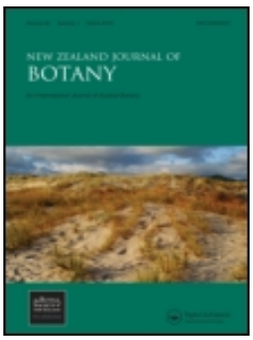

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Observations on aquatic macrophytes in 26 northern New Zealand lakes

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Abstract The presence, depth ranges, and estimated abundance of submerged, emergent, and free-floating aquatic species recorded in exploratory surveys of 26 northern New Zealand lakes are presented. Most of the lakes are small and relatively isolated, being formed in the extensive dune complex of the west coast of Northland. Two of the lakes occur in central Northland in valleys dammed by lava flows. Dense fringes of tall emergent sedges (*Eleocharis sphacelata* and *Baumea* spp. dominant) occurred in most lakes. Native submerged plant communities free of exotic species were recorded in 21 of the surveyed lakes. *Chara corallina* and *C. fibrosa* were the most abundant charophytes, occurring in 21 and 18 lakes respectively. The endangered species *Hydatella inconspicua* and *Myriophyllum robustum* were recorded in 5 and 2 lakes respectively. Three exotic species (*Elodea canadenis, Egeria densa*, and *Ceratophyllum demersum*), which have come to dominate the submerged vegetation in many other New Zealand lakes, were recorded individually in five lakes. Where present, they formed tall, often monospecific growths which displaced native submerged species from mid depths. Characteristics of the vegetation, apparent changes, and the effects of exotic species introductions are discussed.

Keywords Northland lakes; dune lakes; aquatic vegetation; macrophytes; charophytes; exotic plants; adventive plants; endangered species; plant surveys; plant distribution; plant invasions

INTRODUCTION

Over the last 50 years there have been many changes in the aquatic vegetation of New Zealand lakes with a large number now dominated by exotic macrophytes (Chapman 1970; Brown 1975, 1979; Coffey 1975; Mason 1975). A biological survey of 26 coastal North Island dune lakes by Cunningham et al. (1953) during the summers of 1949 and 1950 showed that the majority of these lakes were free of introduced macrophytes. Many of the dune lakes studied by Cunningham et al. are not readily accessible and are infrequently used by the public, and therefore introduction of exotic species dependent on vegetative reproduction might be expected to be uncommon. However, Fish (1966) reported the appearance and spread of *Elodea canadensis* in Lake Waingata (North Kaipara) between 1964 and 1965, and Mason (1975) noted the presence of a small infestation of *Lagarosiphon major* in Lake Waiparera (north of Kaitaia) in 1970, and *Ranunculus fluitans* auct. N.Z. and *Zizania latifolia* in Lake Kareta (South Kaipara). Studies of the Wanganui dune lakes (Gibbs 1973, Kelly 1978) show that *Potamogeton crispus* has become widespread and abundant, while *Vallisneria gigantea, Ranunculus fluitans* auct. N.Z., *Myriophyllum aquaticum, Otellia ovalifolia, Aponogeton distachyus, Nymphaea* sp., and a further five exotic emergent species are present in one or more of these lakes. Recently (March 1985) *Elodea canadensis* was also noted forming dense growths in one of these lakes, Lake Wiritoa (authors' unpublished records).

This paper presents results of exploratory surveys of aquatic vegetation in 26 northern New Zealand lakes over the period 1984–85. Seven of the lakes are in common with the study of Cunningham et al. (1953).

STUDY SITES

The location of the lakes surveyed are presented in Fig. 1 and their map references, areas, and maximum depths summarised in Table 1. They all occur at low altitude (< 100 m, except L. Omapere 238 m) between latitude *c.* 34° 30′ and 36° 30′ in the northern North Island of New Zealand. Lakes Omapere and Owhareiti occur in shale and sandstone valleys dammed by Quaternary basaltic lava flows (Ferrar 1925, Healy 1975). All the remaining lakes are formed in basins or dammed valleys in the extensive sand-dune complex of the west coast. The bathymetry of many of the larger lakes in the present study and limited data on their physical,

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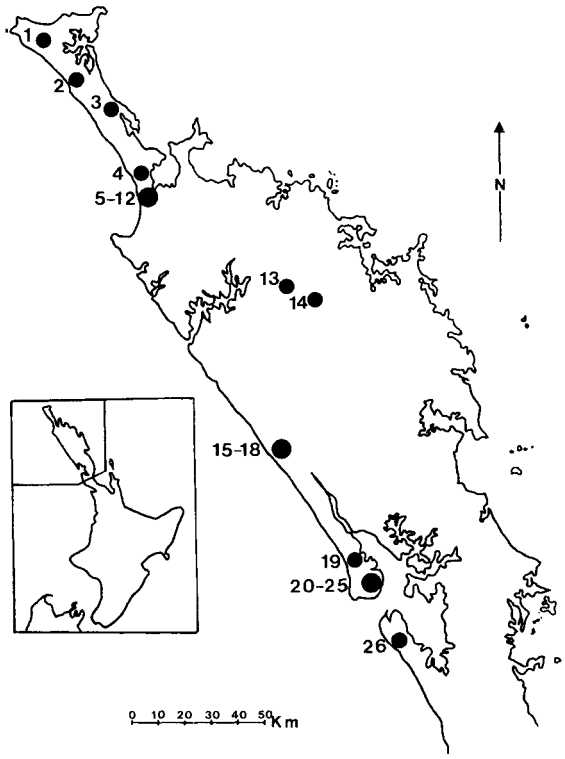

Fig. 1 Map showing geographical location of the 26 lakes studied, in the northern North Island of New Zealand.

chemical, and biological features are noted in Cunningham et al. 1953; Cunningham 1957; Fish 1966; Flint 1970; Irwin 1971–1982; Irwin & Main 1978, 1981; Donovan 1973; Green 1975, 1976; Lam et al. 1979; Cassie & Freeman 1980; McLellan 1985. These authors have noted annual water temperatures in the range of 9–25°C and secchi depths of 0.5–9.2 m in these lakes.

