Turf communities of Lake Whangape and some potential management techniques

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ABSTRACT

At Lake Whangape, Lower Waikato River, New Zealand, almost 14 km of the 29 km shoreline supports turf communities during late summer/early autumn. A 1997 survey discerned 21 community types of turfs, comprising both indigenous and alien species. Most turfs were highly diverse—44 indigenous and 91 alien plant species were reported from an area of 800 m^2 of shoreline. Many species were ephemeral, either facultative or obligate annuals, colonising exposed sediments and dying once submerged. The critically endangered grass *Amphibromus fluitans*, found during 1990, now appears to be extinct here. The lake supports the largest known population of the indigenous annual sedge *Fimbristylis velata.* Regionally important populations of *Pratia perpusilla* and *Carex gaudichaudiana* are present. Cattle grazing and grass-selective herbicides were investigated by constructing cattle exclosures and monitoring vegetation changes inside and outside, over three years. Dominant species were usually perennials, with the alien Mercer grass (*Paspalum distichum*) and the indigenous emergent spike sedge (*Eleocharis acuta*) most common. There was no change in the abundance of turf species. The grass-specific herbicide Gallant® successfully controlled Mercer grass for at least one year. Factors controlling the distribution and composition of the turfs were minimum lake level and timing of drawdown, wave exposure, and the grazing impacts of cattle, waterfowl, and coarse fish. Weedy alien plants were not considered current threats. Cattle access to the lake is detrimental to the whole lake system, reducing plant cover, and preventing establishment of a nutrient buffer of marginal/emergent vegetation. Actions for managing the turf communities include: lowering the existing outlet structure (sill) giving more exposed surface for summer turf development; fencing larger areas of turf against cattle access, or attempting to prevent cattle access to the entire shoreline; monitor impact of waterfowl grazing; control expansion of willows and other weeds; trial fish exclosures for the impact on turfs; attempt restoration of amphibious communities around Plot 4.

Keywords: lake margins, turf vegetation, plant communities, management, grazing, water level fluctuations, Lake Whangape (Whangapae), Meremere Ecological District, New Zealand

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1. Introduction

Lake Whangape (also spelled Whangapae) is one of largest lakes on the floodplain of the Lower Waikato River, within the Meremere Ecological District (Fig. 1). The lake occupies a total area of 11.97 km^2 with a shoreline of approximately 29 km. Lake Whangape is a Wildlife Management Reserve administered by the Department of Conservation.

The flora of the lake and surrounding areas were first explored by Kirk (1871) who described a diverse native submerged flora and catchment dominated by indigenous forest and scrub. A local resident (K. Saxton) described marginal beds of the emergent raupo *(Typha orientalis)* remaining around the lake until the mid 1950's.

Since that time the submerged flora came to be dominated almost totally by the alien *Egeria densa*, first reported in 1958 (Wood & Mason 1977). In 1987 the submerged vegetation of Lake Whangape declined with the lake switching to a turbid algal dominated system, with macrophytes occupying less than 10% of the lake area. Of the 10% of macrophytes remaining, the dominant species was another alien species, hornwort (*Ceratophyllum demersum*). During the late 1980s and early to mid 1990s this species was more or less confined to sheltered parts of the lake e.g. the Tikotiko Arm and on the northern side of Motukauere Island. However, in 1996 it spread dramatically and has since occupied the majority of Lake Whangape with dense beds which occasionally reach the water surface (Champion et al. 1996). It is not known what has caused the recent dramatic spread of hornwort.

Land drainage and clearance of forest and scrub for pasture development has severely altered the vegetation of the catchment and the land immediately

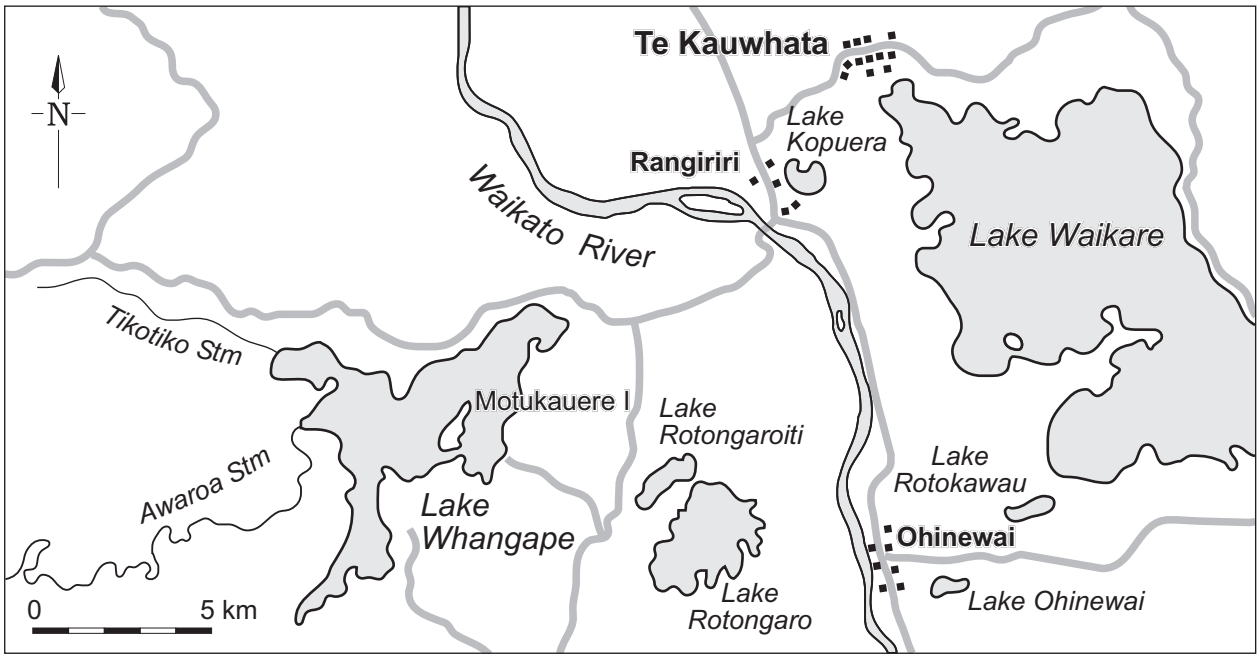

Figure 1. Location of Lake Whangape on the lower Waikato River flood plain.

surrounding Lake Whangape. Much of the area in pasture by the 1930s, with cattle having access to much of the shoreline, as they do today. Large beds of raupo remained on much of the lake's margin until the 1950's, but by 1991 only 9% of the lake shoreline supported a small narrow fringe of this species. In addition to vegetation clearance, the lake margin has also been colonised by alien plants, especially crack and grey willow (*Salix fragilis* and *S. cinerea*), and floating sudds of primrose willow and parrots feather (*Ludwigia peploides* and *Myriophyllum aquaticum*) now occupy two thirds of the lake shore (Champion et al. 1993).

Despite this degradation, a survey of the marginal vegetation in 1991 (Champion et al. 1993) revealed a total of 541 vascular plant species of which 300 were indigenous (excluding 13 species that were previously reported from the area but are now apparently extinct at Lake Whangape). Of these native species a number of endangered plants were found. Several of these were found in an assemblage of low-growing amphibious and annual species, both indigenous and alien, referred to as turf communities. These turfs developed in areas exposed during late summer/autumn, but submerged during winter.

The current study was commissioned by the Department of Conservation (DOC) to better understand these turf communities and recommend methods of managing them. Endangered and uncommon turf plants identified by DOC were *Amphibromus fluitans*, *Fimbristylis squarrosa* (now *F. velata*), *Carex cirrhosa, C. gaudichaudiana, Lachnagrostis striata, Pratia perpusilla, Pilu-laria novae-zelandiae,* and *Ranunculus limosella*. (Some of these species are pictured in Appendix 2, Plates 13–16.) Threats perceived by DOC were encroachment of the weeds *Paspalum distichum, Centipeda cunninghamii, Myriophyllum aquaticum,* and *Ludwigia palustris*, and the effects of cattle grazing.

1.1 SPECIFIC OBJECTIVES

- Survey, characterise and map the present distribution of turf communities.
- Experimentally assess the effect of grazing and weed control on these turfs.
- Assess the effectiveness of propagation and reseeding for the protection and enhancement of selected endangered turf species, where appropriate.
- Identify management initiatives that will maintain and enhance the turf communities.
- Advise on a suitable lake level regime that would maintain or enhance the turf community.

