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Fish exclosures versus intensive fishing to restore charophytes in a shallow New Zealand lake

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ABSTRACT

1. Disturbance by alien, herbivorous and benthivorous fish species has previously been found to limit the colonization of native charophytes in Lake Rotoroa, Hamilton. This paper compares two methods to reduce the impact of fish on charophyte establishment in this water body.

2. A 1 ha compartment of the lake was partitioned off and intensively fished by conventional netting methods. A total of 5115 fish, total weight 451 kg, was removed from the compartment over 17 months. Allowing for growth and reproduction within the sampling period, intensive netting reduced the original fish biomass by 86% from about 200 to 28 kg ha^{-1}.

3. Catfish (*Ameiurus nebulosus* Le Sueur) comprised 74% of the fish numbers and 57% of the fish biomass. Perch (*Perca fluviatilis* L.), shortfinned eel (*Anguilla australis* Richardson), rudd (*Scardinius erythrophthalmus* L.), tench (*Tinca tinca* L.), and goldfish (*Carassius auratus* L.) were present, in order of reducing abundance. These species are alien to New Zealand, with the exception of shortfinned eel.

4. Charophytes were transplanted inside and outside of the fished 1 ha compartment and their subsequent survival and establishment was monitored. Despite the extensive fish removal from the 1 ha compartment, repeat transplants inside it did not establish in the long term.

5. Outside of the 1 ha compartment, charophytes were also transplanted into nine 6.25-m^2 fish exclosures with netting sides to establish 'founder colonies' of charophytes. Within these small exclosures, charophytes established ($\geqslant$75% cover) within 1 yr; when five of the exclosures were removed, these unprotected plants survived and expanded over the next year.

6. This study shows that small exclosures can be used to establish founder colonies of charophytes in the presence of herbivorous and benthivorous fish, and that intensive fish removal is likely to be a less successful and more costly method to restore charophytes in lakes.

KEY WORDS: submerged vegetation; charophytes; biomanipulation; *Ameiurus nebulosus*; fish exclosures; lake restoration

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INTRODUCTION

Submerged vegetation provides benefits to freshwater environments. As well as improving habitat diversity and allowing a range of organisms to co-exist (Carpenter and Lodge, 1986), dense beds of submerged vegetation have positive effects on water quality. In isolating the sediment from the overlying water they reduce re-suspension of sediments and associated nutrients into the water column, assimilate excess nutrients, and provide refuge for phytoplanktivorous zooplankton (Scheffer *et al*., 1993; Barko and James, 1997). In shallow lakes, where submerged vegetation can grow over a large proportion of the total lake area, plants can have a profound impact on the water clarity of a lake. Shallow lakes tend to exist in one of two alternative stable states (Scheffer *et al*., 1993), with either abundant submerged vegetation that encourages and sustains clear water, or devoid of vegetation and with turbid water dominated by phytoplankton.

Locations of high human density often have shallow lakes that are prone to degradation and thus are often the target for restoration. Restoring the submerged plant community of a shallow lake can improve ecological values and water quality. Charophytes are one group of submerged plants that have desirable attributes for lake restoration: they are rapid, primary colonizers that originate from oospore banks, they form low-growing dense meadows, and they are cosmopolitan in their distribution (van den Berg *et al*., 1998). Therefore, charophytes are often the target plant group in lake restoration projects.

Biomanipulation of entire fish communities in lakes has been carried out extensively in Europe to rehabilitate degraded lakes (Gulati and van Donk, 2002), and usually aims to reduce the impact of benthivorous or herbivorous fish by their removal, or to reduce the numbers of zooplanktivorous fish by stocking piscivores. A requirement for the sustainability of these biomanipulations is the establishment or regrowth of submerged vegetation that can maintain improvements in water quality (Perrow *et al*., 1997).

An alternative method to allow plant re-colonization is to establish founder colonies (Vermaat *et al*., 1990; Smart and Dick, 1999). This is achieved by providing 'safe-sites' where conditions are suitable for plant growth in restricted or defined areas of a lake. Once plants have become established in dense colonies they may become self-sustaining and spread over larger areas of the lake.