Although few long term records of lake level fluctuations are available, recent records and observations in lakes 10, 13, 17, 22–25 (see Table 1) suggest seasonal fluctuations of less than *c.* 0.75 m in these lakes (Fish 1966, McLellan 1985, and unpublished records of the Northland Catchment Commission). Seasonal fluctuations of *c.* 1.5 and 1 m respectively have been noted in lakes Taharoa (Lam et al. 1979, McLellan 1985) and Ototoa (Green 1975).

METHODS

Observations of aquatic vegetation were made on 28 May (Lake Ototoa) and 4–11 December 1984 (lakes 9,10, 13, 14, 17–21); January 21–24 (lakes 1–8, 11, 12, 22–25) and 14–15 July 1985 (lakes 15, 16 and additional observations in 17, 18, 20, 22, 23) using a modification of a qualitative profile diving technique (Clayton 1983). This involved recording the same parameters (species presence, depth range, estimated maximum and average covers, and heights) in two or more areas of each lake, without limiting the width of sampling profiles to 2 m. This allowed the synthesis of information from a larger area. The abundance of each species was subjectively assessed as abundant, common, or occasional using recorded cover values and depth ranges. These parameters and plant height records were supplemented with additional observations noted while diving to produce diagrammatic vegetation profiles from representative sites in 9 lakes. Further observations were made in shallow water from a slow moving boat in lakes Ngatu, Taharoa, and Omapere using a mask and snorkel at the surface. The shallow swampy lake at Waipapakauri (no. 9) was surveyed on foot and observations in L. Rototuna were made by wading along the eastern shore. The approximate region sampled in each lake is noted in Table 3.

Most species were identified in the field, while rare plants and plants of uncertain identity were collected and sent to Botany Division, DSIR for confirmation and/or documentation. In comparisons of data from the present study with that of Cunningham et al. (1953) taxonomic nomenclature changes follow Wood & Mason (1977), Orchard (1979), and Healy (1984). Limited observations of sediment texture were made by divers at each sampling site. All water depths are reported relative to lake levels at the time of survey.

RESULTS

Many of the lakes sampled were small allowing extensive areas to be surveyed. Sampling of large lakes and Lake Rototuna was limited by constraints of time and lake access. The results presented should therefore be considered within the constraints of an exploratory survey. The presence, depth ranges, and abundance of aquatic plants recorded for each lake are summarised in Tables 2 and 3 and representative transverse profiles of the vegetation in areas sampled in 9 of the lakes are represented in Fig. 2.

Submerged vegetation

Charophytes The submerged vegetation of many lakes was completely native with charophytes, particularly *Chara corallina* and *C. fibrosa*, present in all the lakes surveyed except Omapere and Owhareiti. Seven species of charophytes were identified.

Chara corallina was recorded in 21 of the lakes

Table 1 Location, area, and maximum depth records for 26 northern New Zealand lakes. All values are from Irwin (1975) except the maximum depth records for lake nos 21–24 from Cunningham et al. (1953) and the approximate values for lake nos 1, 3, 5–9, 11, 15, and 25 from the present study.

Lake number	Lake	Map reference (NZMS1)	Area (km^2)	Maximum depth (m)
1	Ngakeketa	N1&2/259400	0.18	> 7
2	Wahakari	N3&4/417242	0.84	12
3	Waihopo	N3&4/538118	*	*c.*3.5
4	Waiparera	N6/682894	1.25	6
5	unnamed 1	N6/695806	*	*c.*4.5
6	Ngakapua	N6/698802	0.18	> 5
7	Rotokawau 1	N6710803	0.16	*c.*3
8	Carrot	N6/692798	*	*c.*3
9	unnamed 2	N9/688787	*	*c.*1.5
10	Ngatu .	N9/705790	0.61	6.5
11	unnamed 3	N9/700767	0.19	> 4
12	Rotoroa	N9/702759	0.53	8.0
13	Omapere	N15/303415	11.62	1.9
14	Owhareiti	N15/452370	0.76	16
15	Shag	N22/130877	0.20	> 7
16	Waikere	N22/152868	0.35	30
17	Taharoa	N22/170860	2.10	37
18	Kai-iwi	N22/176850	0.31	16
19	Rototuna	N27/565320	*	–
20	Humuhumu	N32/650235	0.70	16
21	Swan	N33/665228	0.32	5.5
22	Rotokawau 2	N33/672210	0.29	12
23	Waingata	N33/675204	0.12	9.5
24	Kanono	N33/668190	0.84	15.5
25	Kahuparere	N33/682183	0.13	> 5
26	Ototoa	N33/763012	1.39	27.5

*Maximum dimension < 0.5 km.