2. Methods

2.1 CHARACTERISATION OF TURF COMMUNITIES

Field inspections of the turf communities were made from 7 to 11 April 1997. All turf communities around Lake Whangape were inspected (114 sites). Distinct vegetation types were identified (based on Atkinson 1985) and their species composition described. Representative examples of turf communities and areas and sites containing significant species were identified as possible sites for assessment of impacts of grazing and weeds on these turfs.

2.2 CATTLE EXCLOSURE AND HERBICIDE TRIAL

2.2.1 Site description

Four paired sites (Fig. 2) were selected around the lake margins in January 1998, based on the survey results from the previous year (Section 3.1). Sites were chosen to represent:

- Typical low diversity turfs (Site 1).
- High diversity turfs (Site 4).
- Turfs exposed to low grazing pressure (Site 3).
- The site where the rare grass *Amphibromus fluitans* had been recorded (Site 2).

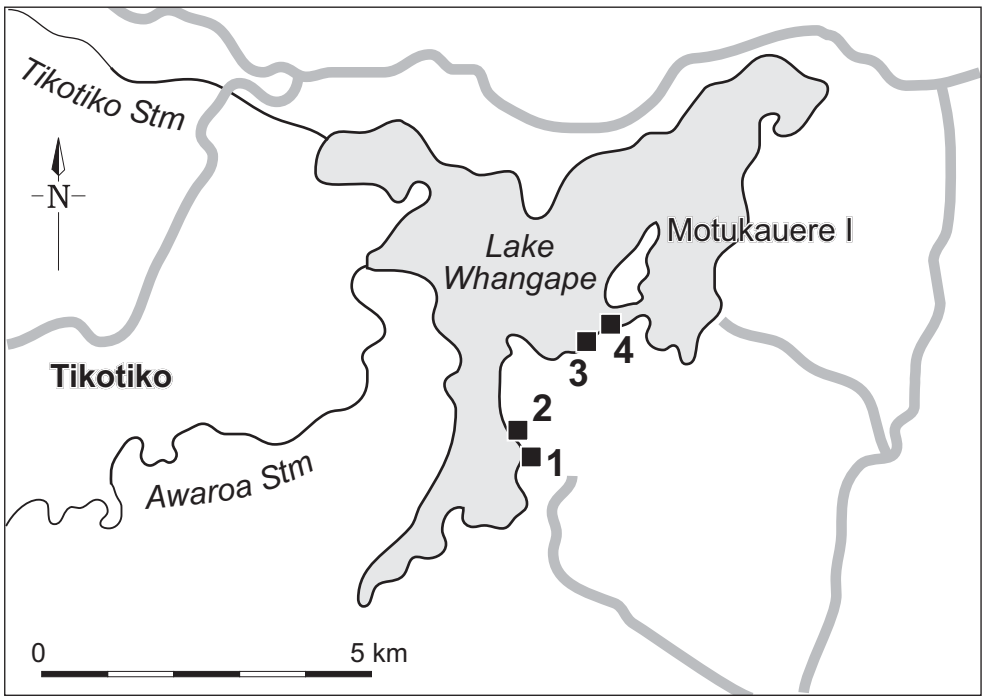

Figure 2. Lake Whangape showing the location of Plots 1–4 on the southeast shore.

Stock-proof exclosures were erected in February 1998. At sites 1, 3, and 4, the dimensions of these were 10 × 10 m square, and at Site 2 the exclosure measured 20 × 20 m. Next to each of these exclosures a 10 × 10 m square control plot was staked out. A 10 × 10 m plot was marked out within the exclosure at Site 2. All the plots were oriented with one side parallel to the shore.

2.2.2 Plot monitoring

Vegetation types were discerned at each of the four sites. Control and exclosure plots were divided into 25, 2 × 2 m quadrats. Total vegetation cover (%), species cover (cover class) and height for all species were determined in each quadrat on six occasions from 1998 to 2000: 30 March 1998, 12–13 May 1998, 19 January 1999, 27–28 April 1999, 17–18 January 2000, and 30 March 2000. The cover scale used was a modified Braun-Blanquet scale—a number from 1 to 6 represents cover from 1 to 100% (Table 1). Note that the scale is not linear.

TABLE 1. COVER CLASSES AND CORRESPONDING COVER PERCENTAGES USED IN THIS STUDY.

COVER CLASS	COVER (%)
1	1–5
2	6–25
3	26–50
4	51–75
5	76–95
6	96–100

2.2.3 Herbicide application

Two grass-specific herbicides, Gallant® and Centurion® were trialed within the exclosures. Gallant® was applied to Plots 2 and 4 and Centurion® was applied to Plots 1 and 3. Herbicide was applied to the eastern half of each exclosure on 14 January 1999 at a rate of 5 L ha^{-1} (Gallant®) or 3 L ha^{-1} (Centurion®) until all plants were wetted. Data on the impact of the broadleaf (dicotyledonous herb)-specific herbicides Versatill™ and Grazon® were obtained from a parallel study on herbicide selectivity carried out in the vicinity of Plot 4 and pot-based trials (Champion 2000).

2.2.4 Treatment of data

Because each plot was chosen to represent different turf communities (see Section 2.2.1) each plot could not be treated as a replicate, plots 1–4 represent 4 separate experiments without true replication. Therefore total vegetation cover (% area occupied) from the quadrats was presented as a box and whiskers plot showing average cover, 25th and 75th percentiles and minimum and

maximum values for each treatment on each date. The cover of the individual species was reported as a cover class (Table 1); therefore the medians of these data were determined instead of the means, other than this, the data was treated the same way as for total vegetation cover. The median cover for each species was taken over the entire plot except for *Eleocharis acuta* which was only present in the lower 4 m of the plots where the ground was waterlogged. Species were also aggregated into four categories—grasses, sedges and rushes, herbs (dicotyledons without a low growing turf habit), and turfs.

2.3 CULTIVATION AND RE-ESTABLISHMENT OF ENDANGERED SPECIES

Plants of *Fimbristylis velata*, *Carex gaudichaudiana, Lachnagrostis striata,* and *Pratia perpusilla* were collected from the shores of Lake Whangape during the summer of 1997. A plant of *Amphibromus fluitans*, collected from Lake Whangape in 1990 (Champion et al. 1993) and grown on at Percy Scenic Reserve nursery, Lower Hutt, was also sent to NIWA Hamilton. These plants were maintained in cultivation until the status of those and other significant plants were ascertained from the 1997 survey.

Plants of *Amphibromus fluitans* were potted up to provide ~50 plants for re-planting into the exclosure and control plots described in Section 2.2.1. Forty plants were transplanted into the 4 plots (5 per exclosure and control) in February 1998. After further division and propagation of stock plants, a further 50 transplants were made in April 1998 and February 1999 (only on the side of Exclosure 4 treated with herbicide in January 1999). Persistence of these plants was recorded as part of the monitoring of plots described in Section 2.2.2.

2.4 LAKE LEVEL

DOC collected water level data for Lake Whangape. The data was continuously monitored on a half-hourly basis from 14 August 1998 to 24 May 2000. Water levels were compared with earlier records from 1968–1982 and 1992–1996 reported in Champion et al. (1996).

3. Results

3.1 CHARACTERISATION OF TURF COMMUNITIES

Turf communities occupied a total of 13.9 km of lake shoreline. This equates to 48% of available shoreline.

Twenty-one vegetation and habitat types were identified (Table 2). The length of shoreline occupied by each vegetation type is also shown in Table 2. Plant species found during the turf survey are shown in Appendix 1. Typical indigenous turf species of Lake Whangape are shown in the plates following Appendix 2.

Most of the vegetation types were highly variable, with composition often changing every 1–2 m. Variation was evident horizontally along the lakeshore and in relation to elevation. The lake level tends to drop over the summer, exposing fresh sites available for colonisation. The lake level was relatively low when fieldwork was undertaken (4.75 m (Moturiki Datum) at the gauge near the outlet, measured on 8 April 1997). This level was typical for Lake Whangape in late summer/early autumn between 1992 and 1999 (Section 3.5). Smaller plants/seedlings often formed a sparser vegetation cover nearer the lake's edge, reflecting the length of time the site has been exposed and available for colonisation.

TABLE 2. TURF VEGETATION AND HABITAT TYPES, WITH LENGTH OF SHORELINE OCCUPIED.

