a). The open water zone where rainbow trout forage was restricted in area by the growth of *Egeria* around the lake margin. Habitat for trout was also reduced in depth. Reduced water transparency during summer resulted in less pelagic feeding near the water surface and more epibenthic feeding (Rowe 1984b) but, when surface water temperatures were too hot for trout (> 21°C) forcing them below the epilimnion, epibenthic feeding was restricted by low oxygen levels (<2.5 g m^{-3}) in the hypolimnion. The habitable water for trout was thus periodically restricted to a thin layer in the metalimnion, and the growth rate and survival of the trout was greatly reduced during summer months. Although the poor water quality and invasion of *Egeria* reduced trout production (Fig. 1), and although the weed beds interfered with fly fishing, the final blow to this fishery was provided by the invasion of rudd. These fish took lures more quickly than the trout did, so preventing anglers from hooking their target species (Fig. 1). As a consequence the trout fishery had collapsed by 1976.

BIOMANIPULATIONS IN LAKE PARKINSON

The restoration of Lake Parkinson proceeded in three phases. Initially the exotic macrophyte *Egeria densa* was eliminated by a herbivorous fish, the grass carp *Ctenopharyngodon idella*. In the second biomanipulation, all fish were removed from the lake. The success of this second operation depended on the prior removal of all aquatic plants, as these could have provided refugia for the fish. In the third biomanipulation, desirable fish species were stocked back into the lake to help re-establish its fishery values.

Removal of Weed

In 1976, *E. densa* occupied approximately half of the lake area of Lake Parkinson outside the beds of the emergent sedge *Eleocharis sphacelata,* which grew to depths of 1.5 m (Mitchell 1980). Potential control options included mechanical harvesting, herbicide application, dewatering, shading, deepening of the littoral zone, covering the littoral zone with a butyl rubber sheet, or biological control with grass carp. The first two options would have provided a level of control but this would have required on-going management. Dewatering has been used to eradicate weed beds in some water bodies but in Lake Parkinson, which is mainly spring fed and has no outlet, this would have been impracticable. Shading, deepening of the littoral zone, or covering the littoral zone bottom with a butyl rubber sheet would also have been costly and impracticable. However, grass carp had been successfully used to control weeds in a drainage ditch in New Zealand in 1973 (Edwards and Moore 1975), and these fish appeared to provide a novel and cost effective control method. As a result the use of grass carp to control aquatic macrophytes was trialed in Lake Parkinson, with fish being stocked incrementally between May 1976 and November 1977 to reach a final density of 44 fish ha^{-1} (Mitchell 1980). The grass carp fed mainly on the shallow water species first and by January 1979 had totally removed all *E. densa* and shoots of *E. sphacelata* (Mitchell 1980). The only remaining vegetation was a low-growing turf of *Glossostigma elatiniodes* and *Myriophyllum propinquum*, in water less than 2 m deep (Fig. 2).

Figure 2 Submerged vegetation profiles from Lake Parkinson before (March 1976), during (November 1977) and after (January 1979) weed removal by grass carp, and 5 years after removal of grass carp (August 1986). (After Mitchell 1980 and Tanner *et al*. 1986).

Regeneration of Native Plants

The grass carp were removed from Lake Parkinson in October 1981 (**See Removal of Fish**), but no attempt was made to re-vegetate the lake by introduction of native plant propagules. Despite this, a totally native aquatic vegetation, comprised mostly of *Potamogeton ochreatus* and *Nitella hookeri* (Fig. 2), was established by 1986 (Tanner *et al*. 1990). Thus the grass carp had successfully eradicated *E. densa* from Lake Parkinson.

The native macrophytes observed in 1981 were thought to have regenerated from seeds present in the lake-bed sediments (Fig. 3). The seed banks of Lake Parkinson were investigated by sediment coring at 1 m depth intervals along transects down the littoral zone (de Winton, unpublished data). Seed numbers within this lake's sediments were within the same order of magnitude as those from Bethell's Lake which has no indigenous vegetation. A 350 mm sediment core taken from the littoral zone in Lake Parkinson was divided into 50 mm deep increments and analyzed for variation in seed type and number (de Winton, unpublished data). The results showed that seed densities were high historically, and that suppression of seed production from native species corresponded in time with the invasion of *E. densa* (Fig. 4).