surveyed, showing greatest abundance in the more northern lakes (nos 2–6, 8, 11, and 18), particularly the smaller lakes with muddy substrates and low to moderate water clarity. It was also common in association with *Chara fibrosa* in many lakes, and with *Nitella hookeri* and/or *C. globularis* in some of the Kaipara lakes (nos 20, 24–26). *Chara fibrosa* was recorded in 18 lakes, being abundant in the four clearest lakes (nos 10, 16, 17, 26) which had sandy sediments, and also in Lakes Rotokawau 1 and 2 and in areas of Lake Rotoroa where *Egeria densa* was not common. Cunningham et al. (1953) also noted the association of *C. fibrosa* with sandy sediments and *C. corallina* with more organic sediments. *Nitella hookeri* (recorded in 9 lakes) was abundant in lakes 15, 20, and 24 and *Chara globularis* (recorded in 6 lakes) in lakes 25 and 26. *Nitella pseudoflabellata* was widespread (recorded in 14 lakes) but, like *N. leptostachys* and *N. hyalina* (both recorded in 6 lakes), not common.

Lakes Waiparera, Humuhumu, Kanono, Kahuparere, and Ototoa had diverse charophyte communities with between 5 and 7 species recorded for each lake. Only 1–2 species of charophytes were recorded for Lake Taharoa, Rotokawau 2 and many of the smaller lakes (nos 3, 5, 6, 8, 9, 11, 19).

Native vascular plants Native *Potamogeton* species were recorded in most lakes. *Potamogeton ochreatus* formed extensive growths in lakes 5, 11, 15, and the north Kaipara lakes (nos 20–25), generally to a depth of 3–5 m (max. 7 m). *Potamogeton cheesmanii* was common in lakes 4, 5, 9, 22, 24, 25. In other lakes *P. ochreatus* and *P. cheesmanii* formed sparse covers, often within or close to emergent plant communities. *Potamogeton pectinatus* was recorded only in Lake Rototuna. Tall growths of *Myriophyllum triphyllum* occurred sparsely in Lake Rotoroa and the Kaipara Lakes (except Lake Waingata).

Shallow water submerged plant communities were largely excluded from lakes with swampy or cattle trampled shores (e.g. lakes 3, 5, 6, 8, 11, 13, 14, 25). *Lilaeopsis lacustris* and *Glossostigma* spp. were common on sandy, low gradient shores. *Myriophyllum pedunculatum* occurred as dense

Table 2 Species codes and frequencies (number of lakes) for aquatic plants recorded in surveys of 26 northern New Zealand lakes.

Species code	Species	No. of lakes
AP	*Azolla pinnata* R. Br.	7
BA	*Baumea articulata* (R. Br.) Blake	8
BH	*B. huttoni* (Kirk) Blake	5
BJ	*B. juncea* (R. Br.) Palla	5
BR	*B. rubiginosa* (Spreng.) Boeck	6
CC	*Chara corallina* Kl. ex Willd, em. R.D.W.	21
CD	*Ceratophyllum demersum* L.	1
CF	*Chara fibrosa* var. *acanthopitys* (A. Br.) Zanev	18
CG	*C. globularis* Thuill	6
CU	*Cyperus ustulatus* A. Rich.	2
EA	*Eleocharis acuta* R. Br.	2
EC	*Elodea canadensis* Michx.	1
ED	*Egeria densa* Planchon	3
EG	*Elatine gratioloides* A. Cunn.	1
ES	*Eleocharis sphacelata* R. Br.	19
GE	*Glossostigma elatinoides* Benth.	8
GM	*Glyceria maxima* (Hartm.) Holmb.	1
GS	*Glossostigma submersum* Petrie	11
HI	*Hydatella inconspicua* Cheeseman	5
IK	*Isoetes kirkii* A. Braun.	1
JA	*Juncus articulatus* L.	2
JB	*J. bulbosus* L.	4
JP	*J. pallidus* R. Br.	1
KS	*Callitriche stagnalis* Scop.	1
LL	*Lilaeopsis lacustris* Hill.	12
LM	*Lagarosiphon major* (Ridley) Moss ex Wager	*
LN	*Limosella lineata* var. *spathulata* Gluck	2
LP	*Ludwigia palustris* (L.) Ell.	9
LS	*Leptocarpus similis* Edgar	5
LX	*Lemna* sp.	2
MP	*Myriophyllum pedunculatum* Hook. f.	3
MQ	*M. propinquum* A. Cunn.	13
MR	*M. robustum* Hook. f.	2
MT	*M. triphyllum* Orchard	8
MV	*M. votschii* Schlindler	*
NH	*Nitella hookeri* A. Br.	9
NL	*N. leptostachys* A. Br. em. R.D.W.	6
NP	*N. pseudoflabellata* A. Br. em. R.D.W.	14
NY	*N. hyalina* (DC.) Ag.	6
OO	*Otellia ovalifolia* A. Br. em. R.D.W.	5
PC	*Potamogeton cheesmanii* A. Benn.	20
PO	*P. ochreatus* Raoul	15
PP	*P. pectinatus* L.	1
PX	*Polygonum* sp.	2
RX	*Ruppia* sp.	3
SL	*Scirpus lacustris* L.	8
SM	*Salvinia molesta* Mitchell	1
SP	*Spirodela punctata* (G. Meyer) C.H. Thompson	6
SR	*Scirpus prolifer* Rottb.	1
TO	*Typha orientalis* C.B. Presl	10
TT	*Triglochin striatum* Ruiz et Pav.	2
UP	*Utricularia protrusa* Hook. f.	8
WA	*Wolffia australiana* (Benth.)Hartog & van der Plas	1

Note: The species codes above are those used in the Ministry of Agriculture & Fisheries, Aquatic Plant Section, Aquatic Vegetation Database.