	VEGETATION TYPE	LENGTH OF SHORELINE OCCUPIED (m)
1.	*Myriophyllum triphyllum* herbfield	246
2.	*Myriophyllum triphyllum*–Indian doab–*Persicaria lapathifolia*–*Bolboschoenus medianus* herbfield	246
3.	*Eleocharis acuta/Lilaeopsis novae-zelandiae*–water purslane herbfield	105
4.	Indian doab–*Carex gaudichaudiana*–water purslane–*Hydrocotyle hydrophila* herbfield	474
5.	*Isolepis marginata*–Indian doab–water pepper–water purslane–*Carex gaudichaudiana* herbfield	351
6.	*Carex gaudichaudiana*–Mercer grass herbfield	193
7.	Water purslane herbfield	1053
8.	Water purslane–umbrella sedge–*Persicaria lapathifolia*–water pepper herbfield	228
9.	Water pepper/nahui–sneezewort–water purslane herbfield	2789
10.	*Fimbristylis velata*–water purslane–nahui herbfield	772
11.	*Persicaria lapathifolia*/nahui–water purslane herbfield	719
12.	*Isolepis marginata*–water purslane herbfield	632
13.	Indian doab–water purslane–nahui herbfield	1632
14.	Indian doab–water purslane–*Isolepis marginata* herbfield	421
15.	Indian doab–water purslane herbfield	3574
16.	Indian doab–Mercer grass grassland	2667
17.	Umbrella sedge–*Juncus articulatus*–Indian doab sedgeland	70
18.	Indian doab grassland	1246
19.	Mercer grass–water purslane–*Myriophyllum triphyllum* herbfield	544
20.	Bare or mud	5000
21.	Beach	1105

3.1.1 Vegetation types

1. *Myriophyllum triphyllum* herbfield

This type was only observed on Motukauere Island. *Myriophyllum triphyllum* dominated a strip about 10 m wide and was almost the only species present. Other species were present only in very low numbers. These included parrot's feather (*Myriophyllum aquaticum*), *Azolla pinnata,* primrose willow (*Ludwigia peploides*), and water purslane (*Ludwigia palustris*).

2. *Myriophyllum triphyllum*–Indian doab–*Persicaria lapathifolia*–*Bolboschoenus medianus* herbfield

This vegetation association was only observed on Motukauere Island, inland of vegetation type 1. *Myriophyllum triphyllum,* Indian doab (*Cynodon dactylon*), *Persicaria lapathifolia*, and *Bolboschoenus medianus* were dominant, in association with scattered *Fimbristylis velata,* nahui (*Alternanthera sessilis*), redroot (*Amaranthus powellii*), sneezewort (*Centipeda cunninghamii*), primrose willow, water purslane, *Schoenoplectus tabernaemontani*, and Scotch thistle (*Cirsium vulgare*).

3. *Eleocharis acuta/Lilaeopsis novae-zelandiae*–water purslane herbfield

This type formed a narrow strip 1–5 m wide, extending about 50 m along the beach. *Lilaeopsis novae-zelandiae* was locally abundant, forming the dominant cover in association with *Eleocharis acuta* and water purslane. Other species present included *Fimbristylis velata,* catsear (*Hypochoeris radicata*), sneezewort, Indian doab, *Pratia perpusilla*, nahui and purple-eyed grass (*Sisyrinchium iridifolium*).

4. Indian doab–*Carex gaudichaudiana*–water purslane–*Hydrocotyle hydrophila* herbfield

This type covered a narrow strip about 2 m wide along the inland margin of the beach. It was dominated by Indian doab, *Carex gaudichaudiana*, water purslane, and *Hydrocotyle hydrophila*. *Glossostigma diandrum* is locally common.

Other species present included *Pratia perpusilla, Isolepis marginata,* nahui, *Azolla pinnata, Fimbristylis velata,* loosestrife (*Lythrum hyssopifolia*), *Gratiola sexdentata, Eleocharis gracilis,* bachelor's buttons (*Cotula coronopifolia*), starwort (*Callitriche stagnalis*), water pepper (*Persicaria hydropiper*), creeping bent (*Agrostis stolonifera*), *Isolepis reticularis*, and *Juncus articulatus.*

5. *Isolepis marginata*–Indian doab–water pepper–water purslane–*Carex gaudichaudiana* herbfield

A small herbfield near the mouth of a small stream. The dominant species were *Isolepis marginata,* Indian doab, water pepper, water purslane, and *Carex gaudichaudiana.* Arrow grass (*Triglochin striata*) and sneezewort were common. Other species present included *Juncus articulatus,* cleavers (*Galium aparine*), barnyard grass (*Echinochloa crus-galli*), *Isolepis reticularis, Myriophyllum propinquum*, and *Fimbristylis velata*.

6. *Carex gaudichaudiana*–Mercer grass sedgeland

This type occurred near the mouth of a small stream. *Carex gaudichaudiana* and Mercer grass (*Paspalum distichum*) were the dominant species in association with *Lilaeopsis novae-zelandiae, Pratia perpusilla* x *angulata*, creeping bent, spearwort (*Ranunculus flammula*), lotus (*Lotus pedunculatus*), sea aster (*Aster subulatus*), sneezewort, *Sagina procumbens, Centella unifolia,* bay grass (*Eragrostis brownii*), *Eleocharis acuta, Myriophyllum propinquum, Juncus tenuis,* beggar's ticks (*Bidens frondosa*), *Isolepis marginata*, swamp millet (*Isachne globosa*), *Schoenus maschalinus, Gratiola sexdentata, Persicaria persicaria,* and *P. decipiens*.

7. Water purslane herbfield

Water purslane was the dominant species at this site and was, in places, almost the only species present. Locally there were a variety of other herbs, and sedges scattered within this type, including *Eleocharis acuta*, water primrose, *Schoenoplectus tabernaemontani, Isolepis marginata, Juncus articulatus,* beggar's ticks, barnyard grass, *Juncus bufonius, Fimbristylis velata,* nahui, Mercer grass, parrot's feather, and sneezewort.

8. Water purslane–umbrella sedge–*Persicaria lapathifolia*–water pepper herbfield

This type occurred near the weir at the lake outlet. Large quantities of broken rock were used to construct the weir and some of this rock has washed up onto the shore. Water purslane, umbrella sedge (*Cyperus eragrostis*), *Persicaria lapathifolia* and water pepper have formed a herbfield. Other species present included *Eleocharis acuta,* sneezewort, nahui, *Rorippa palustris*, beggar's ticks, *Juncus articulatus*, barnyard grass, and *Isolepis marginata*.

9. Water pepper/nahui–sneezewort–water purslane herbfield

Water pepper, nahui, sneezewort, and water purslane were present in various combinations and proportions. There was occasional *Fimbristylis velata, Juncus articulatus,* Indian doab, parrot's feather, and *Isolepis marginata,* and local *Eleocharis gracilis, Myriophyllum triphyllum, Pseudognaphalium luteoalbum*, and *Gnaphalium involucratum, Isolepis reticularis,* and *Rorippa palustris. Persicaria lapathifolia* is locally common.

A variety of other species were present in low numbers, including Scotch thistle, lotus, *Callitriche stagnalis*, marsh bedstraw (*Galium palustre*), and clustered dock (*Rumex conglomeratus*).

9a *Isolepis marginata* was locally abundant at these sites.

9b Mercer grass was common at this site in addition to the above species.

9c Indian doab and umbrella sedge were common at this site, along with the above species.

10. *Fimbristylis velata*–water purslane–nahui herbfield

Similar to type 9, except *Fimbristylis velata* was a significant component. Water pepper and sneezewort were locally common, with occasional Indian doab, *Isolepis marginata,* parrot's feather, *Myriophyllum triphyllum,* lotus, *Rorippa palustris*, and catsear.

10a Lotus, *Myriophyllum triphyllum* and *Isolepis reticularis* were locally common at this site.

11. *Persicaria lapathifolia* /nahui–water purslane herbfield

A small area dominated by nahui and water purslane with emergent *Persicaria lapathifolia.* Other species present included *Lachnagrostis filiformis, Persicaria persicaria, Juncus articulatus,* clustered dock, Indian doab, and Mercer grass.

12. *Isolepis marginata*–water purslane herbfield

Isolepis marginata and water purslane dominated these areas in association with water pepper, Indian doab, Mercer grass, *Myriophyllum propinquum,* sneezewort, and *Fimbristylis squarrosa*. Other species present included parrot's feather, *Myriophyllum triphyllum,* nahui, *Lachnagrostis filiformis,* spearwort, starwort, *Juncus articulatus*, and lotus.

Schoenoplectus tabernaemontani and *Gratiola sexdentata* occurred locally.

13. Indian doab–water purslane–nahui herbfield

This type was similar to 9 except Indian doab was a significant component in the vegetation. Water pepper and sneezewort were locally common. *Isolepis marginata* and *Lycopus europaeus* were common at one site.

