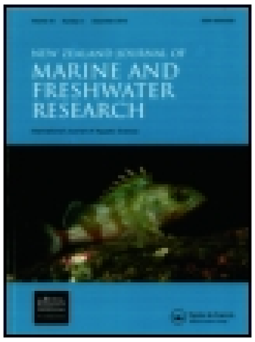

New Zealand Journal of Marine and Freshwater Research

ISSN: 0028-8330 (Print) 1175-8805 (Online) Journal homepage: http://www.tandfonline.com/loi/tnzm20

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To cite this article: Chris C. Tanner , Rohan D.S. Wells & Charles P. Mitchell (1990) Re-establishment of native macrophytes in Lake Parkinson following weed control by grass carp, New Zealand Journal of Marine and Freshwater Research, 24:2, 181-186, DOI: 10.1080/00288330.1990.9516413

To link to this article: http://dx.doi.org/10.1080/00288330.1990.9516413

New Zealand Journal of Marine and Freshwater Research, 1990, Vol. 24: 181–186
0028–8330/2402–0181 $2.50/0

Re-establishment of native macrophytes in Lake Parkinson following weed control by grass carp

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Abstract The macrophyte communities present in Lake Parkinson (37°19′S 174°41′E), a 1.9 ha eutrophic sand-dune lake, are described 5 years after removal of grass carp (*Ctenopharyngodon idella* Val; 218 kg ha^{-1}). Eradication of the adventive submerged species *Egeria densa* Planchon (dependent on vegetative reproduction from stem fragments) as a result of grass carp stocking led to the re-establishment of a predominantly native macrophyte association from seeds, spores, and buried rhizomes after grass carp removal. Emergent *Eleocharis sphacelata* R. Br. re-established around the lake margins and throughout the lake's shallow south-western arm, whereas submerged communities domin ated by *Potamogeton ochreatus* Raoul and *Nitella hookeri* A. Br. grew to a maximum depth of 5 m.

Keywords grass carp; aquatic macrophytes; revegetation; eradication; weed control; native plants

M89043
Received 25 September 1989; accepted 27 March 1990

INTRODUCTION

Lake Parkinson, a small (1.9 ha) eutrophic sand-dune lake near Waiuku, South Auckland (37°19′S, 174°41′E), was one of two New Zealand lakes where field evaluation of grass carp (*Ctenopharyngodon idella* Val.) was undertaken to assess their environmental impact and potential to control aquatic weeds (Rowe & Schipper 1985; Rowe & Hill 1989). The lake is formed in stabilised dunes of black titano-magnetite iron-sands and has a grazed, predominantly pastoral catchment. Declining water quality, introduction of rudd (*Scardinius erythrophthalmus* L.), and development of weed problems had down-graded the trout fishery in the lake during the early 1970s (Rowe & Schipper 1985). *Egeria densa* Planchon had come to dominate the submerged vegetation, forming dense beds over 55% of the lake area deeper than 1 m, often reaching to the water surface. *Egeria* is an adventive species in New Zealand, first collected from the Waikato River in 1946 (Mason 1960). Only male plants have been recorded in the country making this species dependent on vegetative propagation from apical and bud-bearing stem fragments (Mason 1960; Johnstone et al. 1985). It was probably introduced to Lake Parkinson during the early 1960s (Mitchell 1977) and presumably displaced a native macrophyte assemblage as has occurred in many other North Island lakes (Coffey 1975; Tanner et al. 1986).

Incremental stocking of 60 grass carp in the lake (14–218 kg live weight ha^{-1}) between May 1976 and November 1977 led to the apparent eradication of *Egeria*, and a >99% reduction in the cover and biomass of other macrophytes in the lake after the 1977/78 summer (Mitchell 1977, 1980, 1981). Grass carp numbers were then gradually reduced by trammel netting and seining between March 1978 and June 1979 (Mitchell 1980, 1981) with the last 19 fish recovered using rotenone in October 1981 (Penlington 1982; MAF 1982). Changes in the limnology and fish population of the lake associated with grass carp stocking have been studied by Mitchell et al. (1984) and Rowe (1984).

