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Taihoro Nukurangi

THE VEGETATION OF THE LOWER WAIKATO LAKES

Volume 1
Factors affecting the vegetation of lakes in the Lower Waikato

by

M.D. de Winton & P.D. Champion*

NIWA Ecosystems

Hamilton

*MAF Quality Management
Ruakura Agricultural Centre
Private Bag 3080
Hamilton

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National Institute of Water and Atmospheric Research
PO Box 11-115
Hamilton
Telephone: (07) 856- 7026, Facsimile: (07) 856-0151

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1. EXECUTIVE SUMMARY

The Lower Waikato region contains a large number of shallow, natural lakes including the majority of New Zealand's 'peat' lakes. These represent a valuable resource. The lakes support extensive vegetated areas of high productivity, complexity and diversity. Lake vegetation is habitat for wildlife and acts as an important biological filter between the land and inland waters.

A number of anthropogenic and natural factors interact to determine the presence, degree of development, and composition of lake vegetation. The plant communities of lakes reflect the nature of impacts and influences over time.

The Lower Waikato lakes are examples of waterbodies greatly impacted by catchment development and human activities. Some valuable early descriptions of the vegetation of some Lower Waikato Lakes exist although most previous investigations were infrequent, with little botanical or ecological content. A comparison of the present lake flora with past descriptions show large changes in vegetation character have occurred over the last 100 years, culminating in a highly modified lake vegetation. The dynamic nature of the vegetation was evident over a two year period of observation and from reconstructions of past lake vegetation.

This report (Volume 1) summarises the results of a comprehensive botanical survey of the lakes in the Lower Waikato Region between 1989 and 1993. Marginal and submerged vegetation is characterised and described and factors determining vegetation type and development are identified. In addition, the general history of major influences and outcomes on the vegetation of lakes in the region over both geological and recent time scales is outlined.

A total of 269 aquatic species comprised the vegetation of the Lower Waikato Lakes. The majority of these species were present in the marginal vegetation around the lake.

1.1 Marginal vegetation

Three categories of marginal vegetation were recognised and described:

Emergent - rooted in lake sediment with shoots borne above the water surface.
Herbaceous marginal - vegetation influenced by but not within water at summer minimum water level.
Woody marginal - generally taller vegetation further away from the lake than herbaceous communities but tolerant of periodic flooding.

Emergent vegetation comprised predominantly native species in the Cyperaceae and Typhaceae and usually formed monospecific bands of vegetation. Sixteen distinct vegetation types were recognised, with only two vegetation types dominated by exotic species. These exotic species were *Iris pseudacorus* and *Nymphaea* cultivars.

Marginal herbaceous vegetation usually formed diverse and species rich communities, comprising of either completely native, totally adventive but more commonly a mixture of both native and introduced species. Seven vegetation types were recognised in this category, often intergrading with other herbaceous and woody marginal vegetation types.

Marginal woody vegetation was often a vertically tiered community, with a canopy of one dominant species, with few associates and a ground cover of predominantly herbaceous species and seedlings. Nine vegetation types were recognised, four dominated by indigenous species, five by introduced species. The most common vegetation around almost all lakes was dominated by *Salix cinerea* (grey willow).

The vegetation of the Lower Waikato lakes has been invaded by a number of exotic species. The Waikato is the site of introduction for *Lycopus europaeus* and *Ludwigia peploides* ssp. *montevidensis*, both of which formed dominant vegetation types in many lakes and significantly altered the character of lake vegetation. A Lower Waikato lake (Lake Waahi) represents the first adventive site record of *Sagittaria subulata* in New Zealand.

Records were also obtained for rare and endangered native plant species, including *Myriophyllum robustum*, *Utricularia australis*, *Amphibromus fluitans* and *Fimbristylis squarrosa.*

Extensions to species distribution range included the first Waikato records for *Amenanthele lessoniana*, *Hydrocotyle hydrophila* and *Carex cirrhosa*. The survey found extremely limited populations of some plants last recorded in this district by Kirk (1871) including *Pilularia novae-zelandiae*, *Leptocarpus similis*, *Apium filiforme* and *Potamogeton pectinatus*.

1.2 Submerged vegetation

Submerged vegetation communities in the lakes of the Lower Waikato could be categorised according to the lake habitat. The majority of lakes possessed submerged vegetation of low density and diversity or an apparent absence of submerged plants. These comprised a category of waterbodies with low water clarity due to humic staining i.e. peat lakes, or high levels of suspended material i.e. turbid lakes. Only six lakes of moderate water clarity supported extensive areas of submerged vegetation, dominated by *Egeria densa* i.e. oxygen weed lakes.

Peat lakes either did not contain submerged plants, or supported an extremely sparse native vegetation of predominantly *Potamogeton* species, with apparent absence of exotic species such as *Egeria*.

Turbid lakes supported sparse native, a combination of sparse native and exotic species, or no apparent submerged vegetation. The survey confirmed the loss or substantial reduction of submerged vegetation from a number of lakes known to have supported extensive oxygen weed beds in the past. These were termed de-vegetated lakes.

Oxygen weed lakes supported a monospecific, predominantly dense vegetation of *Egeria densa* with few other submerged species.

1.3 Factors affecting marginal vegetation

The factors influencing the development and composition of marginal vegetation include natural variables; water depth or frequency of inundation, degree of exposure, soil type, and anthropogenic factors including; clearance and drainage of wetland for agriculture, grazing and introduction of exotic plants.

A combination of these factors determined the vegetation type present in any marginal situation.

Emergent vegetation was present on permanently inundated substrates, but was excluded by high levels of exposure, grazing, or occasionally by development of willows. Emergent vegetation type was determined in part by soil characteristics; *Typha orientalis* present on mineralised substrates with *Eleocharis sphacelata* tolerant of a wide range of soils including peaty substrates. Exotic species such as *Iris* were restricted to plantings.

Marginal herbaceous vegetation types occurred across a wide range of flooding regimes and nutrient conditions. Sudds dominated by sprawling exotic species were present in high nutrient conditions in sheltered situations. Native communities, e.g. *Phormium tenax* and *Baumea* sedgelands were normally restricted to peaty soils with no cattle access. Grazing was seen as important in maintaining species diversity in other marginal herbaceous vegetation types and also in preventing succession to woody species. Many herbaceous vegetation types were seasonal or ephemeral, only developing when suitable conditions prevail, e.g. sudds of *Ludwigia peploides* ssp. *montevidensis* during summer months.

Woody vegetation was restricted to sites of infrequent inundation, which were inaccessible for cattle or human disturbance. *Leptospermum scoparium* was the most common native dominated vegetation, and was present across a wide range of soil types. The commonest introduced species was *Salix cinerea* which occurred in most places where indigenous vegetation was cleared and grazing pressure was insufficient to prevent its establishment. It was tolerant of a wide range of flood periodicity and all but the most acid soil types, having apparently replaced most native herbaceous and woody vegetation in the Lower Waikato lakes during the last 40 years.

1.4 Factors affecting submerged vegetation

The factors affecting the distribution, composition and abundance of submerged vegetation in the lakes of the Lower Waikato included both natural influences and those resulting from human activities, including water clarity, introduction of exotic plants, degree of exposure, competition and season.

Water clarity was the major factor controlling the abundance of submerged vegetation in the Lower Waikato lakes. Peat lakes presented naturally unfavourable conditions for plant growth due to low light penetration and possibly low nutrients or pH, while high phytoplankton abundance or suspended sediments restricted plant growth within turbid lakes.

The presence or absence of exotic 'oxygen weed' species largely determined the composition of submerged vegetation. *Egeria densa* was the ecodominant in moderately clear Lower Waikato lakes, having spread widely by dispersal of vegetative propagules through river-tributary networks and by deliberate introductions. Once present under conditions favourable for submerged plant growth, dense, surface reaching weedbeds of *Egeria* excluded most other submerged species.

In large lakes high levels of exposure restricted plant presence on windward shores. In small lakes with proportionally larger amount of shore edge, shading by marginal vegetation could exclude submerged species.

During the last 20 years the submerged vegetation in nine out of fifteen *Egeria* dominated Lower Waikato lakes has declined markedly. A review of the possible causes of submerged vegetation declines considers the role of stress, disturbance and competition factors in relation to the characteristics and requirements of *Egeria* and events which occurred in the region over time.

This review highlights the complexity of circumstances leading to the declines. No single factor was responsible in all cases. Instead multiple factors were likely to have interacted, possibly in a synergistic fashion, with a different set of factors operating in each lake. It was also likely that stability mechanisms of the submerged vegetation resisted change prior to decline. These could be overwhelmed by extreme, simultaneous or cumulative impacts.

During the last century the vegetation of lakes of the Lower Waikato have been adversely impacted by human activities, such as agricultural practices, urban development, mining and introduction of exotic flora and fauna. Although the presence of some vegetation types is enhanced by moderate levels of some forms of disturbance, impacts exceeding this range become inhibitory. The catchments of the Lower Waikato lakes are among some of the most highly modified in the country and the present condition of these lakes illustrates the consequences of similar impacts which face other shallow New Zealand lakes in the future. Despite these impacts the lakes support some valuable plant communities of high diversity which are under continued threat from catchment development and exotic invasion. An understanding of vegetation function and dynamics will aid managers in implementing measures to protect and enhance the vegetation of lakes in the Lower Waikato.

2. INTRODUCTION

The Lower Waikato lakes represent a valuable natural resource. The lakes hold considerable physical, spiritual and cultural value for local Maori. Many support eel fisheries of economic value and are a source of water for agriculture. The proximity of lakes to urban populations, and their relative accessibility results in their utility for a wide range of recreational activities.

The lakes support considerable areas of vegetation which has too often been regarded as undeveloped waste-land. In reality the vegetated littoral zone of these lakes act as an important wildlife habitat, and has an important role in protecting water resources by moderating nutrient and sediment transport from the surrounding catchments (Tanner 1992).

The vegetation of the lakes in the Lower Waikato region has undergone repeated change over geological and recent time frames. Palaeolimnological investigations in some lakes suggest a complex sequence of change in characteristics, such as productivity, since their formation around 17,000 years BP (Green & Lowe *In:* Clayton & de Winton in prep.). More recent historical accounts show the lakes have been rapidly altered from a natural state by catchment development during the last 100 years. Accelerated nutrient and sediment loading has increased the fertility of lake waters and hydrosoils. Many lakes now possess low water clarity due to high levels of turbidity as a result of catchment land uses such as farming, mining and urbanisation. Drainage and changes to natural hydrological characteristics have altered lake habitats and invasion by exotic species has greatly modified the floristic character of these lakes.

An extensive botanical survey of the flora of these lakes was undertaken to describe the extent and character of marginal and submerged vegetation. Marginal vegetation is defined as the emergent plants growing within the lake and vegetation adjacent to and strongly influenced by the lakes, and submerged vegetation refers to those plants growing permanently submerged within the lakes.

This report (Volume 1) summarises the results of an extensive botanical survey of the marginal and submerged vegetation of 38 Lower Waikato lakes carried out between late 1989 and early 1993, considers the factors affecting the vegetation, and reconstructs the general history of change in the vegetation from a range of sources. Detailed vegetation descriptions and histories for each lake are contained in Volume 2 (Champion et al. 1993).

2.1 Study area

The 38 lakes investigated during this survey are located within the Lower Waikato region (Fig. 2.1), bounded by the towns of Te Kauwhata in the north (37°25'S, 175°09'E) and Te Awamutu to the south (38°01'S, 175°20'E). Table 2.1 summarises the location, physiography, trophic status, and geological origin of these lakes.

The lakes lie at low altitudes (0 - 55 m a.s.l.), in close proximity to the Waikato and Waipa Rivers. They vary widely in size from <0.5 to 35 km^2, but all are shallow, the deepest being 8.7 m depth. The majority of the lakes in the Lower Waikato Region are classified as eutrophic, and are situated within predominantly pastoral catchments (Boswell et al. 1985). Only three of the lakes investigated are influenced by urban development.

The geological origins of most of the Lower Waikato lakes were riverine, formed by alluvial damming of small valleys during the migration of the ancestral Waikato River 15,000 - 17,000 years ago (McCraw 1967). Some of these waterbodies were further modified by the development of ombrogenous peat bogs within their catchment (Lowe and Green 1987).

A number of the lakes within the study area are situated within or in close proximity to peat bogs, especially the lakes south of Huntly township (Fig. 2.1). Some lakes are influenced by the presence of extensive areas of peat within their catchments and have dystrophic characteristics, being relatively low in nutrients, low in pH and their waters stained by dissolved humic compounds. The conversion of peatland into agricultural land, with drainage and use of fertilisers, has resulted in lakes of decreased peat character.

Local authorities (including Hamilton City Council, Waipa District Council and Waikato District Council), Department of Conservation, and Waikato Regional Council have varying responsibilities and management roles with regard to the lakes of the Lower Waikato. Many of the lakes and/or surrounding land are designated as Wildlife Management Reserves or Recreation Reserves.

2.2 Historical changes in the vegetation of the Lower Waikato lakes

The vegetation of the Waikato Lakes has been influenced by various events since their formation between ~17,000 and 15,000 years BP (McCraw 1967).

Figure 2.1. Map of the Lower Waikato region showing the location of the thirty-eight lakes surveyed in relation to peat bogs.

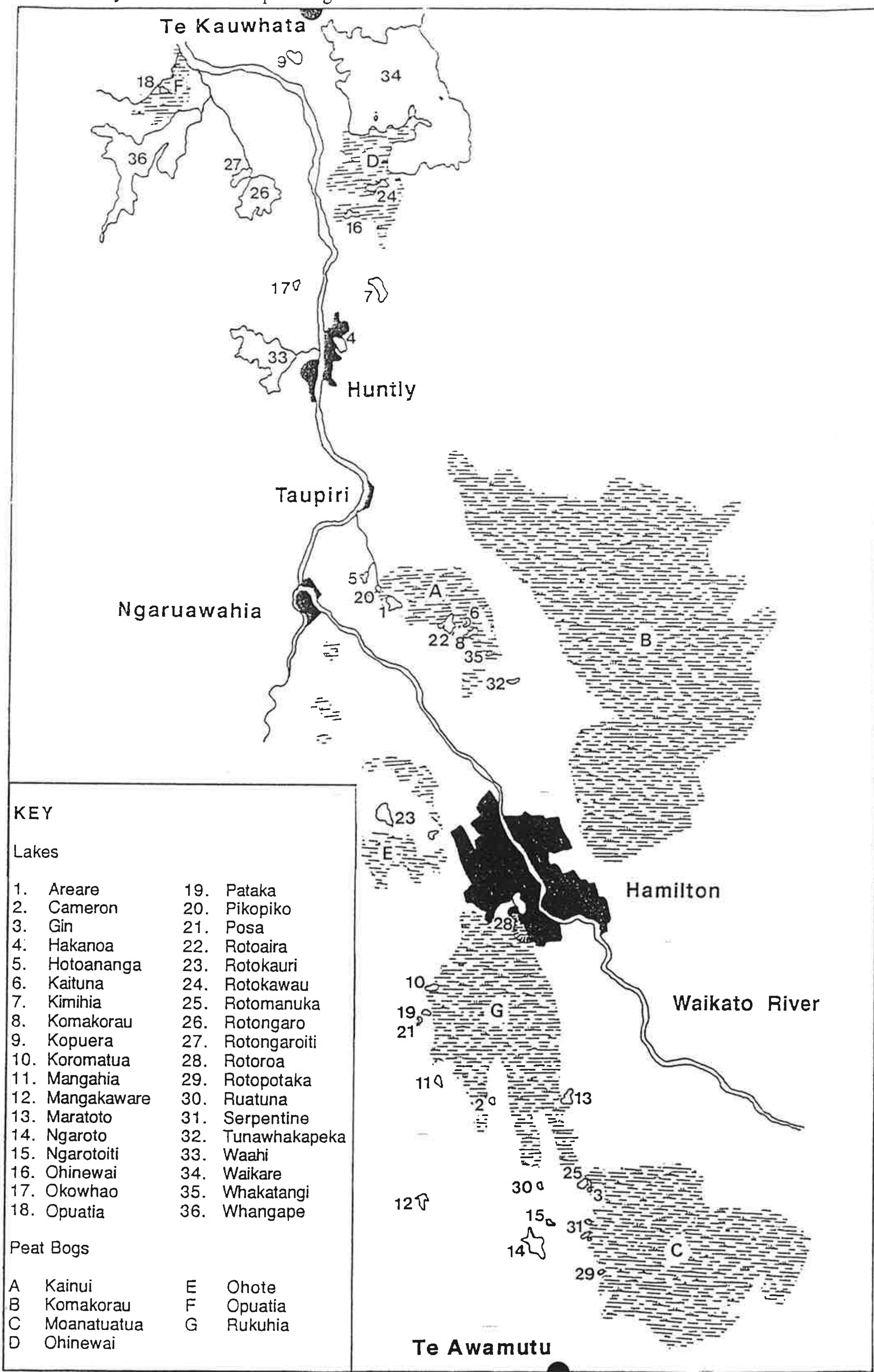


Table 2.1. Location, physiography, trophic status, and geological origin of 38 lakes in the Lower Waikato region. From [1]Irwin 1975, [2]Boswell et al. 1985, Boubee 1978, Etheredge 1987, NIWA Ecosystems this survey.

Lake	NZ MS260 grid reference	Area (km^2)	Shoreline (km)	Maximum depth (m)	Trophic status[2]	Origin[1]
Areare	S14 44903	0.34	2.8	5.1		
Cameron	S15 128694	0.045		1.5		
Gin	S15 141613	0.07	1.0	5.1		
Hakanoa	S13 18032	0.56	4.3	2.5		R
Hotoananga	S14 29916	0.17	1.8	3.0	oligotrophic	
Kaituna	S14 83889	0.21		1.3	eutrophic	S
Kimihia	S13 39061	0.55	3.3	1.0	eutrophic	R
Komakorau	S14 82892					
Kopuera	S13 995175	0.46	3.0	1.5	hypereutrophic	RS
Koromatua	S14 60705	0.068	2.7	0.8	eutrophic	
Mangahia	S15 62670	0.14		3.2	mesotrophic/dystrophic	S
Mangakaware	S15 54609	0.12	0.68	4.8	eutrophic	R
Maratoto	S15 129659	0.18		7.1	mesotrophic	S
Ngaroto	S15 113584	1.29		4.0	eutrophic/hypereutrophic	
Ngarotoiti	S15 139589	0.07		1.0	eutrophic	S
Ohinewai	S13 24098	0.24	1.82	4.5	eutrophic	R
Okowhao	S13 994061	0.17	1.6	2.2	eutrophic	
Opuatia	S13 926165			1.0		

Table 2.1. (cont.)

Lake	NZ MS260 grid reference	Area (km^2)	Shoreline (km)	Maximum depth (m)	Trophic status[2]	Origin[1]
Pataka	S15 55703	0.057		5.0		
Pikopiko	S14 35909		1.1	2.5		
Posa	S15 053700	0.029		4.0		
Rotoaira	S14 72893	0.32	3.1	6.7		S
Rotokauri	S14 37798	0.55	3.2	4.0	eutrophic	
Rotokawau	S13 38112	0.32		1.2	eutrophic	R
Rotomanuka	S15 137614	0.17	1.5	8.7	mesotrophic	S
Rotongaro	S13 975107	3.32		3.3	eutrophic	RS
Rotongaroiti	S13 966117	0.53				RS
Rotoroa	S14 104758	0.54		6.0	mesotrophic	R
Rotopotaka	S15 148571	0.028	1.3	1.0	eutrophic	
Ruatuna	S15 116613	0.17	1.6	3.2	mesotrophic/dystrophic	
Serpentine East	S15 138588	}	0.87	3.0		
Serpentine North	S15 140597	} 0.135	0.55	4.0		
Serpentine South	S15 141588	}	1.15	4.0		
Tunawhakapeka	S14 104864	0.08	1.7	1.0	eutrophic	S
Waahi	S13 980028	5.37		5.0	eutrophic	R
Waikare	S13 41160	34.42		2.0	eutrophic	RS
Whakatangi	S14 93877					
Whangape	S13 916127	11.97	29.2	2.7	eutrophic	R

Origin R = riverine.
S = swamp/phytogenic

2.2.1 Before human influence

Early marginal vegetation would have been dominated by *Leptospermum scoparium* scrub and short forest, *Phormium tenax / Cordyline australis / Coprosma* swamp, *Typha orientalis* and other emergent species. *Dacrycarpus dacrydioides* (kahikatea) pollen first appeared in the sediments of the post-glacial Waikato Basin 13,700 years BP (Newnham pers. comm.) and this species would have formed the dominant forest on the flooded alluvial plains. Tall forest such as described by Captain Cook for the Hauraki Plains in 1769 (Tye 1974) would have extended to the margins of these lakes and can still be seen surrounding the un-impacted lakes of South Westland (eg. Lake Ianthe, NIWA-Ecosystems unpubl. data).

The submerged vegetation of clear water, ancestral lakes prior to major peat development is likely to have resembled that described for 3 Waikato lakes in the late 1800's (Kirk 1871) and shallow Northland lakes that retain a predominantly native submerged vegetation (Tanner et al. 1986). Short growing species (*Glossostigma*, *Lilaeopsis*, *Elatine*, *Ranunculus*, and *Isoetes* spp.) would have formed turfs in shallow water where moderate exposure would have prevented the development of marginal emergents. *Isoetes* may have extended into deeper water and together with charophyte species would have formed an understory to taller growing species. Dense beds of charophytes would have been present across much of the lake bottom, beneath a sparse canopy of pondweeds (*Potamogeton* spp.) and milfoils (*Myriophyllum* spp.).

From approximately 12,000 to 11,000 years BP ombrogenous peat deposits began forming (Davoren 1978). Their expansion affected the majority of the lakes in this study by introducing allochthonous humic materials, initiating a dystrophic condition and also by reducing the influence of flooding and nutrient inputs. For example, palaeolimnological investigations into Lake Maratoto showed that the lake became dystrophic 14,000 to 10,000 years ago (Green & Lowe 1985). These conditions would have promoted the growth of peat bog species and manuka associations at the expense of alluvial kahikatea forests and *Typha* dominated vegetation. Examples of this type of vegetation are still present in the Kopuatai and Whangamarino Peat Bogs. Common bog species from these areas would have included the restiads *Empodisma minus*, *Sporodanthus traversii*, the sedges *Baumea teretifolia*, *Schoenus brevifolius*, the fern *Gleichenia dicarpa*, and the shrubs *Leptospermum scoparium* (manuka), *Epacris pauciflora*, *Dracophyllum lessonianum*. The mosses *Sphagnum cristatum*, *S. falcatulum* and *Campylopus kirkii* and the liverwort *Goeleobryum unguiculatus* are all characteristic of this vegetation (Irving et al. 1984), but unlike most bogs worldwide, the restiad species rather than *Sphagnum* were the major peat forming species. Stands of short manuka forest would have been common in drier areas or areas affected by natural fires. Kahikatea dominated forest would have been restricted to areas with mineralised soils (Cranwell 1939).

Decreases in water clarity associated with the introduction of humic substances into lakes from adjacent peat bogs would have affected the degree of submerged vegetation development of lakes in close proximity to peat bogs. Submerged vegetation would have been absent from heavily stained waters, and only sparse growths of species tolerant of low light levels, low nutrient and acid waters would be able to develop in dystrophic waterbodies.

Lakes located within the present Waikato River floodplain would have been only marginally influenced by peat formation in the region, including the Huntly lakes except Lakes Ohinewai and Rotokawau which had localised lake peat. Kahikatea forest would have continued to dominate the fertile floodplains of the main rivers and streams of the area prior to human habitation.

2.2.2 Maori inhabitance

The Maori would have exerted the first human influence on the vegetation of these lakes. Polynesian settlement approximately 1,000 years BP had a substantial and extensive influence on the original vegetation. Lake sediment cores taken by Newnham et al. (1989) showed a decline in tree pollen numbers and corresponding increase in *Pteridium esculentum* (bracken) and charcoal at around 800 years BP, indicating the effect of Maori clearances by fire. The first Europeans found much of the lowland area covered with manuka scrub and fern (Cranwell 1939). Many of the lakes studied have pa sites on the surrounding high ground. The lakes were a source of food (eg. eels, mussels) and other natural resources such as flax. The influence of Maori on the lake vegetation would have mostly been local, with areas cleared for kumara cultivation and other agriculture. There is evidence of damming of some lakes at this time. For example the water level of Lake Ngaroto was raised to create an island where a pa was situated (Waipa CC 1978). The normally maritime *Bolboschoenus*, whose bulbous rhizomes were used as a source of food by the Maori, may have been planted in the Waipa lakes as a supplement to their diet (Colenso 1880).

2.2.3 European inhabitance

The European colonisation of the Waikato Region from the late 19th century had a massive influence on the composition and distribution of lake vegetation. The effects were manyfold:

1) Much of the lowland forest was logged for timber and/or burned to produce agricultural grazing land, increasing the sediment and nutrient loading into lakes.

2) Wetland areas within lake catchments were drained and developed causing changes to hydraulic conductivity of the land. In the absence of wetland pooling and storage areas and with decreased permeable surfaces, precipitation from rainfall events was discharged to lakes more rapidly and with increased peak flows. This lead to a reduction in biological filtering and infiltration of run-off. Following agricultural development surface waters would run rapidly from land surfaces, carrying larger pulses of suspended solids and nutrients to the lakes with increased frequency. Removal and grazing of buffer margins around the edge of lakes reduced protection from stock access and permitted the entry of increased amounts of nutrients.

Changes to the flow regime of the Waikato River would have impacted on adjacent lakes within the river's flood plain. River flow regulation by upstream hydro-electric dams, together with levee and floodgate construction associated with flood protection schemes would have reduced the frequency of river back-flows to lakes. Residence times for lake waters could have extended and maximum lake levels decreased in the absence of these flushing events.

Lake water level decreases have resulted from dredging of lake outlets, such as have occurred in Lakes Kimihia, Waahi and Rotongaro. Increases in lake level are less common, Lake Rotoroa's level recently increased for utility reasons. Some shallow lakes were completely drained and converted into pasture (eg. Round Lake, Lake Rototuna), further reducing the extent of the wetland network in the region.

Drainage of the peat bogs caused shrinkage due to drying and decomposition of peat deposits. Stephenson (1983) reports peat shrinkage rates of as much as 6 m in the Rukuhia Bog since drainage commenced in 1902, with an annual rate up to 100 mm in newly broken paddocks. This ultimately reduced the amount of humic acid entering the lakes and also reduced the lake levels. The former Lakes Serpentine and Rotomanuka are examples of lake area reduction due to peat shrinkage, now having become divided into a number of smaller lakes. In areas where peat development was reduced e.g. in land adjacent to most lakes, the stumps of many kahikatea and kauri (*Agathis australis*) have been exposed, revealing the vegetation present before the development of these ombrogenous peatlands. When the DSIR mapped the soils of the Waipa District in 1939 (DSIR Bulletin 1939) much of the land surrounding the Waipa lakes was recorded as stumpland.

3) The improvement of pasture, application of fertiliser and increased farming intensity has increased the quantity of nutrients entering into these lakes. Many of the lakes surveyed receive dairy shed effluent either directly or indirectly and two of the lakes, Kopuera and Koromatua, are now classed as hypereutrophic (Boswell et al. 1985). The widespread

conversion of peat bog to farm land following drainage has resulted in lakes losing some of their peat lake characteristics due to decreased supply of allochthonous humic material (Etheredge 1987), and with corresponding increases in nutrients, pH and organic or inorganic turbidity.

4) Introduced fauna have impacted on lake habitat and vegetation. New Zealand's vegetation evolved in the absence of large ungulate grazers. In the past, large birds (extinct native moa, swan and goose) would have exerted a grazing pressure but were likely to have been more selective than grazing mammals (Tanner 1992). Pastoral catchment development has often allowed livestock access to lake margins, with impacts on lake vegetation through direct consumption, trampling of plants, indirect disturbance of lake substrates and promotion of weed invasion (Tanner 1992).