There was occasional parrot's feather, *Fimbristylis velata*, *Lachnagrostis filiformis, Rorripa palustris,* soldier's buttons (*Cotula australis*), catsear, sea aster, clustered dock, rye grass (*Lolium perenne*), redroot, and *Persicaria* spp., *Lachnagrostis striata*, and *Eleocharis acuta*.

A wide variety of other species were present in low numbers. *Glossostigma diandrum* and *Lilaeopsis novae-zelandiae* were present on Motukauere Island

13a Bachelor's button was present.

14. Indian doab–water purslane–*Isolepis marginata* herbfield

Indian doab, water purslane and *Isolepis marginata* formed the cover in association with *Fimbristylis velata*, sneezewort, and water pepper. Other species present included lotus, hawksbeard (*Crepis capillaris*), Mercer grass, *Eleocharis acuta,* parrot's feather, and *Juncus articulatus.*

14a Lotus was common at this site.

15. Indian doab–water purslane herbfield

Indian doab and water purslane were dominant, in association with water pepper, sneezewort, and *Fimbristylis velata*. Other species present included *Eleocharis acuta,* barnyard grass, *Myriophyllum triphyllum, Isolepis marginata, I. reticularis*, and *Persicaria lapathifolia*.

Lilaeopsis novae-zelandiae occurred at one site.

15a *Carex gaudichaudiana* was common at this site.

16. Indian doab–Mercer grass grassland

This type generally occurred furthest from the lake edge. Indian doab and Mercer grass were dominant, in association with water pepper, *Persicaria*

lapathifolia, water purslane, white clover (*Trifolium repens*), and sneezewort. Water purslane and water pepper were locally common.

Other species present locally included *Eleocharis acuta, Centella unifolia, Myriophyllum triphyllum, Carex gaudichaudiana,* nahui, Scotch thistle, broad-leaved fleabane (*Conyza albida*), lotus, *Fimbristylis velata*, and paspalum (*Paspalum dilatatum*).

17. Umbrella sedge–*Juncus articulatus*–Indian doab sedgeland

Umbrella sedge, *Juncus articulatus* and Indian doab were common, in association with sneezewort, beggar's ticks, *Lilaeopsis novae-zelandiae,* clustered dock, Mercer grass, *Rorippa palustris*, water pepper, nahui, *Schoenoplectus tabernaemontani*, purple-eyed grass, and water purslane. *L. novae-zelandiae* formed the dominant cover over a small area (about 6 x 6 m) in association with umbrella sedge, water purslane, Indian doab, lotus, and water pepper.

18. Indian doab grassland

Indian doab was dominant, in association with water pepper, water purslane, sneezewort, and *Persicaria lapathifolia*. Other local species included nahui, *Fimbristylis velata,* penny royal, and *Rorippa palustris.*

19. Mercer grass–water purslane–*Myriophyllum triphyllum* herbfield

Mercer grass, water purslane and *Myriophyllum triphyllum* were dominant with local *Isolepis marginata*, *Eleocharis acuta*, parrot's feather, *Fimbristylis velata*, and *Juncus articulatus*. *Isolepis marginata* was locally dominant.

20. Bare or mud

These areas were unvegetated or had a very sparse scattering of seedlings. The lack of vegetation cover on most of these areas appeared to be induced by cattle trampling and browsing. The extent of trampling varied from relatively narrow cattle tracks to almost the entire lake margin extending up to 50 m inland from the lake edge.

Seedlings present were often those species which were common in the adjacent vegetation at any particular site, and commonly included ryegrass, lotus, sneezewort, nahui, water pepper, Indian doab, water purslane, clustered dock, with local *Fimbristylis velata*. However, many other species were also recorded.

20a A small low bank at the eastern end of this bay supported an uncommon assemblage of indigenous species, albeit with very low covers. Species included *Pratia perpusilla, Lachnagrostis striata, Gnaphalium involucratum,* sneezewort, and *Glossostigma diandrum*.

21. Beach

These were generally unvegetated sandy beaches. A few scattered seedings present at some sites included water pepper, Indian doab, inkweed (*Phytolacca octandra*), *Fimbristylis velata*, water purslane, and sneezewort.

3.2 CATTLE EXCLOSURE TRIAL

Forty-four indigenous and ninety-one alien vascular plant species were found in the four cattle exclosure and grazed plots over the course of this study. Plant species found during the monitoring of these sites are shown in Appendix 1. Results for the four pairs of grazed and ungrazed plots are presented below. Plates 1–12 (Appendix 2) show the progressive differences between grazed and ungrazed areas in Plots 1–4.

3.2.1 Plot 1

Plot 1 was positioned in a small bay with a northern aspect (slope = 2°), exposed to the west (fetch ~1 km). The substrate was silty mud and the vegetation type was Indian doab–Mercer grass grassland (Vegetation type 16) on the upper shore, and on the lower shore bare mud and occasional nahui, water purslane and *Eleocharis acuta* (Vegetation type 20). This site becomes quite dry through the summer with moisture generally only available in the lower portion of the exclosure and control plots closest to the lake edge. This site was exposed to high cattle-grazing pressure. A broken rail in the exclosure at Plot 1 allowed stock access to that area from winter 1999 onwards.

Species richness, abundance and height

Average species number over the trial was more in the control plot (mean 40; max 50; min 29) than in the exclosure (mean 30; max 38; min 28). Native species number averaged 7 in the exclosure and 10 in the control while introduced species averaged 26 in the exclosure and 30 in the control. However, within the exclosure there were a larger number of species with covers greater than 5% and taller than 100 mm shoot height than in the grazed control (mean of 1.5 species versus 0.3).

Total cover

Average vegetation cover in the exclosure was 76% and in the control 53% over the duration of the trial (Fig. 3).

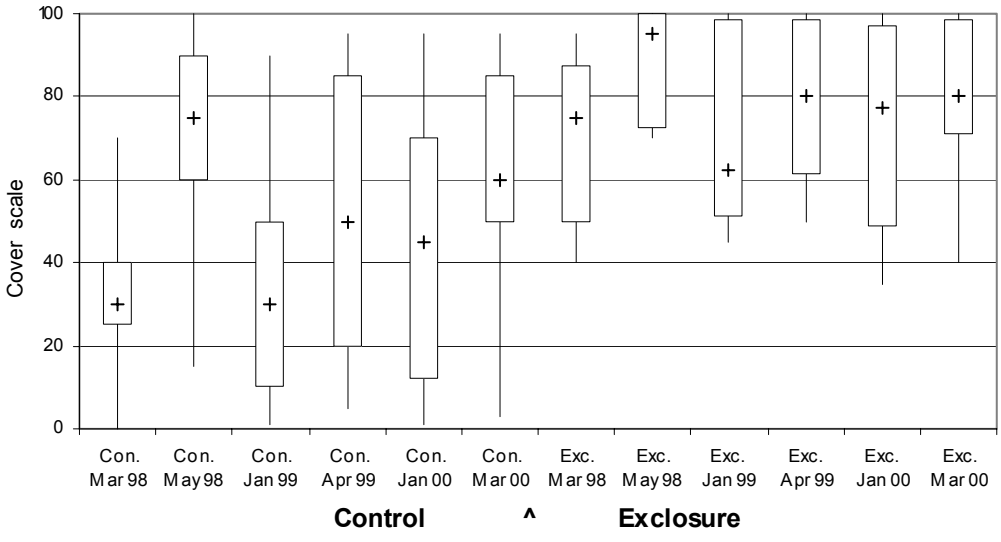

Figure 3. Total vegetation cover (%) for Plot 1 in the control plot and within a cattle exclosure from May 1998 to March 2000. + = mean; box = 25 and 75 percentiles; whiskers = minimum and maximum values.

Grasses

Paspalum distichum was more abundant in the exclosure than the control by 2 (median) cover scale units on most dates (Fig. 4). Cover had a median of 1 and 3 in the control and exclosure respectively. *Cynodon dactylon* had a median cover of 3.5 both in the exclosure and in the control.