* Species not recorded in the present study but recorded by other authors for lakes in the present study — see Table 3.

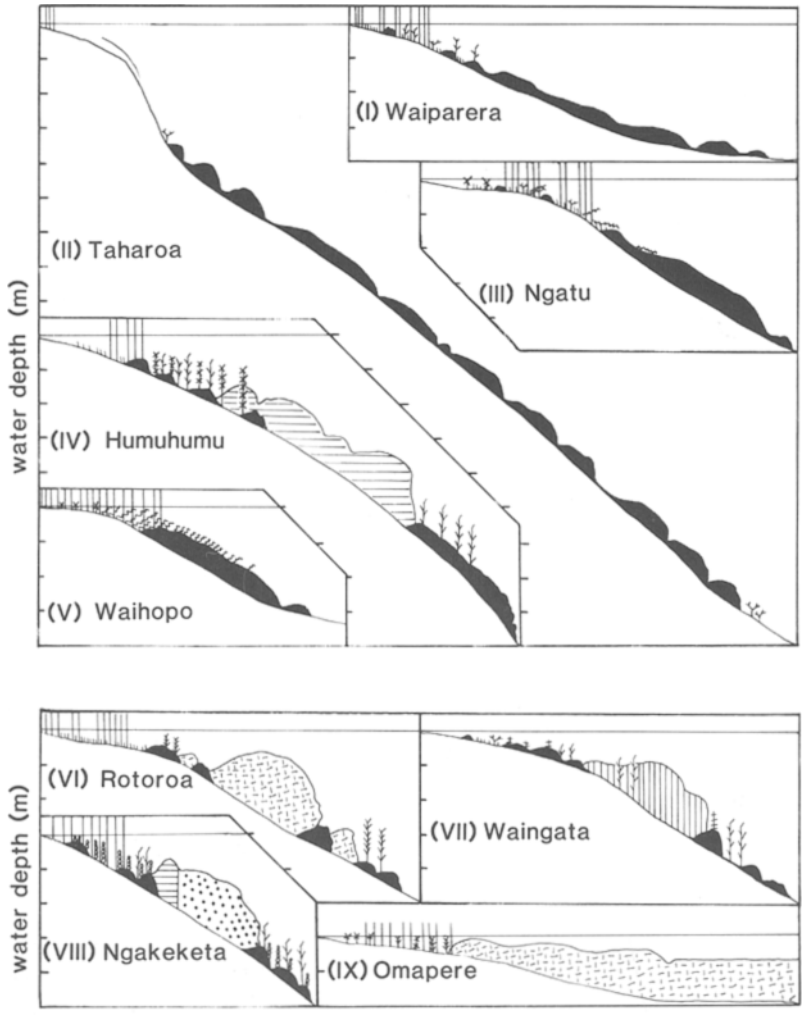

Fig. 2a Representative transverse profiles of aquatic vegetation in areas sampled in 5 Northland lakes with only native submerged species: (i) northern Lake Waiparera (N6/677897), (ii) Hauhatoki Bay, Lake Taharoa (N22/161864), (iii) south-eastern Lake Ngatu (N9/702783), (iv) eastern Lake Humuhumu (N33/656235), (v) Lake Waihopo (N4/542118).

Fig. 2b Representative transverse profiles of aquatic vegetation in areas sampled in four Northland lakes colonised by exotic submerged species: (vi) north-western Lake Rotoroa (N9/703760), (vii) eastern Lake Waingata (N33/677204), (viii) south-western Lake Ngakeketa (N3/261400), (ix) south-western Lake Omapere (N15/287399).

swards in some areas of lakes Ngatu and Rotokawau 2. The endangered species *Hydatella inconspicua* (Williams & Given 1981) was also recorded at low densities in these lakes and in lakes Rotoroa, Waikere, and Waingata. It was flowering profusely in Lake Ngatu during December and less commonly in other lakes during January and July. *Limosella lineata, Ruppia* sp. and *Triglochin striatum* were also recorded occasionally in shallow water. *Isoetes kirkii,* in association with *Lilaeopsis lacustris,* was only noted in a restricted area of Lake Omapere just north of the Utakura River outlet (N15/283402). Rawlings (1974) has previously recorded *Isoetes* in this lake at a site just south of

this. Shallow water plant communities appeared to be excluded from other likely sites in Lake Omapere by dense growths and drift accumulations of *Egeria*.

The distribution and density of shallow water species in the dune lakes was often restricted in exposed areas, to sites sheltered by emergent vegetation. No submerged species except very occasional *Juncus bulbosus* plants were recorded from the wide exposed shallow flats in the areas surveyed in Lake Taharoa, although *Hydatella* has been previously reported there (Pledge 1974). In Lake Ototoa shallow water communities were restricted by the steep unstable shoreline.

The more northern small lakes (nos 3, 5, 6) had dense *Utricularia protrusa* communities growing within their emergent plant fringes and sprawling into deeper water (max. 5 m) over charophyte beds (see Fig. 2a v). Sparser *U. protrusa* communities occurred in a number of other lakes (nos 2, 7–10), predominantly in sheltered sites. Occasional flowers of this species were noted within the shelter of tall emergent plants in Lake Waihopo.