   Following its introduction in the mid 19th century, the black swan (*Cygnus atratus*) established in the Waikato region. A large population of black swans developed in conjunction with extensive *Egeria densa* weedbeds which were recognised as a major food source. Birds numbering in their thousands were recorded at times on the larger Huntly lakes. Black swans are known to impact directly on submerged vegetation, grazing on plants within a depth of approximately 1 metre from the water surface (Mitchell et al. 1988). Swans, mallard ducks (*Anas platyrhynchus*) and canada geese (*Branta canadensis*) have become important grazers of marginal herbaceous communities, in addition to native wildfowl such as Pukeko (*Porphyrio porphyrio melanotus*).

   The release and spread of exotic fish within the Waikato waterways presented additional potential impacts on submerged vegetation. Fish with an omnivorous diet, such as rudd (*Scardinius erythrophthalmus*), may graze on submerged vegetation (Prejs 1984), while benthivorous fish, such as koi carp (*Cyprinus carpio*), impact on submerged plant habitat through disturbance and re-suspension of sediment (King and Hunt 1967).

5) Mining activities were carried out within the Huntly region from 1876 onwards, with major earth works associated with open cast mining from the 1940's. The impacts of mining activities on lakes of the region generally involved increased inputs of fine 'fire clays' from kaolinite strata associated with coal seams. Sediments were contributed to waterways from coal extraction operations, mine de-watering and run-off from unstabilised overburden and waste spoil heaps, particularly during flood rainfall events (WVA 1985).

   Lake specific impacts included reductions of area and depth of Lake Kimihia due to dumping of overburden (Boswell et al. 1985) and increased concentrations of boron detected in Lake Waahi (Kingett 1984).

6) The influence of urban development within lake catchments has been restricted to Lakes Rotoroa, Hakanoa, and Rotokauri, which receive some urban run-off. Diffuse and point source run-off from urban catchments can contribute suspended solids, nutrients, bacteria and pollutants such as heavy metals and hydrocarbons. Stormwater inflows convey run-off from the impermeable surfaces of urban catchments which is often enriched with heavy metals, copper, zinc and lead from vehicular wastes. Elevated levels of heavy metals have been shown to be associated with stormwater inflows into Lake Rotoroa (de Winton et al 1991), while other pollutants may enter lakes as a result of disposal of chemical wastes via stormwater systems.

   Lake Rotoroa is an example of a highly modified urban waterbody, situated within a park reserve and partially residential catchment. The lake has extensive stopbanking via retaining walls, a modified lake level regime and artificially formed sand beaches (Clayton and de Winton in prep.).

7) A large number of exotic aquatic plants have been introduced to New Zealand, some of which have been extremely successful, becoming widely distributed, well established and highly competitive with native species. Exotic introductions resulted in the addition of botanical lifeforms unrepresented in the native aquatic vegetation, such as swamp dwelling dicotyledon trees (eg. willows) and fast-growing sprawling herbs (Howard-Williams et al. 1987).

   Kirk (1871) made no mention of introduced willows (*Salix* spp.) during his expeditions in the region. Willows were originally introduced to stabilise the banks of watercourses and following deliberate plantings and transport of stem fragments soon became widely distributed. Grey willow (*Salix cinerea*) was first documented in New Zealand in 1925 (Webb et al.1988). It had a major impact by forming a dense carr unlike any native plant, becoming the dominant wetland vegetation in the Waikato. Crack willow (*Salix fragilis*) was first collected in 1880 (Webb et al.1988) and was well established along waterways of the Hauraki Plains in 1902 before drainage work began (Tye 1974).

   Other marginal species have been introduced as ornamental plants e.g. waterlily cultivars (*Nymphaea*), parrots feather (*Myriophyllum aquaticum*) and yellow flag (*Iris pseudacorus*), while scrubweeds such as gorse (*Ulex europaeus*) and hawthorn (*Crataegus monogyna*) were introduced for utility as hedges.

   Exotic 'oxygen weed' species of the families Hydrocharitaceae and Ceratophyllaceae were introduced to New Zealand for use in aquaria, ornamental ponds and fish culture. Despite the fact that these species do not produce seed they became widely distributed. Oxygen weeds were repeatedly liberated, further distribution occurring through natural waterway systems (Mason 1960), accidental transport on boating and fishing equipment, and deliberate introduction for 'habitat enhancement' (Howard-Williams et al. 1987).

Elodea canadensis and *Egeria densa* (earliest New Zealand record) were first documented from the Waikato River in 1946 (Mason 1960), and *Lagarosiphon major* collected from Lake Rotoroa in 1953 (Gudex collection, WAIK 3718). However these species could have been present for some time prior to collection, *Elodea* having been introduced to New Zealand as early as 1868, and *Lagarosiphon* first documented in 1950 from this region. Indeed Lake Whangape was described as 'badly overgrown with weeds' as early as the 1920's (Anon 1954). *Ceratophyllum demersum*, first recorded from the upper Waikato River in 1963 (Mason 1975), became widespread more recently and the exotic species *Potamogeton crispus* also became common since noted in the Waikato River in 1958 (Mason 1960).

Once introduced to Lower Waikato lakes, dense beds of oxygen weeds invaded large areas of lake littoral, excluding native submerged species and completely changing the nature of submerged vegetation in these lakes, *Egeria* being particularly successful.

2.3 Previous investigations

There have been occasional investigations of the aquatic flora of some lakes of the Lower Waikato region over time (eg. Lakes Whangape and Waahi) while that of other lakes has remained largely undocumented (eg. Lake Opuatia). An examination of these previous descriptions reveal the dramatic changes that have taken place during the last 100 years.

2.3.1 Late 1800's to early 1900's

The botanist Kirk investigated the Lower Waikato Region during the early phase of European colonisation, in 1869 and 1870 (Kirk 1871). He briefly described the vegetation surrounding and within the Lower Waikato River, the Opuatia Stream and Lakes Whangape, Waikare and Waahi. Kirk described massive raupo swamps, flax / sedge swamps, kahikatea forests with a *Coprosma* understory, *Plagianthus regius* (manautu) bordering the streams and an assemblage of divaricating shrubs including several *Coprosmas*, *Melicytus micranthus*, *Streblus heterophyllus*, *Pseudopanax anomalus*, *Myrsine divaricata* and juvenile *Elaeocarpus hookerianus* (pokaka). Similar assemblages can still be found in the Awaroa Valley adjacent to Lake Whangape (Champion 1988).

Kirk (1871) noted a maritime element of species growing on the margins of the three Waikato lakes he surveyed, including *Tetragonia tetragonoides*, *Apium filiforme*, *Selliera radicans*, *Chenopodium glaucum* var. *ambigium*, *Leptocarpus similis*, and *Bolboschoenus fluviatilis*.

At the time of Kirk's observations the lakes apparently supported an entirely native submerged vegetation. The water of Lake Whangape must have been quite clear as Kirk observed submerged plants through 2 m of water. He described a mixed low growing plant association in the littoral margins of the Lake Whangape, consisting of *Isoetes kirkii*, *Ranunculus limosella*, *Elatine gratioloides*, and *Pilularia novae-zelandiae* . *Potamogeton pectinatus* , *P. ochreatus* and *P. cheesemanii* were abundant, while *Ruppia polycarpa* and *Zannichellia palustris* were common (Kirk 1871). Kirk also collected five species of charophytes: *Chara corallina*, *C. fibrosa*, *C. globularis*, *Nitella hyalina* and *Nitella leptostachys* (Wood & Mason 1977).

Kirk remarked on the 'comparative absence of lacustrine vegetation' in Lake Waikare attributing this to the 'shifting sandy nature' of the lake bed. *Nitella hookeri*, *Ruppia polycarpa*, *Ranunculus limosella* were described as abundant. However, *Isoetes kirkii* was present only in scattered patches which didn't cover the bottom of the lake. Later the botanist Cheeseman (1925) reported *Zannichellia palustris* from Lake Waikare.

In a limited description of the submerged vegetation of Lake Waahi, Kirk suggested its vegetation to be 'more copious' than neighbouring Lakes Whangape and Waikare. *Elatine gratioloides*, *Utricularia australis* and *Ruppia polycarpa* were recorded (Kirk 1871), and *Chara fibrosa* was collected (Wood & Mason 1977). He also observed 'most of the plants previously collected'. These are likely to include the submerged species *Pilularia novae-zelandiae*, *Isoetes kirkii*, *Ranunculus limosella*, *Potamogeton pectinatus*, *P. ochreatus* and *P. cheesemanii* , *Zannichellia palustris*, and a number of charophytes. Cheeseman, in visits to Lake Waahi between 1884 and 1885, collected *Chara corallina*, *C. fibrosa*, *Nitella leptostachys*, *N. pseudoflabellata*, and *N. hyalina* (Wood & Mason 1977).

Kirk's 1870 visit to the Lower Waikato recorded several adventive species around these waterbodies including several introduced docks (*Rumex* spp.) and watercress (*Rorippa nasturtium-aquaticum*) on alluvial ground and the tree *Robinia pseudacacia* (false acacia) freely naturalised near Ngaruawahia.

These investigations represent valuable records of the lakes in their natural state prior to major anthropogenic influences.

2.3.2 Mid to late 1900's

In 1939 Cranwell described the lowland vegetation of the Waipa District including peat bog and vegetation of lake margins, while soil maps prepared by the DSIR indicated the nature of the marginal vegetation of some lakes (DSIR Bulletin 1939).

Further detailed investigations did not take place till late 1958 when Mason and Moar 'examined the Waikato district for aquatic plants' (Mason 1960). Large changes from the original descriptions of lake vegetation were noted, with the widespread presence of exotic plant species including willows and oxygen weeds of the family Hydrocharitaceae. *Egeria densa* and *Lagarosiphon major* were described as 'well established' and 'growing in some waters almost to the exclusion of other aquatic plants' (Mason 1960).

Broad bands of *Egeria* were observed in Lake Whangape, a localised patch was described in Lake Hotoananga, and *Egeria* drift collected from Lake Waikare. *Egeria* was also present in Lake Kimihia; being the suggested source of innoculum for sites north (i.e. downstream) of Huntly township (Mason 1960). *Egeria* was at this time present in the Waikato River downstream of Huntly and drift may have entered lakes adjacent to this stretch of the river within flood waters.

From the 1970's onward observations of submerged vegetation in Lower Waikato lakes became more frequent. Investigators included New Zealand Electricity Department (NZED) staff, who detailed exotic oxygen weed domination of Lakes Kimihia and Waahi during 1974-1975 (Coffey & Coleman 1975, Coffey 1988).

During the mid to late 1970's staff and students of the University of Waikato carried out research on Lake Waahi, spanning a period when the exotic dominated submerged vegetation underwent a large decline, however observations of submerged plants were generally secondary to other purposes. The Waipa Lakes were the focus of a general study by staff and students of the University of Waikato during the 1976-1977 and 1977-1978 summers (Chapman & Boubee 1977, Boubee 1978). These investigations provided the first marginal and submerged vegetation records for many peat influenced waterbodies.

Wildlife Service (now Department of Conservation) staff surveyed the extent of exotic oxygen weed beds in Lakes Waikare and Whangape during 1977-1979. These waterbodies were known as major feeding grounds for the black swan within the Waikato Region, however a submerged vegetation decline had already occurred in Lake Waikare before the study was initiated (M. Williams unpublished data).

The Wildlife Service also carried out botanical resource surveys in Wildlife Management Reserves of some lakes (eg. Irving & Jones 1986), and investigated the vegetation of lakes in the Huntly West area, to assist with environmental impact assessment prior to proposed expansion of mining activities (Garrick et al. 1986).

The Aquatic Plant Group (APG, Ministry of Agriculture and Fisheries, now NIWA-Ecosystems) has maintained a record base of investigations into the submerged vegetation of New Zealand lakes since 1976, including a number of Lower Waikato lakes. In addition extensive research was carried out on weed control in Lakes Rotoroa (Tanner et al. 1990) and Rotokauri, plant decline in Lake Whangape (Wells et al. 1988, Wells & Clayton 1989), and submerged plant status in Lake Waahi (Clayton & de Winton 1989).

The Waikato Valley Authority (WVA, now Waikato Regional Council) carried out an extensive survey of water quality, biota including vegetation and other resources of 24 lakes in the Lower Waikato region during the early 1980's. This information was the basis of 5 reports including assessments of trophic status and resource descriptions (WVA 1980, WVA 1981, WVA 1982, Boswell et al. 1985, McLea 1986).

During the 1980's the University of Waikato conducted studies which included aspects of lake vegetation. Thompson et al. (1983) initiated an ecological survey of the Ohinewai region in response to concerns raised by proposed mining within the area. Students work with relevance to lake vegetation were Wallace (1983); the manuka dominated vegetation of a peat lake, Lockley (1988); *Egeria densa* growth in Lake Waahi, and Etheredge (1987) on phytoplankton communities of 9 lakes. de Lange collected marginal plants from a number of lakes from 1984 onwards, with most specimens being lodged in the University of Waikato herbarium (WAIK).

Local authorities, district and city councils, have initiated investigations into lake vegetation on occasions, particularly when troublesome weed growths have developed, while lake management plans developed by local authorities often included vegetation resource descriptions (HCC 1983, Waipa CC 1978).

In addition, local residents and fishermen have made observations of submerged vegetation in lakes which has assisted in reconstructing vegetation histories.

3. MARGINAL VEGETATION

3.1 Methods

Surveys of the marginal vegetation of 38 lakes within the Lower Waikato region were carried out between late 1989 and early 1993. Marginal vegetation at each lake was surveyed and mapped using enlargements of Department of Survey and Lands aerial photographs, providing 1:5000 scale photographs. Vegetation types were discerned from these and further aerial photographs taken by the authors in 1991. Each lake was visited at least once and all vegetation types discerned from aerial photographs were botanised.

Vegetation types were described according to Atkinson (1962) describing dominant species with associates e.g. *Salix cinerea -S. fragilis /Coprosma* spp. (*S. cinerea* dominant canopy with lesser amounts of *S. fragilis* with a *Coprosma* spp. sub canopy). Qualitative descriptions of the botany of each type were summarised. In addition to vegetation descriptions species lists of submerged and marginal species were made for each lake surveyed.

Representative specimens of marginal plant species were collected and lodged in the University of Waikato Herbarium (WAIK).

3.2 Results

Species lists for all lakes were made from survey results and historical records, recording both submerged and marginal species as present or extinct. The species list includes most wetland species as listed in Johnson and Brooke (1989), with the addition of important dry land species present in the marginal vegetation of these lakes. A total of 269 taxonomic entities (including hybrids) were recorded (Appendix 1).

Several marginal vegetation types were distinguished during the survey and these are described below.

3.2.1 Emergent vegetation

Emergent vegetation is defined as that growing within the range of normal lake levels, with roots in the bottom sediments and foliage emergent above the water. Waterlilies (*Nymphaea* cultivars) are included in this classification even though their leaves usually float at the water/air interface. Emergent vegetation is invariably dominated by one species. Apart from the dicotyledon *Nymphaea*, these are generally monocotyledons from the families Cyperaceae, Typhaceae, Restionaceae, Juncaceae, or Iridaceae. Sixteen vegetation types are reported from this study. Of these, only 7 are found in more than one lake. These vegetation types described by genera are:

a) *Typha*
b) *Eleocharis*
c) *Baumea*
d) *Schoenoplectus*
e) *Bolboschoenus*
f) *Leptocarpus*
g) *Juncus*
h) *Cyperus*
i) *Iris*
j) *Nymphaea*

All species described in this section are also common components of some marginal herbaceous and woody vegetation types with the exception of *Nymphaea*, which is an obligate hydrophyte.

a) *Typha*

Typha orientalis (raupo) is the most common emergent encountered in the survey occurring in all but 6 of the surveyed lakes. In all other lakes it forms a distinctive community, although in 4 of these lakes raupo beds occurred above the present water level, rather than as emergent vegetation.

Typha typically forms dense pure stands growing from the shore to a maximum depth of 2.2 m. Height is usually uniform from 1 to 3 m tall. *Typha* beds were usually 2 to 5 m across (occasionally up to 20 m across) but where cattle could access these stands, they were typically narrower with sparser growth (eg. Lake Ohinewai). In the shallow Lake Rotopotaka 32% of the lake area was occupied by this plant, in all other lakes with this vegetation, it was restricted to littoral zones. A large *Typha* swamp vegetation was noted at Lake Waahi where this species occupied a sheltered, shallow bay on the eastern side of the lake.

Associate species, if present, are normally confined to the outer or inner margins of these stands. Associated emergent species included *Eleocharis sphacelata* which commonly forms a distinct zone on the outer fringe of raupo but may also occur within *Typha* beds. Similarly *Baumea articulata*, *Schoenoplectus validus*, *Bolboschoenus fluviatilis* are occasional components of this outer fringe. In many lakes the sprawling *Ludwigia peploides* ssp. *montevidensis* is a common component in the outer raupo margin. Rare associates with this species were *Paspalum distichum* , *Polygonum salicifolium* and *Myriophyllum aquaticum*. In Lake Rotomanuka the free-floating bladderwort *Utricularia australis* was commonly found amongst the sparse outer culms of *Typha*. Earlier surveys (Chapman & Boubee 1977, Boubee 1978) located this species in Lake Serpentine South but the present survey failed to find *Utricularia* at this site.

On the inner (landward) margins of raupo beds the climber *Calystegia sepium* was commonly found twisting around *Typha* culms. Occasionally *Isachne globosa*, *Polygonum hydropiper*, or other wetland herbs were found amongst raupo on this inner edge.

In 10 of the lakes surveyed the shrubby labiate *Lycopus europaeus* (gypsywort) was almost co-dominant with *Typha* throughout the vegetation. *Lycopus* was established on dead raupo culms and was apparently smothering *Typha* regrowth. At all sites associated with *Lycopus* the raupo appeared unhealthy, beds were less than 1 m across and plants were 1 m or less in height. In wider beds *Lycopus* was confined to the inner marginal few metres of raupo.

On the western shore of Motukauere Island, Lake Whangape one *Typha* bed was affected by an unidentified disease, possibly a fungus. Around 99% of plants were affected with black decaying culms or yellow foliage, giving the appearance that the stand had been burnt. No other raupo stands appeared to be affected in the other lakes surveyed.

b) *Eleocharis*

Eleocharis sphacelata (tall spikerush) formed a distinct community on the lakeward edge of other emergent vegetation in all but 7 of the surveyed lakes. It was also present at 3 of these lakes, but only as a component of swamp meadow vegetation It was the dominant emergent in several lakes, especially those with peat influenced waters.

These tall spikerush beds were typically monospecific, with vegetation covers of 25-50%. They commonly occur at depths from 1 to 2 m. Plants are usually emergent above the water surface to a height of 1 m tall and beds are normally 2 to 4 m across. In Lake Serpentine South, this species forms a large pure community in the wetland area between this and Serpentine North. This area is flooded for most of the year.

Associate species are sparse, the commonest were *Ludwigia peploides* ssp. *montevidensis*, *Myriophyllum aquaticum*, *M. propinquum*, *Isachne globosa*, *Egeria densa* and in Lake Rotomanuka, *Utricularia australis*.

In 6 of the surveyed lakes these tall spikerush beds were heavily infested with a stem boring insect and an associated pathogen causing culm yellowing and atrophy.

Eleocharis acuta, a common component of swamp meadow vegetation, formed an emergent vegetation type in Lake Maratoto where it formed pure stands in 1 m of water. Initially this plant appeared to be the hybrid *E. acuta* x *sphacelata* as described by Cockayne and Allan (1934), but when cultured in shallow water the typical *E. acuta* growth form developed. The authors have since noted this emergent form in several Northland dune lakes.

c) *Baumea*

Baumea articulata was found in all but 6 of the lakes sampled in this survey. It formed an emergent vegetation type in 3 lakes, occurring in herbaceous marginal communities in the remaining lakes.

As an emergent, *Baumea articulata* usually formed dense pure stands up to 2.3 m tall and emergent from depths of 0.5 m, but in Lake Rotoroa it grew to depths of 1.5 m.

Other *Baumea* species, *B. huttonii*, *B. juncea*, *B. rubiginosa* and *B. teretifolia* were rare components of the emergent vegetation. They always grew in water less than 0.5 m deep. These species, especially the latter two, were most common within peat influenced marginal herbaceous vegetation.

d) *Schoenoplectus*

Schoenoplectus validus (kuawa) was an infrequent emergent species, encountered in the lakes in the Huntly area and also Lake Rotoaira (near Ngaruawahia). Kuawa was often associated with *Typha*, but also formed pure beds in Lakes Rotongaro, Waahi, Waikare and Whangape, most commonly on exposed eastern shores.

Schoenoplectus was found in water ranging from 0.1 to 2 m depth and at maximum depths attained a height of 1 m above the surface. There were few associate species in these generally small stands.

e) *Bolboschoenus*

Bolboschoenus fluviatilis (purua grass) occurred in 12 of the surveyed lakes, mostly the Huntly lakes, but also 3 of the Waipa lakes.

This species was confined to the littoral fringes of waterbodies, not growing deeper than 0.4 m. Culms were usually 0.8 to 1.2 m tall and formed dense beds. *Bolboschoenus* was occasionally found scattered within *Typha* or grey willow (*Salix cinerea*) dominated vegetation but in most Waipa lakes only solitary beds of purua grass were found, with average dimensions of 10 m long and 2 to 3 m across.

Typha was found with most sites of purua grass but few other associate species were noted. In Lakes Opuatia and Ruatuna *Lycopus europaeus* formed a dense understory under purua grass, reminiscent of those associated with *Typha* beds described in section 3.2.1a.

Bolboschoenus medianus was only found on the exposed western shore of Motukauere Island in Lake Whangape. It formed extensive swards 1.5 to 2 m tall in shallow water and the adjacent margin. Often this species formed pure stands but where less dense stands occurred associate species included *Schoenoplectus validus*, *Aster subulatus*, *Polygonum hydropiper* and *Rorippa palustris*.

f) *Leptocarpus*

One bed of the restiad *Leptocarpus similis* (oioi) was found on the thermal Punikanae Rock in Lake Waikare. It was a dense bed on the exposed eastern side of the island, with no associate species. It grew to depths of 0.2 m.

g) *Juncus*

Juncus species of the section Genuini (rhizomatous with leaves reduced to basal leaves) were common components of marginal rough pasture and other disturbed habitats and were occasionally emersed when lake levels were high but the species *J. effusus* (soft rush) formed an emergent vegetation in Lake Maratoto growing in 0.5 m of water.

h) *Cyperus*

Cyperus ustulatus was only found as an emergent in Lake Rotoroa, where one small clump was found in association with a submerged willow trunk. It commonly occurred in the marginal herbaceous vegetation of many of the other lakes surveyed.

Papyrus (*Cyperus papyrus*), an introduced ornamental plant, was located on Punikanae Rock in Lake Waikare, on the opposite side of the island to the *Leptocarpus*. It was emergent in 0.2 m of water, associated with a thermally heated pool on the landward side of the clump.

i) *Iris pseudacorus*

Iris pseudacorus (yellow flag) is an adventive plant, only found in 5 of the lakes surveyed during this study. *Iris* is a minor component of the vegetation of all these lakes apart from Mangakaware where it was abundant and Rotoroa where it was a dominant emergent over large areas. It is also a common plant on the Waikato River between Huntly and Ohinewai. In Lake Mangakaware plants are approximately 1 m tall and extend from the shore into shallow water. In Lake Rotoroa this species was usually found on the landward side of the other emergent species rooting to depths of 0.5 m. However *Iris* also formed a dense floating mat comprised of rhizome and root material which appeared to be extending into deeper water displacing other emergent species. This sudd was strong enough to support a persons weight and apart from moss, nothing grew on top of this mat.

j) *Nymphaea*

Introduced ornamental *Nymphaea* cultivars (waterlilies) are a prominent feature of the marginal vegetation of Lakes Mangakaware and Rotoroa, but were also recorded from Lakes Hakanoa, Kimihia and Waahi. In these lakes *Nymphaea* is restricted to sheltered sites adjacent to other emergent species especially tall spikerush and raupo. These waterlilies occupy areas where water depth is less than 2.2 m and form a dense band of floating and emergent leaves and flowers. The large majority of these waterlilies were deliberately planted and have since spread by rhizome extension, however in Lake Rotoroa two cultivars, Gladstoniana and Rose Arey, were spreading by seedling production (I. Wilson pers. comm.).

3.2.2 Marginal herbaceous vegetation

Marginal vegetation is defined as that influenced by the lake waters but not normally growing within the lake during summer months. This definition includes sudd (floating mat) forming species.

Marginal herbaceous communities can be divided into 6 main vegetation types:

a) marginal sudd communities, consisting of floating mats of various species extending from the shore over the lake;
b) swamp meadows, consisting of a mosaic of vegetation types either sudd forming or rooted on the lake shore, but always occurring on the inside of type a) sudds;
c) peat bog vegetation;
d) tall sedgelands, marginal vegetation dominated by cyperaceous species of the genera *Carex* or *Baumea*;
e) *Phormium tenax* dominated vegetation;
f) marginal turf communities;
g) rough pasture and *Juncus* rushlands.

These vegetation types often intergrade and form complex assemblages, often with an additional woody vegetation component.

a) Marginal sudds

These floating mats of the following species, either monocultures or in combination, are a feature of all the small lakes and the sheltered bays of the larger lakes. The dominant species furthest from the shore is the introduced *Ludwigia peploides* ssp. *montevidensis* (primrose willow) which was present in all but 3 of the lakes sampled. These floating sudds may extend up to 5 m out over the lake often engulfing emergent vegetation types when present. The only associate species in these floating mats were the adventives *Myriophyllum aquaticum* (parrots feather), and *Apium nodiflorum* (water celery), both restricted to the lakes of the Huntly area. Parrots feather was not recorded from Lakes Ohinewai or Opuatia, but was abundant in the remaining 10 lakes surveyed in the Huntly area. Water celery was recorded from 7 of these lakes. The outer primrose willow/(parrots feather) sudd frequently graded into an inshore sudd zone dominated by the native *Polygonum salicifolium* (willow weed, tutaniwhai). *Ludwigia, Myriophyllum, Apium* and the native grass *Isachne globosa* were common components of this *Polygonum* sudd. The adventive grass *Paspalum distichum* (Mercer grass) formed distinctive monospecific sudds in 4 of the lakes surveyed. The adventive grasses *Axonopus affinis* (carpet grass) and *Glyceria maxima* (reed sweet grass) also formed marginal sudds in 1 or 2 lakes but did not form the extensive areas occupied by the previously described species.

b) Swamp meadow

A characteristic mosaic of vegetation types forming a low (less than 1 m tall) meadow dominated by various native and introduced sedges, grasses, rushes and dicotyledonous herbs was encountered in the marginal vegetation of most lakes. Dominant species in the mosaic included *Isolepis distigmatosa, I. prolifer, Eleocharis acuta, E. gracilis, Isachne globosa* (swamp millet), *Paspalum distichum* (Mercer grass), *Juncus bulbosus, J. acuminatus, J. holoschoenus, J. prismatocarpus, Ludwigia palustris* (water purslane), *Lysimachia vulgaris* (yellow loosestrife) and *Myriophyllum propinquum* (milfoil). The emergent marginal species and marginal sudd species mentioned in the previous sections were commonly found within these swamp meadows and other associated species include *Carex maorica, C. ovalis, C. virgata, Agrostis stolonifera, Galium palustre* (marsh bedstraw), *Lobelia anceps, Schoenus maschalinus, Lachnagrostis filiformis* (New Zealand wind grass), *Epilobium pallidiflorum, Polygonum strigosum, P. punctatum* , *Myosotis laxa* ssp. *caespitosa* (water forget-me-not), *M. scorpioides* (water forget-me-not), *Ranunculus flammula* (spearwort), *R. amphitrichus* (waoriki), *Hydrocotyle pterocarpa, Stellaria alsine, Pratia angulata, Cardamine pratensis* (cuckoo flower), *Hypericum mutilum, H. japonicum, Lycopus europaeus* (gypsywort)and *Centella uniflora*. The peat bog moss *Sphagnum cristatum* occurred occasionally in this vegetation at several lakes and species associated with hummocks of this moss included the sundew *Drosera binata, Nertera scapanioides, Gonocarpus micranthus* and more rarely the sun orchid *Thelymitra cyanea*.

c) Peat bog vegetation

Many of the lakes surveyed are situated adjacent to peat deposits. However the vast majority of these bogs are now drained and the indigenous vegetation lost. Two of the surveyed lakes still have bog vegetation adjacent to them; a small peat bog on the south eastern arm of Lake Whangape and adjacent to Lake Opuatia. The dominant bog species near Whangape was the restiad *Empodisma minus* with associate sedges *Schoenus brevifolius, S. carsei, Baumea teretifolia* and *Gleichenia dicarpa* (tangle fern). The Opuatia Bog was not surveyed in this study, but its influence on the southern and eastern vegetation surrounding Lake Opuatia, including the presence of bladderwort (*Utricularia australis*) in channels running from the bog, was noted.

d) Tall sedgelands

Carex secta (niggerhead, puniu) was recorded for most of the surveyed lakes but only formed a distinctive vegetation type adjacent to 5 of these lakes. The distinctive tussocks of this species formed an almost monospecific vegetation with occasional plants of *C. virgata* (puawa), *C. maorica* and *C. lessoniana*, with a sparse understory of *Paspalum distichum*, *Isachne globosa*, *Ranunculus amphitrichus* (waoriki) and *R. flammula* (spearwort).