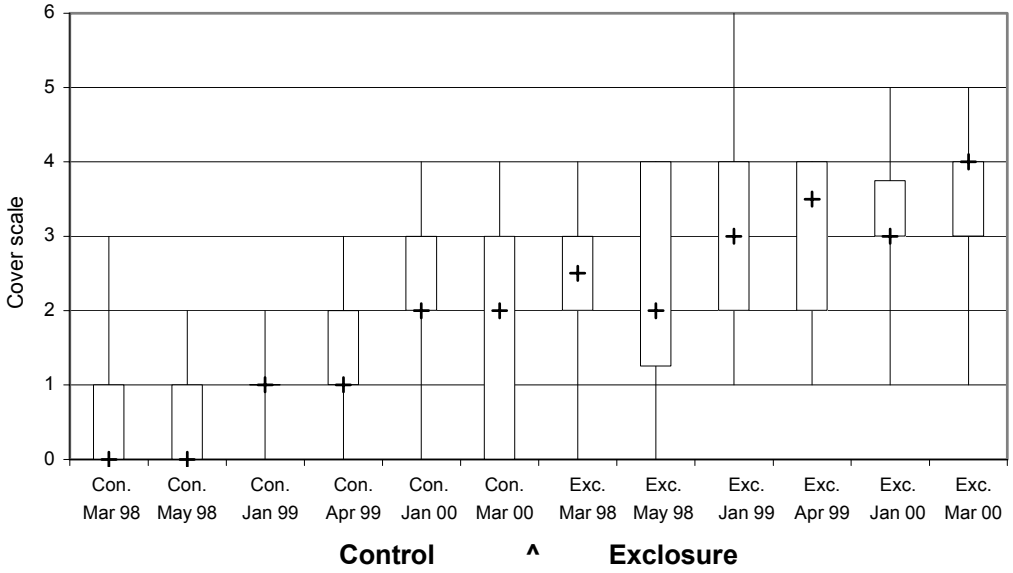

Figure 4. *Paspalum distichum* cover (0–6 Braun-Blanquet cover scale, not linear) for Plot 1 in the control plot and within a cattle exclosure from May 1998 to March 2000. + = mean; box = 25 and 75 percentiles; whiskers = minimum and maximum values.

Tall rushes/sedges

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1 in the control over the period of
stayed the same during the trial, while
the trial progressed. In March 1998
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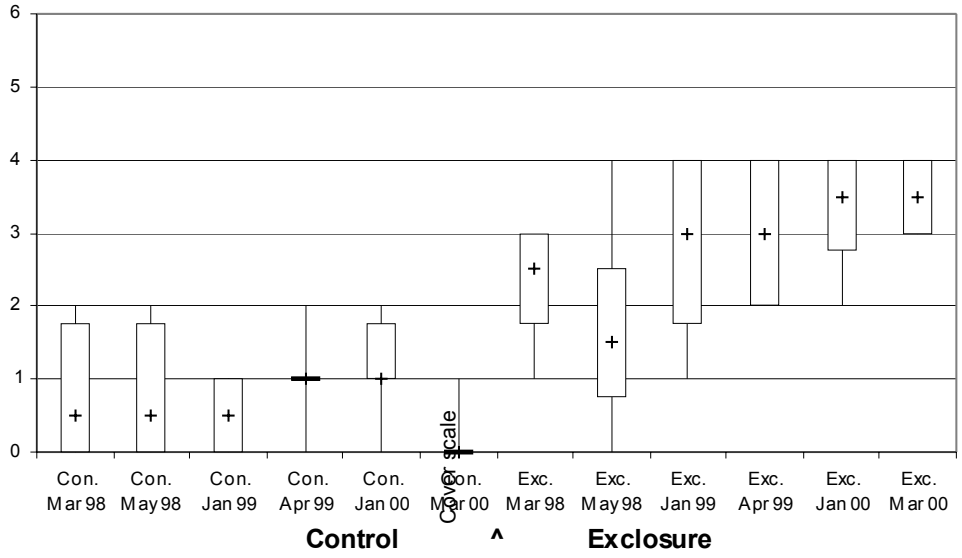


Con. Mar 98 Con. May 98 Con. Jan 99 Con. Apr 99 Con. Jan 00 Con. Mar 00 Exc. Mar 98 Exc. May 98 Exc. Jan 99 Exc. Apr 99 Exc. Jan 00 Exc. Mar 00

Figure 5. *Eleocharis acuta* cover (0–6 Braun-Blanquet cover scale, not linear) for the lower 4 m within Plot 1 in the control plot and within a cattle exclosure from May 1998 to March 2000. + = mean; box = 25 and 75 percentiles; whiskers = minimum and maximum values.

Herbs and turfs

Herb and turf species were not abundant in this plot and showed no changes in abundance in relation to grazing.

3.2.2 Plot 2

Plot 2 was positioned in a small bay with a southern aspect (slope; control 4°, exclosure 2°), exposed to the west (fetch ~1 km). The substrate was silty clay with mudstone pebbles (~5 mm diameter). The vegetation types present at this site were water pepper/nahui–sneezewort–water purslane herbfield with Mercer grass (Vegetation type 9b), *Isolepis marginata*–water purslane herbfield (Vegetation type 12) and Indian doab–water purslane herbfield (Vegetation type 15). The upper half of this site became quite dry through the summer while the lower half remained flooded. Grazing was by horses at a low intensity.

Species richness, abundance and height

Native species number was the same in the exclosure as in the control, averaging 6 (range 5–7) for the duration of the trial. Introduced species were much more abundant with 30 and 34 species in the control and exclosure plots respectively in March 1998 reducing to 25 species in both the control and exclosure in March 2000. Within the exclosure there was a larger number of species with covers greater than 5% and taller than 100 mm shoot height than in the grazed control (mean of 4.8 species versus 1.7).

Total cover

Total vegetation cover was always greater inside of the exclosure than in the control plot (Fig. 6). In the first year cover was ~20% greater inside of the exclosure, however in the second and third years this difference was much greater. This difference was driven by a decline in the cover of the control plot, whereas the cover in the exclosure remained constant over the duration of the trial

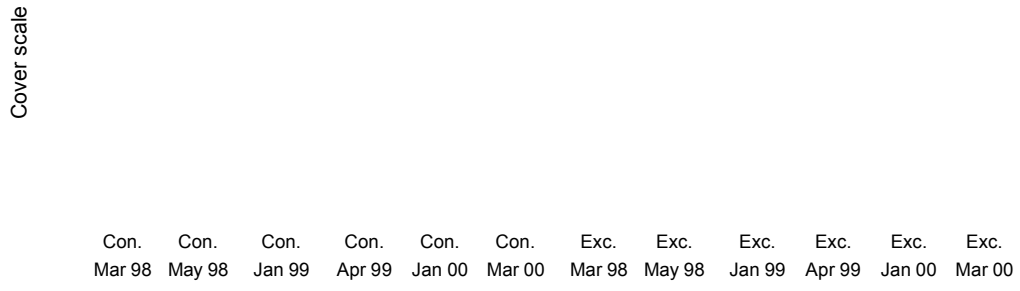


Figure 6. Total vegetation cover (%) for Plot 2 in the control plot and within a cattle exclosure from May 1998 to March 2000. + = mean; box = 25 and 75 percentiles; whiskers = minimum and maximum values.

Grasses

Both *Paspalum distichum* and *Cynodon dactylon* had a median increase in cover class in the exclosure relative to the control, Fig. 7 shows this increase for *Paspalum distichum* which had a final cover of 3 in the control and 5 in the exclosure. Both species were well represented in and out of the exclosure.

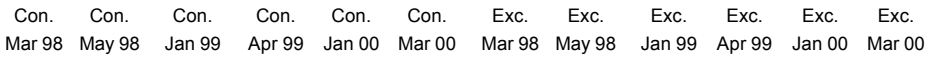
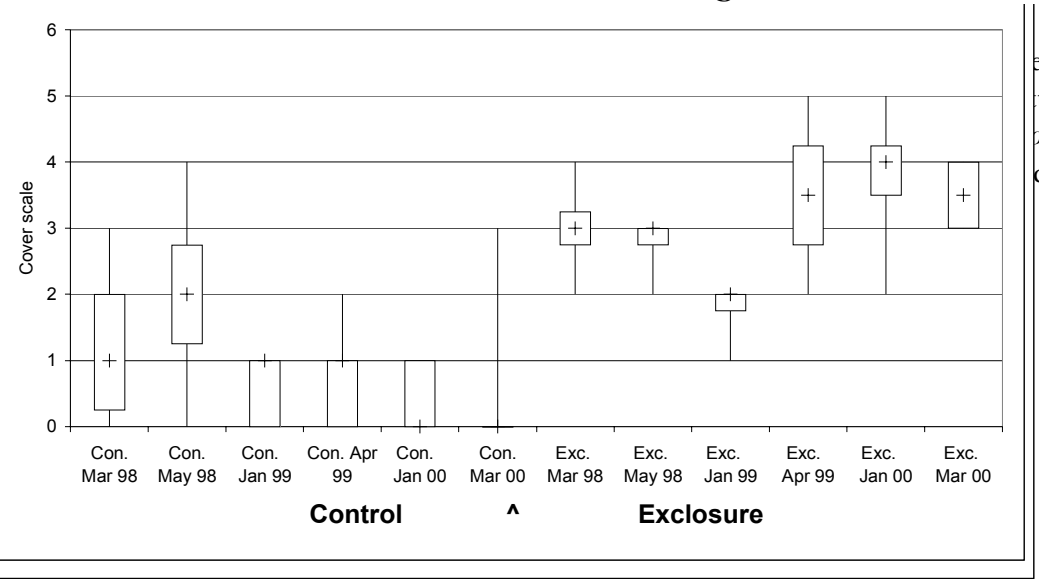


Figure 7. *Paspalum distichum* cover (0–6 Braun-Blanquet cover scale, not linear) for Plot 2 in the control plot and within a cattle exclosure from May 1998 to March 2000. + = mean; box = 25 and 75 percentiles; whiskers = minimum and maximum values.