Exotic vascular plants The submerged vegetation in areas sampled of Lakes Omapere and Owhareiti was dominated by dense monospecific growths of *Egeria densa* (see Fig. 2b ix). Introduced species also dominated large areas in lakes Ngakeketa (*Ceratophyllum demersum*) (Fig. 2b viii), Waingata (*Elodea canadensis*) (Fig. 2b vii) and parts of L. Rotoroa (*Egeria densa*) (Fig. 2b vi) where they formed dense growths which excluded other species.

Although a small infestation of *Lagarosiphon major* was found in Lake Waiparera in 1970 (Mason 1975, CHR 214406) this plant was not found in the present study despite a search of the northern and eastern shores. The adventive *Otellia ovalifolia* was present at low densities in submerged and floating leaved forms in a number of the Kaipara lakes. It was not recorded in lakes further north despite its presence in farm ponds (e.g., N9/706799, < 2 km from lakes 5–10) and streams (e.g., the Waitiki Stream near Te Paki) in the area. Occasional plants of *Juncus bulbosus* were noted growing submerged in shallow water in the Taharoa Lakes Domain.

Emergent vegetation

Fringes of tall emergent species were typical of all of the smaller lakes surveyed and were present in the more sheltered areas of larger lakes. *Eleocharis sphacelata* (recorded in 19 lakes) was the dominant emergent in most lakes, commonly forming dense stands to water depths of 1–1.75 m (max. 2.25 m in sheltered areas of Lake Ngatu). In shallower water *Baumea* spp., *Scirpus lacustris*, and *Typha orientalis* were also common. Although *Typha* dominated the marginal vegetation of northernmost L. Ngakeketa it was recorded as only occasional in the other nine lakes in which it was noted and was more characteristic of swampy valleys around lakes.

The sprawling emergent *Myriophyllum propinquum* occurred commonly amongst tall emergents and on swampy lake margins. The adventive *Ludwigia palustris* was present in similar habitats in nine lakes. It was particularly common around Lake Omapere.

Tall emergents including the adventive *Glyceria maxima* had spread to dominate the shallow lake no. 9 (N9/688787). This lake had undergone a marked drop in water level since the previous summer (1983–84) when it was subject to further herbicide application as part of a *Salvinia molesta* eradication programme (whole lake last sprayed with paraquat at 2 kg ha^{-1} a.i. in April 1983, authors' unpublished records). The vulnerable species *Myriophyllum robustum* (Williams & Given 1981)was noted in areas of this lake and in another (no. 11) less than 3 km away which had not been sprayed. This plant was not observed elsewhere, despite casual searches in swamps in this area and further north. It appears to have been last recorded in Northland in 1950 (Orchard 1979).

Surface-floating vegetation

Small surface-floating plants, particularly *Azolla pinnata* and *Spirodela punctata*, were often present in areas sheltered by marginal vegetation. *Wolffia australiana* was common in Carrot Lake, but was not seen elsewhere. *Salvinia molesta* formed dense but scattered communities within the wide *Eleocharis sphacelata* margin of lake 5 (N6/695806). *Salvinia molesta* was not found in intensive searches of lakes 8 and 9 or in any of the smaller ponds and swamps in a 2 km radius which previously harboured this plant and have since been subject to an eradication programme (Harper 1984).

DISCUSSION

General characteristics of the vegetation

Three depth related plant communities have been recognised in previous studies of submerged vegetation in New Zealand lakes (summarised by Brown 1975). The submerged vegetation of the 26 lakes in the present study was variable in species composition and community development. In lakes with only native submerged species (see Fig. 2a) the aquatic vegetation characteristically consisted of dense fringes of emergent sedges (*Eleocharis sphacelata* and *Baumea* spp. dominant), abundant submerged charophyte communities (particularly *Chara corrallina* and *C. fibrosa*), and sparse to well-developed submerged vascular plant communities dominated by *Potamogeton* spp. A shallow-water

Table 3 Aquatic macrophytes recorded from exploratory surveys of 26 northern New Zealand lakes in December 1984, January 1985, and July 1985. The areas of the lakes which were sampled and other published records are also noted. Charophytes are noted first and vascular plants second.