Swards of the rhizomatous sedges *Carex gaudichaudiana* and *C. subdola* were encountered at several of the Huntly Lakes, occurring amongst swamp meadow, *Baumea* dominated vegetation, open *Salix cinerea* carr and lightly grazed pastures.

A third *Carex* dominated association comprised of *C. virgata, C. maorica, C. fascicularis and C. lessoniana* was found in association with native swamp forest and *Coprosma propinqua* scrub.

Baumea rubiginosa, *B. teretifolia*, *B. huttonii* and *B. articulata* formed a further vegetation type encountered between swamp meadow and *Leptospermum* (manuka) scrub or occasionally willow carr. Although all four species were rarely found together, various combinations of these were found at 15 of the lakes. Common associates were the *Sphagnum cristatum* assemblage (see section 3.2.2b), *Phormium tenax* (flax), *Carex virgata*, *Eleocharis acuta* and *E. gracilis*.

e) *Phormium tenax*

Phormium tenax (New Zealand flax, harakeke) was present in all but 7 lakes, although at some of the remaining lakes its presence is due to ornamental and riparian rehabilitation plantings, especially in the Waipa Lakes. Associate species in planted areas were mostly introduced scrub weeds especially *Rubus fruticosus* agg. (blackberry). Local ecotypes of flax could be distinguished from these plantings by the red rather than black laminal line.

Naturally occurring *Phormium* communities were characteristically associated with *Sparganium subglobosum* (burr reed, maru), a species uncommon outside of this vegetation type. Other common associate species were *Carex virgata, C. secta, Baumea huttonii, B. rubiginosa,* *Isachne globosa, Leptospermum scoparium* and many swamp meadow species (see section 3.2.2b).

f) Marginal turf communities

A distinct community of short (usually less than 100 mm tall) amphibious and annual species was recorded from the exposed shorelines of the largest 5 Huntly Lakes. These communities were present on consolidated substrates, in areas where grazing is permitted to the lake edge.

Species typical of this community were the amphibious *Glossostigma elatinoides*, *G. diandrum*, *Limosella lineata*, *Lilaeopsis novae-zelandiae*, *Elatine gratioloides*, *Gratiola sexdentata*, *Pilularia novae-zelandiae*, *Pratia perpusilla*, *Hydrocotyle hydrophila*, *Ludwigia palustris*, *Myriophyllum propinquum*, and the terrestrial forms of *M. triphyllum, Potamogeton cheesemanii* and *Sagittaria subulata*. Annual species included *Alternanthera sessilis* (naumai), *Amphibromus fluitans, Isolepis marginata, I. sepulcralis, Aster subulatus* (sea aster), *Cotula coronopifolia, Centipeda cunninghamii, Juncus bufonius* (toad rush) and *Fimbristylis squarrosa*. Some of the amphibious species were recorded as components of the submerged vegetation in section 4.2.1b.

This community appears to be an ephemeral one, developing during summer when amphibious species are exposed and annual species germinate on drying sediments.

g) Rough pasture and *Juncus* rushland

Virtually all the lakes investigated during this survey had a well developed pastoral catchment surrounding the waterbody. Where pasture bordered the lakes various rushes (*Juncus* spp.) dominated the areas influenced by periodic flooding.

The commonest rush was the native *J. gregiflorus* with the adventive soft rush *J. effusus* almost as abundant, especially on peaty substrates where it was the most common rush. Other rushes encountered in decreasing order of abundance were *J. australis*, *J. sarophorus*, *J. tenuis* and *J. articulatus*. The latter two species were turf forming (*Juncus* Section Septati) whereas the remainder were tall (~ 1 m) clump forming rushes (*Juncus* Section Genuini). Between these clumps and associated with wetter pastures were the introduced grasses *Paspalum distichum* (Mercer grass), *Agrostis stolonifera* (creeping bent), *Festuca arundinacea* (tall fescue), *Alopecuris geniculatus* (kneed foxtail) and *Axonopus affinis* (carpet grass) and herbs *Mentha pulegium* (pennyroyal), *Polygonum hydropiper* (water pepper), *Bidens frondosa* (beggars ticks), *Lotus pedunculatus* (Lotus major) and *Lycopus europaeus*. In drier areas rushes and pennyroyal were scarce and a typical ryegrass/white clover pasture was found.

The tall introduced palustrine grass, *Phalaris arundinacea* (reed canary grass) formed a distinctive vegetation type at the Lake Whangape outlet where in association with *Bolboschoenus medianus*, *Bidens frondosa*, *Polygonum hydropiper* and *P. punctatum* it formed a dense 2 m tall marginal sward. Apart from Lake Whangape this grass was only found in Lake Kopuera where it was recorded as a rare component of the marginal vegetation.

3.2.3 Marginal woody vegetation

Woody marginal vegetation was commonly found further away from the lake margins than many of the herbaceous vegetation types described in section 3.2.2. Nine woody vegetation types were recognised although 2 of these are basically dry land communities that, due to their common occurrence adjacent to most lakes, are also described in this section. The vegetation types described are:

a) *Dacrycarpus* swamp forest
b) *Sophora* dominated treeland
c) *Coprosma propinqua* scrub
d) *Leptospermum* dominated vegetation
e) *Salix cinerea* carr
f) *S. fragilis* carr
g) *S. babylonica* and other planted exotic wetland trees
h) *Alnus* dominated vegetation
i) scrub weeds
j) plantations

a) *Dacrycarpus* swamp forest

Dacrycarpus dacrydioides (kahikatea) forest is still a common component of the Waikato lowlands. Most stands are small, surrounded by fertile pasture, and are no longer intermittently flooded as would have been the case historically. Stands are common close to several of the lakes studied e.g. Lakes Serpentine and Waikare, but flooded lakeside stands are restricted to the northern margins of Lake Whangape. The Awaroa River feeding into this lake supports probably the best remaining example of this indigenous swamp forest in the North Island (Champion 1988).

Kahikatea formed tall (~ 30 m) forests around the Tikotiko Arm of Lake Whangape, which graded into *Salix* carr. These forests were very wet, situated at the base of the steep banks rising above the lake, with many pools supporting *Myriophyllum robustum*, *Ranunculus amphitrichus* and other amphibious species. Associate canopy species included *Sophora microphylla* (kowhai) and much rarer *Syzygium maire* (maire tawaike) and *Plagianthus regius* (ribbonwood, manautu). The shrub layer was dominated by divaricating shrubs, including *Coprosma tenuicaulis, C. rigida, C. propinqua* x *robusta, Melicytus micranthus* and *Streblus heterophyllus* (turepo). Ground cover away from the pools was sparse comprised of the ferns *Blechnum minus, Cyclosorus pennigera* and the sedges *Gahnia xanthocarpa* and *Carex virgata* (kuawa). The climbers *Rubus australis, Ripogonum scandens* (supplejack) and *Passiflora tetrandra* (kohia) were common scrambling through shrub and canopy layers.

Seedling and sapling kahikateas were noted at several of the lakes e.g. Serpentine North, Cameron, Kaituna, usually as a rare component of ungrazed wet *Salix cinerea* carr.

b) *Sophora* dominated treeland

An open treeland dominated by mature trees (over 4 m tall) of *Sophora microphylla* (kowhai) with a grazed pasture understory was noted on the margins of Lakes Waikare and Whangape.

c) *Coprosma propinqua* scrub

Coprosma propinqua formed a distinct scrub vegetation on the north western margin of Lake Waahi. The margins of this vegetation were browsed and a rank pasture had developed under much of this area apart from pools occupied by *Alisma plantago-aquatica* and tussocks of *Cyperus ustulatus*. Wetter parts of this *Coprosma* scrub was overtopped by an open emergent canopy of *Cordyline australis* (cabbage tree, ti kouka) with a few kahikatea and one *Syzygium maire* (maire tawaike). Grazing was precluded due to wetness and a dense understory of the sedges *Carex virgata, C. maorica, C. lessoniana, Baumea tenax* and *Gahnia xanthocarpa* was noted. *Rubus australis* was a common scrambling liane in this area.

d) *Leptospermum scoparium* dominated vegetation

Leptospermum scoparium (manuka) was present at all lakes apart from Lakes Cameron and Whakatangi forming a distinct vegetation type at most of the remaining lakes. Two main vegetation types dominated by manuka were discerned in this study, separated on the height attained by this species.

Manuka formed a dense 4 to 7 m tall forest at Lakes Mangahia, Maratoto, Rotokawau, Rotongaro and Ruatuna. Apart from the latter site where cabbage tree was almost co-dominant, these forests were pure dense monospecific stands of manuka. Understory vegetation was usually lacking apart from near the edges of this forest, although at Lake Maratoto some areas of old trees were open enough to support a similar fern dominated understory as described below for scrub vegetation.

At most lakes, manuka formed dense 1 to 3 m tall scrub, usually without other canopy species, although *Salix cinerea* (grey willow) was occasionally present. Understory shrubs included

Coprosma species as described for willow carr, although the dominant species was usually *C. tenuicaulis*. A well developed fern assemblage was present at most lakes, the main species including the native *Hypolepis distans*, *Blechnum minus* (swamp kiokio), *Pteridium esculentum* (bracken), *Histiopteris incisa* (water fern), *Paesia scaberula* (ring fern), *Gleichenia dicarpa* and *G. microphylla* (tangle ferns) and the tall adventive royal fern *Osmunda regalis*. The sedges *Baumea tenax, B. teretifolia, B. rubiginosa*, and the *Carex* species common under *Salix cinerea* were all typical understory associates of this community. *Phormium tenax* (flax), *Dianella nigra* (inkberry, turutu) and the herbs *Nertera scapanioides*, *Centella uniflora*, *Hydrocotyle novae-zelandiae* and *Drosera binata* (scented sundew) were predominant ground cover species under the manuka canopy. The tree ferns *Cyathea dealbata* (ponga, silver fern), *C. medullaris* (mamuku) and *Dicksonia squarrosa* (wheki) were common in drier manuka scrub and were occasionally dominant locally. The scrub weeds *Ulex europaeus* (gorse) and *Rubus fruticosus* agg. (blackberry) were also common in dry manuka scrub.

e) *Salix cinerea* carr

The introduced willow *Salix cinerea* (grey or pussy willow) was present at all the lakes sampled and formed the dominant marginal vegetation type encountered at most of these lakes, in many cases completely surrounding the lake.

Typically grey willow forms a dense community of trees, with many fallen tree trunks with lateral branches that develop into new trunks. The canopy height ranges from 3 to 5 m and usually occupies a band landward from the lake edge, covering the area influenced by flooding. *S. cinerea* also encroached over the margins of many of the lakes studied, spreading up to 5 m over the water. In many lakes drainage activities within the lake catchment have restricted the willow carr to a narrow (<10 m) band.

Associate canopy species included *S. fragilis* (crack willow) and occasional *Cordyline australis* (cabbage tree), with rare kahikatea (*Dacrycarpus dacrydioides*) and alder (*Alnus glutinosa*). The introduced crack willow is commoner where inlet or outlets of the lakes occur and formed a distinct vegetation type at several of the larger lakes (see section 3.2.3f)

The shrub vegetation understory was well developed when carr was fenced from grazing and consisted of the *Coprosma* spp., *C. tenuicaulis*, *C. robusta* (karamu), *C. propinqua* (mingimingi),and the hybrid *C. robusta* x *propinqua* (*C.* x *cunninghamii*), *Leptospermum scoparium* (manuka) and the adventive scrub weeds *Crataegus monogyna* (hawthorn) and *Rubus fruticosus* agg. (blackberry).

Lonicera japonica (Japanese honeysuckle), *Muehlenbeckia australis* (pohuehue) and *Calystegia sepium* were the commonest climbing plants, often festooning the canopy and subcanopy vegetation.

A range of ground cover species were recorded, their presence dependant on willow density, access by stock and wetness . At most lakes the following species were characteristic; *Carex virgata* (kuawa), *C. secta* (puniu), *C. lessoniana*, *C. maorica*, *C. fascicularis*, *C. ovalis*, *Juncus pauciflorus*, *Blechnum minus* (swamp kiokio), *Pratia angulata*, *Bidens frondosa* (beggars ticks), *Polygonum hydropiper* (water pepper), *Lobelia anceps* and the seedlings of *Coprosma* spp. and occasionally kahikatea. In the wettest areas *Hydrocotyle pterocarpa*, *Ranunculus amphitrichus* (waioriki), *R. flammula* (spearwort), *Callitriche stagnalis* (starwort) and *C. petriei* were noted and at one site at Lake Whangape, the rare *Myriophyllum robustum* grew in pools in association with *M. aquaticum* (parrots feather).

f) *Salix fragilis* carr

Salix fragilis (crack willow) dominated vegetation was noted in the marginal vegetation of Lakes Ngaroto, Opuatia, Waahi, Waikare and Whangape. This carr was generally taller than that dominated by grey willow, growing up to a height of 10 m. *Alnus glutinosa* (alder) was an occasional associate canopy species. The understory vegetation was very similar to that described for grey willow (section 3.2.3e), although pools of water were rarely encountered in crack willow vegetation, with a corresponding lack of those herbs described in that section.

g) *Salix babylonica* and other planted exotic wetland trees

Salix babylonica (weeping willow) was commonly planted around the margins of many of these lakes, being recorded from 23 of the 38 lakes. Normally these trees were planted individually but a vegetation dominated by this species with an understory of *Carex secta* (puniu) and *Lycopus europaeus* (gypsywort) rooted on fallen willow trunks and branches was noted in Lake Ngaroto.

Specimens of *Salix matsudana* (tortured willow) were found at Lakes Cameron and Rotoroa.

Taxodium distichum (swamp cypress) was recorded from Lakes Cameron, Ngarotoiti and Waikare. In Lake Waikare stunted specimens of swamp cypress were emergent from the lake on the northern side of the Kapongaro Peninsula.

h) *Alnus glutinosa* dominated vegetation

The introduced tree, *Alnus glutinosa* (alder) was found in the marginal vegetation of Lakes Kopuera, Rotokauri, Tunawhakapeka, Waahi, Waikare and Whangape, but was commonest in Lake Waikare where individual trees were found around much of the northern basin and a distinct dry forest type dominated by alder was noted on the eastern shore. Under the alder canopy was a shrub layer comprised of manuka, *Coprosma areolata*, *Podocarpus totara* (totara) and tree ferns, with a ground cover including *Cortaderia selloana* (pampas), *Carex virgata* (puawa), *Cyperus eragrostis* and *Lotus pedunculatus*.

i) Scrub weeds

In dry areas that had been cleared of indigenous vegetation, the scrub weed *Ulex europaeus* (gorse) commonly formed a dense impenetrable vegetation to the exclusion of all other species. Wetter cleared areas were usually vegetated by tangles of *Rubus fruticosus* agg. (blackberry), again forming dense monocultures. These species were common in other woody vegetation types where openings in the canopy were present due to human activities.

The thorny adventive shrub *Crataegus monogyna* (hawthorn) formed almost pure thickets along parts of the lake shoreline of Lake Whangape and was a common woody weed at several other lakes. Hawthorn was apparently tolerant of periodic inundation by flood waters.

The introduced wattles, *Racosperma mearnsii* and *Paraserianthes lophantha* formed a scrub association on the islands of Lake Waikare and also on the island situated in the North-west Arm of Lake Waahi.

The exotic giant tussock forming grass *Cortaderia selloana* (pampas) although not strictly a scrub weed is included in this category as it often forms dense colonies in disturbed areas to the exclusion of all other species. It formed the vegetation adjacent to the bridge dividing the North-west Arm from the remainder of Lake Waahi.

j) Plantations

Exotic tree plantations of *Pinus radiata*, *Racosperma melanoxylon* (Tasmanian blackwood) and *Eucalyptus* species were present at several of the lakes surveyed in this study. Occasional seedlings of these species were present within these areas.

3.3 Factors affecting the distribution of marginal vegetation

The distribution of the different marginal vegetation types was influenced by :

a) Water depth or frequency of inundation
b) Shore exposure
c) Soil fertility and type
d) Cattle and waterfowl grazing intensity
e) Vegetation clearance
f) Fire
g) Competition by exotic plants

These factors can be grouped as either stress, disturbance, or competition factors (Grime 1977), depending on their effect. Stress factors decrease plant growth rate (a, b and c), and disturbance factors destroy plant biomass (b, d, e and f).

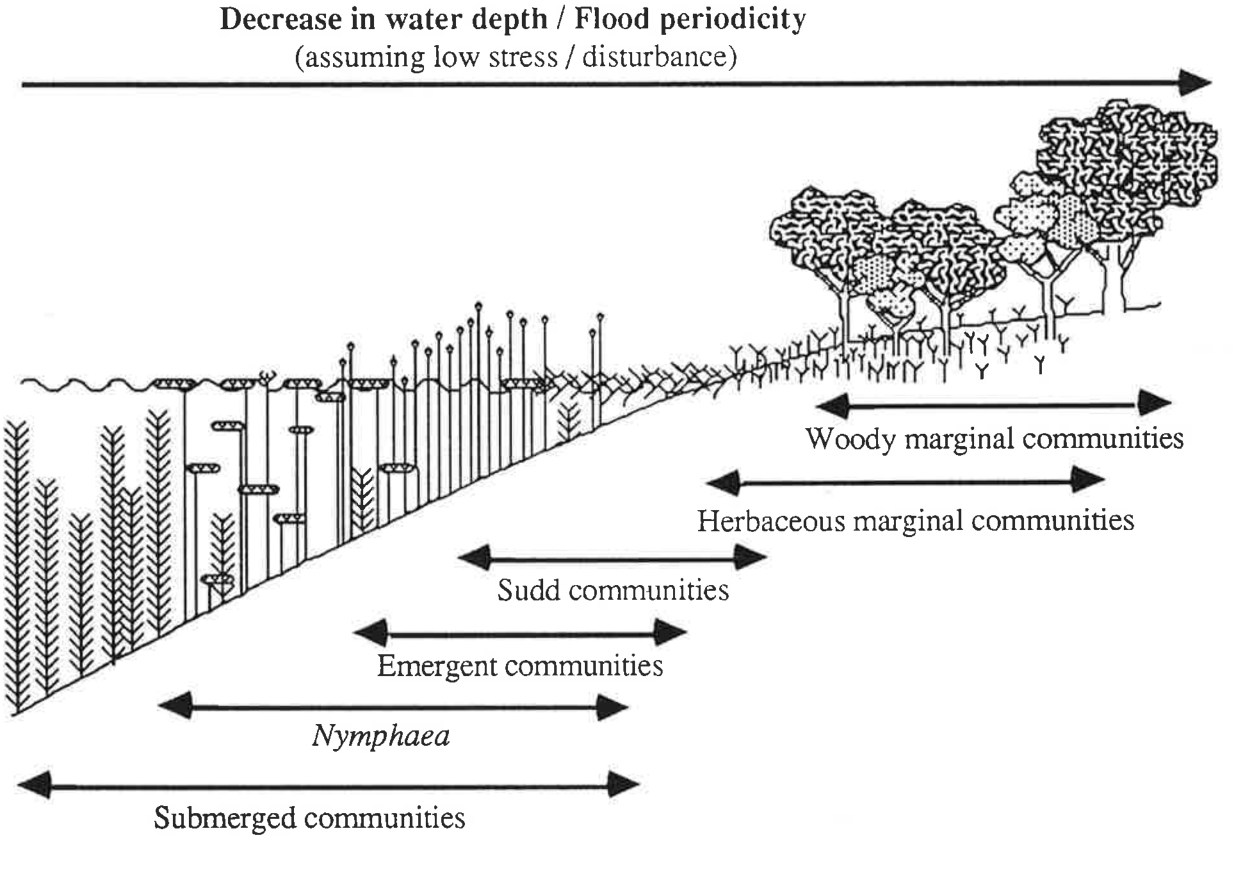
In response to these factors plants can be categorised into 3 groups, depending on stress and disturbance levels, which intergrade into each other (Grime 1977). Extremes of these plant categories are summarised below (Menges & Waller 1983, after Keddy 1989, Shipley et al. 1991).

Category	Plant characteristics
productive, undisturbed	competitive plants, clonal growth, fast growing with maximum resource capture, flowering at end of growth season
continuously unproductive	slow growing, stress tolerant, often clonal growth, with low constant reproductive effort
productive, highly disturbed	fast growing, short life span, high seed production

All marginal plants are exposed to both stress and disturbance factors, their distribution determined by levels of each factor and competition with other species.

Exotic plants which are such a prominent component of the present lake vegetation are influenced by all the above factors but are also a factor influencing the distribution of indigenous communities.

Factors affecting the distribution of marginal vegetation can be represented as a gradient on which each vegetation type may be arranged. Keddy (1989) organised communities along resource gradients or gradients constraining access to resources. Generally, vegetation is affected by water depth and flooding periodicity and a stylised diagram illustrates the distribution of the various vegetation communities of the Lower Waikato lakes along this gradient.



3.3.1 Factors

The effect of each of the factors discerned will be discussed individually and then their impacts on the distribution of the 3 marginal vegetation types.

a) Water depth or frequency of inundation

Water level and flood periodicity relate to the position of vegetation in the vertical gradient from permanent submergence to a zero flooding level. By definition, marginal vegetation is influenced by the lake waters and therefore has at least some tolerance to flood episodes. Generally a gradient of decreasing inundation from the emergent sedges and *Typha*, to herbaceous and then woody marginal vegetation was discerned.

The major impact of flooding or waterlogging on plants is the accompanying deoxygenation of the root zone. Soil anaerobiosis also results in major effects on nutrient speciation, availability and toxicity (Gambrell & Patrick 1978) and microbial decomposition of organic matter can give rise to phytotoxic levels of short-chain organic acids (Drew & Lynch 1980). Tolerant species often have mechanisms to overcome these problems, either by aerenchyma development to enhance oxygen diffusion system to the roots (Justin & Armstrong 1987), metabolic adaptations (Crawford 1982), or the production of ephemeral water roots during inundations (Gill 1970).

b) Shore exposure

Degree of exposure depends on wave fetch, prevailing wind direction, size and location of the waterbody, with greatest levels of exposure exerted on the largest lakes predominantly on eastern shores (due to prevailing westerly or north westerly winds). Resulting wave action is both a disturbance and stress factor with mechanical damage to shoots and uprooting of plants during storm events. Mechanical sorting of sediments by wave action results in the coarsest sediments containing little organic material in areas of highest exposure (Wilson & Keddy 1985). Plants tolerant of high levels of exposure can have their highest amplitude of depth range at the highest exposures due to the preclusion of intolerant competitors (Keddy 1983). Typical growth forms in exposed sites are low growing rosette or creeping plants.

c) Soil fertility and type

As discussed above, wave sorting of littoral sediment may greatly affect their texture and fertility. Marginal vegetation is efficient at trapping sediment and can accumulate nutrients in this way. The presence of peat in many of the smaller lakes also has a major influence on plant communities with low available nutrients and pH compared to the alluvial soils in the larger Huntly lakes. Few species are tolerant of peat conditions and those species are generally xeromorphic, slow growing and intolerant of disturbance. Peat drainage, burning, or addition of fertiliser increase the nutrient status of peat, allowing invasion of this stress tolerant vegetation by faster growing, disturbance tolerating species.

d) Cattle and waterfowl grazing intensity

Pastoral catchment development has often allowed livestock access to lake margins, with impacts on lake vegetation through direct consumption, trampling of plants, indirect disturbance of lake substrates and promotion of weed invasion (Tanner 1992). Waterfowl grazing, trampling and defecation in marginal vegetation is also a major influence. Looijen and Bakker (1987) found that geese (*Branta* spp.) exerted a similar, if not greater influence on salt marsh vegetation than that of cattle. Waterfowl are able to access areas with unconsolidated substrates and therefore can influence a wider range of marginal vegetation than cattle.

Most investigators conclude that heavy stocking rates of cattle are detrimental to plant communities but, in moderation it is an important tool in maintaining high species diversity of early successional, disturbance tolerant species (Bakker 1989, Molloy 1989, Wardle 1989, Tanner 1992). Any grazing influence will have a negative impact on palatable and disturbance intolerant species (Pacala & Crawley 1992), so although diversity may be increased by moderate levels of grazing, susceptible species or communities may be threatened.

e) Vegetation clearance

Vegetation clearance and drainage activities for production of agricultural land was a major influence on the composition of marginal vegetation types in the past, and minor clearances and construction of new drains were still occurring during the period of this study. This disturbance resulted in the artificial maintenance of herbaceous communities, which if combined with a grazing regime could form a relatively stable, disturbance tolerant vegetation. If sufficient grazing pressure is not exerted then reversion to disturbance tolerant woody vegetation would occur i.e. scrub weeds. Clearance of slow growing stress tolerant vegetation appears to permanently alter these communities by changing the nutrient status and providing invasion sites for more competitive species.

f) Fire

Fire is an episodic disturbance factor which is seen as important in the cycling of peat vegetation (Irving et al. 1984). Peat vegetation by definition accumulates large amounts of undecomposed organic matter, making it vulnerable to fire damage. Before human colonisation of the Waikato, natural fires would have occurred by lightning strikes, volcanic activity etc. and would be important in the release of nutrients from burnt peat and corresponding vegetation diversity. Since human occupation fire periodicity has increased and the drainage of peatlands has increased the impact of such events. Fire adapted plants often have subterranean rhizomes, or seed germination stimulated by fire, with rapid regrowth occurring after the fire event. The native *Baumea, Schoenus* spp., *Leptospermum scoparium* and introduced *Ulex europaeus* are examples of fire adapted vegetation.

g) Competition by exotic plants

The dominant exotic species in the vegetation types recorded in this survey were mostly competitive, fast growing, disturbance tolerant species. Other exotic dominated vegetation comprised annual or short lived species, tolerant of extreme disturbance.

The effects of the above factors on specific vegetation types are discerned as follows:

3.3.2 Emergent vegetation

Presence of emergent vegetation was affected by degree of exposure and influences of cattle grazing, all occurring on permanently inundated substrates. All the emergent vegetation types were restricted to sheltered sites on the larger lakes e.g. Whangape, Rotokauri, but on smaller lakes e.g. Lakes Serpentine South and East, a more or less continuous band was observed. Where cattle could access the lake margin emergent species were restricted, if present, to depths greater than 1 m. Cattle presumably do not forage in water deeper than this and may only access this vegetation during low water level episodes.

The type of emergent vegetation present was dependent on water depth, degree of exposure, soil type and the presence of ornamental plantings or development of willows.

Typha dominated vegetation is reliant on a nutrient rich, mineralised soil, or the pale organic soils produced by its own disintegrating foliage (Johnson & Brooke 1989). It usually grew from the shore to water over 1 m deep. *Typha* can be regarded as a competitive, fast growing clonal plant with an annual flowering periodicity, typical of relatively undisturbed habitats. It is not tolerant of moderate exposure. In lakes where peat soils predominate e.g. Lake Serpentine, *Typha* is restricted to areas where inflows from the pasture catchment influence the nutrient status. *Typha* is a palatable species to cattle and is commonly restricted to areas inaccessible to these animals. The introduced shrubby herb, *Lycopus europaeus* was often evident in the stands damaged by grazing and appears to be having an adverse effect on the raupo. This may reflect the damage caused by grazing rather than a direct result of *Lycopus* growth. The situation should be monitored over a longer time frame to assess this.