Tall rushes/sedges



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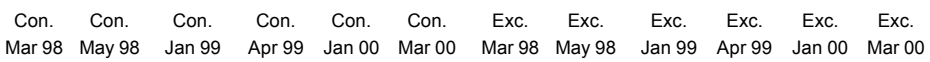

Figure 8. *Eleocharis acuta* cover (0–6 Braun-Blanquet cover scale, not linear) for the lower 4 m within Plot 2 in the control plot and within a cattle exclosure from May 1998 to March 2000. + = mean; box = 25 and 75 percentiles; whiskers = minimum and maximum values.

Herbs

Ludwigia palustris increased in cover during the trial to be 1.5 cover units more abundant in the exclosure than the control. *Bidens frondosa* also increased in cover in the exclosure by the end of the trial (2 cover scale units).

Turfs

Alternanthera sessilis and *Centipeda cunninghamii* were the only turf species present in Plot 2, but were in low abundance (±1 cover class) in both the exclosure and the control.

3.2.3 Plot 3

Plot 3 was positioned on a small point (slope = 3°) exposed to the north (fetch ~2 km) and northwest (fetch ~2.5 km). The substrate was sandy silt. The vegetation types present at this site were Indian doab–Mercer grass grassland (Vegetation type 16), *Fimbristylis velata*–water purslane–nahui herbfield (Vegetation type 10), Isolepis marginata–water purslane herbfield (Vegetation type 12) and bare mud with nahui, sneezewort, white clover (*Trifolium repens*) and water pepper (Vegetation type 20). Initially open water was present in the lakeward portion of the exclosure. However, over summer/autumn 2000 the entire exclosure was 10–20 cm underwater, while only half of the control plot remained submerged. Grazing by cattle was intermittent and at a low intensity (dependent on when individual cattle managed to breach the fenced-off area in which Plot 3 is situated).

Species richness, abundance and height

Average species number over the monitoring period was 36 in the control plot and 31 in the exclosure. Native species increased slightly from 8 to 13 in the control plot and from 9 to 16 in the exclosure over the duration of the trial. The opposite occurred for the number of introduced species in the exclosure, which dropped from 39 at the beginning to 15 by the end of the trial. In the control plot a similar drop in the number of introduced species occurred, from 34 to 17. This was then followed by an increase to 28 by the end of the trial. Vegetation height was significantly greater in the exclosure than in the control.

Total cover

Initially (March and May 1998) total cover was greater inside of the exclosure than in the control plot (Fig. 9), however, by the end of the trial average cover was 10% or less both in the exclosure and control plots. Average total cover in the exclosure ranged from 30–80% until January and March 2000 when it dropped to 10% or less. The exclosure was permanently flooded during this time.

Grasses

Grasses were not abundant in this plot and showed no change in abundance in relation to grazing, apart from the two monitoring periods in 2000 where *Paspalum distichum* showed a slight increase in abundance (Fig. 10).

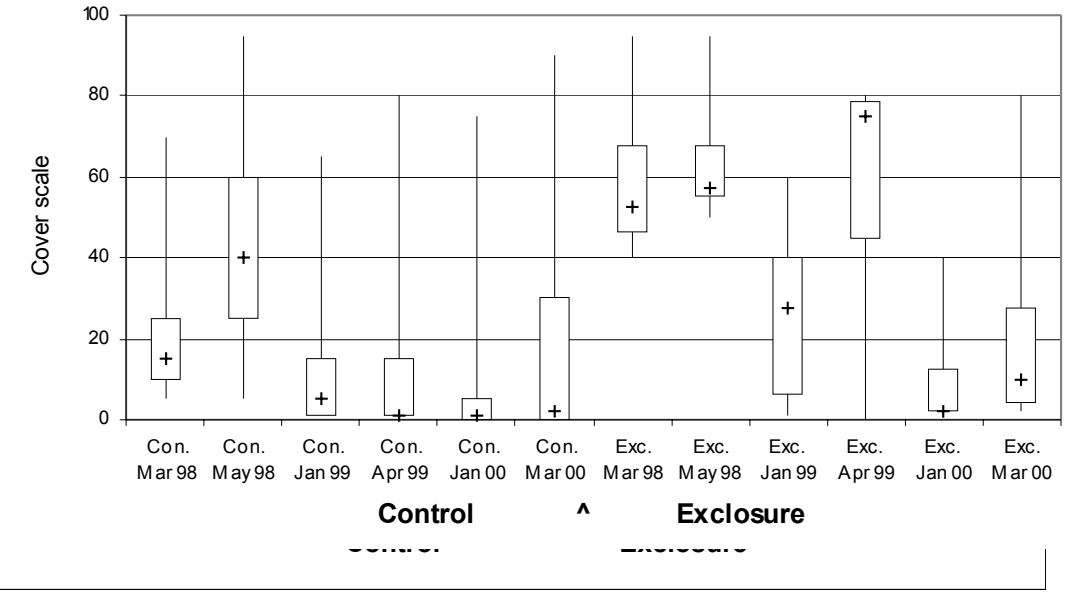

Figure 9. Total vegetation cover (%) for Plot 3 in the control plot and within a cattle exclosure from May 1998 to March 2000. + = mean; box = 25 and 75 percentiles; whiskers = minimum and maximum values.

over scale, not linear) for Plot 3 in
to March 2000. + = mean; box = 25
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exclosure over the course of
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Herbs

Ludwigia palustris had a greater cover (0.5–3 cover units) inside the exclosure from the beginning of the trial until January and March 2000 when it was not present inside or outside of the exclosure. *Myriophyllum aquaticum* was not present at the control site for the whole trial, but had a median cover class in the exclosure of 0.5 in January 1999 increasing to 2 by March 2000.

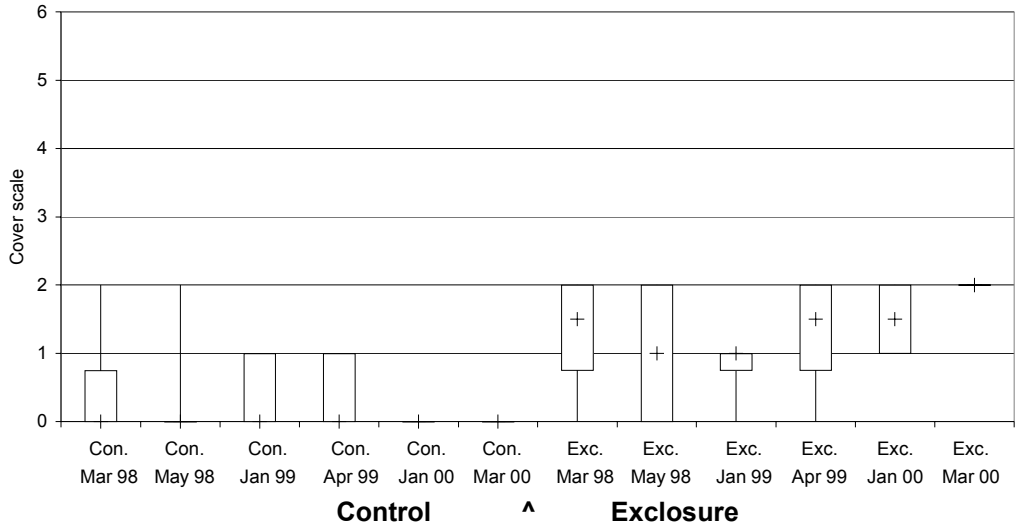

Figure 11. *Eleocharis acuta* cover (0–6 Braun-Blanquet cover scale, not linear) for the lower 4 m within Plot 3 in the control plot and within a cattle exclosure from May 1998 to March 2000. + = mean; box = 25 and 75 percentiles; whiskers = minimum and maximum values.