In New Zealand, interest in fish manipulation is increasing following the introduction and spread of alien freshwater fish from the northern hemisphere, particularly with regard to the impact of alien fish on submerged vegetation and lake restoration initiatives. Lake Rotoroa, Hamilton, has a long history of alien fish introductions. Before European colonization of the area in the mid-1800s, the lake's native fish community probably consisted of shortfinned eel (*Anguilla australis* Richardson), a sparse population of longfinned eel (*Anguilla dieffenbachii* Gray), common bullies (*Gobiomorphus cotidianus* McDowall), and common smelt (*Retropinna retropinna* Richardson). In 1907, European perch (*Perca fluviatilis* L.) were introduced by sport fishery managers, and common smelt subsequently disappeared. Goldfish (*Carassius auratus* L.) and mosquitofish (*Gambusia affinis* Baird and Girard) were introduced at indeterminate times, possibly as aquarium releases, and brown bullhead catfish (*Ameiurus nebulosus* Le Sueur) first appeared in catches in low numbers in 1976. Rudd (*Scardinius erythrophthalmus* L.) were introduced at some time between 1978 and 1980, and subsequently exploded in numbers. Tench (*Tinca tinca* L.) were released by the sport fishery managers in 1989 and 1990 (Hicks, 2003).

The vegetation in Lake Rotoroa has also undergone recent changes. The lake once had a diverse community of native aquatic macrophytes, but this was largely replaced by Hydrocharitacean weeds alien to New Zealand. *Lagarosiphon major* (Ridl.) Moss ex Wager from South Africa was introduced sometime after 1950, and was itself largely replaced by *Egeria densa* Planchon from South America. In 1987, a mixture of Hydrocharitacean weeds and native charophytes covered 80% of the lake area to a maximum depth of 5 m (Tanner *et al*., 1990). In 1989, the vegetation rapidly declined leaving the lake devoid of submerged vegetation (Clayton and de Winton, 1994); this collapse coincided with abundant rudd populations (Wise, 1990). Over recent years, submerged vegetation has made a slow recovery, so that between 2000 and 2003, charophyte beds occupied between 15 and 21% of the lake area to a maximum depth of 1.9 m (de Winton *et al*., 2000; 2003a). However, this recovery did not occur over one-third of the lake bed that otherwise had a suitable depth range.

Lake *et al*. (2002) showed that rudd graze charophytes preferentially; furthermore, alien fish hindered charophyte establishment in devegetated areas of Lake Rotoroa by direct disturbance or grazing (de Winton *et al*., 2002). The authors hypothesize, therefore, that recovery of the charophyte vegetation within the lake is restricted by the current fish population. This paper compares the outcome of fish exclosures and intensive fishing to promote charophyte establishment in Lake Rotoroa, Hamilton.

METHODS

Study site

Lake Rotoroa (37° 48′ S; 175° 16′ E) is a small (54 ha), eutrophic water-body located within the city of Hamilton (New Zealand) and managed by the Hamilton City Council as a park reserve. The lake is shallow, with > 54% of its area < 2 m deep (Figure 1). The submerged vegetation is currently dominated by the charophyte, *Chara australis* Brown.