Species[1]	Depth range (m)	Abundance[2]
1. *Ngakeketa* (whole)		
CC	0.1–3	c
NH	1–4	o
NL	1	o
NP	0.1–1.5	o
BA	0–1	o
CD*	0–4.5	a
GS	0.3–1	o
LN	0.2	o
LP*	0–0.2	o
MQ	0–0.5	o
PC	0.2–3.5	o
PO	0.1–4	c
SP	+	o
TO	0–1.5	a
2. *Wahakari* (S end)		
CC	1–7	a
CF	0.3–3	a
NP	0.5–1	o
BJ	0–0.5	o
ES	0–1	
LL	0.5–2	c
LS	0–0.3	o
MT	1	o
PC	1–4.5	o
PO	1–4	o
SL	0–1	o
TO	0–2	o
TT	1	o
UP	+	o
3. *Waihopo* (whole)		
CC	0.1–3	a
BR	+	o
CU	+	o
ES	0–1.25	a
MQ	0–0.5	c
PC	1–2.5	o
SL	+	o
SP	+	o
UP	0.1–3	a
4. *Waiparera* (N & E shores)		
CC (i)(ii)	0.5–4	a
CF (i)(ii)	1–3	c
CG (ii)	0.1–3	c
NH (ii)	0.5–4	o
NL (ii)	0.2	o
NP (ii)	0.2	o
NY (ii)	0.1–0.5	o
BH (i)	0–0.5	c
BR	0–0.5	o
ES (i)	0–0.75	c
LL	0.1–1.5	c
LP*	0–0.2	o
LS	0–0.3	o
PC	0.1–2.25	c
SL (i)	0–0.75	c
(i) BA, TO; (iii) MT, MV; (v) HI; (viii) LM		
5. *N6/695806* (whole)		
CC	1–3.5	a
CF	2	o
BA	0–0.3	c
ES	0–1.2	a
PC	1–3.5	c
SM*	+	c
SP	+	o
UP	0.5–3.5	a
6. *Ngakapua* (W end)		
CC	0.1–5	a
CF	1.5–4.5	c
AP	+	o
BA	0–0.5	o
ES	0–2	a
PO	1.5–2	o
TO	0–0.5	o
UP	0.2–5	a
7. *Rotokawau 1*[3] (whole)		
CC	0.1–3	c
CF (ii)	0.1–3	a
NL (ii)	0.5–2	o
BJ	0–0.2	o
BR	0–1	c
ES	0–1.5	a
GS	0–0.1	o
MQ	0–0.1	o
PC	0–3	o
UP	0.1–3	o
(ii) NH		
8. *Carrot* (whole)		
CC	0–2.5	a
BA	0–0.5	c
LX	+	c
MQ	0–0.1	o
PC	0–2	o
PO	1.5–2.5	o
TO	0–0.5	c
UP	0–2.5	o
WA	+	c
9. *N9/688787*[3] (whole)		
NL	+	o
AP*	+	c
BA	+	o
CU	+	o
EA	+	o

Table 3 continued.

Species[1]	Depth range (m)	Abundance[2]
ES	+	c
GM*	+	o
JA*	+	a
LP*	+	c
MQ	+	c
MR†	+	c
PC	+	c
SL	+	o
SR	+	c
UP	+	c
10. *Ngatu*[3] (whole)		
CC (i)	0.2–5	c
CF (i)(ii)	0.2–5	a
NL (ii)	0.5–5	c
NP	0.3–3	o
BA	0–1.5	o
BH (i)	0–1.25	c
ES (i)	0–2.25	a
GS	0.5–1	o
HI† (v)	0.3–1	o
JA*	+	o
LL	0.5–2	o
LN	0.4–1.5	o
MP (iii)	0.4–1.5	o
MQ	0.1–1	o
LS	+	o
PC	0.1–3	o
SL	+	o
TT	0.5	o
UP	0.5–3.5	o
(i) TO; (ii) NH		
11. *N9/700767* (S end)		
CC	0.3–2.5	a
CG	0.5	o
AP*	+	o
BR	+	c
ES	0–1	c
LP*	+	o
LX	+	o
MQ	+	c
MR†	+	o
PC	0.3–0.5	o
PO	0.5–3	a
PX*	+	c
TO	0–0.5	c
12. *Rotoroa* (N end)		
CC	0.5–4.5	c
CF (ii)	0.3–3.5	a
NH	0.1–0.5	o
BJ	0–1	a
BR	0–0.75	o
ED*	1–4.5	a
HI† (v)	0.3–0.6	o
LL	0.3–2	o
MT	0.5–1.5	o
PC	0.3–4	o
PO	0.5–4.5	o
13. *Omapere*[3] (W, S, & E shores)		
AP	+	o
BA	0–0.75	c
EA	0–0.25	o
ED*	0.25–2	a
ES	0–0.75	c
GS	0.1	o
IK (vi)	0–0.5	o
KS*	0–0.1	o
LL	0–0.5	o
LP*	0–0.5	c
MQ (iii)	0–0.5	c
PX*	0–0.25	o
SL	0–0.5	c
SP	+	o
TO	0–0.5	o
(vi) EG		
14. *Owhareiti* (NW arm)		
AP	+	o
ED*	0.5–4.5	a
ES	0–1	a
LP*	0–1	c
MO	0–1	c
PC	3	o
SP	+	o
15. *Shag* (E side)		
CC	1–6	o
CF	0.5–2	a
NH	1.5–6.5	a
NP	1–1.5	o
ES	1–2	o
GE	0.1–1	o
GS	0.5	o
JB*	0.2–0.4	o
LL	0.3–1	o
MQ	0.2	o
PC	0.1–5	o
PO	0.5–5	c
16. *Waikere* (S end)		
CC	2–10	o
CF	1–12	a
NH	1.5–10	o
NP	1–10	o
HI†	0.5	o
JB*	0.2	o
17. *Taharoa*[4]		
CF (ii)	3.0–18	a
NP	4–7	o
BH	0–1	o
JB*	0.5	o
(iii) MQ; (vii) HI		

Table 3 continued.