Turfs

Alternanthera sessilis was present both in the exclosure and in the control with a median cover of 1 in the control and 2 in the exclosure throughout the duration of the trial.

3.2.4 Plot 4

Plot 4 is positioned on a beach (slope = 2°) exposed to the north (fetch ~2 km) and north west (fetch ~2.5 km). The substrate was sandy with mudstone outcrops (~0.5 m tall). The vegetation types in the lower part of the site were *Fimbristylis velata*–water purslane–nahui herbfield (Vegetation type 10), *Glossostigma* spp.–nahui–*Gratiola sexdentata*–water purslane–*Hydrocotyle hygrophila* herbfield (not reported from the 1997 survey), *Eleocharis acuta/ Lilaeopsis novae-zelandiae*–water purslane herbfield (Vegetation type 3) and bare mud with scattered water purslane and *Glossostigma* spp. (Vegetation type 20). The upper vegetation types were *Carex gaudichaudiana*–Mercer grass sedgeland (Vegetation type 6), Indian doab–*Carex gaudichaudiana*–water purslane–*Hydrocotyle hydrophila* herbfield (Vegetation type 4). The lower 1–2 m were underwater through most of the monitoring period. The remaining area was always wet due to seepages throughout the area. This plot was exposed to high cattle-grazing pressure.

Species richness, abundance and height

Total species averaged 49 for both the control and exclosure plots. Introduced species averaged 35 (control) and 34 (exclosure) while native species were 14 (control) and 16 (exclosure). However, within the exclosure there was a larger number of species with covers greater than 5% and taller than 100 mm shoot height compared with the grazed control (mean of 3.8 species versus 1.5).

Total cover

Average total vegetation cover inside and outside the exclosure was similar until January and March 2000 when cover was greater in the exclosure (Fig. 12). In

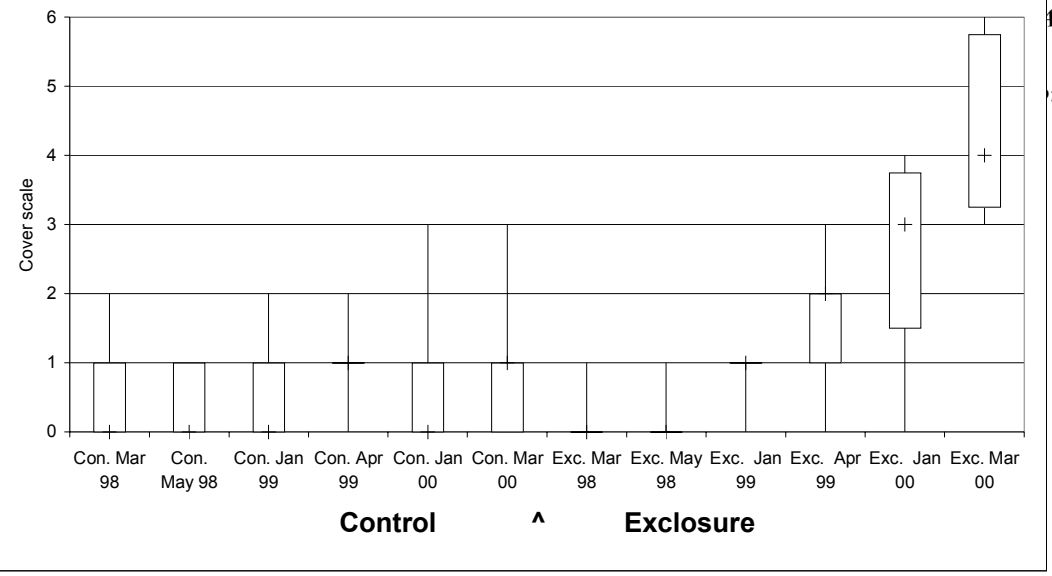

Figure 12. Total vegetation cover (%) for Plot 4 in the control plot and within a cattle exclosure from May 1998 to March 2000. + = mean; box = 25 and 75 percentiles; whiskers = minimum and maximum values.

March 2000 cover in the exclosure was 60% greater than the control. Average cover in the exclosure before April 1999 was 30%, increasing to 70% on later monitoring occasions.

Grasses

Paspalum distichum cover was the same in the exclosure and the control until January 1999 (median cover of £1), however by March 2000 median cover was 4 [illegible] *Agrostis stolonifera* also became [illegible] April 1999, but disappeared [illegible] *n* was of similar abundance in

Figure 13. *Paspalum distichum* cover (0–6 Braun-Blanquet cover scale, not linear) for Plot 4 in the control plot and within a cattle exclosure from May 1998 to March 2000. + = mean; box = 25 and 75 percentiles; whiskers = minimum and maximum values.

Rushes/sedges

Eleocharis acuta had a maximum cover of 1 in the control plot during the trial, in the exclosure it attained a median cover of 2.5 in April and January 2000 (Fig. 14).

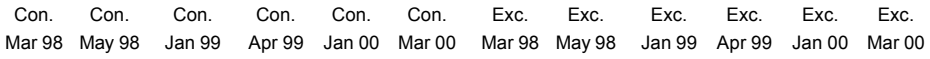

Figure 14. *Eleocharis acuta* cover (0–6 Braun-Blanquet cover scale, not linear) for the lower 4 m within Plot 4 in the control plot and within a cattle exclosure from May 1998 to March 2000. + = mean; box = 25 and 75 percentiles; whiskers = minimum and maximum values.

Herbs

Persicaria hydropiper was more abundant inside the exclosure in January 1999 (+1), January 2000 (+0.5) and March 2000 (+1.5) after being less abundant initially. *Aster subulatus* was more abundant in March 2000 (+1.5). (Both species were present in low covers.)

Turfs

Alternanthera sessilis was present (cover = 2) in the exclosure in March 2000 and absent in the control, however prior to this there was no trend.

3.3 HERBICIDE TRIAL

3.3.1 Gallant®

Total vegetation

In Plot 2 cover in the control and Gallant treated areas of the exclosure were the same for the duration of the trial except for April 1999 (3 months post treatment), where cover in the treated area averaged 85% while cover in the control area was 100%. In Plot 4 there was no difference in total vegetation cover in the treated area relative to the untreated at any time after Gallant® application (January 1999).

Grasses

In Plot 2 prior to treatment *Paspalum distichum* initially had equal covers on the herbicide-treated and non-treated sites (median cover of 3) (Fig. 15). After treatment (April 1999), median cover in the untreated area was 4.5 while the

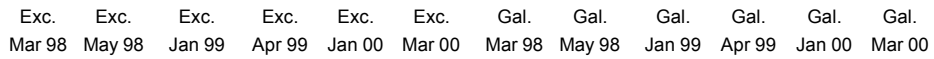

Figure 15. Cover (0–6 Braun-Blanquet cover scale, not linear) of *Paspalum distichum* on the untreated (Exclosure) and Gallant® treated (Gallant) side of cattle exclosure 2. Gallant was applied in January 1999. + = mean; box = 25 and 75 percentiles; whiskers = minimum and maximum values.

treated area was 2, this increased to 4 by March 2000 to be similar to the untreated area. *Cynodon dactylon* was not reduced by the herbicide treatment despite having a median cover of 3 in the treated and untreated area.

In Plot 4 median *Paspalum distichum* cover was 1 in January 1999 in both the treated and untreated areas. After application cover in the treated area remained ncreased to 4 by March 2000. *·tis stolonifera* and *Cynodon* 5 and 1 respectively in January uary 2000.