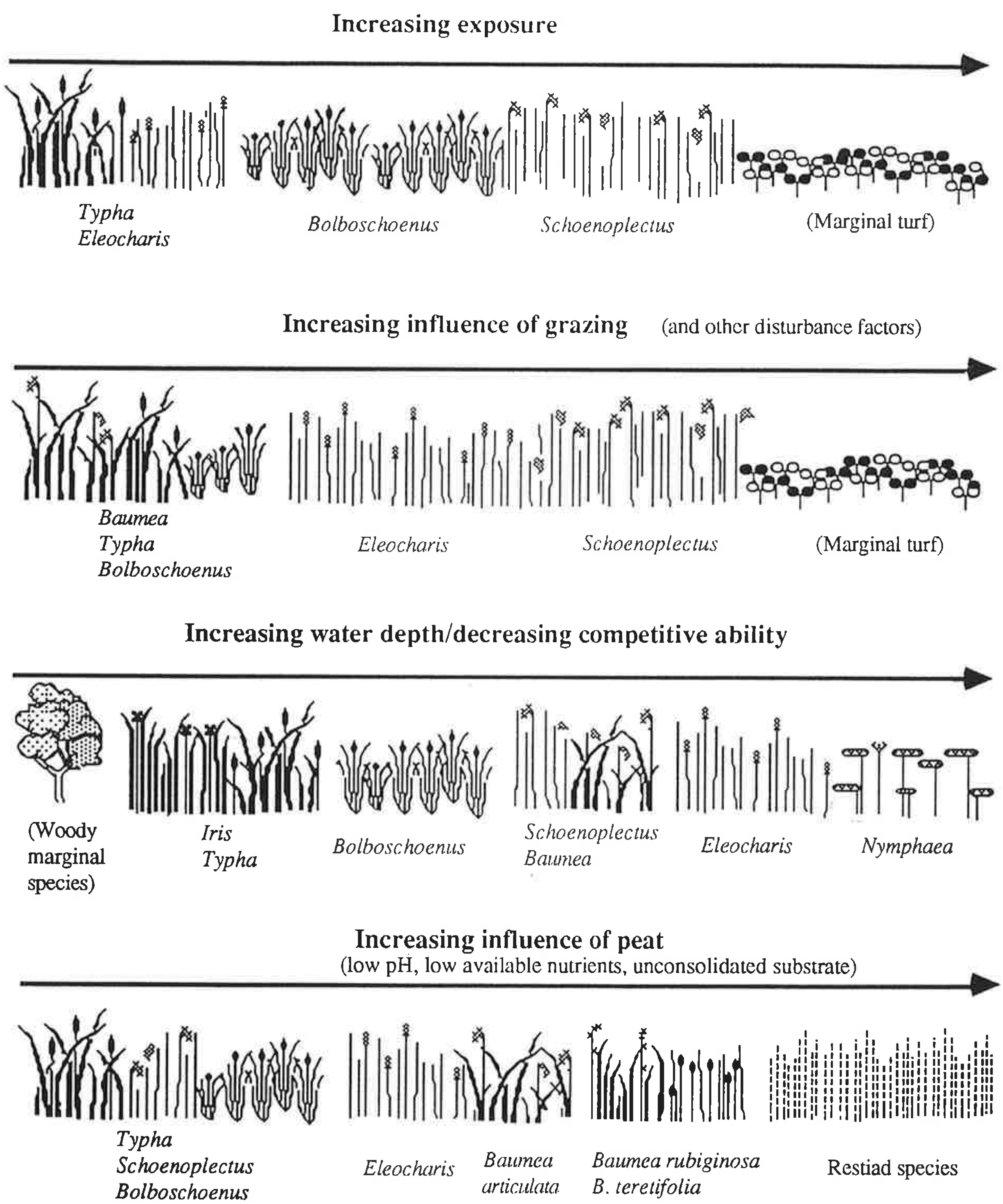
Eleocharis sphacelata appears to be tolerant of a wide range of soils, nutrient status or water depth, but is apparently displaced by raupo or other emergent sedges which are more dense and taller in fertile sites. Where other species occur tall spike rush is almost always found as the outer deep water band of vegetation, to a depth of 2.2 m. The largest beds are found in peat influenced lakes e.g. Serpentine South. *Eleocharis sphacelata* is indicative of low nutrient acid conditions and also a very common component of swamp meadows, where *Baumea* spp. and *Sphagnum* are found. In lakes where nutrient status has increased due to eutrophication and peat decomposition, beds of this species are open, with evidence of disease and insect damage. Cizkova-Koncalova et al. (1992) attributed decline of the reed (*Phragmites australis*) to changes in the carbon balance of the plant brought about by eutrophication, with increasing nitrogen levels causing a reduction in carbon allocated to storage and structure of that species. Enhanced palatability lead to increased grazing pressure, while decreased fitness of reeds reduced their ability to tolerate disturbance and disease.

Schoenoplectus and *Bolboschoenus* are more commonly found in tidal estuaries or riverine sites but in this survey they were more or less restricted to mineralised sites. *Schoenoplectus* is tolerant of higher levels of exposure than other emergent species, often found on exposed shores of the larger lakes. *Bolboschoenus* species are more typically littoral, found either in shallow water or on the lake shore.

Baumea articulata was recorded on either peaty or mineralised soils, but formed an emergent vegetation only in peat lakes and in most of the lakes surveyed it formed marginal stands amongst swamp meadow often with other *Baumea* species.

The distribution of *Iris pseudacorus* and *Nymphaea* cultivars are, at present, restricted to areas where planted by humans. Both species were found in sheltered sites with nutrient rich, mineralised soils and are invasive, usually out competing other emergents. *Iris pseudacorus* is well naturalised in Lake Rotoroa and on the Lower Waikato River between Huntly and Ohinewai and spreads by seed and rhizome fragmentation. The floating raft of *Iris* rhizome enables it to colonise deeper water and overtop the submerged rhizomes of other native emergents. Seedlings of *Nymphaea* have been noted in Lake Rotoroa but the predominant method of spread in this and the other lakes is rhizome extension and fragmentation.

From this study the following gradients in relation to emergent vegetation distribution have been recognised.



3.3.3 Marginal herbaceous vegetation

Marginal herbaceous vegetation was determined by the degree of exposure, soil type, presence and intensity of grazing both by cattle and predominantly introduced waterfowl, fire and the introduction of exotic plants.

The large sudds formed by the adventive *Ludwigia peploides* ssp. *montevidensis* and other introduced sprawling herbs and grasses are restricted to sheltered areas in nutrient rich waters. This growth form is not found in native species apart from *Polygonum salicifolium*, which is a minor component on these sudds in some lakes. In small sheltered lakes, sudds developed around the entire margin over water depths of greater than 2 m. There would be direct competition with submerged and emergent plants over this depth range; the sudds shading out other plants. These sudds are seasonal, mostly dying off during winter months.

The more diverse swamp meadows consist of a mosaic of different communities, each probably dependent on differing nutrient status and wetness. As these communities occur on unconsolidated sediments or floating sudds, cattle grazing is excluded. However the browsing effects of waterfowl were noted and probably restrict the development of woody species and the domination of the meadows by tall palatable species. Within these associations, localised acid peat communities dominated by *Sphagnum* are often found. Bakker (1989) relates the occurrence of similar peat vegetation in calcareous soils to micro-topography patterns, where this vegetation is spatially separated from nutrient sources by organic depositions.

Peat bog vegetation represents an extreme stress tolerant, but disturbance intolerant community, with slow growing, clonal species present. It's restriction in present area reflects the increased levels of disturbance exerted on the Waikato lakes at present.

Carex secta (puniu) dominated vegetation occurred either on mineralised or peaty soils, usually in shallow water or seasonally inundated areas. This and other *Carex* species appeared to be tolerant of moderate levels of grazing.

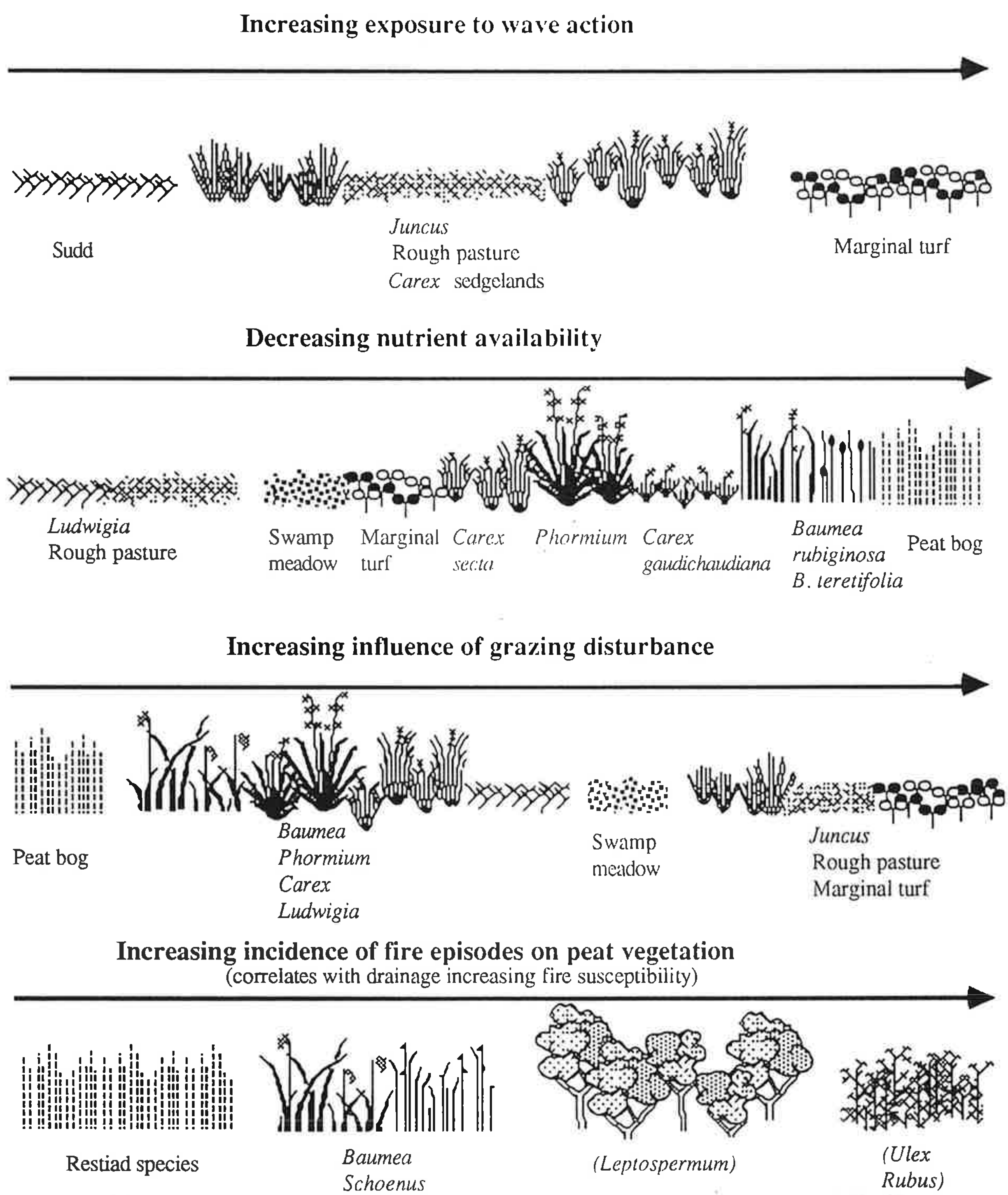
Baumea species with the exception of *B. articulata* and *B. huttonii* were restricted to acid influenced soils. These species are slow growing, clonal species, typical of stress tolerators. They are apparently intolerant of grazing or mechanical disturbance, but are adapted to fire episodes, provided the substrate is wet enough to prevent rhizome damage.

Phormium tenax is typical of intermediate soils, not as nutrient rich as raupo dominant vegetation, or as nutrient poor as *Sphagnum* or other peat bog vegetation, often occurring with *Carex secta*. It is apparently vulnerable to damage by cattle or mechanical disturbance.

The short turf communities occur on the moderately exposed wave cut beaches of the larger Huntly lakes. Heavy cattle grazing is seen as essential for the continuance of this vegetation, by removal of more competitive, taller species. The resulting community consists of stress and disturbance tolerant, low growing, amphibious creeping species and adventive ruderal species which are seasonally present when lake sediments are exposed.

Where pasture bordered these lakes, inundation tolerant grass species e.g. *Paspalum distichum*, *Alopecurus geniculatus* and *Festuca arundinacea* replace the intolerant *Lolium* species (ryegrass) and unpalatable rushes and *Mentha pulegium* are characteristic. Moderate to heavy grazing by cattle is responsible for the maintenance of this vegetation by preventing the invasion of *Salix cinerea* and other woody species.

From this study the following gradients in relation to herbaceous marginal vegetation distribution have been recognised.



3.3.4 Woody marginal vegetation

Woody vegetation was affected by frequency of inundation, soil fertility and type, grazing influence and human disturbance.

Dacrycarpus forest is restricted to seasonally flooded alluvial flats and is (or rather was) the dominant vegetation on these surfaces. Human influences are responsible for the demise of this vegetation type, its survival around Lake Whangape probably due to inaccessibility. Nicholls (1976) classification of North Island forest types failed to recognise kahikatea forest type, due to lack of areas represented (in the South Island approximately 60,000 hectares remain in South Westland, Symes 1982). Other native woody communities found on mineralised soils e.g. *Coprosma propinqua* scrub, have also been cleared for pasture production and only tiny remnants persist.

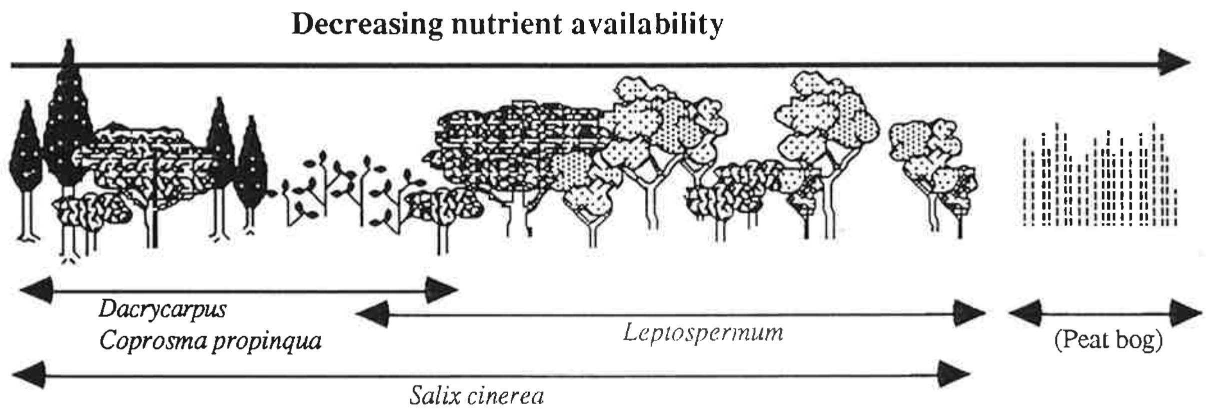
As kahikatea would have been the dominant vegetation on mineralised soils, so would manuka scrub have been on all but the most acid peat soils, where a restiad assemblage would dominate. Although present at all the lakes surveyed, only small areas of manuka dominated vegetation were recorded, probably due to clearance for pasture development and fire. This species is well adapted to survive inundation and low nutrient availability (Cook et al. 1980) and fire episodes. It would have been self perpetuating on all but the most ombrogenous peat soils (Wallace 1983). It was recorded in areas disturbed by early clearances (Cranwell 1939), but now drainage of peat and the introduction of *Ulex europeaus* and *Salix cinerea* (both more competitive on dry and wet soils respectively), has reduced areas suitable for the establishment and continuance of this manuka dominated vegetation.

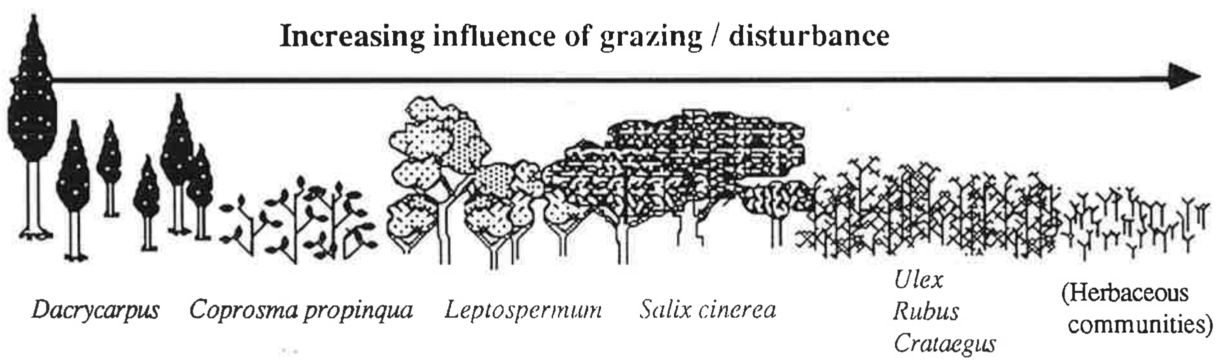
Salix cinerea is an introduced species typical of wet marginal areas on all but the most acid soils. It was found bordering the study lakes but only rarely growing in them, and is probably intolerant of permanent flooding. The establishment of willow carr would be restricted by grazing, but once trees have established, grazing would only affect the understory, selecting for unpalatable species e.g. *Crataegus* (hawthorn).

Salix fragilis is apparently less tolerant of acid soil types, being restricted to mineralised soils, usually adjacent to inflows or outflows apart from large Huntly lakes. *S. babylonica* is a commonly planted ornamental which does not appear to be more than sparingly naturalised. *Alnus glutinosa* is another species restricted to mineralised soils and is common only on the largest lakes.

Scrub weed assemblages predominated in areas where grazing pressures were not sufficient to prevent either *Ulex* (gorse), *Rubus fruticosus* (blackberry), *Crataegus* (hawthorn) or a combination of these developing into impenetrable thickets. Gorse is apparently intolerant of flooding but the other species are tolerant of periodic inundations.

From this study the following gradients in relation to woody marginal vegetation distribution have been recognised.





4. SUBMERGED VEGETATION

4.1 Methods

The submerged vegetation of 38 lakes within the Lower Waikato region was investigated between October 1991 and March 1993 using a qualitative survey technique modified from Clayton (1983). The number and location of sites investigated in each lake depended on lake size and development of submerged vegetation, with a maximum of 10 sites in larger lakes supporting extensive submerged vegetation. Sites were approximately evenly spaced around the margin of lakes, however in lakes supporting extremely sparse submerged vegetation, additional sites were chosen where submerged plant growth was considered most likely.

At each site submerged vegetation within a 2 metre (m) wide band was described from shore to the maximum depth of plant growth. Direct observations by SCUBA or snorkel divers were possible in lakes of sufficient water clarity, while tactile assessments, or the use of rakes and grapnels to recover plants to the surface was employed in lakes of restricted clarity.

Depth range, maximum and average % cover and height of each plant species was recorded at each site. Depths were measured by capillary gauge readings in clear water conditions, and sounding lines in low clarity water. % cover was subjectively assessed with reference to the following modified Braun-Blanquet scale.

1	1 - 5%
2	6 - 25%
3	26 - 50%
4	51 - 75%
5	76 - 95%
6	96 - 100%

An abundance rating was formulated for each submerged species encountered in each waterbody following the technique reported by Clayton in Garrick et al. (1987).

$$\% \text{ sites} \times 100 \times \frac{\text{Depth range of species}}{\text{Total depth range}} \times \text{average species cover \% (midpoint of range)}$$

<10 = occasional
10 to 50 = common
>50 = abundant

Representative specimens of submerged plant species were collected from each lake and lodged in the University of Waikato Herbarium (WAIK).

Secchi disc depth and lake depth were measured near the geographical centre of each water body.

Specific submerged vegetation descriptions for each lake are contained in Volume 2 of this report (Champion et al. 1993).

4.2 Results

The lakes in the Lower Waikato can be categorised into 2 groups according to the degree of submerged vegetation development (Table 4.2). The majority of the Lower Waikato Lakes supported only extremely sparse submerged vegetation. This group comprised those waterbodies with low water clarity, due either to humic staining in the case of strongly peat influenced lakes, or high organic or inorganic turbidity. Only a small number of lakes supported an extensive submerged vegetation, dominated by the exotic oxygen weed *Egeria densa* .

4.2.1 Low clarity lakes

a) Peat lakes

Eleven of the lakes investigated were best described as peat lakes (table 4.2) as they are situated in close proximity to either the Kainui, Rukuhia or Moanatuatua Peat Bogs (fig. 2.1), and exhibited humic stained water with low apparent amounts of suspended materials. Secchi disc depths of the peat lakes ranged widely between 0.32 and 1.15 m (table 4.2).

The peat lakes had either no recorded submerged vegetation, or sparse growths comprised of a few native plant species. The pondweeds, *Potamogeton ochreatus* and *P. cheesemanii*, and the charophyte *Nitella hookeri/cristata*[1] were most frequently recorded. Rarely encountered species included *Myriophyllum propinquum* (Lake Areare), *Chara corallina* and *C. fibrosa* (Lake Serpentine North). Occasional plants formed a sparse plant cover to shallow depths. The maximum recorded plant depth in the peat lakes was 3 m for *Potamogeton ochreatus* in Lake Serpentine North (table 4.2). Submerged species were most commonly encountered within low cover *Eleocharis sphacelata* reed-beds.

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[1] The differentiation between *Nitella hookeri* and *N. cristata*, considered a 'dioecious-monecious species pair' (Wood and Mason 1977), was not possible in the absence of fruiting material.

Table 4.2. Classification of 38 Lower Waikato lakes into categories according to water clarity and submerged vegetation characteristics, and listing Secchi disc depth (single visit) and maximum depth of plants (- indicates plant absence, + indicates plants present at maximum lake depth).

Category	Lake	Secchi disc depth (m)	Maximum plant depth (m)
Low clarity lakes			
Peat lakes	Areare	0.40	1.3
	Mangahia	0.32	-
	Maratoto	0.69-0.76	-
	Pataka	0.37	1.5
	Posa	0.52	0.5
	Rotoaira	0.45	-
	Ruatuna	0.45	0.5
	Serpentine East	1.15	2.5
	Serpentine North	0.97	3.0
	Serpentine South		2.0
	Whakatangi	1.00	-
Turbid lakes	Cameron	0.38	-
	Gin	0.60	1.8
	Hakanoa	0.40	-
	Kaituna	0.25	-
	Kimihia	0.20	-
	Komakorau	0.20	-
	Kopuera	0.30	-
	Koromatua	0.35	-
	Ngaroto	0.60	-
	Ngarotoiti	0.30	-
	Ohinewai	0.45	-
	Opuatia	0.38	1.0+
	Rotokawau	0.35	0.3
	Rotongaro	0.60	2.0
	Rotongaroiti	0.20	0.1
	Rotopotaka	0.45	0.8
	Rotoroa	0.79	-
	Tunawhakapeka	0.20	-
	Waahi	0.30	1.3
	Waikare	0.15	0.3
	Whangape	0.05-0.12	1.3
Oxygen weed lakes	Hotoananga	~2.50	3.0+
	Mangakaware	0.80	2.8
	Okowhao	>1.65	2.0+
	Pikopiko	~2.50	2.5+
	Rotokauri	0.85	4.2+
	Rotomanuka	3.50	5.5

Two separate visits to Lake Serpentine North revealed a large change in the abundance and depth range of pondweeds over a relatively short period of time (4 months). During the first visit in November 1991 the most frequent species, *Potamogeton ochreatus*, was recorded at covers of up to 75% extending to 3 m depth, while in March 1992 this species was present at covers up to 25%, to only 1.5 m depth.

Exotic 'oxygen weed' species (Hydrocharitaceae and Ceratophyllaceae) were not recorded from the peat lakes.

b) Turbid Lakes

The majority of the remaining lakes (21) could be described as turbid lakes (table 4.2) as they had low water clarity due to large amounts of organic or inorganic suspended materials visible in the water column. A number of these lakes were also peat influenced. Secchi disc depths of the turbid lakes at the time of survey ranged between 0.12 and 0.79 m (table 4.2).

Submerged species were not recorded from 12 of the turbid lakes (table 4.2). Within Lakes Rotokawau, Rotopotaka, Rotongaroiti and Lake Waikare, submerged plant species were extremely rare, and confined to depths less than 1 m. In Lakes Gin, Opuatia, Rotongaro, Waahi, and Whangape submerged plants were occasionally recorded, present to maximum depths of 1 to 2 m .

Exotic oxygen weed species were only recorded from 5 turbid lakes. *Egeria densa* drift only was noted from Lake Waikare, and occasional plants of *Egeria* were present in Lakes Gin and Rotongaro. *Ceratophyllum demersum* and *Egeria* had a limited distribution in Lake Whangape, and sparse growths of *Egeria densa*, *Elodea canadensis*, *Lagarosiphon major*, and *Ceratophyllum demersum* were recorded from Lake Waahi.

Other submerged plant species recorded from turbid lakes were the pondweeds; *Potamogeton ochreatus*, *P. cheesemanii* and *P. crispus* (an exotic species), milfoils; *Myriophyllum triphyllum* and *M. propinquum*, and charophytes; *Chara corallina*, *Nitella hookeri/cristata*, *N. pseudoflabellata*. *Chara fibrosa*, *Nitella hyalina* and *N. leptostachys* were only recorded in Lake Waahi. Submerged growths of the exotic aquarium plant *Sagittaria subulata* were also recorded from Lake Waahi, representing the first adventive record of this species in New Zealand. Although limited in abundance, this species occupied two discrete sites and appeared to have expanded in distribution within the lake over the period of observations. Lake Opuatia was the only lake in the Lower Waikato region where *Potamogeton pectinatus* was recorded.

Lakes Waahi, Whangape and Rotongaro had occasional growths of short growing, shallow water species on lake margins to 0.2 m depth at the time of the surveys. Species included *Elatine gratioloides, Eleocharis pusilla, Glossostigma elatinoides, Lilaeopsis novae-zelandiae*, and *Pilularia novae-zelandiae*.

4.2.2 Oxygen weed lakes

6 lakes (table 4.2) had an extensive submerged vegetation across significant areas of lake bed which was dominated by the exotic oxygen weed, *Egeria densa*. These oxygen weed lakes exhibited relatively clear water with Secchi disc depths ranging between 0.8 and 3.5 m (table 4.2).

Dense *Egeria* weedbeds were present across the entire bottom of the smaller, shallower (~2 m) lakes, Okowhao and Pikopiko. Development of *Egeria* in Lake Mangakaware was variable over time according to local residents with flowering surface reaching weedbeds of *Egeria* observed on occasions (Mr J. Krippner pers comm.). These observations were not sufficient to determine if variations were seasonal in nature or on a year to year basis. Weedbed development at the time of the survey was limited to occasional surface reaching plants at generally less than 25% cover, to a maximum of 2.8 m depth. Much of the littoral zone ≤2 m depth within the larger lakes was occupied by dense weedbeds. *Egeria* formed lower covers within deeper areas (>2 m) of Lakes Hotoananga and Rotokauri. Weedbeds were most extensive within Lake Rotomanuka, *Egeria* being present at 75-100% cover to 4.5 m depth, with occasional plants to a maximum depth of 5.5 m.

Egeria weedbed development was observed to be seasonal over multiple visits. During summer (November to April) surface reaching weedbeds comprised a tangled mat of flowering branches above less dense, woody parent stems. The condition of surface branches deteriorated toward the end of summer, especially in the smaller oxygen weed dominated lakes. During winter the weedbed canopy sank from the water surface but plant tissue remained green and numerous new branches were observed over spring (September to November).