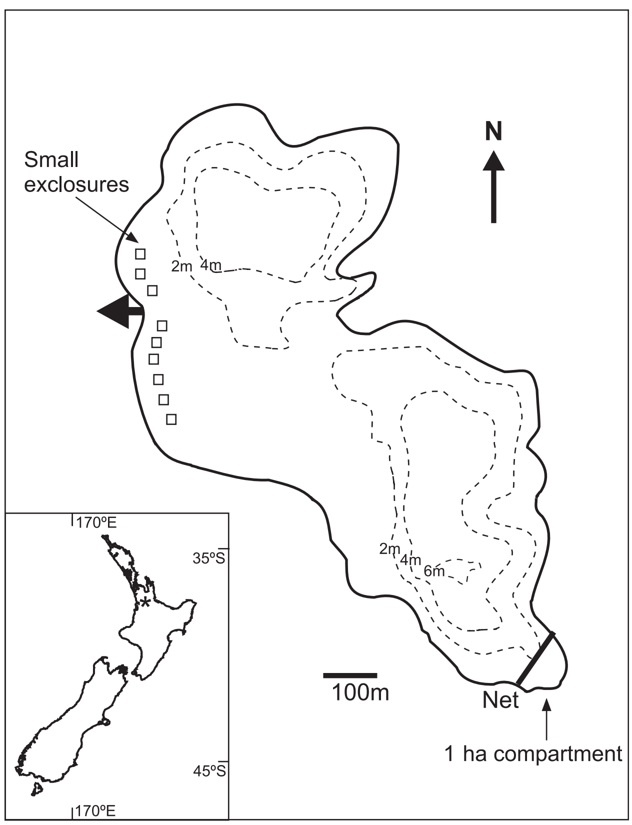

Figure 1. Map of Lake Rotoroa, Hamilton, New Zealand, showing the location of the nine small exclosures and a 1 ha, intensively fished compartment. Bold arrow to the left indicates outflow.

Small exclosures

Nine exclosures 6.25 m^2 in area were positioned in water *ca* 1.0 m deep where submerged vegetation was absent (Figure 1). An exclosure consisted of a square, floating frame with attached netting (7 mm aperture) extending from the surface to the lake bed. Disturbance during deployment was sufficient to exclude large fish from the exclosure.

Plugs of dense ($\geqslant$75% cover) charophytes (*C. australis*) and sediment 0.4 m^2 in area were collected from vegetated areas of the lake and transplanted into all exclosures by scuba divers. One year later, five of the exclosures were removed and the areas were marked with buoys. Charophyte cover was recorded regularly by scuba divers, as percentage cover in the exclosures.

Intensive fish removal from a 1 ha compartment

A 1 ha compartment was constructed by deploying a net 150 m long across a bay at the southern end of the lake (Figure 1). The net (10 mm aperture) was supported by a floating boom extending *ca* 70 mm above the water surface; its lower edge was anchored 200–300 mm into the soft sediment, or where the sediment was hard it was weighted with a continuous line of bricks. The integrity of the net was checked at regular intervals by scuba divers. Marginal vegetation, consisting of reeds (*Baumea* spp.), yellow flag iris (*Iris pseudacorus* L.) and water lilies (*Nymphaea* spp.) occupied approximately one-third of the area within the compartment but no submerged vegetation was present.

Water clarity was measured within the 1 ha compartment and nearby in the open lake at eight intervals over 13 months with a Secchi disc. Differences in water clarity were identified by a *t*-test comparison.

Fish were removed from the compartment on 13 occasions between 18 December 2000 and 3 May 2002 with 7–29 5 mm mesh fyke nets with 3 m long leaders. Trap nets and gill nets were also used, but with limited success. Nets were usually set for about 24 h then emptied and reset over 1–4 successive days on each of these occasions. The total effort was 989 net nights over 39 days.

All fish removed from December 2000 to the end of February 2001 were weighed and measured for length. Subsequently, a subsample of eels was weighed and measured, and for other fish only weight or length was recorded and data estimated from weight–length regressions. Growth of catfish was estimated from cohort analysis by classifying each mode to its brood year, i.e. the year of egg hatch. Growth was estimated from differences between means for each successive mode within a brood year.

Within the 1 ha compartment, two methods of charophyte transplant were used:

(1) In April and October 2001 plugs of charophytes (as for small exclosures) were placed at 10 m intervals along the 1.2 m bathymetric contour. Plant cover was checked 1 month after the April transplant and 6 months and 18 months after the October transplant.
(2) Twenty-four pots with pre-established plants were positioned 1.2 m deep at two sites within the compartment, with a further 24 pots placed at two sites in the adjacent open lake. Half of the pots at each site were covered by small cages (0.14 m^2 in area with 15 mm mesh aperture) to exclude fish disturbance. Transplants were made in October 2001 and February 2003. After 2.5 months, the October 2001 transplants were harvested and dried (80°C) to constant weight ($\pm$ 0.001 g). For the February 2003 transplants, plant cover was assessed 10 days and *ca* 3 months later. This short time between transplantation and cover assessment was necessary because of the rapid disappearance of unprotected plants.