Species[1]	Depth range (m)	Abundance[2]
18. *Kai-iwi* (E end)		
CC (ii)	1.5–11.5	a
CF (ii)	0.75–6	c
NL	1.5–7	o
NP	1.5–2.5	o
BH	0–1.5	a
BJ	0–1	o
ES	0–2	a
JB*	1–1.2	o
PC	2–2.5	o
PO	1.5	o
(vii) HI		
19. *Rototuna*[5]		
NY (ii)	+	–
NP	+	–
GE	+	–
LP	+	–
MT (iii)	+	–
OO	+	–
PC	+	–
PO	+	–
PP	+	–
SL	+	–
(ii) CG		
20. *Humuhumu* (E side)		
CC	1–8	c
CF	0.5–1	o
CG	0–3	c
NH	6–9	a
NY	0–2	o
BJ	0–1.5	c
ES	0.3–1.5	c
GE	0.1–1.5	o
GS	1–1.5	o
LL	0–1.5	o
LS	0–0.3	o
MT	0.3–3	c
OO*	1.0	o
PC	1.5–4	o
PO	0.5–7	a
RX	0–1.5	c
(vii) HI		
21. *Swan* (E section)		
CC (i)	0.5–4.5	c
CF (i)	0.5–1	c
NH	4	o
NP	0.5–1	o
AP*	+	o
BA (i)	0.5–1.25	o
BH (i)	0–2	o
ES (i)	0–1.5	c
GE	0–1	o
GS	0–1	o
LL	0–1	o
LP*	0–1	c
MQ	0–0.5	c
MT	1–3	o
OO*	0.5–1	o
PC	0.5–1.5	o
PO (i)	1–4.5	a
SP	+	o
TO (i)	0–1	o
(v) HI		
22. *Rotokawau 2* (SE shore)		
CC (i)	3–8.5	c
CF (i)	0.2–8.5	a
ES (i)	0.5–1.75	c
GE	1	o
GS	0.2–1	o
HI† (v)	0.2–0.5	o
JP	+	o
LL	0.2–1.5	c
MP	0.5–1.25	o
MQ	1–1.5	o
PC	0.5–3.5	c
PO	1–5	c
(i) BA, BH		
23. *Waingata* (E end)		
CC	0.2–4	c
CF (i)	0.2–1	c
NH	1–5.5	c
NP	0.2	o
EC* (iv)	0.5–4	a
EG	1	o
ES (i)	0–1	c
GE	0–0.5	o
HI†	0.5–1	o
LL	0–0.5	o
LS	+	o
MP	1	o
PO (iv)	0.8–4	c
(i) BH		
24. *Kanono* (S end)		
CC (i)	0.3–7	a
CF	0.2–1.5	o
CG	0.3–7	c
NH	4.5–8.5	a
NP	0.5–8	o
NY	0.2–1	o
GE	0.3–1.5	o
GS	0.8–1	o
LL	0.2–1.75	c
MQ	+	o
MT	0.5–2.5	o
PC	0.5–3	c
PO (i)	0.5–5	a

Table 3 continued.

Species[1]	Depth range (m)	Abundance[2]
RX	0.2–1	o
TO (i)	0–1	c
(i) ES, BH, SL; (iii) MV		
25. *Kahuparere* (whole)		
CC	0.4–2	c
CF	0.2–1	o
CG	0.1–1.5	a
NP	0.1–0.5	o
NY	0.1–0.5	o
AP	+	o
BR	+	o
ES	0.5–1	a
GS	0–0.1	o
LP*	0–0.2	o
MT	1–1.5	o
OO*	0.1–0.75	c
PC	0.5–3	c
PO	0.5–5	a
RX	0.2–1	o
SL	+	o
TO	0–0.5	c
(iii) MR		
26. *Ototoa* (S end)		
CC (i)	0.5–7	c
CF	0.5–9	a
CG (ii)	0.5–8	a
NP	0.5–9.5	c
NY	0.5–9.5	o
ES (i)	0–2	a
GE	0.5	o
GS	0.5	o
LL	0.5	o
MT	0.5–2	c
OO*	0.2	o
TO (i)	0–1	o
(i) BA		

[1]See Table 2 for species codes. Other published records: (i) Cunningham et al. (1953), (ii) Wood & Mason (1977), (iii) Orchard (1979), (iv) Fish (1966), (v) Edgar (1966), (vi) Rawlings (1974), (vii) Pledge (1974), (viii) Mason (1975).
[2]a = abundant, c = common, o = occasional, + = present.
[3]Colonised by macrophytes to maximum depth sampled in the present study.
[4]Sampled at Pine Beach, Nob Point, Hauhatoki Bay, and Western Bay.
[5]Shoreline survey only — eastern shore.
*Exotic species.
†Rare and endangered species.

low mixed community (sensu Chapman et al. 1971) was present on sandy substrates in some lakes, often amongst tall emergent species or in sites sheltered by them (e.g., Fig. 2a i, iii, iv). This community appeared to be excluded in the smaller lakes by swampy shores and dense growths of *Utricularia protrusa* and *Myriophyllum propinquum* (e.g., Lake Waihopo, Fig. 2a). The low mixed community appeared to be restricted in lakes Ngakeketa (Fig. 2b viii) and Ototoa by steep shores, and in Lake Taharoa (Fig. 2a ii) by wave exposure and water level fluctuations; however, this and the additional features of low species diversity and absence of mid depth vascular plant communities in the latter lake could also be related to the oligotrophic nature of its fine silicaceous sand substrates and overlying waters and the presence of subsurface filamentous algae communities to water depths of 21 m (Lam et al. 1979).