A low diversity of submerged species was recorded from *Egeria* dominated lakes. Submerged species *Potamogeton ochreatus*, *P. cheesemanii*, *Elodea canadensis*, *Myriophyllum propinquum*, and *Nitella hookeri/cristata* were variably recorded but were generally scarce, except in Lake Hotoananga. Here *Potamogeton ochreatus* formed unusually dense growths at depths of 2-3 m.

4.3 The decline of submerged vegetation in the Lower Waikato lakes

Permanent reductions in the abundance of submerged plants have occurred in a number of Lower Waikato lakes over the last 20 years. These submerged vegetation declines represent a considerable loss of botanical resource from the region. Deteriorations in lake fisheries have been described following decline events (Ward et al. 1987, Huntly Mining and Cultural Museum), and the loss of feeding grounds has resulted in reductions in black swan populations (Kingett 1984).

4.3.1 Submerged vegetation decline events

Table 4.3.1 lists 15 Lower Waikato lakes documented as once possessing extensive vegetation, including the 9 lakes from which submerged vegetation declines have been recorded; de-vegetated lakes, and 6 which still retain significant weedbeds; oxygen weed lakes.

Lakes Hakanoa, Kimihia, Ngaroto, Ohinewai, Rotoroa, Waahi, Waikare and Lake Whangape have lost the extensive *Egeria densa* weedbeds which previously dominated these lakes. Casual observations by a local eel fisherman suggests a similar decline occurred in Lake Rotongaroiti (Mr R. Clarke pers. comm.). No submerged vegetation has been recorded for Lake Kopuera, however it is considered likely that it supported submerged vegetation similar to that documented for neighbouring Huntly lakes, with possible *Egeria* domination at some stage prior to an undocumented decline event.

Submerged vegetation declines have been described from many other lakes around the world (Forsberg 1964, Jupp & Spence 1977, Davis & Carey 1981, Kemp et al. 1983, Taylor 1983, Best et al. 1984, Balls et al. 1989). Submerged vegetation declines have been documented from waterbodies in other areas of New Zealand (Judd & Kokich 1986, Hooper 1987, Gerbeaux 1989). Temporary declines in submerged plant abundance have also been reported (Gibbs 1973, Johnstone & Robinson 1987, Mitchell 1989).

A review of this literature reveals the variable nature of submerged vegetation decline events. All declines involve an unseasonal decrease in the overall abundance of submerged plants. In many cases declines have been poorly documented, with the loss of submerged vegetation not noted until well advanced. Nevertheless, it is apparent that decline events may take a number of different forms. The time scale of declines vary from a rapid plant loss over one or two years to gradual reduction over the order of decades, with either complete elimination of vegetation or maintenance of variable amounts of residual vegetation. Marked declines in the abundance of submerged plant species have occurred in fresh, brackish and saline waters, many of which were shallow. Both native and exotic submerged floras have undergone decline. Declines have been of both a permanent, and temporary nature over the time frame of observations.

Table 4.3.1 Classification of 15 Lower Waikato lakes according to present submerged vegetation status, earliest record of *Egeria* and date of vegetation decline.

Lake	Category	Earliest record of *Egeria*	Date of decline
Hakanoa	De-vegetated	Early 1970's	1973
Kimihia	De-vegetated	1958	Between 1975 and 1980
Ngaroto	De-vegetated	1984	Between 1984 and 1992
Ohinewai	De-vegetated	1981	1983-1984
Rotongaroiti	De-vegetated	Early 1960's?	1980?
Rotoroa	De-vegetated	1977	1989 to 1990
Waahi	De-vegetated	1974	1978 to 1979
Waikare	De-vegetated	1958	1977 to 1978
Whangape	De-vegetated	1958	1985-1987
Hotoananga	Oxygen weed	1958	-
Mangakaware	Oxygen weed	1990	-
Okowhao	Oxygen weed	1981	-
Pikopiko	Oxygen weed	1990	-
Rotokauri	Oxygen weed	1977	-
Rotomanuka	Oxygen weed	1977?	-

Submerged vegetation declines observed in lakes of the Lower Waikato had a common sequence. The 9 lakes were once described as supporting dense *Egeria* weedbeds over considerable lake area for varying periods of time before the decline (table 4.3.1). Decline in *Egeria* abundance within these lakes appeared to be rapid, over a time span of 2 to 3 years, and resulted in either the apparent absence of submerged plant species or maintenance of vegetation at a fraction of previous abundance. These de-vegetated states have persisted without any indication of submerged vegetation recovery, currently for periods of up to 19 years.

4.3.2 Factors leading to the decline of submerged vegetation

A number of retrospective investigations have sought the cause of submerged vegetation declines. The identification of the causes of declines in the Lower Waikato lakes has concentrated on the three waterbodies for which any significant relevant information exists; Lakes Waahi (WVA 1987, Kingett 1984), Whangape (Wells et al. 1988, Wells & Clayton 1989, Davies-Colley et al. 1993) and Rotoroa (de Winton et al. 1991, Coffey & Edgar 1993, Clayton & de Winton in prep.). A number of specific causal factors were considered but even in these cases insufficient evidence existed to do more than speculate. It appeared that no one factor accounted for the declines and that different factors operated within each lake. Similarly, intensive overseas studies could not identify single factors and have suggested more than one causal factor operates, these interacting in an additive or synergistic manner (Carpenter 1980, Kemp et al. 1983, Stanfield et al. 1989, Balls et al. 1989).

The submerged vegetation declines in the Lower Waikato lakes could be viewed in terms of the affects of stress, disturbance or competition factors on *Egeria* populations. It is first important to examine the characteristics and requirements of this species in the lakes of the Lower Waikato before reviewing the nature and operation of possible deleterious factors on this vegetation.

a) *Egeria* characteristics

In order for *Egeria* to establish and persist within a waterbody it must possess favourable conditions. *Egeria* requires a permanently submerged habitat of less than 10 m in depth. Plant available nutrients and light levels must be adequate to sustain growth, and water temperatures enable efficient biochemical processes. Overseas studies have suggested temperatures below 10^{o}c slow *Egeria* growth significantly while biomass production is reduced under conditions in excess of 30^{o}c (Getsinger & Dillon 1984). Once introduced to such favourable habitats *Egeria* has the ability to invade existing submerged vegetation, expanding to overtop and shade out native species and other oxygen weeds (Howard-Williams et al. 1987, Tanner et al. 1990).

Egeria was extremely successful in the shallow lakes in the Lower Waikato. Much of the lake areas were within the potential depth range of *Egeria*, they possessed fertile sediments and adequate water clarity for colonisation. In addition water temperature extremes were absent due to a mild temperate climate. Dense surface reaching *Egeria* weedbeds occupied almost the entire water column over extensive areas within the Lower Waikato lakes, excluding other submerged plant species (section 4.2.2). Plants are exclusively dioecious male and reliant solely upon vegetative reproduction although surface reaching weedbeds of *Egeria* flowered extensively over summer months.

Egeria weedbeds in the Lower Waikato would need to maintain a positive energy balance to persist in the long term, sufficient photosynthesis being vital to meet energy requirements for growth and reproduction. Under low water clarity conditions and with a high degree of self shading, it would be essential for weedbeds to maintain adequate photosynthetic tissue within the photic zone. Any factor which prevented the formation of, or caused the destruction of the photosynthetic canopy would impact greatly on photosynthetic ability.

Egeria has a perennial life strategy in the lakes of the Lower Waikato. Although limited senescence of *Egeria weedbeds* was often observed in late summer following flowering, *Egeria* maintained the bulk of its biomass from year to year.

Perennial herbaceous plants such as *Egeria* accumulate carbohydrate reserves over more than one growing season (Crawford 1989). Carbohydrates produced by photosynthesis in excess of immediate needs become important reserves during periods of stress which restrict growth and reproduction (Crawford 1989), such as overwintering (Haramotò & Ikusima 1988), recovery following perturbation and reproduction. Leaf and stem tissue are the sites for starch storage in *Egeria* (Haramoto & Ikusima 1988). *Egeria* plants rely upon the production of specialised vegetative areas for initiation of growth following quiescence and for production of new plants. Double nodes along *Egeria* stems are of primary importance for branching and, with rootcrowns, as vegetative propagules (Getsinger & Dillon 1984). These regions would require energy reserves to initiate growth at critical times.

Perennial herbaceous plants have a cost associated in maintaining living, respiring but non-photosynthesising tissue (Crawford 1989). The architecture of *Egeria* plants within dense weedbeds of these shallow lakes (see section 4.2.2) represents a spatial separation of the photosynthetic canopy within the photic zone and non-photosynthetic tissue beneath. Maintenance of this self-shaded older tissue would be a large respiratory burden. Dense *Egeria* weedbeds retard water movement resulting in localised areas of low oxygen in bottom waters (Tanner et al. 1987). In addition the supply of organic debris to sediments may enhance anoxic sediment conditions. Oxygen generated by photosynthesis must be transported to *Egeria* roots and non-photosynthetic shoots to fulfil respiration demands (Sorrell & Dromgoole 1987). Significant and sustained reductions in photosynthesis and hence the supply of oxygen to these tissues could result in physiological death, and loss of anchorage and nutrient uptake from the sediments.

It has been suggested that there may be an intrinsic tendency for exotic populations such as *Egeria* to decline some time after successful invasion (Carpenter 1980, Johnstone 1982). The apparent dominance of *Egeria* prior to submerged vegetation declines in the lakes of the Lower Waikato supports the concept that this plant in particular, is susceptible to decline.

Johnstone (1982) suggested that surface-flowering, submerged species such as *Egeria* are predisposed to decline because upon reaching the water surface the shoots switch allocation of reserves from vegetative to sexual reproduction. This allocation of resources between vegetative and flowering shoots decreases the ability of mature plant stands to replace themselves. In addition the physical limits of depth and space within the water column, the limited production of vegetative-only propagules, and the simultaneous nature of invasion, growth and senescence cycles of plants such as *Egeria* was suggested to increase their vulnerability to decline. As evidence to support this hypothesis Johnstone experimentally determined that surface-reaching, flowering plants of *Egeria* allocated proportionally less reserves to vegetative growth than did subsurface vegetative plants.

Egeria population 'vigour', as the ability of weedbeds to maintain biomass or regenerate would have been affected by stress, disturbance and competition factors. In addition intrinsic *Egeria* characteristics such as 'population cycles' may have influenced plant vigour.

The role of potential stress, disturbance and competition factors in the decline of *Egeria* vegetation in the lower Waikato lakes is considered and illustrated with examples from lakes which have undergone decline events.

b) Stress factors

Stress factors operate to restrict the growth and reproduction of plant populations (Grime 1977). Possible stress factors experienced by *Egeria* populations in the Lower Waikato lakes would include insufficient light or nutrients, or the presence of toxins deleterious to growth.

<u>Light limitation</u>

Decreases in water clarity are commonly cited in the literature as contributing to submerged vegetation decline (Kemp et al. 1983, Best et al. 1984, Taylor, 1983). Large reductions in the light levels experienced by *Egeria* weedbeds would lead to inadequate photosynthisis to fulfil plant energy requirements. Such shading may be due to increased suspended material in the water column, sudden water level increases or formation of periphytic material on leaf surfaces.

Overall reductions in water clarity accompanied plant declines in many Lower Waikato lakes (eg. Lake Waahi, Kingett 1984, Lake Rotoroa; de Winton et al. 1991). However the role of water clarity in decline events is complicated by considerations of cause and effect. Because submerged vegetation is known to have a role in sediment stabilisation and phytoplankton suppression, it is often unclear if water clarity reductions in the Lower Waikato lakes precipitated plant loss or were a result of the loss of vegetation.

Some direct evidence for the role of water clarity reduction in plant declines comes from events in Lakes Rotoroa and Ohinewai. During the early phase of plant decline in these lakes single measurements of water clarity parameters showed light levels were insufficient to support plant growth at the maximum depths to which *Egeria* was recorded (<1% Photosynthetically Active Radiation; McLea 1986, <1% sub surface irradiance; de Winton et al. 1991). Although plant stems may have extended upwards from these depths and into higher light conditions, subsequent observations showed retraction of *Egeria* to shallower water.

The release of mining wastewaters to receiving waterways has been implicated in submerged vegetation declines of Lakes Whangape (Davies-Colley et al. 1993) and Waahi (Kingett 1984), and could have also operated in Lake Kimihia. In Lake Whangape mining discharges were suggested to produce longer periods of unfavourable light conditions for plant growth than background catchment erosion, with mining discharges alone continuing during long lake residence times (Davies-Colley et al. 1993).

Meteorological events influence plant light regimes by flood inputs of suspended materials and waterlevel increases. Sudden water level increases reduce the light reaching bottom rooted plants, but plants could adjust to moderate increases in depth (c.<0.5 m) relatively rapidly by growing in height.

A turbid water event resulting from heavy rainfall (a '10 year flood') was monitored in Lake Whangape in winter 1986 which, together with water level increases, created an unfavourable light climate for plant growth. Light levels over much of the lake bed were considered insufficient for maintenance of submerged plant communities for a period of 7 weeks (Vant 1987). The duration of the low water clarity conditions in this lake was not sufficient to directly result in a regression of the submerged vegetation, but may have contributed to plant stress which culminated in a later decline.

Within Lake Rotoroa a rapid water clarity decline occurred in association with the initial phase of plant decline (late 1988). A period of higher than average rainfall together with a short term decrease in chlorophyll *a* concentrations, suggested inorganic suspended solids were determining water clarity. Observations of sedimented material on plants during this time were consistent with this idea (de Winton et al. 1991), and would have added to stress experienced by the plants.

Nutrient limitation

Depletion of sediment nutrients has been considered as a cause of vegetation declines (Carpenter 1980). The eutrophic nutrient status of Lower Waikato lakes may suggest that this factor is not likely, however changes in availability of nutrients for plants are possible.

Evidence for the role of nutrient deficiency in the submerged vegetation decline in Lake Rotoroa was somewhat inconclusive. Analysis of concentrations of major and essential elements in *Egeria* tissue collected towards the end of the vegetation decline (1990) implied that these were not limiting (Rajendram 1992). Although tissue phosphorus levels were above a critical level for growth (0.13%), they were lower for Lake Rotoroa material than material analysed from other sites. The existence of high concentrations of arsenic in the sediments of Lake Rotoroa (see below) raised the possibility of competition between arsenic and phosphorus uptake by plant roots. If so phosphorus depletion of sediments by *Egeria* may have contributed to its decline (Rajendram 1992), however factors of sediment depletion are considered more likely to result in gradual reductions in plant biomass rather than the rapid decline witnessed in Lake Rotoroa.

Toxic conditions

Large sediment accumulations of organic matter have been shown to be inhibitory to submerged plant growth, probably because highly organic sediments are anoxic, or release organic acids and growth inhibiting gases (van Wijck et al. 1992). Increased plant biomass production may lead to increased organic matter in shallow water ecosystems (van Wijck et al. 1992). The dual effects of nutrient enrichment and presence of productive *Egeria* weedbeds may have modified sediments in the Lower Waikato lakes over time, however this role of sediment degradation has not been investigated.

Although there are few industries discharging wastes to static waterbodies within the Lower Waikato Region, potentially deleterious levels of pollutants have been detected in some lakes.

A carbonisation plant discharged potentially toxic phenol to Lake Waahi via the Awaroa stream during the years preceding the submerged vegetation decline. The levels of phenol released could have had an impact on biota of the stream and lake, however WVA (1985) suggested the 'presence, persistence and fate of phenolic wastes in the environment is not known'.

Lake Waahi also received high concentrations of boron in mining wastewaters, with levels recorded up to 2.4 times the United States Environmental Protection Agency criteria for fresh water life (WVA 1985). However studies by Thompson (1987) established levels in the lake were within the optimal range for *Egeria* growth, and later trials established that plants survived under conditions where boron concentrations were 4 times greater than levels in Lake Waahi (Clayton 1988).

Lake Rotoroa has elevated sediment levels of potentially toxic pollutants, heavy metals (zinc, lead and copper) which are contributed to the lake from the urban catchment via stormwater systems, and arsenic which was applied to the lake in the 1950's as sodium arsenate herbicide (de Winton et al. 1991). High concentrations of arsenic were measured in submerged plant tissues prior to the vegetation decline (Tanner & Clayton 1990, Rajendram 1992). Although this toxic element is known to be accumulated by freshwater plants, mechanisms for rapid detoxification exist. The submerged vegetation of Lake Rotoroa was seemingly unaffected by arsenic persistence over a considerable time, and in the absence of major changes in lake processes the contribution of arsenic to the decline is thought to be minor. In addition similar arsenic concentrations have been recorded in submerged plant material from geothermally influenced areas without any apparent deleterious effect (Aggett & Aspell 1978). High available concentrations of heavy metals have deleterious effects on the biota of aquatic systems. However heavy metals were considered an improbable cause of the submerged vegetation decline in Lake Rotoroa as submerged plants are well known to be tolerant of elevated element tissue concentrations, heavy metals were likely to be well bound in the lake sediments, and they had accumulated, or persisted over decades therefore were unlikely to have a sudden effect. In addition plants persisted for longest in the most heavily contaminated sector of the lake (Rajendram 1992).

c) Disturbance

Disturbance factors such as grazing, storms and disease limit plant biomass through partial or total loss (Crawford 1989), and regulate population density through mortality. Destruction of *Egeria* plant material may add to stress experienced by plants, become a major drain on plant resources, and limit reproductive potential. For example decreases in the amount of photosynthetic canopy of weedbeds within the photic zone would contribute to energy restrictions on growth. The removal of tissue containing stores of carbohydrates and nutrients would add to resource limitations, and removal of terminal apices, or vegetative propagules would slow growth responses to perturbation.

Grazing, browsing and foraging

The loss of vegetation through grazing, browsing and foraging activities of fauna would have affected *Egeria* weedbeds to some extent in every Lower Waikato lake, but the impacts of fauna are unlikely as a cause of vegetation decline unless plant biomass production rates fell below consumption or destruction rates due to stress or other forms of disturbance.

Prior to submerged vegetation decline Lakes Waahi, Waikare and Whangape were major feeding grounds of black swans (*Cygnus atratus*). Swans can graze the plant canopy within 1 m of the water surface (Mitchell et al. 1988) and have been estimated to consume up to 30-50 % of annual plant production in shallow water ecosystems (Mitchell 1989), while also damaging unconsumed plants during feeding. Swan grazing of *Egeria* in particular results in cropping of young, actively growing shoot apices which are near to the water surface.

Evidence of the impact of swan grazing on *Egeria* weedbeds came from swan exclusion experiments carried out in Lake Whangape before, during, and following the vegetation decline. Plant biomass within un-grazed exclusion cages was considerably greater than adjacent grazed areas both before and during the decline. *Egeria* and other palatable species were dominant within exclosures, whereas the relatively unpalatable *Ceratophyllum* formed a larger proportion of the vegetation where grazing continued (Wells & Clayton 1989). Recent surveys also showed *Egeria* only persists in Lake Whangape within cages and around other obstacles to swan grazing.

The effect of swan grazing as a disturbance factor on submerged vegetation within the lakes of the Lower Waikato region would depend on swan population dynamics and behaviour. Swan grazing may have been sustained, or slowly increased over time as populations established. Alternatively, migratory feeding behaviour, particularly as feeding grounds within the region were successively lost, may have caused acute grazing impacts. Annual counts of lake populations of black swans prior to vegetation declines showed numbers to be highly variable with up to 12,000 birds recorded on Lake Whangape and temporary increases over 7,000 on Lake Waahi (Kingett 1984). Periods of intensive grazing are likely to have accompanied these population peaks.

Fish are known to affect submerged vegetation abundance and distribution by direct consumption, damage or uprooting, and promotion of turbid conditions. Overseas experiments involving the reduction of fish stocks in waterbodies (biomanipulation) have revealed suppression of submerged vegetation by large fish populations (Shapiro & Wright 1984, Meijer et al. 1989, Balls et al. 1989, Ozimek et al. 1990). The development of high fish abundances through artificial stocking, especially of benthivorous fish, have been implicated in the loss of submerged vegetation from waterbodies (Ten Winkel & Meulemans 1984, Meijer et al. 1989, Wright & Phillips 1992).

A role for coarse fish in the submerged vegetation decline in Lake Rotoroa has been suggested (Hicks in Clayton and de Winton in prep.). Although no direct evidence exists, certain factors suggest an effect was possible. A population of coarse fish was established in Lake Rotoroa by limited artificial stocking and migration, with rudd (*Scardinius erythrophthalmus*) illegally introduced some 13 years prior to the submerged vegetation decline. Studies during the period of plant decline showed rudd were numerous, and stomach contents were comprised of 84% submerged plants (Wise 1990). There were no rudd stocking events immediately prior to the plant decline, but fish impacts may have become more important as the stocked fish bred, populations matured and diets changed.

Koi carp (*Cyprinus carpio*) are known to exert a deleterious influence on submerged vegetation (King & Hunt 1967, Crivelli 1983). Koi carp were first recorded from the Waikato River in 1983 (McDowall 1984), with access to many Lower Waikato lakes. Monitoring surveys suggested they were well suited to the Waikato River system, were breeding, and that the population was rapidly expanding. Concerns for the impact of koi on aquatic vegetation were first raised in 1985, with a prediction that koi would reach nuisance proportions by 1990 and widespread destruction of submerged vegetation in the Lower Waikato Region could occur (Pullan 1985).

Despite these predictions no direct association between koi populations and submerged vegetation decline can be substantiated. Some vegetation declines took place before koi were well established in the Waikato Region, and within lakes where koi were unrecorded (eg. Lake Rotoroa; Clayton & de Winton in prep., Lake Waahi; Kingett 1984).

<u>Meteorological events</u>
Windstorms affect submerged vegetation through dislodgment and physical damage from increased wave action. The destruction of *Egeria* weedbeds by windstorms have been implicated in the submerged vegetation decline of Lakes Whangape and Waahi (Davies-Colley et al. 1993). However such events may not be revealed by examination of meteorological records (eg. Lake Waahi, WVA 1987).

<u>Hydrological changes</u>
Small changes in water level within shallow lakes of uniform depth can have extreme effects on plant biomass and survival. Low lake levels, such as caused by extended periods of drought, would subject submerged plants to possible desiccation, an increased level of wave disturbance and also increased exposure to grazing by swans. Temporary increases in water depth could

leave weedbed canopies vulnerable to wave exposure when water levels revert. Unfortunately lake level data for Lower Waikato lakes is often incomplete over the time of vegetation declines, although it is apparent that lake level regimes of many have been altered by outlet modification (Lakes Kimihia, Waahi and Rotongaro), by flood protection schemes. and flow regulation of the Waikato River (section 2.2).

Herbicide application

Herbicides have been applied to nuisance *Egeria* weedbeds within some lakes of the Lower Waikato region including Lakes Hakanoa, Ngaroto, Rotoroa, Waikare, and also to Lake Rotokauri which retains extensive oxygen weed beds.

The submerged vegetation decline in Lake Hakanoa was associated with application of diquat across the entire surface of the lake (Mr R. Clarke pers. comm., Huntly Mining and Cultural Museum). But in the absence of detailed observations at the time of the decline diquat application cannot be confirmed as a major cause of *Egeria* weedbed collapse.

In contrast, events in Lake Rotoroa indicated herbicide treatment did not directly trigger submerged vegetation collapse. This lake was the site of repeated diquat application together with detailed observations which showed promotion of charophyte species, which are resistant to diquat (Tanner et al. 1990). Post spray observations confirmed that diquat resistant charophytes rapidly colonised most areas where target *Egeria* weedbeds had been removed. Subsequent *Egeria* regeneration was also rapid, occurring within 30 weeks of diquat application (Tanner et al. 1987).

The possibility of indirect influences of herbicide spraying were also considered. Extensive water quality monitoring was carried out in Lake Rotoroa in conjunction with spraying events, including effects on water clarity, dissolved oxygen, and nutrient levels. The effects of applications of diquat on water clarity in Lake Rotoroa were difficult to distinguish from natural water clarity decreases in the annual cycle, and longer term trends were not affected. Refined herbicide application techniques did not result in discernible changes to the natural dissolved oxygen regime of Lake Rotoroa, and no significant increase in inorganic nitrogen or phosphorus were detected (Henriques 1979, Tanner et al. 1987, de Winton et al. 1991).

The role of diquat in the decline of submerged vegetation in Lake Rotoroa is thought to be negligible.

Disease or parasites

No symptoms of disease or parasite damage were described from submerged vegetation during decline events, nor were observed any density dependant 'waves' of deleterious effects that may be expected with disease or parasite epidemics. Disease or parasite infection is more likely to occur in plant populations which are already stressed and further increase their vulnerability to decline.

d) Competition

Interactions between populations of species that share a limited resource (eg. light, nutrients, space) can lead to the exclusion of one.

High phytoplankton abundance has detrimental effects on submerged plants via competition for light, nutrients and inorganic carbon, and possibly through allelopathic interactions (Daldorph & Thomas 1991). Although increases in phytoplankton have been observed in association with submerged vegetation declines in Lakes Rotoroa (as chlorophyll *a*; de Winton et al. 1991), and Ohinewai (as organic suspended solids; McLea 1986), it is not clear if phytoplankton increases were causative of, or subsequent to plant decline.

High levels of epiphytes on plants has been suggested as a major mechanism of vegetation decline (Phillips et al. 1978). However there are few confirmed observations of excessive epiphytic algal development on plants prior to plant decline in the lakes of the Lower Waikato. Observations of filamentous algal abundance in Lake Whangape suggested that blanketing growths of *Oedegonium* sp. were concurrent with the partial decline of *Egeria* in 1985, but filamentous algae were not a conspicuous component of the vegetation prior to a total vegetation decline in 1987 (Wells & Clayton 1989).

Within Lake Whangape *Ceratophyllum demersum* had replaced *Egeria* as the dominant submerged plant a year or so prior to the major vegetation decline (Wells & Clayton 1989). Biomass composition measurements over the time of *Ceratophyllum* replacement of *Egeria* (Wells & Clayton 1989) did not indicate if *Egeria* declined independently of opportunistic *Ceratophyllum* increase or if competition led to changed dominance. *Ceratophyllum* dominance may have been a short-term, unstable stage in the final decline as in the absence of an *Egeria* sub-canopy 'substrate', the poorly anchored *Ceratophyllum* vegetation was vulnerable to storm damage.

4.3.3 Stability mechanisms of submerged vegetation

Submerged plant dominance and turbid water conditions due to phytoplankton abundance or sediment re-suspension, are regarded as alternate stable states in shallow, freshwater systems (Hosper, 1989, Irvine et al. 1989, Scheffer 1989, Moss 1990). Although the factors that cause the change from one stable state to the other are not fully understood it is apparent that each state possesses mechanisms that are self-maintaining, and that resist change. There is growing evidence for a number of plant mediated mechanisms that operate to preserve aquatic ecosystems dominated by submerged vegetation (Moss 1983, Balls et al. 1989, Hosper 1989, Irvine et al. 1989, Scheffer 1989, Moss 1990). Conditions created directly or indirectly by submerged plants buffer the system against phytoplankton or epiphyte dominance, and increased inorganic turbidity.

The considerable areas of *Egeria* dominated submerged vegetation in shallow lakes of the Lower Waikato would have had a strong influence on processes and properties of the lakes prior to declines. Plant mediated mechanisms that may have maintained *Egeria* weedbeds within these lakes include :

Nutrient limitation of phytoplankton and epiphytes

Submerged plants may take up and store nutrients in excess of their immediate needs, so buffering the effects of increased nutrient loading (Balls et al. 1989, Hosper 1989, Moss 1990). They may also promote loss of nutrients from the water column by microbial de-nitrification and sedimentation of plant debris.

Calculation of the amount of nutrients tied up in plant biomass in Lake Rotoroa (Clayton & de Winton in prep.) and Lake Whangape (Vant & Hoare 1987) prior to decline show a substantial storage of nutrients, but the fate of these with annual plant turnover is not known. It may be that plant debris was predominantly contributed to lake sediments without becoming available to phytoplankton.