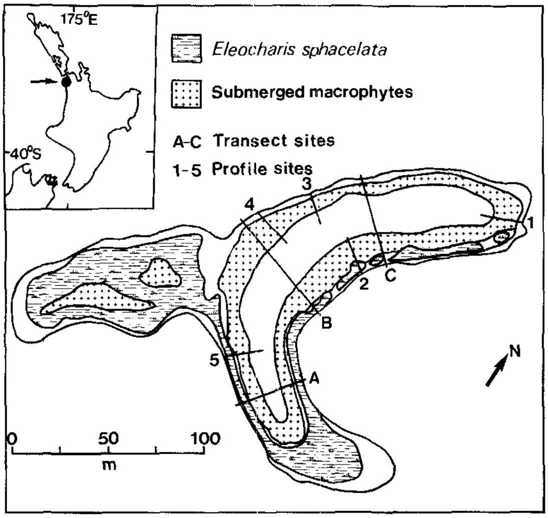

Fig. 1 Map of Lake Parkinson, showing sampling sites and the extent of weed beds during the summer of 1986/87. Inset shows the lake's location in the North Island of New Zealand.

The only aquatic macrophyte species recorded in March 1978, 2 years after grass carp stocking, were occasional growths of *Glossostigma elatinoides* Benth. in water <0.4 m deep and *Myriophyllum propinquum* A. Cunn above high-water level, and ungrazed emergent species remaining in exclosure areas (Mitchell 1980, 1981). However, regeneration of species which grow readily from seed or buried rhizomes was noted in shallow water during the winter of 1978. This was attributed to decreased grass carp feeding rates as water temperatures dropped to 10°C.

By the spring of 1978, *Myriophyllum propinquum* was the dominant species from 0 to 0.3 m depth with *Potamogeton cheesmanii* A. Benn., *Otellia ovalifolia* (R. Br.) Rich., and *Glossostigma elatinoides* common from 0.2 to 0.4 m. Occasional plants of *P. cheesmanii* and *P. ochreatus* Raoul were present in deeper water and numerous *Eleocharis sphacelata* R. Br. seedlings were noted growing among the decomposing remains of old rhizomes. *Paspalum distichum* L., one of the first species removed by grass carp grazing, invaded the shallow lake margins from the surrounding pasture as water levels declined during the 1978/79 summer. Although grass carp numbers had been reduced from 44 to 18 ha^{-1}, submerged macrophytes (apart from low-growing turfs of *Glossostigma*) were again eliminated as rising water temperatures (25°C) promoted increased feeding activity.

The present paper describes the macrophyte vegetation found in Lake Parkinson in the spring and summer of 1986/87, nearly 9 years after *Egeria* was last recorded in the lake and 5 years after removal of grass carp from the lake. Comparison is made with previous vegetation records.

METHODS

The macrophytes in Lake Parkinson were described at four sites (Sites 1–4, Fig. 1) on 11 August 1986 and three sites (Sites 3–5) on 14 January 1987 using a qualitative profile diving technique (Method 2, Clayton 1983a, 1983b), in which the species present, their depth ranges, and height and cover estimates (1–6 scale, see Table 1) were recorded along 1 m wide transects. Quantitative descriptions were also made along submerged transect lines at Sites 1 and 2 on 14 January 1987; depth, species presence, and estimates of height and cover were recorded within 0.1 m^2 quadrats at 1 m intervals (Method 3, Clayton 1983a). Further vegetation descriptions were made at 1 m intervals along surface transects for each shore of three permanently marked reference sites (A–C, Fig. 1) on 19 November 1986 using the method previously employed by Mitchell (1980). Water depth, species presence, and height were recorded while diving down graduated sounding lines.

Data from all sites and visits (a total of 15 datasets) were combined to calculate the percentage frequency of each species in the lake. An estimate of the proportion of vegetated area occupied by each species was calculated assuming a uniform bottom gradient for each sampling profile: the frequency of each species was multiplied by the average proportion of the vegetated depth range it occupied and its average percentage cover (Clayton 1983b).

Additional observations of shallow and emergent vegetation were made by wading around the perimeter and across the lake's south-western arm, and a series of oblique photos were taken from the hill to the west of the lake. In January 1987, three 1 m^2 biomass quadrats were collected using SCUBA near Site 2 in dense surface-reaching beds of *Potamogeton ochreatus* growing in 2.5 m deep water. Samples were weighed after free-draining in a mesh bag and a subsample (~200 g) dried in a forced air oven at 80°C for 48 h to determine dry weight. Secchi depth and a dissolved oxygen and temperature profile were recorded (Yellow Springs Instruments, Model 54A oxygen meter, Ohio, USA) in the centre of the