The species composition of the native plant community differed markedly from that of the seeds in the sediments (Fig. 3). Several charophyte species (especially *Nitella* *pseudoflabellata)* were much more prevalent in the seeds than in the aquatic vegetation. Such a difference may be caused by differing seed outputs, different seed dispersal mechanisms (Sculthorpe 1967), or by differences in the seasonal timing of shoot formation and growth between species.

Removal of Fish

The fish fauna in Lake Parkinson in 1980 included smelt (*Retropinna retropinna*), tench rudd (*Scardinius erythrophthalmus*), and common bullies (*Gobiomorphus cotidianus*). A stocked (i.e. non-reproducing) population of grass carp (*Cteropharyngoton idella*)was also present, the trout having died out as none were stocked into the lake after 1979. In order to restore the aquatic flora, grass carp had to be removed, and in order to restore the trout fishery, rudd had to be reduced or eliminated.

Several options were available for removing the unwanted fish species, and for restructuring the fish fauna. A regular netting programme would have reduced the grass carp and rudd populations, but would have had to have been repeated every 2 to 3 years to control rudd numbers. Piscivorous fish, such as pike *(Esox lucius*), keep rudd populations in balance in European and British waters. Although the introduction of pike was not contemplated here, other fish predators could have possibly achieved the same purpose. For example, deliberate stocking of eels has been used to selectively thin coarse fish in the USSR (Pihu and Maemets 1982). However, whereas New Zealand freshwater eels, particularly those over 40 cm long, are piscivorous, they are not selective and could be expected to prey on newly stocked trout and on bullies as well as on small rudd and tench. Brown trout (*Salmo trutta*) are more piscivorous than rainbow trout, and prey on rudd in lakes (Kennedy and Fitzmaurice 1974). However, brown trout are more difficult to catch by

Figure 3 Macrophyte cover (% of submerged species) and relative abundance of seeds (%) in the sediments of Lake Parkinson.

Figure 4 Depth distribution of plant seeds at 50 mm intervals in a 35 cm deep sediment core from Lake Parkinson.

angling and would reduce the production of the more desirable rainbow trout. This left a piscicide as the only feasible option for restructuring the fish populations.

Rotenone is a commonly used piscicide and was chosen for several reasons. Firstly, it has been successfully used in a number of other countries to eradicate fish in small ponds and lakes. A complete eradication was feasible in Lake Parkinson as the weed beds, which can provide a refuge for small young-of-the-year fish, had been eliminated and there were no inlet or outlet streams that could harbour fish, and from which re-population could occur. Secondly, because rotenone blocks oxygen uptake at the gills, affected fish move to the lake surface where oxygen levels are highest. They can be readily caught by dip netting at the lake surface when they are first affected by the rotenone and reversal of the toxic effect is possible by placing the fish in water without rotenone, or in water containing methylene blue. The grass carp and other desirable fish species could therefore be captured alive. Thirdly, at the concentrations needed to eradicate fish, rotenone is non-toxic to birds, cattle and humans so there was no reason why a water right for its use in Lake Parkinson should not be obtained.

Early spring was chosen as the best time for the application of rotenone. At this time the lake would be isothermal allowing mixing of the rotenone into deeper waters. Furthermore, this was the time of year when the concentration of suspended matter (mainly phytoplankton), which reduces the toxicity of rotenone, was minimal. A further important consideration was that the coarse fish species would not have spawned by spring, so there would be no eggs present to hatch and repopulate the lake after all juveniles and adults were eradicated.

Chemfish (containing 5% rotenone) was systematically applied to each part of the lake

Table 2 Fish introductions into Lake Parkinson after all fish were removed by rotenoning.