Compensation for shading

Submerged plants can make morphological and biochemical changes to adjust for low water clarity, but their ability to compensate may be exceeded (Moss 1990). Tall growing species such as *Egeria* can overcome phytoplankton shading by alterations to weedbed morphology (Moss 1990, Tanner et al. 1993), including the development of a dense plant canopy close to the water surface. They may compensate for epiphyte shading by sustained new growth or regular shedding of colonised leaves. Also the use of stored carbohydrate reserves by stems to extend into higher light conditions is an important mechanism to 'escape' the effects of turbidity (Scheffer et al. 1992, Tanner et al. 1993).

There is evidence that *Egeria* can survive occasional excursions of low water clarity (Vant 1987, Davies-Colley et al. 1993), however the duration of these episodes in relation to plant energy reserves for survival is likely to be critical.

Allelopathy

Submerged plants may release allelopathic compounds which restrict the development of phytoplankton populations (Phillips et al. 1978, Balls et al. 1989, Moss 1990).

Enhancement of zooplankton grazing

Weedbeds may harbour zooplankton grazers by providing colonisable surfaces or shelter from planktivorous fish, thus resulting in indirect control of phytoplankton populations by these grazers (Balls et al. 1989, Hosper 1989).

Sediment stabilisation, wave baffling and sedimentation

Submerged vegetation preserves water clarity suitable for plant growth by mechanisms additional to interactions with phytoplankton. Extensive vegetation cover stabilises bottom sediments against re-suspension by wind and wave action (Crawford 1977, 1979, Rørslett et al. 1986), while dense plant growths also promote sedimentation of particles suspended in the water column (Mickle & Wetzel 1979, Carpenter & Lodge 1986).

The extensive *Egeria* weed beds in Lower Waikato lakes prior to vegetation decline would have strongly counteracted any moderate regime of stress, disturbance or competition by these mechanisms. However extreme or simultaneous impacts, and critical timing of these could have overwhelmed the stability mechanisms of the submerged vegetation.

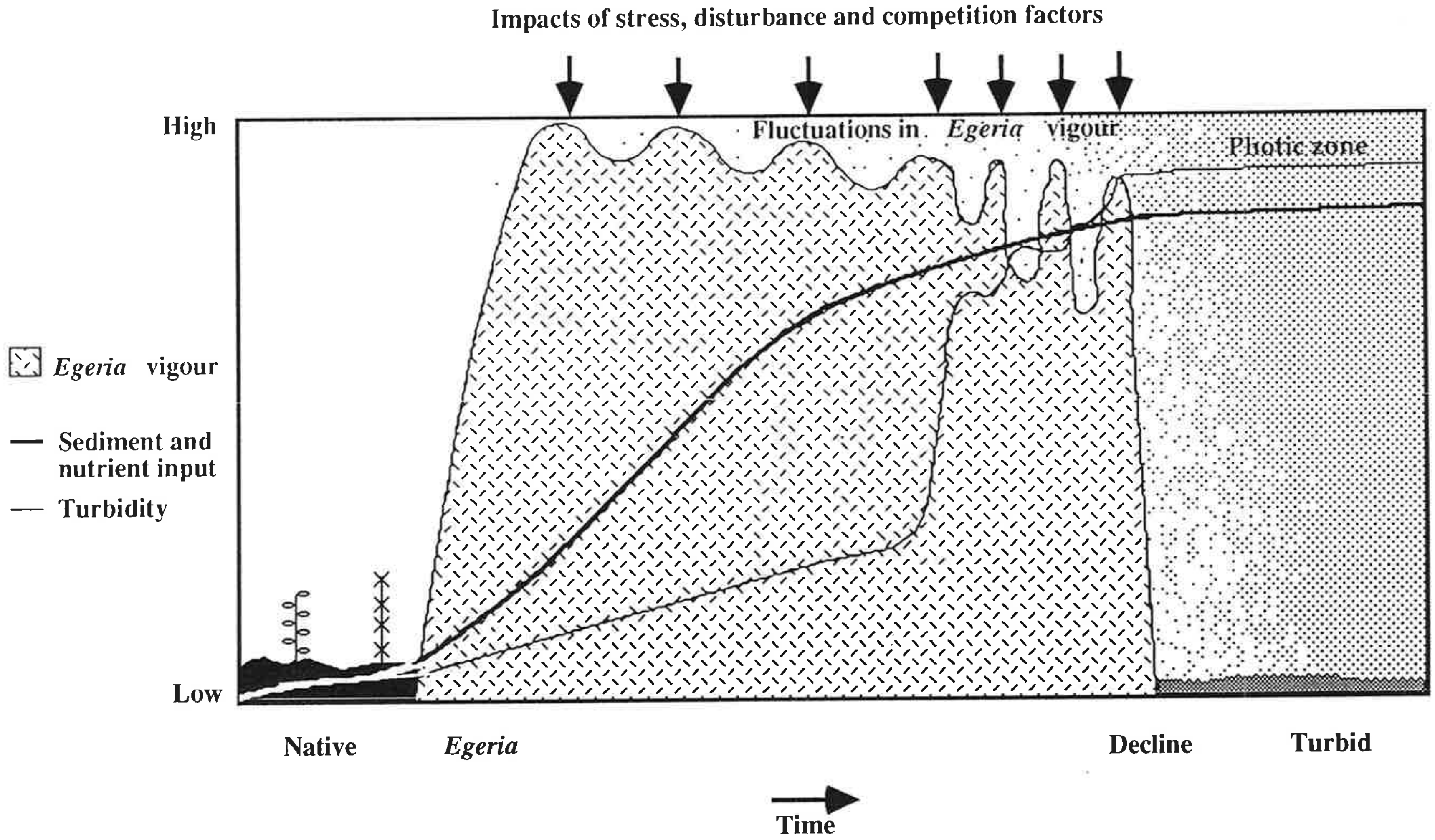
4.3.4 Interactions between stress, disturbance and competition factors

It is evident that the submerged vegetation decline events in the lakes of the Lower Waikato involved a complex interaction of stress, disturbance and competition factors, with different types of factors operating in each lake. In order to understand the cause of submerged vegetation declines across these lakes as a whole it is instructive to consider decline events against a background of sequential changes in the region.

Figure 4.3.4 presents a suggested scenario of the outcome of regional events and impacts of stress, disturbance and competition factors on the vegetation in the lakes of the Lower Waikato over time.

One major change in the region was the replacement of original diverse native submerged vegetation by virtually monospecific growths of *Egeria densa* (fig. 4.3.4). At a similar time the catchments of the Lower Waikato lakes were undergoing extensive development. Section 2.2 of this report outlines some of the impacts on these lakes of human colonisation and expansion. The most significant result of lake catchment development would have been increased, then sustained higher nutrient and sediment loading to the lakes (fig. 4.3.4).

Figure 4.3.4. A stylised time sequence of events leading to the decline of submerged vegetation in the Lower Waikato lakes.



Egeria 'vigour', as the ability of populations to maintain biomass or regenerate, would have fluctuated over time due to the actions of the stress, disturbance and competition factors discussed in section 4.3.2. Different combinations of factors were likely to operate in a lake at any one time, each at variable frequencies and at differing magnitudes. Each factor on its own may have had little effect on plant vigour but together they would have a cumulative, or possibly synergistic effect.

The homeostatic capacity of extensive *Egeria* weedbeds would initially have mitigated the adverse effects of these factors (section 4.3.3). For example *Egeria* would be able to compensate for moderate shading, while increased or sustained catchment loads of nutrients and sediments to lakes would not be directly translated into increased turbidity due to the water clarity preserving mechanisms of the vegetation (fig. 4.3.4).

Eventually however, multiple impacts could overwhelm vegetation stability mechanisms, with subsequent increase in turbidity (fig. 4.3.4). In order to survive, *Egeria* weedbeds would need to maintain sufficient photosynthetic biomass within the photic zone for an energetic return. Energy and oxygen supply to respiring tissue and roots would be essential to maintain functions of anchorage and nutrient uptake. In addition maintenance of carbohydrate reserves would be required to compensate for further disturbances.

It can be seen that the actions of various factors could decrease the fitness of *Egeria* populations to a level where maintenance of biomass is untenable. These considerations serve to illustrate how complex the circumstances are leading to submerged vegetation decline, and explain why the identification of any one causal factor is impossible.

4.4 Factors affecting the submerged vegetation

The presence, degree of development and species composition of the submerged vegetation in the lakes in the Lower Waikato was influenced by a number of interacting factors including:

a) Water clarity
b) Introduction of exotic species
c) Competition by marginal vegetation
d) Exposure
e) Season

Factors a, c, d and e influenced the presence or abundance of submerged vegetation, while vegetation composition was largely determined by the presence or absence of exotic species. Although these factors may currently operate in de-vegetated lakes they are not necessarily the same as those operating prior to submerged vegetation decline, or considered in the previous section for their role in submerged vegetation decline.

a) Water clarity

Light is a primary factor affecting the growth and distribution of submerged vegetation. Light quantity and quality is critical to maintain photosynthetic energy balance and as a stimulus to switch on growth responses, however submerged vegetation can survive periods of inadequate light. The light climate for plants is determined by light attenuation by dissolved and particulate matter in the water column of lakes.

Water clarity of the Lower Waikato lakes as measured by Secchi depth at the time of surveys appeared to be the major determinant of submerged vegetation development, with only sparse plants of limited depth distribution present in low clarity lakes. Secchi depths ranged from less than 0.2 m within the most turbid lakes, moderately low clarity in peat stained lakes (0.3 - 1.1 m), and highest clarity displayed by those lakes supporting an extensive submerged vegetation (up to 3.5 m, table 4.2). Although the limited nature of these Secchi depth readings was recognised, measurements were considered indicative of predominant water clarity conditions.

Submerged vegetation development in the peat lakes (eg. Serpentine Lakes and Lake Whakatangi) appeared more restricted in depth penetration and abundance than that of oxygen weed dominated lakes of comparable Secchi depth readings (eg. Lakes Mangakaware and Rotokauri, table 4.2). An influence of humic staining in lakes on submerged vegetation distribution and development has been suggested in the literature. Humic acid/dissolved organic material was the prime determinant of dissolved water colour in a number of Canadian lakes studied by Chambers and Prepas (1988), who found that for any one Secchi depth aquatic angiosperms colonised to greater depths in lakes with low levels of dissolved colour. They hypothesised that light quality (colour) and quantity (irradiance) control the maximum depth of angiosperm colonisation because lakes of different water colour with similar Secchi depth can differ in spectral energy distribution for plant photosynthesis. The restricted submerged vegetation of peat lakes is therefore likely to be a result of naturally low water clarity due to humic staining and the highly coloured nature of lake water. Alternatively low nutrient, or pH conditions may contribute to low abundance. There are few previous records of submerged plants from the peat influenced Lower Waikato lakes, and they would never have supported extensive submerged vegetation.

Turbid lakes possess higher levels of suspended particulate matter in the water column than would have been the case historically, due to increased catchment disturbance and sources of nutrients and suspended solids. Increases in turbidity have caused water clarity decreases in many of the Lower Waikato lakes and deleteriously impacted on the submerged vegetation. Indeed, decreases in water clarity are considered one of the primary causes of submerged vegetation declines, and largely account for the lack of re-colonisation of de-vegetated lakes by submerged plant species.

Resuspended bottom sediments became a major source of turbidity within large de-vegetated Lakes Waahi, Waikare and Whangape following the loss of submerged vegetation. The water clarity of these lakes has been found to be variable within time and space. Rapid water clarity reductions occur in Lake Waahi in association with wind speeds of a critical velocity (Schicker 1988, Clayton & de Winton 1989). Water clarity also varied spatially, exposed areas within Lake Whangape recorded lower Secchi depths than more sheltered sites, while areas which supported relatively dense growths of *Ceratophyllum demersum* (sheltered backwaters) possessed noticeable clearer water. In this case vegetation development was influencing water clarity by preventing re-suspension of bottom sediments and promoting sedimentation of suspended particles.

Water clarity conditions presently appear to prevent plant re-establishment in the large de-vegetated lakes. Tanner et al. (1993) experimentally determined light conditions and corresponding suspended solid concentrations favourable for potential *Egeria* re-establishment in Lake Waahi. This study found a significant inverse relationship between relative growth rates of *Egeria* propagules and levels of suspended solids, and confirmed that plant growth would be severely retarded under the existing light regime in the lake. Plants grown under high suspended solid levels exhibited morphological adaptations to shading; reduced lateral branching, greater reliance on shoot elongation and reduced root growth. Expression of these adaptations may assist plant survival in the lake but would also increase plant vulnerability to disturbance and uprooting by wave action.

An additional stress for plants in turbid waterbodies would be the further reduction of light by sedimentation and accumulation of suspended debris on leaf surfaces.

The energy reserves in propagules would be critical for plant establishment under low light conditions in peat or turbid lakes. Energy reserves are required to enable shoots of propagules to grow upwards to a favourable light climate, this being an extremely important mechanism for plants to 'escape' the effects of high turbidity (Scheffer et al. 1992), while the physiological condition of propagules would determine growth response to light stimuli.

The water clarity of oxygen weed lakes was sufficient to maintain extensive areas of submerged plants. Due to the shallow nature of the Lower Waikato lakes water depth did not greatly influence the within lake distribution of *Egeria* dominated vegetation. This species formed surface reaching growths from depths of approximately 2.5 m and could maintain a photosynthetic canopy within favourable light levels over a wide range of depths. The only lake with a clear maximum depth limit for submerged vegetation was Lake Rotomanuka.

b) Introduction of exotic submerged species

Egeria densa was once widely distributed within the lakes of the Lower Waikato despite the fact that it only reproduces vegetatively, being recorded from upwards of 19 lakes. The common presence of this species amongst the Huntly lakes was likely a result of transport of *Egeria* innocula via lake-Waikato River tributaries during the frequent flood events in the past, while it was more likely to have been deliberately introduced to some lakes in the Waipa area which do not have such direct connections to innocula sources. The absence of exotic oxygen weeds from Waipa peat lakes suggests that either oxygen weeds have never been introduced, or conditions were unfavourable for their establishment.

Egeria densa was the ecodominant of submerged vegetation under favourable conditions in lakes of the Lower Waikato, present in one case (Lake Hotoananga) for upwards of 35 years.

Egeria was highly competitive under the low light conditions within the shallow lakes due probably to physiological characteristics (Brown et al. 1974), and to a tall, canopy forming growth that fully utilised the limited photic zone.

Although water clarity conditions in oxygen weed dominated lakes were suitable for submerged plant growth, species diversity was low. Dense growths of *Egeria* excluded less competitive oxygen weeds and native species over much of the lakes area, particularly within the smaller, shallow lakes where the maximum lake depths of approximately 2 m were well within the depth range of dense *Egeria* weedbed formation. An exception was observed in Lake Hotoananga where *Egeria* co-existed with beds of *Potamogeton ochreatus* that occurred at depths where light levels appeared to be sub-optimal for *Egeria* growth.

Once introduced to a waterbody *Egeria* could replace existing oxygen weed species, *Elodea canadensis* and *Lagarosiphon major,* such as occurred in Lake Rotoroa (Tanner et al. 1990).

Competitive interactions between *Egeria* and the more recent invader *Ceratophyllum demersum* are less clear. Persistence of *Egeria* in the presence of *Ceratophyllum* is suggested by early (1975) records of both species in Lake Waahi (Coffey 1988), and their presence (all be it limited) at the time of this survey. Alternatively, the apparent replacement of *Egeria* by

Ceratophyllum in Lake Whangape may suggest the latter species is competitive with *Egeria* under some circumstances. *Ceratophyllum* was suggested be competitively dominant over *Egeria* due to possible allelopathic interactions, lower light requirements, lower affinity for epiphytic algal growths and lower palatability for swans (Wells & Clayton 1989). In addition *Ceratophyllum* does not form true roots or require access to sediments, and can establish over the top of existing *Egeria* weedbeds. Biomass composition measurements in this lake over the period of the change in dominance did not elucidate whether *Ceratophyllum* actively displaced *Egeria*, or opportunistically expanded after *Egeria* decline (Wells & Clayton 1989). The rapid demise of *Ceratophyllum* following *Egeria* decline in Lake Whangape suggests this species is reliant on other weed beds for anchorage in large, exposed lakes.

Other oxygen weed species, *Elodea canadensis*, *Lagarosiphon major* and *Ceratophyllum demersum*, are likely to have been introduced in a similar manner to *Egeria*, and the exotic *Potamogeton crispus* distributed as seed by waterfowl. All 5 of these exotic species have been introduced to Lake Waahi, which is also the first adventive site of *Sagittaria subulata*. The method of introduction of this aquarium plant, or its performance under field conditions are not known, and the extent of future spread and establishment within this lake and possible spread to adjacent waterbodies should be monitored.

Following submerged vegetation declines only 6 lakes continue to support dense weedbeds of *Egeria*. Thirteen out of the 21 turbid lakes have at some stage have had *Egeria* present but during this survey *Egeria* was only recorded from turbid Lakes Gin, Rotongaro, Waahi, Waikare and Whangape.

c) Competition by marginal vegetation

Competition by marginal vegetation for space and light decreased the habitat available for submerged vegetation, especially in the smaller lakes which had a large 'edge effect' and sheltered shores. The complete absence of submerged vegetation from small lakes of low water clarity was due to the dual effects of shading of shallow water by marginal vegetation and insufficient light levels beyond. In addition large quantities of leaf litter produced by marginal vegetation smothered submerged plants. Well developed marginal sudds which extended over the water surface prevented the growth of submerged plants, for example sudds in Lake Posa sprawled out over water depths of up to 3 m depth. The extension of *Typha* beds into deeper water and shading due to overhanging willows also excluded submerged species from the shallow littoral margins. Extensive *Eleocharis sphacelata* reedbeds of peat lakes often occupied the shallow littoral most suitable for submerged vegetation growth, with submerged species restricted to regions within *Eleocharis* reedbeds where the open growth form of the emergent plant permitted coexistence.

d) Degree of exposure

The influence of exposure on submerged vegetation was discernible only within the larger lakes of the Lower Waikato region. The more exposed shores of Lakes Rotongaro, Waahi, and Whangape supported a lower presence of submerged plants than sheltered bays. Short, shallow water plant communities (i.e. *Glossostigma* spp., *Lilaeopsis*) were only recorded from the larger lakes, and within Lakes Rotongaro and Waahi occurred only where moderate exposure prevented the formation of emergent vegetation.

e) Season

Seasonal changes in *Egeria* development were pronounced in the smaller lakes of the Lower Waikato. In these waterbodies *Egeria* weedbeds initiated growth of new apices over the spring (September to November), followed by deteriorations in the condition of plants during the summer, with a reduction of buoyancy of the plant canopy and maintenance of predominantly woody stems over the winter. These observations are similar to those described for *Egeria densa* in Lake Marion, U.S.A. (Getsinger & Dillon 1984) where a late summer senescence was suggested to be associated with elevated surface water temperatures of >30^{o}c. These authors also detailed an acceleration of growth in spring, formation of a mat of branches at the water surface during the summer, and found *Egeria* over-wintered along the bottom of the lake in a green condition in association with slow but continuous growth.

Pondweed (*Potamogeton* spp.) abundance can be seasonal or opportunistic, involving periodic regeneration from seed during suitable conditions (Clayton et al. 1989). This behaviour may explain the large changes evident in the pondweed dominated vegetation of Lake Serpentine North over time, particularly if temporal variations in conditions suitable for plant growth occur in the peat lake.

5. SPECIES RECORDS OF INTEREST

5.1 Coastal Plants

Kirk (1871) noted the presence of several maritime plants in the Huntly Lakes area. These include *Chenopodium glaucum* ssp. *ambiguum*, *Potamogeton pectinatus*, *Ruppia polycarpa*, *Lepilaena bilocularis* and *Zannichellia palustris* from Lake Whangape, *Bolboschoenus fluviatilis*, *Ruppia*, *Leptocarpus similis* and *Selliera radicans* from Lake Waikare, *Tetragonia tetragonoides* and *T. trigyna* from Lake Waahi and *Apium filiforme* from Opuatia Creek.

The present survey located *Leptocarpus* on the geothermal island, Punikanae in Lake Waikare, *Potamogeton pectinatus* from Opuatia Lake, *Bolboschoenus fluviatilis* from 12 of the lakes surveyed and *Apium filiforme* from the shores of Lake Whangape. Other coastal species collected at Lake Whangape during this survey include *Bolboschoenus medianus* and *Isolepis nodosa*. *Triglochin striata*, a common salt marsh species, was collected from Lake Rotongaro and the marginal swamp meadows of Lakes Serpentine South and Opuatia.

Kirk (1871) discussed the origin of these coastal elements, considering a former link between the Firth of Thames and the Huntly lakes. This seems unlikely as these areas have been separated by the Maramarua Range since the formation of the Huntly lakes.

Clarkson (1991) describes a similar coastal element of for the lakes of the Rotorua district. He categorises this element into 3 groups, with plant presence due to Maori cultivation, thermal influences and habitat suitability, or a combination of these.

The presence and distribution of *Bolboschoenus fluviatilis* in the Waipa lakes would suggest early cultivation of this plant for it's edible rhizomes (Colenso 1880). The presence of many archaeological sites around these lakes and growth of karaka (*Corynocarpus laevigatus*), a coastal tree with edible fruit, in many bush remnants of this area, indicate a large population of Maori in this area prior to European colonisation. *Tetragonia tetragonoides* and *T. trigyna* are coastal species and the former species was noted by Kirk (1871) as common around Maori cultivations. He collected specimens from Lake Waahi which are deposited in WELT herbarium. de Lange has recently examined these specimens and determined both *T. tetragonoides* and *T. trigyna* from Kirk's collections. Both species are now regarded as extinct from the lake.

Leptocarpus similis was recorded by Kirk as common on the southern shores of Lake Waikare (Kirk 1871). It is now apparently restricted to the thermal island, Punikanae in this lake.

Edgar (1969) notes the presence of *Leptocarpus similis* in thermal areas near Rotorua and Taupo.

Clarkson (1991) reports *Isolepis nodosa, Triglochin striata, Bolboschoenus fluviatilis* and *Chenopodium glaucum* ssp. *ambiguum* as species occupying similar lake habitats to their typical sea shore habitat. These species and also *Apium filiforme, Selliera radicans, Bolboschoenus medianus* and the submerged brackish water species *Potamogeton pectinatus, Ruppia polycarpa, Lepilaena bilocularis* and *Zannichelia palustris* reported from the Waikato lakes would also fit into this category. The close proximity of the Huntly lakes to the Waikato River may explain the pathway of introduction of these species, many of which have been recently collected by the authors from Port Waikato.

5.2 Extinctions

Several of the species recorded by Kirk (1871) for the Huntly lakes were not located by this survey and may be regarded as extinct regionally. These include *Chenopodium glaucum* ssp. *ambiguum, Ruppia polycarpa, Lepilaena bilocularis, Zannichelia palustris, Selliera radicans, Ranunculus limosella, Isoetes kirkii* and *Isolepis fluitans*. These extinctions would probably be due to a combination of out-competition by adventive species, eutrophication and drainage activities.

The recent finds of *Potamogeton pectinatus* from Opuatia Lake, *Pilularia novae-zelandiae* from Lake Waahi, *Leptocarpus similis* from Lake Waikare and *Apium filiforme* from Lake Whangape, species not seen in the region since Kirk's 1870 records, illustrate the benefit of a thorough search of all the waterbodies of the region.

5.3 Rare and Endangered Species

Six of the plants recorded from this survey and from historical records are listed as threatened species in Cameron et al. (1993). They rank species in various cagegories, decreasing in rarity from extinct, endangered, vulnerable, rare and local.

Amphibromus fluitans is ranked as an endangered plant in New Zealand. This grass is also found in Australia where it is not considered a threatened plant. The type locality of this species is the outlet of Lake Waahi (collected by Kirk in 1884) and although not relocated here, it was collected from the shores of Lake Whangape during this survey and by de Lange from Lakes Opuatia and Rotokawau. This grass is only distinctive from other common wetland grasses in its flowering state and may have been overlooked at other sites in this area.

Baumea complanata is ranked as vulnerable by Cameron et al. (1993). This endemic sedge was collected by V. J. Cook from Lake Waahi in 1946 (AK 8081, 22279), the only collection this century from outside of the Ngawha Springs area, Bay of Islands. It is now presumed extinct at Lake Waahi, but may have been overlooked as the exact collection site is not known.

Juncus holoschoenus is also ranked as a vulnerable species nationally. This endemic rush was recorded as a common component of swamp meadow vegetation of Lakes Kaituna, Komakorau, Mangahia, Opuatia, Rotongaro, Rotongaroiti and Whangape. This species is superficially similar to several other species in the section Septati of this genus and may be more widespread within the Waikato. The status of *J. holoschoenus* as a rare plant needs to be re-assessed.

Myriophyllum robustum was historically reported as a widespread but often local plant of the northern North Island wetlands (Cheeseman 1925) but since that time its range has decreased dramatically. It is ranked as rare by Cameron et al. (1993) and the only extant population of this endemic plant found by this survey was in kahikatea forest bordering the Tikotiko Arm of Lake Whangape. Previous records of this species from Lakes Ohinewai and Waahi (Mason & Moar in Orchard 1979) and Lake Serpentine South (Bates pers. comm.) were not relocated during this survey. The North Island stronghold of *M. robustum* is apparently the Whangamarino swamp, north of Lake Waikare.

Utricularia australis is also ranked as a rare endemic found in Lake Rotomanuka and in the marginal vegetation of Lake Opuatia by this survey. Previous investigations had located this plant in Lake Waahi (Kirk 1871) and Lake Serpentine (Boubee 1978), but was not located at either site by this survey. Its apparent decline could be due to increasing nutrient status in these lakes, this species commonly occurring in oligotrophic waters (eg. Northland dune lakes and Whangamarino peat bogs).

Fimbristylis squarrosa is ranked as a local plant but was previously thought to be much rarer, only reported from the thermal areas around Rotorua and a few other scattered localities e.g. Port Waikato (Moore & Edgar 1970). It was extremely common in the marginal turfs of Lake Rotongaroiti and also on Motukauere Island on Lake Whangape, and de Lange (1990) notes other localities for this sedge, including central Hamilton. It is a common Australian species and Hooker (in Cheeseman 1925) regarded the species as adventive in New Zealand. In this survey *F. squarrosa* was essentially ephemeral, growing with the superficially similar *Juncus bufonius* on exposed lake bed during low lake level episodes and was absent from the same sites after inundation. The plant may easily have been overlooked at similar sites in other lakes.

The *Baumea* collected from Lake Kopuera may have been a hybrid between *B. articulata* and *B. huttonii* or possibly a new taxonomic entity, of the same stature as *B. articulata* but with flattened, glaucous leaves and erect, rather than drooping, inflorescences. There are apparently no descriptions of this plant in the literature.

5.4 Interesting Patterns of Distribution

5.4.1 Native species

The herbs *Pratia perpusilla* and *Galium perpusilla* and the sedge *Carex cirrhosa* reach their northern limit of distribution at Lake Whangape. *P. perpusilla* was recorded as common from Lake Waahi and Whangape but *G. perpusilla* is apparently extinct from the region. *C. cirrhosa* is recorded from Lake Rerewhakaaitu (de Lange WAIK), Lake Waikaremoana and further south (Johnson and Brooke 1989), so the collection from Whangape is an important extension in the range of this species. *Pilularia novae-zelandiae* probably reaches its northern limit in Lake Waahi, but may occur in the Waikato River north of this lake (although not presently recorded north of Hamilton).

Anemanthele lessoniana (Lake Rotoaira), *Hydrocotyle hydrophila* (Lake Whangape) and *Eleocharis pusilla* (Lakes Waahi and Waikare) are not recorded from any other Waikato Region locality, these records representing the first collections in this region.

5.4.2 Introduced species

Sagittaria subulata is reported from this survey as adventive in Lake Waahi. This North American species, commonly grown in aquaria and ornamental ponds in this country, has not been recorded as adventive prior to this report. It is apparently spreading within this lake.

Lysimachia vulgaris is reported only from the South Island in Webb et al. (1988), this report noting its presence from Lakes Rotokawau and Waahi.