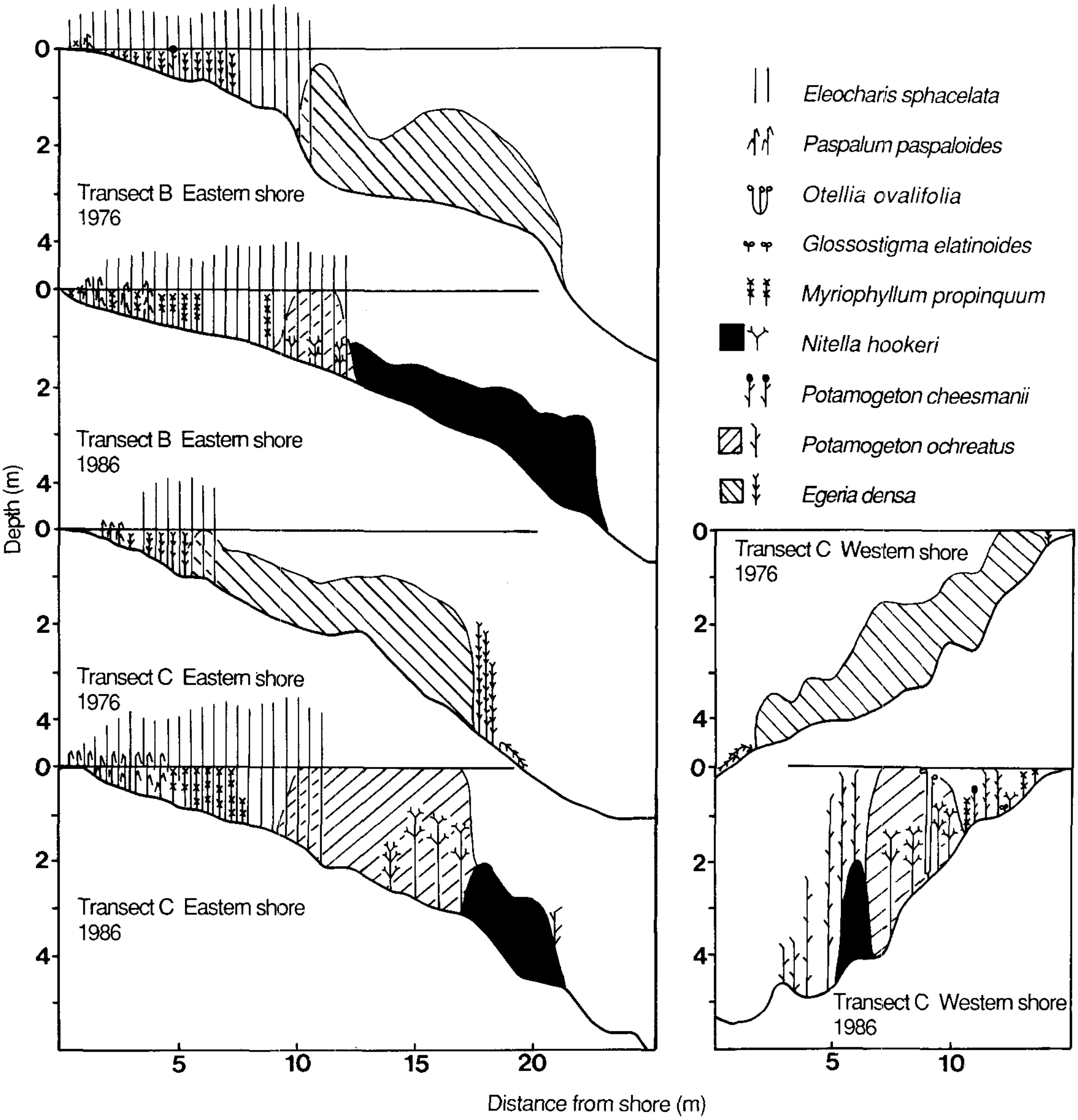

Fig. 2 Representative transverse profiles of aquatic vegetation recorded along permanent transects in Lake Parkinson in March/April 1976 before grass carp introduction, and in November 1986, 5 years after their removal.

lake opposite Site 2. Herbarium specimens have been lodged in the University of Waikato herbarium, Hamilton.

RESULTS

The area of the lake colonised by macrophytes is indicated in Fig. 1, with the species present, their maximum and average depth ranges, and cover estimates summarised in Table 1.

Submerged macrophytes

The submerged vegetation was dominated by tall growths of the native species *Potamogeton ochreatus* (maximum height 4.5 m) and *Nitella hookeri* A. Br. (maximum height 2.5 m). Fig. 2 shows the variable development of *Potamogeton* and *Nitella* assemblages along representative vegetation profiles in the lake and compares these with the *Egeria*-dominated vegetation recorded at the same sites in

1976 before grass carp stocking (redrawn from data of Mitchell 1980). During the present study, *Nitella hookeri* was generally the deepest-growing plant with a maximum lower depth limit of 5 m recorded. It was often present as a low cover understorey beneath *Potamogeton* growths at mid depths, but had a >95% cover in deeper water. *Potamogeton ochreatus* was recorded at depths of 0.3–4.9 m, commonly forming dense growths between 1.2 and 3.5 m depth. Biomass figures of 264–313 g dry weight m^{-2} were recorded in 2.5 m deep surface-reaching stands.