Species	Date	Number	Source	Outcome
Gobiomorphus cotidianus	Jul 86	150	Lake Tomorata	successful
Gobiomorphus cotidianus	Nov 86	500	Lake Tomorata	successful
Oncorhynchus mykis	Oct 88	100	Ngongotaha Hatchery	successful
Retropinna retropinna	Mar 91	1000	Waikato River	failed
Galaxias maculatus	Mar 91	5	Waikato river	failed
Retropinna retropinna	Apr 92	500	Waikato River	failed

surface in October 1981. Mixing into deeper waters was achieved by pumping the formulation down a weighted tube to a depth of 3 to 4 m, while the shallow margins of the lake were treated by backpack spraying. A final concentration of 3 mg l^{-1} of **Chemfish** (0.15 mg l^{-1} rotenone) was needed to affect cyprinid fish which are more resistant to rotenone than salmonids. To bioassay the effectiveness of mixing we placed caged goldfish (*Carassius auratus*) in the deepest part of lake. Within 2 to 3 hours of the application, fish started rising to the surface of the lake. All the grass carp still present in the lake were recovered, revived and successfully transported back to the hatchery. All other fish, including the goldfish used to bioassay the effectiveness of the treatment, died and were removed from the lake. Surveys by Scuba divers who criss-crossed the lake bottom revealed that few fish had sunk to the lake bottom, testifying to the efficiency of the teams of dip netters who removed the fish from the lake as they came to the surface. The census of the fish populations in Lake Parkinson, taken when it was rotenoned, revealed that this lake contained relatively few limnetic fish such as rudd and smelt, and a comparatively large population of benthic fish such as bullies and tench (Fig. 5).

Intensive fisheries surveys with gill nets, traps and fyke nets, carried out a week later, and two years after the rotenoning revealed no fish in the lake. In November 1983, the only aquatic vertebrates present were the tadpoles of *Littoria aurea* (Pullan 1983).

Restocking with Fish

Common bullies were successfully restocked into the lake to provide a forage fish for trout by the Auckland Acclimatization Society in 1986 (Table 2). A subsequent attempt to establish smelt from the Waikato River into this lake was unsuccessful. In 1989 rainbow trout were stocked into the lake to re-establish the put-and-take trout fishery. The growth rate of the trout stocked in 1989, and in later years, has consistently exceeded that recorded in 1976, with trout up to 2 kg being caught with reasonable consistency. Catch rates for trout are also acceptable for this type of fishery and the lake is now regarded as one of the more popular and successful put-and-take fisheries for anglers in the Auckland region (pers. comm. B. Wilson, Auckland-Waikato Fish and Game Council).

LESSONS FROM THE PLANT AND FISH BIOMANIPULATIONS

The biomanipulations carried out in Lake Parkinson revealed some important lessons for the management of problem plant and fish species in other small New Zealand lakes. Firstly, it is clear that the invasive oxygen weeds (*Egeria densa, Elodea canadensis, Lagarosiphon major, Ceratophyllum demersum*) can be controlled if not eradicated in such lakes. Grass carp have also removed all shoot material for *Hydrilla verticillata* in Elands Lake (Hawkes Bay) within two years of stocking and continued browsing pressure over the next two years is expected to remove all turions and tubers so preventing regeneration of this plant (Clayton *et al*. in prep). The removal of all aquatic plants from these two lakes has not had any major impact on water quality, nor has it led to algal domination as has occurred in other lakes (e.g. Lake Waihi in the Waikato) when macrophytes crash. Grass carp also virtually eliminated *Potamogeton ochreatus, Eleocharis sphacelata* and *Nitella hookeri* from the Waihi Beach Reservoir (Mitchell 1980) without any noticeable effects on water quality or native fish (Mitchell and Rowe 1979). Grass carp are therefore a useful tool for lake managers to restructure vegetation and eradicate problem species.

After the removal of all plants, and after all grass carp had been taken out of the lake, regeneration of native plants occurred naturally from seed banks in the sediments of Lake Parkinson. This natural regeneration of native plants can be expected in other lakes provided that seeds are still present and viable. In the case of Lake Parkinson *E. densa* had

Figure 5 Composition of the fish fauna in Lake Parkinson determined from the fish population census carried out after rotenoning in October 1981 (absolute values for fish number and biomass in brackets).

dominated the lake for 15 to 20 years, but viable seeds from native plants were still present in the lake sediments. Investigation of lake seed banks can reveal the species of plant present prior to exotic plant invasion, and indicate whether restoration of this native vegetation can be expected after weed removal by grass carp.