The Hamilton Basin was most probably the first introduction site for several naturalised species including *Lycopus europaeus* (gypsywort), *Ludwigia peploides* ssp. *montevidensis* (primrose willow) and *Osmunda regalis* (royal fern). Gypsywort was first collected in 1940 (Webb et al. 1988) and it is recorded as an uncommon plant of riverbanks and wet pasture. The present survey reveals that this is a very common plant, found in all but 3 of the lakes surveyed. The dense growth of this plant in disturbed wetland areas indicate that it has the potential to become a major weed of these areas. Primrose willow (first collected in 1933) is more widespread than gypsywort and its invasive nature over sheltered waterbodies, causes major problems in drainage systems, farm dams and duck shooting ponds (the major recreational use of several of the surveyed lakes). This species has spread as far south as Levin (de Lange pers. comm.) and is reported from several sites near Auckland. Royal fern is also very common in the Lower Waikato lake vegetation, where it now occupies *Leptospermum* dominated peat vegetation. It is one of few invasive adventive species in these situations.

Polygonum strigosum is not recorded further south than Whangarei (Webb et al. 1988) although Irving collected this plant from the Whangamarino Swamp (WAIK). It is apparently spreading through the Lower Waikato. *Hypericum mutilum* was also recorded mainly from Northland with isolated records from the eastern Bay of Plenty and Lake Tutira (Webb et al. 1988), other new adventive records for the Hamilton Basin include *Lysimachia nummularia*, *Juncus dichotomus* and *Juncus flavidus*, which is apparently common in the Whangamarino Swamp (de Lange pers. comm.).

Several species including *Alnus glutinosa* (alder), *Myriophyllum aquaticum* (parrots feather), *Apium nodiflorum* (water celery) and *Polygonum strigosum* were only found in the lakes adjacent to the Waikato River and spread to these sites most probably would have occurred from flood episodes.

The Class A Noxious Plant *Salvinia molesta* has been collected from a dam feeding into Lake Hakanoa (1989) and also in the Kimihia wetland adjacent to that lake (1986). Both sites are now considered eradicated (MAF Class A Eradication Programme files). This species would cause major weed problems in most of the small lakes surveyed were it to establish.

The noxious plant *Alternanthera philoxeroides* (alligator weed) was recently reported from the Lower Waikato River (Champion 1990). Its spread upstream to these lakes would completely alter the present communities. Waikato Regional Council are at present implementing a containment / eradication programme for this infestation.

6. CONCLUSION

The importance of the vegetation at lake margins is being increasingly recognised. Plant communities growing on such an environmental gradient can produce an area of high productivity, habitat complexity, and species diversity. Lake vegetation provides a wildlife habitat, being a refuge, food source and nesting area for fauna such as wildfowl. In addition, vegetation has a role in protecting water quality by intercepting and processing diffuse sources of pollutants which may enter lakes. Despite the importance of these land-water ecotones, little is understood of plant community dynamics and the result of various impacts upon vegetation presence, abundance, and composition.

The Lower Waikato lakes are situated within catchments where extensive human development has been concentrated over a period of approximately 100 years. The lake vegetation reflects the consequence of anthropogenic impacts of agricultural practices, urban development, mining and introduction of exotic flora and fauna, as well as natural influences.

The lakes now possess a highly modified lake vegetation. There has been an extensive loss of wetland area due to drainage and development, and widespread invasion by exotic plant species. Massive declines have occurred in native *Phormium tenax* / *Cordyline australis* / *Coprosma* swamps and kahikatea swamp forest. Previously widespread, peat bog vegetation has become extremely restricted in distribution with limited examples recorded from lake margins. *Salix cinerea* is now the most common marginal vegetation of the lakes. The 'oxygen weed' *Egeria densa* replaced native submerged vegetation of many lakes, dominating for an extended period and more recently undergoing extensive decline in many lakes with lake beds remaining largely de-vegetated.

The vegetation showed a number of different stages of change in a sequence of continuing modification. The two year study has afforded a short term view of change in lake vegetation from observations over multiple visits, while the existence of a large amount of information from previous investigations has enabled a long term view of vegetation dynamics. Change apparent over both time scales has permitted the identification of the major influences and impacts which combine to determine presence, abundance and composition of the vegetation of shallow eutrophic lakes. The description of the current vegetation will be a baseline for future investigations of the Lower Waikato lakes.

The vegetation of the Lower Waikato lakes will continue to be modified in the future. There will certainly be further loss of habitat for lake vegetation with catchment activities such as vegetation clearance and drainage. Additional drying and subsidence of peatland will result from both previous and present development, and together with increased nutrient status will contribute to loss of peat plant communities. Future decline events are likely in lakes currently dominated by *Egeria*, while natural recolonisation of de-vegetated lakes appears improbable without intervention.

There is potential for further invasion by exotic species at the expense of native communities. The algae *Hydrodictyon reticulatum* (water net) is present within the Upper Waikato catchment and spreading downstream, while the introduction of *Ceratophyllum demersum* to *Egeria* dominated lakes may result in a change in dominance. Willow species will continue to expand in relatively undisturbed areas, and the future spread of *Alternanthera philoxeroides* (alligator weed) from the Waikato River mouth to these lakes could substantially alter the marginal vegetation reported here. Similarly other species e.g. *Salvinia molesta* would have massive impacts on these lake systems were they to establish.

Importance ranking is a useful aid in assigning priority for management of natural resources. The results of the present study are a basis by which the lakes of the Lower Waikato can be ranked according to the importance of their vegetation character, from lakes that retain significant native communities or unique vegetation aspects, to highly modified waterbodies of low vegetation value.

Management initiatives are required to protect the value and functions of lake vegetation in the Lower Waikato region. The future risk of impacts from agricultural land development, mining, urban development and weed invasion need to be assessed and protection measures put in place. Possible management actions include the reservation of esplanade zones around lakes, such as those proposed by Waipa District Council for land under their administration. Sufficient information is required to reserve marginal areas of a suitable size and shape to allow wetland processes to function and maximise wildlife habitat, with buffer zones to resist outside influences. The use of light stock grazing to promote habitat diversity has promise as a management tool (Tanner 1992), but appropriateness would require a site by site assessment of foreshore characteristics and vegetation. Routine monitoring of lake vegetation is seen as essential to identify future management needs, such as the requirement to control invasive weeds. While complimentary information such as lake level data, flood/drought periodicity, groundwater inputs and rates of peat subsidence would contribute to appropriate decision making.

Despite considerable modification many lakes of the Lower Waikato continue to support a diverse aquatic flora which is further threatened by continued catchment development and exotic plant invasion. The present condition of this lake vegetation illustrates the consequences of similar impacts which may face other shallow New Zealand lakes in the future, while an understanding of plant dynamics and the consequence of impacts will assist the identification of relevant management practices to protect and enhance these important ecosystems.

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8. REFERENCES

Aggett, J.; Aspell, A.C. 1978. Release of arsenic from geothermal sources. New Zealand Energy Research and Development Committee, Report No 35. 12 pp.

Anon 1954. Waikato River catchment- collected engineering reports Ministry of Works, Wellington. Cited in draft Management Plan for Lake Whangape prepared by Department of Conservation.

Atkinson, I.A. 1962. Semi-quantitative measurements of canopy composition as a basis for vegetation mapping. *Proceedings of the Ecological Society of New Zealand 9:* 1-8.

Bakker, J.P. 1989. Nature management by grazing and cutting. Kluwer Academic Publishers, Dordrecht.

Balls, H.; Moss, B.; Irvine, K. 1989. The loss of submerged plants with eutrophication, I experimental design, water chemistry, aquatic plant and phytoplankton biomass in experiments carried out in ponds in the Norfolk Broads. *Freshwater Biology 22:* 71-87.

Best, E.P.; de Vries, D.; Reins, A. 1984. The macrophytes in the Loosdrecht Lakes : a story of their decline in the course of eutrophication. *Verh. Internat. Verein. Limnol. 22:* 868-875.

Boswell, J.; Russ, M.; Simons, M. 1985. Waikato small lakes: resource statement. Waikato Valley Authority.

Boubee, J.A.T. 1978. Preliminary recommendations for the management of the Waipa Lakes. Unpublished report prepared for the Waipa County Council.

Brown, J.M.A.; Dromgoole, F.I.; Towsey, M.W.; Browse, J. 1974. Photosynthesis and photorespiration in aquatic macrophytes. *In* : Bieleski, R.L.; Ferguson, A.R.; Cresswell, M.M. (eds), Mechanisms of regulation of plant growth. *The Royal Society of New Zealand Bulletin 12:* 243-249.

Cameron, E.K.; de Lange, P.J.; Given, D.R.; Johnson, P.N.; Ogle, C.C. 1993. Threatened and local plant lists. *New Zealand Bot. Soc. Newsletter 32:* 14-28.

Carpenter, S.R. 1980. The decline of *Myriophyllum spicatum* in a eutrophic Wisconsin Lake. *Can. J. Bot. 58:* 527-535.

Carpenter, S.R.; Lodge, D.M. 1986. Effects of submersed macrophytes on ecosystem processes. *Aquatic Botany 26:* 341-370.

Chambers, P.A.; Prepas, E.E. 1988. Underwater spectral attenuation and its effect on the maximum depth of angiosperm colonisation. *Can. J. Fish. Aquat. Sci. 45:* 1010-1017.

Champion, P.D. 1988. The ecology and management of kahikatea (*Dacrycarpus dacrydioides* (A. Rich.) de Laubenfels) in the Waikato, North Island, New Zealand. Unpublished MSc Thesis, University of Waikato.

Champion, P.D. 1990. Alligator weed on the Waikato River - Control Options. MAF Quality Management Report to Waikato Regional Council.

Champion, P.D.; de Winton, M.D.; de Lange, P.J. 1993. The vegetation of the Lower Waikato lakes, Volume 2: Vegetation of thirty-eight lakes in the Lower Waikato. *NIWA Ecosystems Publication No 8*. NIWA-Ecosystems, Hamilton.

Chapman, M.A.; Boubee, J.A.T. 1977. Biological survey of the Lakes of the Waipa County, Report No 1, a general summary of survey results. Biological Sciences, University of Waikato.

Cheeseman, T.F. 1925. Manual of the New Zealand flora. 2nd Edition, Government Printers, Wellington.

Cizkova-Koncalova, H.; Kvet, J.; Thompson, K. 1992. Carbon starvation: a key to reed decline in eutrophic lakes. *Aquatic Botany 43:* 105-113.

Clarkson, B.D. 1991. Coastal plants inland. *In* : Clarkson, B.D.; Smale, M.C.; Ecroyd, C.E., Botany of Rotorua. Forest Research Institute, Rotorua.

Clayton, J.S. 1983. Sampling aquatic macrophyte communities. *In* : Biggs, B.J.; Gifford, J.S.; Smith, D.G. (eds), Biological methods for water quality surveys. *Water and Soil Division Miscellaneous Publication No 54*. Ministry of Works and Development, Wellington.

Clayton, J.S. 1988. Experimental culture of aquatic plant species on different substrates within Huntly West No. 1 Effluent ponds. Aquatic Plant Group, Ministry of Agriculture and Fisheries, Ruakura Agricultural Centre. Unpublished report to Coal Corporation NZ Ltd.

Clayton, J.S.; de Winton, M.D. 1989. Aquatic macrophytes in Lake Waahi. Aquatic Plant Group, Ministry of Agriculture and Fisheries, Ruakura Agricultural Centre. Unpublished report to Coal Corporation NZ Ltd.

Clayton, J.S.; de Winton, M.D.; Wells, R.D.S.; Tanner, C.C.; Miller, S.T.; Evans-McLeod, D. 1989. The aquatic vegetation of 15 Rotorua lakes. Aquatic Plant Section, Ministry of Agriculture and Fisheries, Ruakura Agricultural Centre. pp 101.

Clayton, J.S.; de Winton, M.D. [eds] in prep. Lake Rotoroa: Change in an urban lake, information review and bibliography.

Cockayne, L.; Allan, H.H. 1934. An annotated list of groups of wild hybrids in the New Zealand flora. *Ann. Bot. Lond. 48:* 1-55.

Coffey, B.T.; Coleman, P.L. 1975. Notes on inspection of Lake Kimihia, July 16, 1975. New Zealand Electricity Department, Hamilton. Unpublished report to Wildlife Division of the Department of Internal Affairs.

Coffey, B.T. 1988. Evidence of Dr Brian Coffey to the Standing Tribunal, Waikato Catchment Board, hearing Water Right Applications from Coal Corporation of N.Z. Ltd for the Huntly West Underground Coal Mine. Brian T. Coffey and Associates Limited.

Coffey, B.; Edgar, N. 1993. Review of the current status of Lake Rotoroa, Hamilton. Report prepared for the Executive Director, WWF-New Zealand. Brian T. Coffey and Associates Limited.

Colenso, W. 1880. On the vegetable food of the ancient New Zealanders before Cooks visit. *Transactions of the New Zealand Institute 12*.

Cook, J.M.; Mark, A.F.; Shore, B.F. 1980. Responses of *Leptospermum scoparium* and *Leptospermum ericoides* (Myrtaceae) to waterlogging. *New Zealand Journal of Botany 18:* 223-246.

Cranwell, L. 1939. Native vegetation. *In* : Soils and agriculture of part of the Waipa County, *DSIR Bulletin 76*. Government Printer, Wellington.

Crawford, S.A. 1977. Chemical, physical and biological changes associated with Chara succession in farm ponds. *Hydrobiologia 55:* 209-217.

Crawford, S.A. 1979. Farm pond restoration using *Chara vulgaris* vegetation. *Hydrobiologia 62:* 17-31.

Crawford, R.M.M. 1982. Physiological responses to flooding. *In* : Lange, O.L.; Nobel, P.S.; Osmond, C.B.; Zeigler, H. (eds), Physiological Plant Ecology III. Springer Verlag, Berlin.

Crawford, R.M.M. 1989. Studies in plant survival: ecological case histories of plant adaptation to adversity. (Studies in Ecology II). Blackwell Scientific Publications, Oxford; Boston.

Crivelli, A.J. 1983. The distruction of aquatic vegetation by carp. *Hydrobiologia 106:* 37-41.

Daldorph, P.W.G.; Thomas, J.D. 1991. The effect of nutrient enrichment on a freshwater community dominated by macrophytes and molluscs and relevance to snail control. *Journal of Applied Ecology 28:* 685-702.

Davies-Colley, R.J.; Vant, W.N.; Smith, D.G. 1993. Colour and clarity of natural waters : science of management of optical water quality. Lake Whangape : changed optical quality linked to macrophyte decline, pg 208-214. Ellis-Horwood, Chichester, England, 300 p.

Davis, G.J.; Carey, D.F. 1981. Trends in submerged macrophyte communities of the Currituck Sound, 1977-1979. *J. Aquat. Plant Manage. 19:* 3-9.

Davoren, A. 1978. A survey of New Zealand peat resources. *Water and Soil Technical Publication No 14*. Published by the University of Waikato, for the National Water and Soil Conservation Organisation.

de Lange, P.J. 1990. Some notes on *Fimbristylis squarrosa*. *New Zealand Botanical Society Newsletter 22:* 8-9.

de Winton, M.D.; Clayton, J.S.; Wells, R.D.S.; Tanner, C.C. 1991. Review of Lake Rotoroa monitoring and management issues; 1987-1991. Aquatic Plant Group, Ministry of Agriculture and Fisheries, Ruakura Agricultural Centre. Unpublished report to the Community Services Group of the Hamilton City Council.

Drew, M.C.; Lynch, J.M. 1980. Soil anaerobiosis, microorganisms and root function. *Ann. Rev. Phytopathol. 18:* 37-66.

DSIR 1939. Soils and agriculture of part of the Waipa County. *DSIR Bulletin 76*. Government Printer, Wellington.

Edgar, E. 1969. The New Zealand species of *Leptocarpus* (Restionaceae). *New Zealand Journal of Botany 6:* 467-469.

Etheredge, K.M. 1987. The phytoplankton communities of nine lakes, Waikato, New Zealand: a comparative study of floristics, seasonal dynamics and the influence of herbivory. Unpublished PhD Thesis, University of Waikato.

Forsberg, C. 1964. The vegetation changes in Lake Tåkern. *Svensk Botanisk Tidskrift. Bd 58 H. 1:* 44-54.

Gambrell, R.P.; Patrick, W.H. 1978. Chemical and microbiological properties of anaerobic soils and sediments. In : Hook, D.D.; Crawford, R.M.M. (ed). Plant life in anaerobic environments. Ann Arbour Sci., Ann Arbour, Mitchigan, pp 375-423.

Garrick, A.S.; Saunders, A.J. 1986. Flora and fauna in the Huntly West No. 1 coalfield area, a preliminary assessment. A Wildlife Service Environmental Investigations Unit Report in collaboration with the Fisheries Research Division, Aquatic Plants Section of the Ministry of Agriculture and Fisheries, and the Biological Sciences Department of the University of Waikato.

Gerbeaux, P.J. 1989. Aquatic plant decline in Lake Ellesmere: a case for macrophyte management in a shallow New Zealand lake. Unpublished PhD Thesis, Lincoln College.

Getsinger, K.D.; Dillon, C.R. 1984. Quiescence, growth and senescence of *Egeria densa* in Lake Marion. *Aquatic Botany 20:* 329-338.

Gibbs, G.W. 1973. Cycles of macrophytes and phytoplankton in Pukepuke Lagoon following a severe drought. *Proceedings of the New Zealand Ecological Society 20:* 13-20.

Gill, C.J. 1970. The flooding tolerance of woody species - a review. *Forestry Abstracts 31:* 671-688.

Green, J.D.; Lowe, D.J. 1985. Stratigraphy and development of c. 17,000 year old Lake Maratoto, North Island, New Zealand, with some inferences about postglacial climatic change. *New Zealand Journal of Geology and Geophysics 28:* 675-699.

Grime, J.P. 1977. Plant strategies and vegetation processes. Wiley, Chichester, England.

Haramoto, T.; Ikusima, I. 1988. Life cycle of *Egeria densa* Planch., an aquatic plant naturalized in Japan. *Aquatic Botany 30 (4):* 389-403.

HCC 1983. Hamilton Lake Management Plan. Hamilton City Council report.

Henriques, P.R. 1979. Hamilton Lake Monitoring Programme: summer 1978/9. Waikato Valley Authority. *Technical Publication 12.*

Hooper, G.W. 1987. Hawkes Bay small lakes water quality survey. Hawkes Bay Catchment Board and Regional Water Board unpublished report 57 pp.

Hosper, S.H. 1989. Biomanipulation, new perspectives for restoration of shallow, eutrophic lakes in The Netherlands. *Hydrobiological Bulletin 23:* 5-10.

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.

Huntly Mining and Cultural Museum (undated). Lake Hakanoa. 22-24 Harlock Place, Huntly.

Irvine, K.; Moss, B.; Balls, H. 1989. The loss of submerged plants with eutrophication, II relationships between fish and zooplankton in a set of experimental ponds and conclusions. *Freshwater Biology 22:* 89-107.

Irving, R.M.; Skinner, M.; Thompson, K. 1984. Kopuatai Peat Bog - a vegetation survey. Crownland Series no. 12, Department of Lands and Survey.

Irving, R.M.; Jones, K. 1986. Lake Kaituna and Lake Komakorau vegetation report. Unpublished Wildlife Service report.

Irwin, J. 1975. Checklist of New Zealand lakes. New Zealand Oceanographic Institute Memoir 74.

Johnson, P.N.; Brooke, P.A. 1989. Wetland plants in New Zealand. DSIR Publishing, Wellington.

Johnstone, I.M. 1982. Waterweed decline : a resource allocation hypothesis. *Proceedings European Weed Research Society 6th Symposium on Aquatic Weeds 6:* 45-53.

Johnstone, I.M.; Robinson, P. 1987. Light level variation in Lake Tutira after transient sediment inflow and effects on the submerged macrophytes. *N.Z. Journal of Marine and Freshwater Research 21:* 47-53.

Judd, B.; Kokich, D. 1986. Water quality problems in Lake Omapere : a report by the Lake Omapere Task Force to the Northland Catchment Commission, May 1986. Northland Catchment Commission, Whangarei. 35 pp.

Jupp, B.P.; Spence, D.H.N. 1977. Limitations on macrophytes in a eutrophic lake, Loch Leven, I effects of phytoplankton. *J. Ecol. 65:* 175-186.

Justin, S.H.F.W.; Armstrong, W. 1987. The anatomical characteristics of roots and plant response to soil flooding. *New Phytol. 106:* 465-495.

Keddy, P.A. 1983. Shoreline vegetation in Axe Lake, Ontario: effects of exposure on zonation patterns. *Ecology 64 (2):* 331-344.

Keddy, P.A. 1989. Competition. Chapman & Hall, London.

Kemp, W.M.; Twilley, R.R.; Stevenson, J.C.; Boynton, W.R.; Means, J.C. 1983. The decline of submerged vascular plants in the Upper Chesapeake Bay: summary of results concerning possible causes. *Marine Technology Society Journal 17 (2):* 78-89.

King, D.R.; Hunt, G.S. 1967. Effect of carp on vegetation in a Lake Erie marsh. *Journal of Wildlife Mangaement 31 (1):* 181-188.

Kingett, P. 1984. An environmental history: Lake Waahi. Kingett and Associates, unpublished report prepared for Mines Division, Ministry of Energy.

Kirk, T. 1871. Notes on the botany of certain places in the Waikato District. *Trans. N.Z. Inst. 3:* 142-147.

Lockley, J.W. 1988. The growth of *Egeria densa* in Lake Waahi. Unpublished MSc Thesis, University of Waikato.

Looijen, R.C.; Bakker, J.P. 1987. Utilisation of different salt-marsh plant communities by cattle and geese. *In* : Huiskes, A.H.L.; Blom, C.W.P.M.; Rozema, J. (eds), Vegetation between land and sea, Chapter 5. Dr. W. Junk Publishers, Dordrecht.

Lowe, D.; Green, J.D. 1987. Origins and development of the lakes. *In* : Viner, A.B. (ed). Inland waters of New Zealand. DSIR Bulletin 241, Wellington.

Mason, R. 1960. Three waterweeds of the family Hydrocharitaceae in New Zealand. *New Zealand Journal of Science 3 (3):* 382-395.

Mason, R. 1975. The macrophytes. *In* : Jolly, V.H.; Brown, J.M.A. (eds), New Zealand Lakes. Auckland University Press, Oxford University Press.

McCraw, J.D. 1967. The surface features and soil pattern of the Hamilton Basin. *Earth Science Journal 1:* 59-74.

McDowall, R.M. 1984. New Zealand freshwater fishes, a natural history and guide. Heinemann Reed, Auckland (in association with MAF Publishing Group, Wellington).

McLea, M.C. 1986. Ohinewai Regional Resource Study: biology and water quality. Waikato Valley Authority. *Technical Publication No. 37.*

Meijer, M.L.; Raat, A.J.P.; Doef, R.W. 1989. Restoration by biomanipulation of Lake Bleiiswijkse Zoom (The Netherlands): first results. *Hydrobiological Bulletin 23:* 49-57.

Menges, E.S.; Waller, D.M. 1983. Plant strategies in relation to elevation and light in floodplain herbs. *The American Naturalist 122 (4):* 454-473.

Mickle, A.M.; Wetzel, R.G. 1979. Effectiveness of submerged angiosperm-epiphyte complexes on exchange of nutrients and organic carbon in littoral systems. *Aquatic Botany 6:* 339-355.

Mitchell, S.F.; Hamilton, D.P.; MacGibson, W.S.; Nayar, P.K.B.; Reynolds, R.N. 1988. Interrelationships between phytoplankton, submerged macrophytes, black swans (*Cygnus atratus*) and zooplankton in a shallow New Zealand lake. *Int. Revue ges. hydrobiol. 72:* 145-170.

Mitchell, S.F. 1989. Primary production in a shallow eutrophic lake dominated alternately by phytoplankton and by submerged macrophytes. *Aquatic Botany 33:* 101-110.

Molloy, B. 1989. The management of semi-natural areas; some factors to consider. *In* : Norton, D.A. (ed). Management of New Zealand's natural estate. New Zealand Ecological Society Occasional Publication No. 1, Wellington.

Moore, L.B.; Edgar, E. 1970. Flora of New Zealand II. Government Printer, Wellington.

Moss, B. 1983. The Norfolk Broadland : experiments in the restoration of a complex wetland. *Biological Reviews 58:* 521-561.

Moss, B. 1990. Engineering and biological approaches to the restoration from eutrophication of shallow lakes in which aquatic plant communities are important components. *Hydrobiologia 200/201:* 367-377

Newnham, R.M.; Lowe, D.J.; Green, J.D. 1989. Palynology, vegetation, and climate of the Waikato Lowlands (North Island, New Zealand) since c. 18, 000 years ago. *Journal of the Royal Society of New Zealand 19:* 127-150.

Nicholls, J.L. 1976. A revised classification of the North Island Indigenous Forests. *New Zealand Journal of Forestry 21 (1):* 105-132.

Ozimek, T.; Gulati, R.D.; van Donk, E. 1990. Can macrophytes be useful in biomanipulation of lakes? - the Lake Zwemlust example. *Hydrobiologia 200/201:* 399-407.

Pacala, S.W.; Crawley, M.J. 1992. Herbivores and plant diversity. *The American Naturalist 140 (2):* 243-260.

Phillips, G.L.; Eminson, D.; Moss, B. 1978. A mechanism to account for macrophyte decline in progressively eutrophicated freshwaters. *Aquatic Botany 4:* 103-126.

Prejs, A. 1984. Herbivory by temperate freshwater fishes and its consequences. *Environmental Biology of Fishes 10 (4):* 281-296.

Pullan, S. 1985. Workshop, New Zealand Limnological Society Conference Proceedings 1985.

Rajendram, G. 1992. Study of selected chemical constituents in water, sediments, plants and fish in Lake Rotoroa, Hamilton, and their possible effects on the lake's ecosystem. Unpublished MSc Thesis, University of Waikato.

Rørslett, B.; Berge, D.; Johansen, S.W. 1986. Lake enrichment by submersed macrophytes: a Norwegian whole lake experience with *Elodea canadensis*. *Aquatic Botany 26:* 325-340.

Scheffer, M. 1989. Alternate stable states in eutrophic, shallow freshwater systems: a minimal model. *Hydrobiol. Bull. 23:* 73-83.

Scheffer, M.; de Redelijkheid, M.R.; Noppert, F. 1992. Distribution and dynamics of submerged vegetation in a chain of shallow eutrophic lakes. *Aquatic Botany 42:* 199-216.

Schicker, K.P. 1988. Sediments and hydrodynamics of Lake Waahi, Huntly, New Zealand. Unpublished MSc Thesis, University of Waikato.

Shapiro, J.; Wright, D.I. 1984. Lake restoration by biomanipulation : Round Lake, Minnesota, the first two years. *Freshwater Biology 14:* 371-383.

Shipley, B.; Keddy, P.A.; Gaudet, C.; Moore, D.R.J. 1991. A model of species density in shoreline vegetation. *Ecology 72 (5):* 1658-1667.

Sorrell, B.K.; Dromgoole, F.I. 1987. Oxygen transport in the submerged freshwater macrophyte *Egeria densa* Planch. I. Oxygen production, storage and release. *Aquatic Botany 28 (1):* 63-80.

Stanfield, J.; Moss, B.; Irvine, K. 1989. The loss of plants with eutrophication, III potential role of organochlorine pesticides : a palaeoecological study. *Freshwater Biology 22:* 109-132.

Stephenson, G.K. (Convenor) 1983. Wetlands : a diminishing resource. *Water and Soil Miscellaneous Publication No 58*. Ministry of Works and Development, Wellington.

Symes, G.W. 1982. Kahikatea (*Podocarpus dacrydioides*). Diploma of Natural Resources Dissertation, Lincoln College, Canterbury.

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

Tanner, C.C.; Wells, R.D.S.; Clayton, J.S. 1987. Lake Rotoroa, Hamilton: aquatic weed control, dissolved oxygen, water clarity and recommendations for future management. Unpublished report for the Recreation and Welfare Department of the Hamilton City Council. Aquatic Impact Unit, Ruakura Agricultural Centre, Ministry of Agriculture and Fisheries.