Chara corallina Kl. ex Willd em. R.D.W. was found occasionally in shallow water (average 0.9–1.3 m) in the main body of the lake, but was abundant in association with *Myriophyllum propinquum* and *Otellia ovalifolia* in shallow pools within *Eleocharis* stands in the south-western arm of the lake. Low-growing submerged turfs of *Glossostigma elatinoides* and *Myriophyllum propinquum* occurred on the sandy northern shores of the lake devoid of *Eleocharis*. A low cover (average <5%) of *Otellia ovalifolia* was present in shallow water in nearly half of the sampling sites, with occasional surface-floating leaves.

In January 1987 a marked reduction in the cover and height of *Nitella* was noted at depths greater than 3 m compared with observations in August and November 1986. Very low levels of light were present below this depth (SCUBA observations) and plants growing in the deoxygenated hypolimnion showed blackened coatings on their surfaces. Weak thermal stratification and a secchi depth of 1.6 m were noted at this time (Fig. 3).

Emergent and floating macrophytes

Eleocharis sphacelata dominated the emergent vegetation forming tall stands (maximum 3.3 m) over 30% of the total lake area. It was abundant throughout the south-western arm of the lake and formed a nearly continuous fringe to an average

Table 1 Aquatic vegetation of Lake Parkinson recorded during the spring and summer of 1986/87; species inventory, frequency of occurrence, maximum and average depth range and cover, maximum height, and estimated proportion of vegetation. Cover Scale: 1, 1–5%; 2, 6–25%; 3, 26–50%; 4, 51–75%; 5, 76–95%; 6, 96–100%. + Present outside sampling sites. – Not recorded.

	Percentage frequency (*n* = 15)	Maximum depth range (m)	Average depth range (m)	Maximum cover[1]	Average cover[1]	Maximum height (m)	Estimated proportion of vegetated area[2] (%)
Submerged							
Charophytes							
Chara corallina Kl. ex Willd em. R. D. W.	27	0.5–1.7	0.9–1.3	3	2	1.0	<1
Nitella hookeri A. Br.	100	1.2–5.0	2.1–4.3	6	3	2.5	22
Tracheophytes							
**Callitriche stagnalis* Scop.	+	0.3	–	–	–	–	<1
Glossostigma elatinoides Benth.	27	0.25–1.0	0.5–0.7	5	2	–	<1
§‡*Otellia ovalifolia* (R. Br.) Rich.	47	0.1–2.4	1–1.5	2	1	2.4	<1
‡*Potamogeton cheesmanii* A. Benn.	40	0.3–3.5	1–2.2	5	2	2.5	3
Potamogeton ochreatus Raoul	87	0.3–4.9	1.2–4.0	6	5	4.5	55
Emergent							
Eleocharis acuta R. Br.	20	0–0.5	–	5	1	0.8	<1
Eleocharis sphacelata R. Br.	47	0–2.2	0.3–1.5	6	5	3.3	12
§*Juncus articulatus* L.	+	0–0.2	–	–	–	–	<1
Juncus gregiflorus Johnson	+	0–0.1	–	–	–	–	<1
§*Ludwigia palustris* (L.) Ell.	+	0–0.2	–	–	–	0.5	<1
Myriophyllum propinquum A. Cunn.	100	0–2.2	0.5–1.3	6	1	1.5	<1
§*Paspalum distichum* L.	47	0–0.8	0.2–0.5	6	4	0.9	3
§*Polygonum decipiens* R. Br	+	0–0.2	–	–	–	–	<1
Floating							
§*Azolla pinnata* R. Br.	+	–	–	–	–	–	<1
§*Spirodela punctata* (G. Meyer) C. H. Thompson	+	–	–	–	–	–	<1

[1]Not recorded for Transects A–C
[2]Excluding shallow south-western arm of lake
§Adventive species
‡Species with submerged and surface-floating foliage