In lakes colonised by exotic submerged species (see Fig. 2b) mid depth communities of native species were often displaced. Lake Omapere (Fig. 2b ix) represents an extreme case where remnant submerged native communities (*Isoetes kirkii* and *Lilaeopsis lacustris*) appear to be restricted to sheltered pools amongst tall emergent plants and large rocks. In other lakes native plant communities coexisted outside zones dominated by exotic species. Similar effects of exotic plant colonisation have occured in the Waikato (Coffey 1975, Wood & Mason 1977 (Lake Whangape), and authors' unpublished data), Rotorua (Chapman et al. 1971, Brown 1975), and Nelson lakes (Brown 1979).

Vegetation changes

The aquatic plant communities reported in the present study are similar to those previously reported by Cunningham et al. (1953) for the seven lakes common to both studies (nos 4, 10, 21–24, 26. However, in comparison to the remote grab sampling techniques used in the former study, our survey techniques employed direct underwater visual observation which has enabled improved sampling, particularly of less common submerged plants.

There have been three apparent changes in the vegetation of these lakes in the intervening *c.* 35 years. Firstly, the displacement of charophytes by *Elodea canadensis* in L. Waingata. *Chara fibrosa* which was previously recorded throughout the lake basin (Cunningham et al.) was only recorded to depths of 1 m in the present study with *C. corallina* and *Nitella hookeri* recorded to 4 and 5.5 m water depth (see Fig. 2b vii). Four other lakes (nos 1, 12, 13) not studied by Cunningham et al. have presumably undergone similar displacement of native plant communities by *Egeria densa* or *Ceratophyllum demersum* during this period. Secondly,

there has been an apparent reduction in bottom depth limits for submerged vegetation in lakes Waiparera (*c.* 6 m to 4 m), Rotokawau 2 (*c.* 12 m to 8.5 m), and Waingata (*c.* 8 m to 5.5 m), suggesting a possible decrease in water clarity during the period. Cunningham et al. reported submerged vegetation extending to the maximum depths of these lakes while considerably shallower bottom depth limits and reduced plant distribution were observed in the present study. In the low gradient basin of Lake Waiparera this represents a more than one third reduction in area colonised (cf. bathymetric vegetation map of Cunningham et al.). Thirdly, there appears to have been increased colonisation of lakes Kanono and Ototoa by submerged plants. The bathymetric vegetation maps of Cunningham et al. show no submerged macrophytes in the southern basin of Lake Kanono where abundant communities (7 species) to maximum depths of 8.5 m were recorded in the present study. Similarly submerged macrophytes, not apparent in Lake Ototoa at the time of Cunningham et al.'s survey, were common (10 species to a maximum depth of 9 m) in sites sampled at the southern end of the lake. Green (1975) has also noted abundant growths of charophytes in this part of the lake. These changes may reflect greater substrate stability resulting from stabilisation, by marram grass and pine plantings, of the western dunes which were previously noted as actively encroaching upon these lakes.

Exotic plants

The results of the present study extend the recorded range (Mason 1960, 1970, 1975; Chapman & Bell 1967, Healy & Edgar 1980, and unpublished records of Botany Division, DSIR) of *Ceratophyllum demersum* and *Egeria densa* to almost the northern tip of the North Island. *Egeria* was noted during the present study as widespread in rivers in the Kaikohe area, and in the Waitiki Stream near Te Paki (*c.* 13 km SE of Cape Reinga). It has also been recorded in the Awanui River near Kaitaia (CHR 126751, 1964), Te Hana near Wellsford (CHR 140367, 1964), the Hotea R. near Warkworth (CHR 236701, 1972), and in scattered sites in Whangarei and Hobson Counties. Similarly, *Lagarosiphon* is reported to be present in streams around Kaikohe, Kerikeri, Whangarei, and Hobson County (Tanner 1981). Despite the widespread distribution of these species in Northland, most records are from streams and rivers.

Many of the lakes studied have no obvious inflows or outflows and have small catchments. Their relative geographical isolation and restricted public access have undoubtedly been major factors in minimising exotic plant invasion. Few of the lakes surveyed are used for recreational boating, the agent most commonly implicated in the spread of submerged weed species (Brown 1975, Johnstone et al. 1985). Where invasions have taken place, they appear to have been related to human activities. For example, *Elodea* appears to have been introduced to Lake Waingata either during annual trout liberations from 1953–1964, or more likely on nets during the netting study from 1960–1965. Fish (1966) first recorded *Elodea* in 1964 and by the following year it had become well established. The lake has no boating or public access and this remains a remote infestation of a plant which Mason (1975) noted had scarcely spread north of the Auckland isthmus.

Northland dune lakes are commonly used by duck hunters and some by anglers. It appears that, as with exotic fish releases in Northland (McDowall 1980), exotic water weed species may also have been purposely introduced, possibly to attract waterbirds. For example, Lake Rotoroa had a population of *Egeria* which appeared to be extending either side of the only duck hunters hide (mimi) at the north-western end of the lake.

The absence of any records for *Potamogeton crispus* L. and *Ranunculus fluitans* auct. N.Z. was unexpected since both are spread readily from seed by waterbirds in areas south of Auckland and the latter species has been reported in Lake Kareta in South Kaipara (Mason 1975).

The aquatic vegetation in many of the northern New Zealand lakes in the present study is native, providing a rare example of the vegetation which would have predominted elsewhere in New Zealand before the spread of exotic species. Furthermore, a number of the lakes support aquatic plant species unrepresented or rare elsewhere in New Zealand. It is suggested that representative lakes in this region are worthy of further study and active protection.

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