RESULTS

Small exclosures

One year after the initial transplants (April 2001), mean charophyte cover was $\geqslant$75% within the exclosures (Figure 2), whereas charophyte cover adjacent to the exclosures was $\leqslant$5%. After almost 2 yr

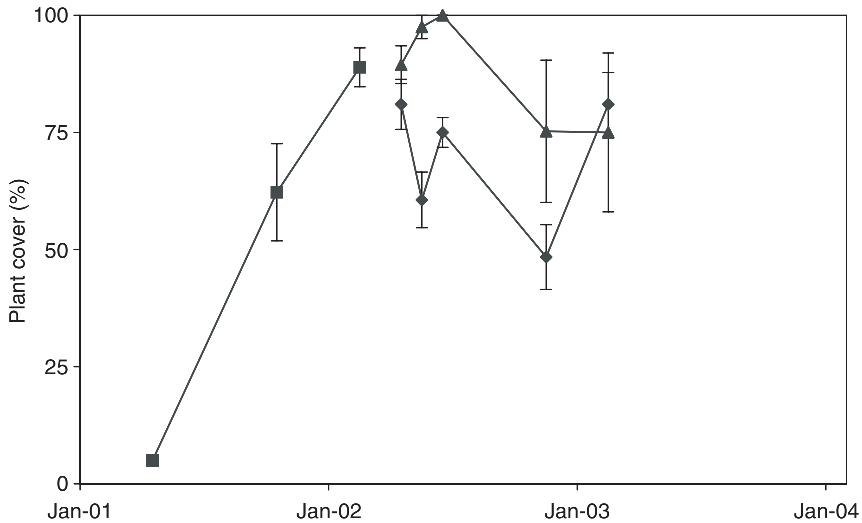

Figure 2. Mean charophyte cover (% area) over time within small (6.25-m^2) exclosures (■ $n = 9$, ▲ $n = 4$) and where the exclosures were removed (◆ $n = 5$). Vertical bars represent 1 standard error of the mean.

Table 1. Total number and biomass of fish removed from a 1 ha compartment in Lake Rotoroa, New Zealand, using a range of netting methods

Species	Total number	Total biomass (kg)	Proportion of total (%)	
			Number	Biomass
Catfish	3801	256.9	74.3	56.9
Perch	651	26.7	12.7	5.9
Shortfinned eels	425	149.2	8.3	33.1
Rudd	192	7.1	3.8	1.6
Tench	32	9.2	0.6	2.0
Goldfish	13	2.1	0.3	0.5
Total	5115	451.3		

(February 2003), charophyte cover inside the remaining exclosures was ⩾75%. For those exclosures removed after 1 yr, charophytes persisted at ⩾75% cover (Figure 2) and had also colonized areas outside the initial exclosure area.

1 ha compartment

A total of 5115 fish with a combined weight of 451 kg was removed from the 1 ha compartment. Catfish comprised 74% of the catch numerically, and 57% of the biomass (Table 1). Shortfinned eel comprised only 8% of the captured fish numerically, but made up 33% of the biomass. Alien species in the catch included goldfish, rudd, and tench (Table 1), whereas the only other native species captured was common bullies.

Sequential catches showed that despite the large number of individuals removed, netting did not eradicate any fish species. After initial high catch rates up to 22.1 fish per net per night, catches of catfish in particular were almost as high numerically in April and May 2002 (1.9–5.7 fish per net per night) as they were in January 2001 (1.2–6.1 fish per net per night). Catches over successive days showed localized depletion within each 3–6 day netting period (Figure 3). Considering only fish caught up to, and including, August 2001 (the last fishing event before spawning), a total of 221 kg of fish was removed. Given that a small percentage of this biomass was growth within the period, it may be assumed that the original biomass of fish was at least 200 kg ha^{-1}. The CPUE for the netting in December 2000 for all species combined was 2.32 kg per net per night, and this was reduced to 0.32 kg per net per night by May 2002, suggesting that sequential fish removals had reduced fish biomass by 86%. The original fish biomass was therefore reduced from about 200 kg ha^{-1} to about 28 kg ha^{-1}.