Eradication of exotic fish from lakes, particularly cyprinid species, is rarely possible because juvenile fish are often present in inlet or outlet streams which cannot be treated, or in dense vegetation and holes among rocks and submerged wood where the rotenone treated water does not penetrate. The successful eradication of all exotic fish species was achieved in Lake Parkinson only because of the prior removal of all weed and because of the lack of other refuges.

After the removal of all fish, and as regeneration of native plants occurred, a marked improvement in the water clarity of the lake was observed. Similar improvements in water clarity have been recorded in some small northern hemisphere lakes when all fish have been removed. This increase in water transparency following fish removal has been ascribed to the removal of the "top down" influence of planktivorous fish on zooplankton and hence phytoplankton. When planktivorous fish prey on large zooplankters, this can result in less efficient zooplankton browsing on phytoplankton, and increase phytoplankton densities which decreases water transparency (Northcote 1988). In lakes where this occurs, the removal or reduction of planktivorous fish leads to a reduction in phytoplankton densities and an improvement in water transparency. The improved water clarity following removal of all fish in Lake Parkinson suggests that planktivorous fish in this lake exerted a "top down" influence on zooplankton and hence on phytoplankton densities and water quality. Knowledge of such processes is important as it provides another way in which biomanipulation can be used to improve lakes, however, the identity of the planktivorous fish in Lake Parkinson is unknown.

Lacustrine smelt feed primarily on zooplankton in the limnetic zone of lakes and were thought to be the main planktivores in Lake Parkinson. However, the fish census revealed a relatively small population of smelt in this lake and a comparatively high population of tench and bullies (Fig. 5). These latter two species may have been more important planktivores than the smelt. Post larval bullies are thought to be planktivorous because of their small size (FL 10-25 mm) and the fact that they occupy the open water limnetic zone of lakes where zooplankton are abundant. Tench are generally benthic fish and can be expected to feed on benthic foods, however, all specimens examined, even quite large (FL >20 cm) ones, contained large quantities of the planktonic cladoceran, *Bosmina meridionalis.* Because of their planktivorous diet, their numerical dominance and their size, the tench may have had the greatest impact on the ecology of Lake Parkinson, even though the rudd were the main problem species.

FUTURE DIRECTIONS

The biomanipulation techniques outlined above are now to be used under contract to the Department of Conservation for the recovery of rare species of plant and native fish in Northland dune lake. Dwarf inanga (*Galaxias gracilis*), the only native fish adapted for living exclusively in Northland lakes, is now rare or extinct in 9 of the 13 lakes from which it has been recorded. These fish once thrived in Lake Waingata near Dargaville but became rare after the lake was stocked with rainbow trout. Although the trout are now gone, dwarf inanga are still rare so the subsequent invasion of the exotic macrophyte *Elodea canadensis* and/or a decline in water quality may have compounded the effects of trout predation on the dwarf inanga. This lake also supported a population of the vulnerable, endemic macrophyte *Hydatella inconspicua,* which is now apparently extinct. Seed bank studies have demonstrated the presence of *H. inconspicua* seed in Lake Waingata (Champion *et al*. 1993) raising the prospect of revegetation, either naturally from the seeds, or from transplants, once the *Elodea* is removed. The removal of *Elodea* by grass carp is therefore planned to help restore this lake and the two rare species in it. Such large-scale lake-manipulations are the only way in which important conservation questions, needed to determine which exotic species influence the natives, can be answered.

Many of the exotic problem species of plants and fish are introduced into lakes through ignorance and carelessness. Fragments of aquatic weeds are carried to other lakes by boat trailers, and we also suspect that fyke nets used by eel fishermen transfer weeds and even fish between lakes. Removal of exotic fish and plants from lakes would slow the spread of these species by removing a source of infection. This would be particularly useful in areas such as Northland, where most lakes are still free from introductions of exotic species. However, some introductions of exotic fish are deliberate and illegally made to propagate coarse fishing opportunities. Education programmes are needed to link such activities with "environmental degradation" and to label the perpetrators as "eco-vandals". The long term success of biomanipulations to remove exotic problem species and hence to restore lakes depends on public education programmes so that accidental and intentional acts do not compromise the restored lakes.