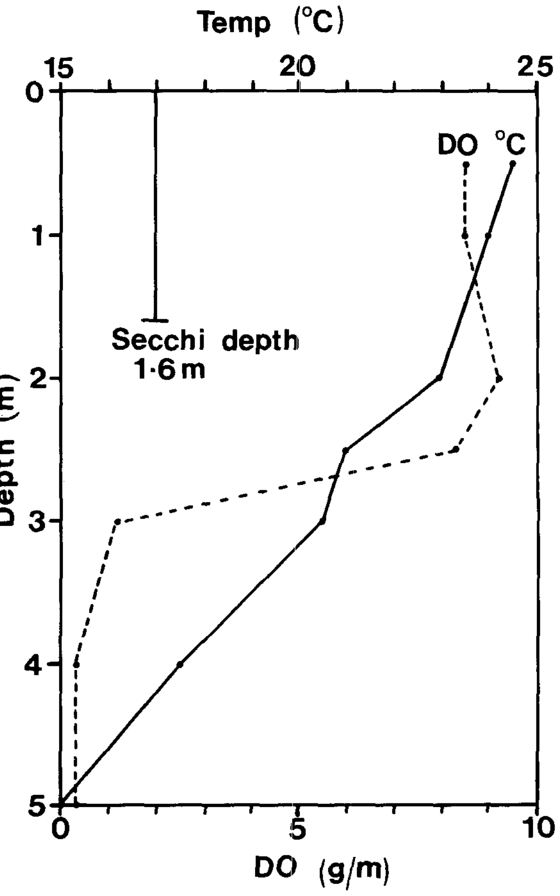

Fig. 3 Secchi depth, and dissolved oxygen and temperature profiles recorded in Lake Parkinson at noon, on 13 January 1987.

depth of 1.5 m (maximum 2.2 m) along all but the north-western shores of the remainder of the lake (Fig. 1). The distribution of *Eleocharis* recorded in the present study was similar to that noted before grass carp stocking (Mitchell 1980; Rowe 1984), except that open pools remained in the deeper central sections of the lake's south-west arm.

Dense mats of *Paspalum distichum* grew out to depths of 0.5 m around much of the lake. *Myriophyllum propinquum* was present at all sampling sites in the lake, both sprawling amongst emergent species and as a low-growing amphibious turf on sandy shores. Other emergent and floating species listed in Table 1 were less common, occurring predominantly on the shallow margins of the *Eleocharis* stands.

DISCUSSION

Egeria was not recorded in Lake Parkinson in the present study, nearly 9 years after its presence was last recorded in the lake. This supports an earlier claim of eradication of *Egeria* from Lake Parkinson associated with grass carp stocking (Mitchell 1980). Leslie et al. (1983), Van Dyke et al. (1984), and Richard et al. (1984) similarly noted apparent eradication of *Hydrilla verticillata* from a number of Florida lakes after grass carp stocking.

A predominantly native submerged and emergent macrophyte assemblage was recorded in Lake Parkinson in the spring and summer of 1986/87. The lake's vegetation was characterised by a dense marginal emergent community dominated by *Eleocharis sphacelata*, a sparse amphibious low mixed community of *Glossostigma elatinoides* and *Myriophyllum propinquum* on the sandy north-western shores, and submerged communities dominated by *Potamogeton ochreatus* at mid depths and *Nitella hookeri* in deeper water (maximum 5 m). This species composition may be similar to the lake's native condition before the introduction of *Egeria*.

Most of the major species found were also recorded in the lake in March 1976 before grass carp stocking (Mitchell 1980). However, at this time *Egeria* dominated the submerged vegetation, forming dense growths (maximum biomass 430 g dry weight m^{-2}) to depths of 5 m with only sparse growths of charophytes (species not identified) noted. The maximum depth of macrophyte colonisation recorded in the present study (5 m) was similar to that noted before grass carp stocking (Mitchell 1980). This, with the limited limnological data collected during the present study, suggests that water clarity and hypolimnetic deoxygenation in Lake Parkinson were similar to that recorded before grass carp stocking.

The submerged predominantly native macrophyte community recorded in Lake Parkinson during the present study was similar to that found in a number of Northland dune lakes; Lakes Kahuparere, Shag, Swan, Humuhumu, and Kanono (Tanner et al. 1986). These larger dune lakes (13-84 ha) showed a greater diversity of charophytes with 4-6 species recorded for each lake.

Eradication of adventive submerged macrophytes from lakes is rarely feasible by physical or chemical means once invasion is well established. As demonstrated in Lake Parkinson, temporary heavy stocking of grass carp for total vegetation control can achieve eradication of exotic macrophyte species dependent on vegetative reproduction from stem fragments. This may enable removal of problem weed species and re-establishment of native macrophyte species reproducing from seeds, spores, or buried rhizomes.

ACKNOWLEDGMENTS

We thank John Clayton for reviewing the manuscript and Glennis Steiner for typing.

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