There was a substantial size reduction in catfish in response to the removal; the modal size was 220–230 mm in December 2000, but was 100–110 mm in May 2002. Calculations of the growth of catfish from cohort analysis showed that fish of age 0, age 1 and age 2 at the end of the 2002 summer were 12–16% larger in size (Mean FL) than equivalent aged fish at the end of the 2001 summer.

The charophyte plugs transplanted within the 1 ha compartment decreased in number and were reduced in cover. One month after the April 2001 transplant, only fragments of plants could be found. After 18 months, only a single patch measuring 1 m^2 of 10% cover was located.

Two and a half months after the October 2001 transplant of plants in pots, the biomass of un-caged plants within the 1 ha compartment averaged 72% of the mean biomass of caged plants (Figure 4). In contrast, the average biomass of transplants placed in the adjacent open lake was equivalent to 4% of the caged plants (Figure 4). Nearly 3 months after the February 2003 transplant, the caged plants had expanded to occupy the entire cage (100% cover), with plants inside the compartment extending approximately 20 cm outside the cage (*ca* 0.5 m tall). At one site within the compartment, un-caged plants were a similar size and cover to the caged plants, but at the other site the un-caged plants had disappeared after 10 days. Un-caged plants placed in the adjacent open lake were <50 mm tall and $<10\%$ cover.

Mean Secchi disc depth over 13 months was significantly higher ($P = 0.026$) in the adjacent open lake (mean 1.87 m, range 1.6–2.2 m) than in the 1 ha compartment (mean 1.58 m, range 1.3–1.75 m).

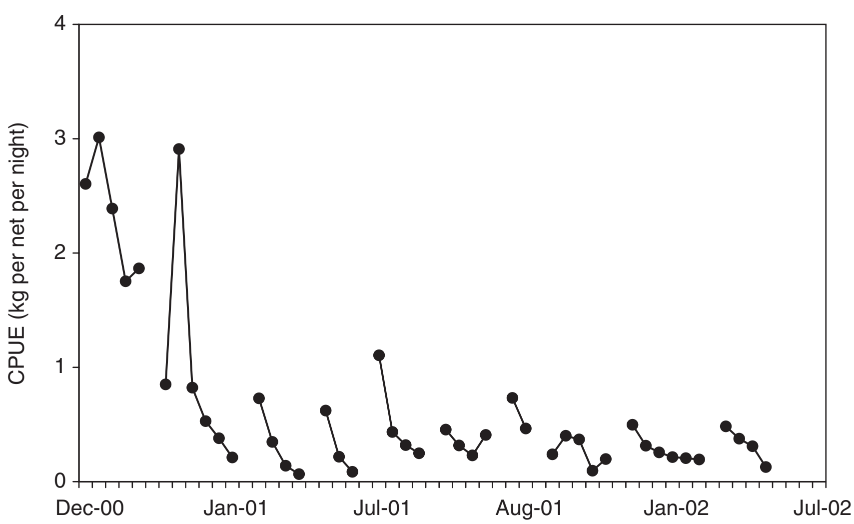

Figure 3. Catch per unit effort (CPUE) of fish removed from the 1 ha compartment in Lake Rotoroa, New Zealand. Note, single day fishing periods were combined when they were separated from other periods by 1 week or less.