ACKNOWLEDGEMENTS

We thank the many people who have contributed to the work on Lake Parkinson, and in doing so have helped pioneer the use of plant and fish biomanipulation techniques for use in small New Zealand lakes. In particular we thank Mary de Winton for the use of her data and information on seed distribution in lake sediments.

REFERENCES

Champion, P.D., Clayton, J.S., de Winton, M.D. 1993. Study on *Hydatella inconspicua* seed germination and maintenance of habitat in the Northland dune lakes. NIWA Consulting Report No. DOC 001. Department of Conservation, Wellington.

Clayton, J.S., Champion, P.D., McCarter, N.H. In prep. Control of *Hydrilla verticillata* in a New Zealand lake using triploid grass carp. *Proceedings of the VIIIth International Symposium on Biological Control.*

Edwards, D.J. and Moore, E. 1975. Control of water weeds by grass carp in a drainage ditch in New Zealand. *New Zealand Journal of Marine and Freshwater Research 9:* 283-292.

Howard-Williams, C., Clayton, J.S., Coffey, B.T., Johnstone, I.M. 1987. Macrophyte invasions. In Viner, A.B. (Ed), Inland Waters of New Zealand. *DSIR Bulletin 241*, Wellington.

Kennedy, M. and Fiztmaurice, P. 1974. Biology of the rudd *Scardinius erythrophthalmus* (L.) in Irish waters. *Proceedings of the Royal Irish Academy Section B 74*: 245-303.

Mitchell, C.P. 1980. Control of water weeds by grass carp in two small lakes. *New Zealand Journal of Marine and Freshwater Research 14*: 381-390.

Mitchell, C.P. 1986. Effects of introduced grass carp on populations of two species of small native fishes in a small lake. *New Zealand Journal of Marine and Freshwater Research 20:* 219-230.

Mitchell, C.P. and Rowe, D.K. 1979. Report on grass carp (*Ctenopharyngodon idella*) trials in New Zealand. Report to the Fisheries Research Division, Ministry of Agriculture and Fisheries, Wellington, New Zealand.

Mitchell, C.P., Fish, G.R., Burnet, A.M.R. 1984. Limnological changes in a small lake stocked with grass carp. *New Zealand Journal of Marine and Freshwater Research 18*: 103-114.

Northcote, T.G. 1988. Fish in the structure and function of freshwater ecosystems: a top-down view. *Canadian Journal of Fisheries and Aquatic Science 45*: 361-379.

Pihu, E. and Maemets, A. 1982. The management of fisheries in Lake Vortsjarv. *Hydrobiologia 86*: 207-210.

Pullan, S.G. 1983. Parkinson Lake survey. Report to the Fisheries Management Division, Ministry of Agriculture and Fisheries, Auckland, New Zealand.

Rowe, D.K. 1984a. Some effects of eutrophication and the removal of aquatic plants by grass carp (*Ctenopharyngodon idella*) on rainbow trout (*Salmo gairdnerii*) in Lake Parkinson, New Zealand. *New Zealand Journal of Marine and Freshwater Research 18*: 115-127.

Rowe, D.K. 1984b. Factors affecting the foods and feeding patterns of lake-dwelling rainbow trout (*Salmo gairdnerii*) in the North Island of New Zealand. *New Zealand Journal of Marine and Freshwater Research 18*: 129-141.

Sculthorpe, C.D. 1967. *The biology of aquatic vascular plants*. Edward Arnold Publications, London.

Tanner, C.C., Wells, R.D.S., Mitchell, C.P. 1990. Re-establishment of native macrophytes in Lake Parkinson following weed control by grass carp. *New Zealand Journal of Marine and Freshwater Research 24*: 181-186.

Tanner, C.C., Clayton, J.S., Harper, L.M. 1986. Observations on aquatic macrophytes in 26 northern New Zealand dune lakes. *New Zealand Journal of Botany 24*: 539-551.

Viner, A.D. 1987. Inland Waters of New Zealand. *Department of Scientific and Industrial Research Bulletin 241*, Wellington.