Tanner, C.C.; Clayton, J.S. 1990. Persistence of arsenic 24 years after sodium arsenite herbicide application to Lake Rotoroa, Hamilton, New Zealand. *New Zealand Journal of Marine and Freshwater Research 24:* 173-179.

Tanner, C.C.; Clayton, J.S.; Coffey, B.T. 1990. Submerged-vegetation changes in Lake Rotoroa (Hamilton, New Zealand) related to herbicide treatment and invasion by *Egeria densa. New Zealand Journal of Marine and Freshwater Research 24:* 45-57.

Tanner, C.C. 1992. A review of cattle grazing effects on lake margin vegetation with observations from dune lakes in Northland, New Zealand. *New Zealand Natural Sciences 19:* 1-14.

Tanner, C.C.; Clayton, J.S.; Wells, R.D.S. 1993. Effects of suspended solids on the establishment and growth of *Egeria densa. Aquatic Botany 45:* 299-310.

Taylor, D.I. 1983. The effects of a major macrophyte regression upon primary productivity in the littoral of Swartvlei. *Arch. hydrobiol. 96 (3):* 345-353.

Ten Winkel, E.H.; Meulemans, J.T. 1984. Effects of fish upon submerged vegetation. *Hydrological Bulletin 18 (2):* 157-158.

Thompson, K. 1987. Studies of the toxicity of boron and of Huntly West Mine wastewaters to the aquatic macrophyte *Egeria densa.* Unpublisherd technical report, Water Research Unit, University of Waikato, 65 pp.

Thompson, K.; Silvester, W.V.; Cameron, B.; Edwards, J.; Howie, R.; Irving, R.; McLae, C.; Verstappen, M. 1983. Ohinewai - an ecological survey. A report prepared by the University of Waikato for the Mines Division, Ministry of Energy.

Tye, R.E. 1974. Hauraki Plains story. Thames Valley News Ltd, Paeroa.

van Wijck, C.; de Groot, C.; Grillas, P. 1992. The effect of anaerobic sediment on the growth of *Potamogeton pectinatus* L.: the role of organic matter, sulphide and ferrous iron. *Aquatic Botany 44:* 31-49.

Vant, W.N. 1987. Lake Whangape - muddy waters and macrophytes. *Soil and Water 23 (3):* 20-24.

Vant, W.N.; Hoare, R.A. 1987. Determining input rates of plant nutrients. *In* : Vant, W.N. (ed). Lake Managers Handbook. *Water and Soil Miscellaneous Publication No 103*, Wellington.

Waipa CC 1978. Lake Ngaroto inventory and management plan. Waipa County Council report.

Wallace, S.W. 1983. A study of manuka vegetation growing in peat adjoining Lake Maratoto, Rukuhia. University of Waikato.

Ward. F.J.; Northcote, T.G.; Chapman, M.A. 1987. The effects of recent environmental changes in Lake Waahi on two forms of the common smelt *Retropinna retropinna*, and other biota. *Water Air Soil Pollut. 32:* 427-443.

Wardle, P. 1989. Grazing and management of natural areas; re-introducing an indigenous factor? *In* : Norton, D.A. (ed). Management of New Zealand's natural estate. New Zealand Ecological Society Occasional Publication No 1, Wellington.

Webb, C.J.; Sykes, W.R.; Garnock-Jones, P.J. 1988. Flora of New Zealand IV. Botany Division, DSIR, Christchurch.

Wells, R.D.S.; Vant, W.N.; Clayton, J.S. 1988. Inorganic suspensoids and submerged macrophytes in Lake Whangape, New Zealand. *Verh. Internat. Verein. Limnol. 23:* 1969-1972.

Wells, R.D.S.; Clayton, J.S. 1989. Lake Whangape: the macrophytes. Unpublished report, Aquatic Plant Group, Ministry of Agriculture and Fisheries, Ruakura Agricultural Centre.

Wilson, S.D.; Keddy, P.A. 1985. The shoreline distribution of *Juncus pelocarpus* along a gradient of exposure to waves: an experimental study. *Aquatic Botany 21:* 277-284.

Wise, R.G. 1990. The biology of three exotic freshwater fish species in Hamilton Lake. Unpublished MSc Thesis, University of Waikato.

Wood, R.D.; Mason, R. 1977. Characeae of New Zealand. *New Zealand Journal of Botany 15:* 87-180.

Wright, R.M.; Phillips, V.E. 1992. Changes in the aquatic vegetation of two gravel pit lakes after reducing the fish population density. *Aquatic Botany 43 (1):* 43-49.

WVA 1980. Lake trophic status and water quality. Waikato Valley Authority. *Technical Publication No 16.*

WVA 1981. Lake trophic status. Waikato Valley Authority. *Technical Publication No 19.*

WVA 1982. Lake trophic status and water quality. Waikato Valley Authority. *Technical Publication No 22.*

WVA 1985. The Lower Waikato Catchment: a bibliography and information review. Waikato Valley Authority. *Technical Publication Number 32.*

WVA 1987. Lake Waahi catchment resource statement. Waikato Valley Authority. *Technical Publication No. 50.*

Appendix 1 : Species lists for 38 Lower Waikato Lakes

\+ present at lake   e extinct

	Areare	Cameron	Gin	Hakanoa	Hotoananga	Kaituna	Kimihia	Komakorau	Kopuera	Koromatua	Mangahia	Mangakaware	Maratoto	Ngaroto	Ngarotoiti	Ohinewai	Okowhao	Opuatia	Patuka	Pikopiko	Posa	Rotoaira	Rotokauri	Rotokawau	Rotomanuka	Rotongaro	Rotongaroiti	Rotopataka	Rotoroa	Ruatuna	Serpentine E	Serpentine N	Serpentine S	Tunawhakapeka	Waahi	Waikare	Whakatangi	Whangape
Adiantum cunninghamii																																				+		+
Agrostis stolonifera *	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+			+		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Alisma plantago-aquatica *																								+											+			+
Alnus glutinosa *									+														+											+	+	+		+
Alopecuris geniculatus *				+																								+		+	+	+	+	+				+
Alternanthera sessilis *																																+		+	+			+
Amphibromus fluitans																								+														+
Amenanthele lessoniana																						+																
Apium filiforme																																						+
Apium nodiflorum *				+			+		+									+						+												+		+
Arundo donax *				+																			+					+								+		
Astelia grandis																																						+
Aster subulatus *	+			+	+	+	+		+	+										+		+	+											+	+	+		+
Axonopus affinis *		+				+						+				+						+		+	+	+				+					+	+		
Azolla pinnata *	+		+	+	+		+		+	+		+			+	+		+		+			+		+	+	+	+		+	+	+	+	+	+			+
Azolla rubra		+		+		+		+	+				+					+	+					+		+												+
Baumea articulata	+		+	+	+	+	+		+	+	+	+	+			+	+	+		+		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		+
Baumea complanata																																			e			
Baumea huttonii			+	+	+		+		+		+	+				+		+				+		+	+	+	+			+	+	+	+		+	+		+
Baumea juncea																	+							+					e						+			+
Baumea 'Kopuera'									+																													
Baumea rubiginosa			+	+		+	+	+	+		+	+					+	+		+	+	+	+	+	+	+	+	+	+	+	+	+	+		+	+		+
Baumea tenax		+		+	+		+		+				+				+								+	+				+	+	+	+		+			+
Baumea teretifolia	+			+	+	+	+	+	+		+		+			+	+				+	+	+	+							+	+	+	+	+	+		+
Bidens frondosa *	+	+	+	+	+	+	+	+	+	+	+	+	+	+		+	+	+	+	+		+	+	+	+	+	+	+		+	+	+	+	+	+		+	+
Blechnum minus	+	+	+	+	+	+	+	+	+	+	+	+	+			+	+			+	+	+	+	+	+	+	+	+	+	+	+	+	+		+	+	+	+
Bolboschoenus fluviatilis				+			+		+	+		+						+						+		+				+					+	+		+
Bolboschoenus medianus																																						+
Bulbophyllum tuberculatum																																						+
Callitriche muelleri									+																													+
Callitriche petriei				+														+																+		+		+
Callitriche stagnalis *	+		+	+		+	+	+	+	+	+	+	+			+	+	+		+		+	+		+	+		+	+	+		+	+	+	+			+
Calystegia sepium	+		+	+	+	+	+		+	+	+	+		+		+	+	+		+		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Cardamine flexuosa *				+			+		+									+											+									+
Cardamine pratense *			+	+								+												+						+					+			+
Carex cirrhosa																																						+
Carex dipsacea																		+																	+			+
Carex dissita				+	+		+		+								+							+														+
Carex fascicularis				+	+		+	+	+							+	+							+	+					+	+	+	+		+			+
Carex gaudichaudiana				+			+											+																	+			+
Carex geminata			+	+		+	+		+								+						+		+		+			+					+	+		+
Carex inversa			+	+	+		+		+	+		+				+	+								+					+								+
Carex lessoniana	+			+	+		+		+	+		+	+			+	+					+	+	+	+					+				+	+			+
Carex maorica	+		+	+	+		+		+	+		+				+	+	+		+		+	+	+	+			+		+	+	+	+	+	+	+		+
Carex ochrosaccus																																						+
Carex ovalis *	+	+	+	+			+		+	+		+				+	+			+		+	+	+	+	+		+		+	+	+	+	+	+	+		+
Carex scoparius *						+		+																											+			
Carex secta	+	+	+	+		+	+	+	+	+	+	+		+	+	+	+	+	+	+		+	+	+	+			+	+	+	+	+	+	+	+	+		+
Carex sinclairii									+			+																							+			
Carex solandri																																						+
Carex subdola				+			+		+			+						+																	+	+		+
Carex virgata	+	+	+	+		+	+	+	+	+	+	+	+	+	+	+	+	+		+		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Carex vulpinoidea *																																	+					+
Centella uniflora	+	+		+		+	+	+	+	+	+	+	+			+	+	+		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Centipeda cunninghamii *									+																	+	+								+			+
Ceratophyllum demersum *														e																					+			+
Chara corallina					e?									e				+								+	e		e			+			+			
Chara fibrosa																e																+			+			
Chara globularis																																						e
Chenopodium glaucum ssp ambiguum																																						e
Coprosma propinqua			+	+			+		+	+		+				+	+	+					+	+	+			+		+	+		+		+	+		+
Coprosma propinqua x robusta	+		+	+	+		+		+	+		+				+	+	+				+	+	+	+		+	+			+	+	+	+	+	+		+
Coprosma rigida										+																												+
Coprosma robusta	+		+	+	+	+	+		+	+		+	+			+	+			+		+	+	+	+	+	+	+	+	+	+		+	+	+	+		+
Coprosma tenuicaulis	+	+		+	+		+		+	+	+	+	+				+	+		+		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		+
Cordyline australis	+	+	+	+	+	+	+	+	+	+		+				+	+	+		+		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Cortaderia selloana *	+		+	+			+		+											+		+		+	+	+		+		+		+		+	+	+		+
Cotula coronopifolia				+																				+		+									+			+
Crassula sinclairii																																			+			

Appendix 1 : Species lists for 38 Lower Waikato Lakes

\+ present at lake e extinct

	Areare	Cameron	Gin	Hakanoa	Hotoananga	Kaituna	Kimihia	Komakorau	Kopuera	Koromatua	Mangahia	Mangakaware	Maratoto	Ngaroto	Ngarotoiti	Ohinewai	Okowhao	Opuatia	Pataka	Pikopiko	Posa	Rotoaira	Rotokauri	Rotokawau	Rotomanuka	Rotongaro	Rotongaroiti	Rotopataka	Rotoroa	Ruatuna	Serpentine E	Serpentine N	Serpentine S	Tunawhakapeka	Waahi	Waikare	Whakatangi	Whangape
Crataegus monogyna *		+		+			+		+	+		+	+				+	+						+		+	+			+					+	+		+
Cuscuta campestris *																																						+
Cyathea dealbata			+	+	+	+			+	+														+	+	+	+								+	+		+
Cyathea medullaris				+	+	+			+	+																+	+								+	+		+
Cyperus involucratus *																													+									
Cyperus congestus *									+																													
Cyperus eragrostis *	+			+	+		+		+	+		+				+	+	+		+		+	+	+										+	+	+		+
Cyperus papyrus *																																				+		
Cyperus ustulatus	+			+	+		+		+	+										+			+	+					+						+	+		+
Dacrycarpus dacrydioides	+	+	+	+	+	+	+		+	+	+	+				+	+			+		+	+	+	+			+	+	+	+	+	+	+	+	+		+
Dacrydium cupressinum																														+								+
Dianella nigra	+		+	+	+		+		+	+	+	+	+							+		+			+	+		+	+		+	+	+					+
Dicksonia squarrosa	+	+	+	+	+	+	+	+	+	+		+		+		+	+						+	+	+	+	+	+	+	+		+	+		+	+		+
Drosera binata	+			+	+		+		+		+	+	+									+	+		+						+	+						
Egeria densa *			+	e	+		e					+		e		e	+			+			+	e	+	+	e	e	e						+	+		+
Elatine gratioloides																										+	+								+			+
Eleocharis acuta	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		+
Eleocharis gracilis	+		+	+	+	+	+	+	+		+	+						+				+	+	+	+	+				+	+	+	+					+
Eleocharis pusilla																																			+	+		
Eleocharis sphacelata	+		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		+	+	+	+	+		+	+		+
Elodea canadensis *														e									+				e		e						+	e		e
Epilobium chionanthum																																						+
Epilobium pallidiflorum				+	+		+																	+														+
Epilobium nerterioides							+																															+
Erechtites hieraciifolia *																										+												+
Eucalyptus macarthuri																														+								
Eucalyptus viminalis																						+																
Festuca arundinacea *	+		+	+	+		+		+	+		+				+	+			+		+	+		+								+			+		+
Fimbristylis squarrosa																											+											+
Fuchsia excorticata																																						+
Gahnia xanthocarpa																																			+			+
Galium palustre *	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Galium perpusillum																																						e
Gleichenia dicarpa									+				+											+									+					+
Gleichenia microphyllum									+		+		+											+					+		+	+				+		
Glossostigma diandrum																										+	+		+						+	+		+
Glossostigma elatinoides							+		+			+					+									+	+								+	+		+
Glossostigma sp. (a)																																						+
Glyceria declinata *			+																						+					+								
Glyceria fluitans *	+		+	+	+		+		+	+		+				+	+			+		+	+	+	+			+				+		+	+			+
Glyceria maxima *				+			+		+	+		+					+						+		+										+	+		+
Glyceria striata *																																			+			+
Gonocarpus micranthus	+		+	+	+	+	+	+	+	+	+	+	+			+	+				+	+	+	+	+	+		+	+	+	+	+	+	+	+	+		+
Gnaphalium audax																																						+
Gnaphalium involucratum	+			+	+		+		+			+				+																			+	+		+
Gnaphalium limosum												+				+						+													+	+		+
Gratiola sexdentata							+																			+	+								+			+
Histiopteris incisa	+		+	+	+	+	+		+	+	+	+	+			+	+					+	+	+	+	+		+	+	+	+		+	+	+	+		+
Holcus lanatus *	+	+	+	+	+	+	+	+	+	+	+	+	+	+		+	+			+		+	+	+	+			+		+	+	+	+	+	+	+	+	+
Hydrocotyle heteromeria				+			+		+														+						+					+				+
Hydrocotyle hydrophila																																						+
Hydrocotyle moschata																																						+
Hydrocotyle novaezeelandiae		+	+	+			+		+	+		+				+	+	+					+		+					+				+	+			+
Hydrocotyle pterocarpa	+	+	+	+	+	+	+	+	+	+	+	+	+			+	+	+		+	+		+	+	+	+	+	+		+	+	+	+	+		+		+
Hypericum humifusum *																																						+
Hypericum japonicum							+		+			+				+															+							+
Hypericum mutilum *							+									+										+	+											+
Hypolepis distans	+	+	+	+	+	+	+	+	+	+	+	+	+			+	+	+		+	+	+	+	+	+	+		+	+	+	+		+	+	+	+		+
Iris pseudacorus *				+						+		+											+						+									
Isachne globosa	+		+	+	+		+	+	+	+	+	+		+		+	+	+		+		+	+	+	+			+		+	+	+	+	+	+			+
Isoetes kirkii																																			e	e		e
Isolepis distigmatosus	+			+	+	+	+		+		+	+				+	+	+		+	+	+	+	+	+	+	+	+		+	+	+	+	+	+			+
Isolepis fluitans																																						e
Isolepis inundatus	+			+	+		+		+	+		+	+			+	+					+	+		+			+	+	+				+				+
Isolepis marginata *	+			+	+		+		+	+		+				+	+			+		+	+				+	+			+	+	+			+		+
Isolepis nodosa																																						+
Isolepis prolifer	+		+		+																			+	+						+	+	+	+			+	+
Isolepis sepulcralis *	+		+	+	+		+		+	+		+				+	+			+		+	+		+	+	+	+		+	+	+	+	+	+	+		+
Isolepis reticularis	+	+	+	+	+	+	+		+	+	+	+				+	+			+		+	+		+			+		+	+	+	+	+	+			+

Appendix 1 : Species lists for 38 Lower Waikato Lakes

\+ present at lake   e extinct

	Areare	Cameron	Gin	Hakanoa	Hotoananga	Kaituna	Kimihia	Komakorau	Kopuera	Koromatua	Mangahia	Mangakaware	Maratoto	Ngaroto	Ngarotoiti	Ohinewai	Okowhao	Opuatia	Pataka	Pikopiko	Posa	Rotoaira	Rotokauri	Rotokawau	Rotomanuka	Rotongaro	Rotongaroiti	Rotopataka	Rotoroa	Ruatuna	Serpentine E	Serpentine N	Serpentine S	Tunawhakapeka	Waahi	Waikare	Whakatangi	Whangape
Juncus acuminatus *	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		+
Juncus amabilis						+				+																												+
Juncus articulatus *	+	+		+	+	+	+	+	+	+	+	+	+			+	+	+		+		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Juncus australis	+			+	+		+		+	+		+				+	+		+	+		+	+		+	+		+		+		+	+	+		+		+
Juncus bufonius *	+		+	+	+		+		+	+		+				+	+					+	+		+	+	+	+		+	+	+	+	+	+	+		+
Juncus bulbosus *	+		+	+	+		+		+	+	+	+	+			+	+	+		+	+	+	+	+	+	+	+	+		+	+	+	+	+	+			+
Juncus dichotomus *																												+	+									
Juncus distegus	+																					+																
Juncus effusus *	+	+	+	+	+	+	+	+	+	+	+	+	+		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Juncus flavidus *				+																																		
Juncus fockei *	+																			+			+												+			
Juncus gregiflorus	+	+	+	+	+	+	+	+	+	+	+	+		+		+	+	+		+		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		+
Juncus holoschoenus						+		+			+							+								+	+											+
Juncus microcephalus *	+		+	+	+		+		+	+		+				+	+			+		+	+	+	+			+	+	+	+	+	+	+	+	+		+
Juncus pallidus								+		+						+				+		+		+									+		+			
Juncus pauciflorus				+	+		+		+	+		+				+	+							+	+			+		+	+							+
Juncus planifolius	+		+	+	+		+		+	+	+	+	+			+	+			+		+	+	+	+			+	+	+	+			+				+
Juncus prismatocarpus *	+	+	+	+	+	+	+	+	+	+	+	+		+		+	+	+		+		+	+	+	+	+		+		+		+		+	+	+		+
Juncus sarophorus		+		+	+	+	+		+	+	+					+	+		+				+					+								+		+
Juncus tenuis *	+	+	+	+	+		+		+	+	+	+	+	+		+	+	+	+	+		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		+
Lachnagrostis filiformis	+				+															+										+	+							+
Lagarosiphon major *																													e						+			
Laurelia novæ-zelandiæ									+																													+
Lemna minor	+		+	+	+	+	+	+	+	+		+				+	+	+	+	+			+	+	+	+	+	+	+	+	+	+	+	+	+	+		+
Lepilæna bilocularis																																						e
Leptocarpus similis																																				+		
Leptospermum scoparium	+		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		+
Ligustrum lucidum *																																			+	+		+
Ligustrum sinense *																																			+	+		+
Lilæopsis novæ-zelandiæ																										+	+								+	+		+
Limosella lineata							+		+																				+						+			+
Lobelia anceps	+		+	+	+	+	+		+	+	+	+	+			+							+		+	+				+				+			+	+
Lonicera japonica *		+		+							+															+		+	+						+		+	+
Lophomyrtus bullata																																						+
Lotus pedunculatus *	+	+	+	+	+	+	+	+	+	+	+	+	+	+		+	+	+		+	+	+	+	+	+	+	+	+		+	+	+	+	+	+	+		+
Ludwigia palustris *	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		+
Ludwigia peploides ssp. montevidensis *	+	+	+	+	+	+	+	+	+	+	+	+		+	+	+	+	+	+	+	+		+	+	+	+	+	+	+	+	+	+	+	+	+	+		+
Lycopus europæus *	+		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		+	+	+		+	+	+	+	+	+	+	+	+	+	+	+	+		+
Lysimachia nummularia *																																						+
Lysimachia vulgaris *																								+											+			
Lythrum hyssopifolium *	+		+	+	+		+		+	+		+				+	+	+		+		+	+		+	+	+	+		+	+	+	+	+	+	+		+
Lythrum juncea *																																						+
Machærina sinclairii																																						+
Melicytus micranthus																																						+
Mentha pulegium *	+	+	+	+	+	+	+		+	+	+	+	+	+		+	+	+		+		+	+	+	+	+	+		+	+				+	+	+		+
Mentha X piperita var. piperita *																																				+		+
Mentha X piperita var. citrata *				+			+					+																	+									
Muehlenbeckia australis	+		+	+	+	+	+		+	+	+	+	+			+	+			+		+	+	+		+	+	+	+	+	+	+	+	+	+	+		+
Muehlenbeckia complexa																																						+
Myosotis laxa ssp. cæspitosa *	+	+	+	+	+		+		+	+		+				+	+	+		+		+	+		+			+		+	+	+	+	+	+	+		+
Myosotis scorpioides *																									+					+	+	+			+			+
Myriophyllum aquaticum *				+			+		+								+							+		+	+								+	+		+
Myriophyllum propinquum	+		+	+	+	+	+	+	+		+			+	+	+	+	+		+			+	+	+	+	+		+			+		+	+	+		+
Myriophyllum robustum			?																														e		e			+
Myriophyllum triphyllum														e		e																			+	e		+
Nertera depressa																																						+
Nertera scapanoides	+			+	+		+	+	+		+		+								+	+	+	+		+		+		+	+	+	+			+		+
Nitella hookeri/cristata	+		+		e?		e					+		e		e	+	+	+		+	+	+	e	+	+	+	+	e	+	+				+	e		e
Nitella hyalina																																			+			e
Nitella leptostachys																																			+			e
Nitella pseudoflabellata																										+	+		e						+			
Nymphæa cvs *				+			+					+																	+						+			
Osmunda regalis *			+	+		+		+	+								+	+				+		+	+	+	+				+				+	+		+
Otellia ovalifolia *																																			+			
Pæsia scaberula	+	+		+	+	+	+		+	+	+	+	+				+				+	+	+	+	+	+		+			+		+		+	+		+
Panicum sphaerocarpum *																																						+
Paspalum distichum *	+		+	+	+		+	+	+	+	+	+	+	+	+	+	+		+	+	+	+	+	+	+	+	+	+	+	+		+		+	+	+		+
Phalaris arundinacea *									+																													+
Phormium tenax			+	+	+		+	+	+	+	+	+		+	+	+	+	+		+	+		+	+	+	+	+	+	+	+	+	+	+	+	+	+		+

Appendix 1 : Species lists for 38 Lower Waikato Lakes   + present at lake   e extinct

	Areare	Cameron	Gin	Hakanoa	Hotoananga	Kaituna	Kimihia	Komakorau	Kopuera	Koromatua	Mangahia	Mangakawere	Maratoto	Ngaroto	Ngarotoiti	Ohinewai	Okowhao	Opuatia	Pataka	Pikopiko	Posa	Rotoaira	Rotokauri	Rotokawau	Rotomanuka	Rotongaro	Rotongaroiti	Rotopataka	Rotoroa	Ruatuna	Serpentine E	Serpentine N	Serpentine S	Tunawhakapeka	Waahi	Waikare	Whakatangi	Whangape
Pilularia novæ-zelandiæ																																			+			e
Plagianthus regius																																						+
Plantago australe *			+	+	+		+		+	+		+	+				+			+					+				+		+			+				+
Podocarpus hallii																																						+
Podocarpus totara								+																														+
Polygonum hydropiper *	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		+
Polygonum punctatum *																																			+			+
Polygonum salicifolium	+	+	+	+	+	+	+	+	+		+	+	+	+	+	+	+	+		+		+	+	+	+	+	+	+		+	+	+	+	+	+	+	+	+
Polygonum strigosum *							+		+																													
Potamogeton cheesemanii			+	+	+		+					+			e			+				+	+		+	+	+		e		+	+	+		+			+
Potamogeton crispus *														e			+	+					+				+		e						+	e		+
Potamogeton ochreatus				+	+		+					+		e	e	e	+			+		+	+	e	e	+	e		e		+	+	+		+	e		e
Potamogeton pectinatus																		+																	e			e
Potentilla anserinoides																																			+			+
Pratia angulata	+		+	+	+		+		+	+		+					+			+		+	+		+	+	+	+	+	+	+	+	+	+	+	+		+
Pratia angulata x perpusilla																																				+		+
Pratia perpusilla																																			+			+
Prumnopitys taxifolia																																						+
Pteridium esculentum	+	+	+	+	+	+	+	+	+	+	+	+	+			+	+			+		+	+	+	+	+		+	+	+	+		+	+	+	+		+
Ranunculus amphitrichus				+			+		+																										+			+
Ranunculus flammula *	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		+		+	+	+	+	+	+	+		+	+	+	+	+	+	+		+
Ranunculus limosella																																			e	e		e
Ranunculus sceleratus *									+			+										+			+													
Rorippa amphibia *																																						+
Rorippa nasturtium-aquaticum *																							+												+			+
Rorippa palustris																																						+
Rorippa sylvestris *																																						+
Rubus australis																																			+			+
Rubus fruticosus agg. *	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		+		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Rumex conglomeratus *	+	+		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+		+		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Rumex crispus *				+			+		+																													+
Ruppia polycarpa																																			e	e		e
Sagittaria subulata *																																			+			
Salix babylonica *	+	+	+	+	+		+		+	+		+		+	+	+	+		+				+		+			+	+	+				+	+	+		+
Salix cinerea *	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Salix fragilis *	+		+	+	+		+	+	+	+		+		+		+	+	+		+		+	+	+	+	+		+		+	+	+	+	+	+	+		+
Salix matsudana *		+															+					+							+									
Schoenoplectus validus				+			+											+								+	e								+	+		+
Schoenus maschalinus	+		+	+	+		+		+	+		+	+			+	+			+		+	+	+	+	+	+	+		+	+	+	+	+	+	+		+
Selaginella kraussiana *																																						+
Sophora microphylla																																				+		+
Sparganium subglobosum								+			+							+						+											+			
Spirodela punctata *	+	+		+	+		+		+	+		+	+			+	+	+		+		+	+	+				+				+	+	+	+	+		+
Stellaria alsine *				+																															+			+
Streblus heterophyllus																																						+
Syzygium maire																																			+			+
Taxodium distichum *		+													+																					+		
Tetragonia tetragonoides																																			+			
Tetragonia trigyna																																			+			
Thelymitra cyanea																															+							
Tmesipteris elongata																																						+
Tmesipteris lanceolata																																						+
Triglochin striata																		+						+		+							+					
Typha orientalis	+		+	+	+	+	+	+	+	+	+	+		+	+	+	+	+	+	+	+		+	+	+	+	+	+	+	+			+	+	+	+		+
Ulex europaeus *			+			+					+		+	+	+									+		+	+		+		+	+	+		+	+		
Utricularia australis																		+							+						e		e		+			
Verbascum blattaria *																																						+
Viola lyallii																																						+
Wolffia australiana *		+								+		+																		+								
Zannichellia palustris																																			e	e		e
Zantedeschia æthiopica *																							+					+							+			
Zantedeschia 'Green Goddess' *																													+		+							
* denotes introduced species																																						