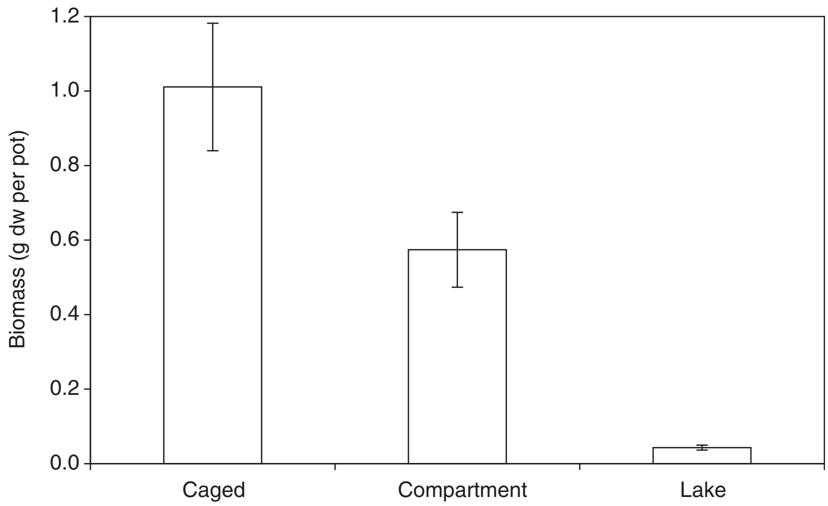

Figure 4. Biomass of transplanted charophytes (g dw per pot) after 10 weeks within a 1 ha, intensively fished compartment in Lake Rotoroa ($n = 12$) and in the adjacent lake ($n = 12$), relative to all caged plants ($n = 24$). Vertical bars represent 1 standard error of the mean.

DISCUSSION

The results of these trials present further evidence of impacts of fish alien to New Zealand, here through reduced colonization of charophyte vegetation in Lake Rotoroa. Alien fish, particularly catfish, dominated the catch from the 1 ha littoral compartment of the lake in both number and biomass. When unprotected from fish, the survival and growth of charophyte transplants was inferior to that of transplants protected by small exclosures or cages. Similar evidence of direct impacts by fish on plants has been found by other workers (Crivelli, 1983; Ten Winkel and Muelemans, 1984; Wright and Phillips, 1992).

The outcome of the two approaches, i.e. the use of small exclosures versus intensive fishing to enhance the establishment of charophytes, probably reflects a complex relationship between fish disturbance and charophyte productivity, growth, and colonization. For example, one conceptual model demonstrates that the relationship between intensity of fish disturbance and plant density is unlikely to be smooth, and that critical breakpoints, or thresholds, for plant density will exist at certain intensities of fish disturbance (Scheffer, 1998; de Winton *et al.*, 2003b). The use of small exclosures to establish founder colonies recognizes that a higher plant density may be sustainable in the presence of fish disturbance, but at a lower plant density the equivalent fish disturbance can cause a substantial biomass reduction. In contrast, intensive fishing seeks to reduce the intensity of fish disturbance, and so reduce the density of plants necessary to be sustainable.

Establishment of founder colonies of charophytes within small fish exclosures was the most successful method to enhance charophyte distribution in Lake Rotoroa. These founder colonies persisted over 1 yr and were beginning to expand. In the intensively fished compartment of the lake, the performance of un-caged versus caged charophyte transplants suggested that fish disturbance could be reduced to a level that was compatible with charophyte survival in the short term. In the longer term, however, the fish population recovered sufficiently to affect the survival and expansion by the plugs of charophyte transplants. Although water clarity was reduced within the 1 ha compartment, conditions were still suitable for charophyte survival as shown by the growth of caged plants.

The cause of reduced water clarity within the compartment is unknown but there are two likely possibilities. First, whereas eight small storm-water inflows are located around the lake perimeter, two of these empty into the 1 ha compartment. It is possible that the net acted as a barrier and prevented rapid mixing of turbid inflows with the rest of the lake. Second, the compartment may have presented more favourable habitat for the benthivorous catfish than the remainder of the lake, as suggested by their persistence despite intensive removal, and their bioturbation could have reduced water clarity.

Grazing by herbivorous waterfowl is known to cause significant disturbance to submerged vegetation (Lauridsen *et al.*, 1994), but is unlikely to be a significant factor in this case. de Winton *et al.* (2002) reported that counts of resident swan (*Cygnus atratus*) and coot (*Fulica atra*) on Lake Rotoroa over the previous 5 yr were one or two orders of magnitude lower than the waterfowl densities suggested by Lauridsen *et al.* (1994) to affect macrophyte presence.

Likewise, the small exclosures were unlikely to have enhanced charophyte establishment through reduced wave exposure. Previously, charophyte transplants to sites across a gradient of exposure within the lake did not show differences in growth, whilst the establishment of charophyte germlings was highest at the most exposed site (de Winton *et al.*, 2002). Sediment characteristics in the vicinity of the two types of exclosures were also similar, at 15% and 20% organic matter respectively, and comprising 89% silt/clay ($<63\,\mu m$) particle fraction (de Winton *et al.*, 1999).

It may be concluded that differing levels of fish disturbance created the difference in charophyte establishment between the two types of exclosures tested, and that the fishing methods and intensity adopted in the 1 ha compartment were insufficient to reduce the fish population to a critical threshold to allow charophyte transplants to grow and expand. On the contrary, it is likely that removal of large adult catfish allowed increased survival and growth of younger catfish, so despite the removal of 3801 catfish, catch rates at the end of the experiment persisted at about 5 fish per net per night. This is a classic density-dependent response of increased growth and survival of young fish to the removal of large, old adults. The high proportion of the fish biomass in large adults at the start of fishing suggests that the catfish population was probably near carrying capacity (e.g., Johnson, 1994).

Fish populations in finite environments such as lakes, or indeed compartments within lakes, are usually limited by competition for resources, such as food (Romare, 2000). When the abundance of cyprinid fish is reduced, competition pressure is lowered and the recruitment of year classes improves (Hansson *et al.*, 1998). This occurred within the 1 ha compartment in Lake Rotoroa, confounding efforts to lower fish biomass further. In addition, piscivores (adult perch and shortfinned eels) were removed from the compartment, and therefore survival of juvenile fish could have been improved by their absence. For example, Ludgate and Closs (2003) reported that survival of perch young-of-the-year increased when adult perch were removed from small lakes. Another factor limiting the success of the fish removal effort was the presence of significant areas of marginal vegetation that made netting less effective.

Fish removal by netting has been used to reduce fish populations in Europe in successful biomanipulation projects. For example, in Lake Wolderwijd, Netherlands (2650 ha, mean depth 1.5 m), $205\,kg\,ha^{-1}$ of fish (mainly bream; *Abramis brama* L. and roach; *Rutilus rutilus* L.) was reduced to $45\,kg\,ha^{-1}$ by fishing with large seines, trawls and fykes. Although this intensive fishing had only a temporary effect on water clarity, the area of charophyte vegetation increased 16-fold over the subsequent 2 yr (Meijer and Hosper, 1997). That project demonstrated that fish populations can successfully be reduced using net-based fishing, provided that sufficient resources are available. Various combinations of nets, electro-fishing and lake de-watering have also been used to remove fish in successful biomanipulation projects (van Donk *et al.*, 1989; Meijer *et al.*, 1990; Lauridsen *et al.*, 1994). Other methods, such as use of the piscicide, rotenone, has also been used to reduce or eradicate fish populations (Hanson and Butler, 1994; Rowe and Champion, 1994). With improved fish removal methods, such as the use of rotenone or a greater netting effort, and site modification (i.e. removal of marginal vegetation), intensive fishing could remain a viable option for establishing submerged vegetation in water bodies such as Lake Rotoroa.

Based on estimated fish abundance before and after removal, fish reduction was similar to that in Lake Wolderwijd. However, this reduction did not result in widespread charophyte re-establishment in the 1 ha compartment and so was not considered successful. This difference in success may not be surprising given that there are many other factors, in addition to fish abundance, that can govern the success of biomanipulation, such as the fish species present, lake nutrient levels and sediment characteristics.

Degraded lakes are frequently the targets of whole lake restoration attempts. One challenge is to overcome direct impacts on vegetation recovery by abundant benthivorous and herbivorous fish. This study demonstrates that small-scale fish exclosures may be successful in allowing founder colonies of charophytes to establish and expand. The advantage of this approach is that considerably fewer resources are required to allow re-establishment to occur, and despite being of a small scale, once dense, suitably sized beds are established, they may persist and expand.

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