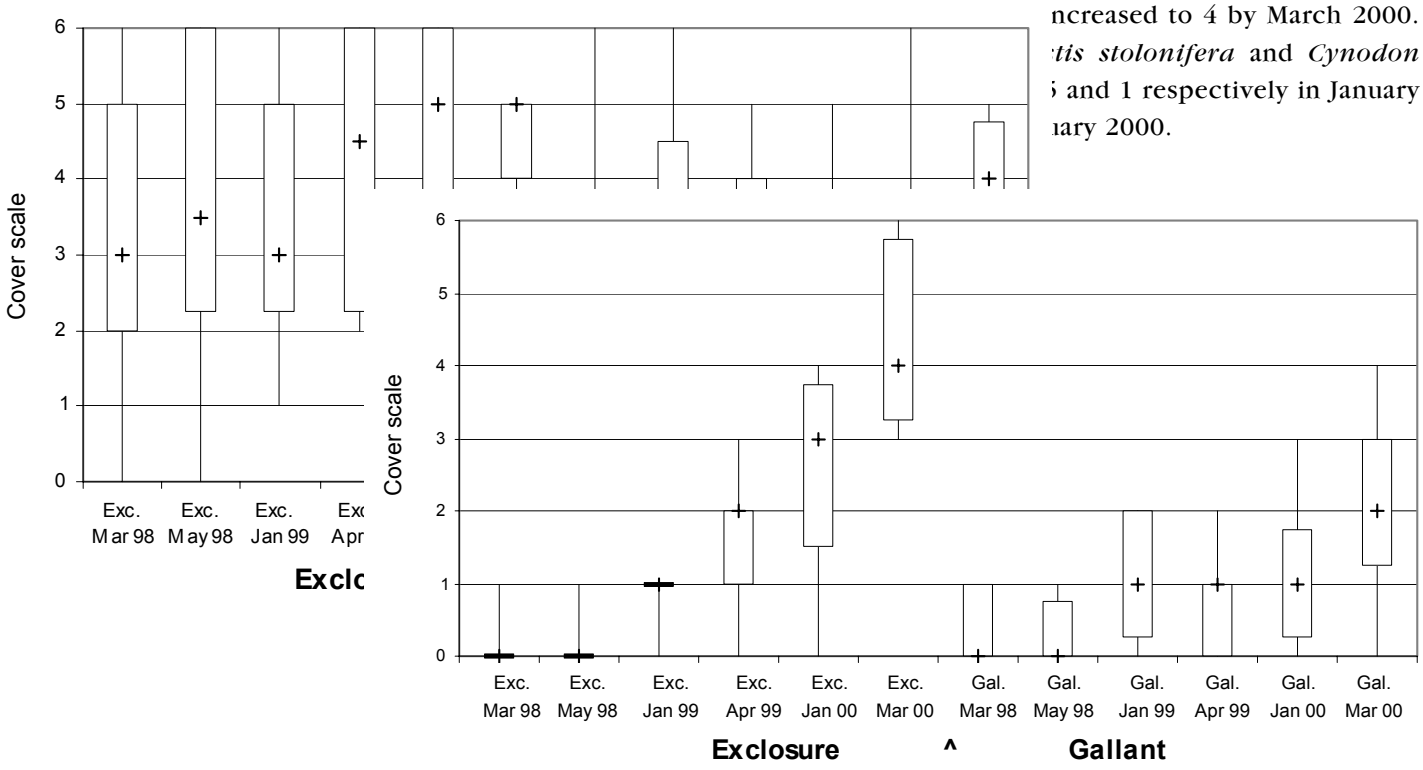

Figure 16. Cover (0–6 Braun-Blanquet cover scale, not linear) of *Paspalum distichum* on the untreated (Exclosure) and Gallant® treated (Gallant) side of cattle exclosure 4. Gallant was applied in January 1999. + = mean; box = 25 and 75 percentiles; whiskers = minimum and maximum values.

Other species

At Plot 4 *Myriophyllum aquaticum* and *Ludwigia peploides* colonised the treated area (cover of 1) in April 1999 and were present until January 2000. Also at Plot 4 *Eleocharis acuta* cover was higher on the herbicide-treated area (cover = 2) than the non-treated side (cover = 0.5) before herbicide was applied. After application, median cover on the treated side increased to 3.5 while the untreated side increased to 1.5. The area of the exclosure in the deepest water had the same *E. acuta* cover regardless of herbicide treatment.

No other species showed any change in abundance relative to Gallant® application.

3.3.2 Centurion®

Total cover

The was no total vegetation cover in the treated and untreated areas before and after Centurion® application was the same in both Plot 1 and 3.

Grasses

In Plot 1 *Paspalum distichum* median covers ranged from 2–4.5 both in the treated and untreated areas with no apparent change in cover associated with herbicide application (Fig. 17). No change in abundance associated with herbicide application was observed for *Cynodon dactylon* either. In Plot 3 grass abundance was very low (Fig. 18).

3.3.3 Versatill™ and Grazon®

Both herbicides appeared to reduce the cover of the introduced *Ludwigia palustris*, the dominant alien dicotyledon in the trial area. However standard errors were high and impacts of cattle grazing and trampling affected comparisons between sample dates.

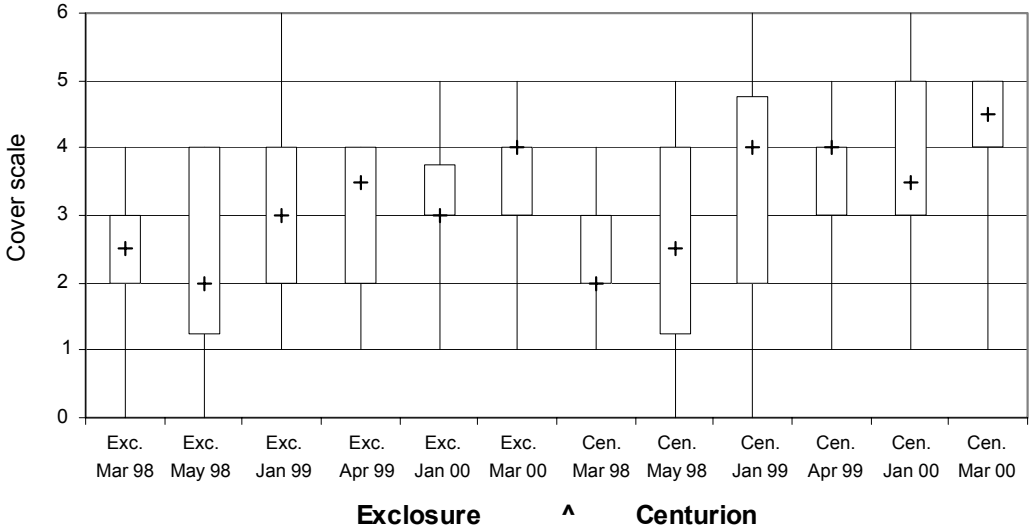

Figure 17. Cover (0–6 Braun-Blanquet cover scale, not linear) of *Paspalum distichum* on the untreated (Exclosure) and Centurion® treated (Centurion) side of cattle exclosure 1. Centurion was applied in January 1999. + = mean; box = 25 and 75 percentiles; whiskers = minimum and maximum values.

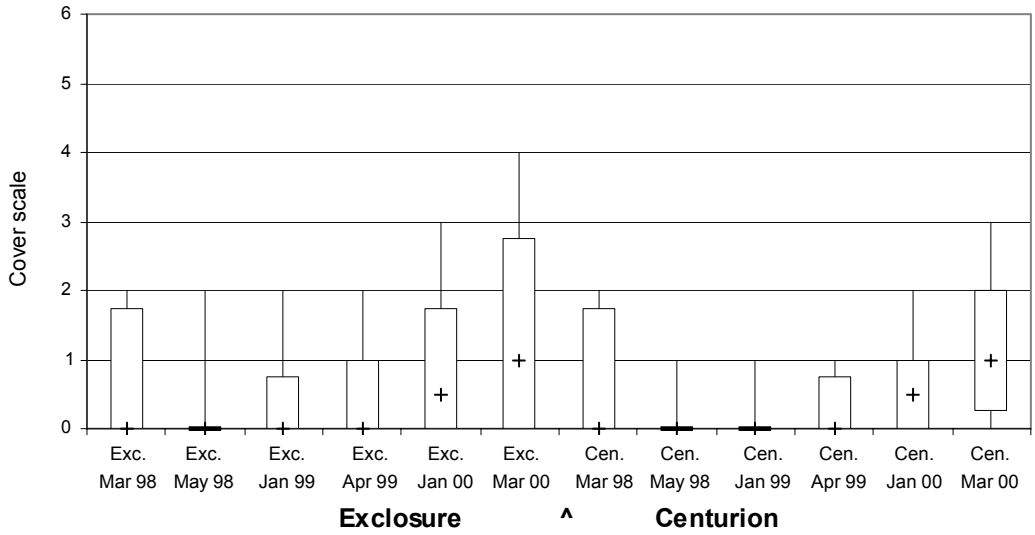

Figure 18. Cover (0–6 Braun-Blanquet cover scale, not linear) of *Paspalum distichum* on the untreated (Exclosure) and Centurion® treated (Centurion) side of cattle exclosure 3. Centurion was applied in January 1999. + = mean; box = 25 and 75 percentiles; whiskers = minimum and maximum values.

Pot-based trials demonstrated effective control of *L. palustris, Trifolium repens* and *Lotus pedunculatus* by both herbicides. Most indigenous dicotyledonous species were not eliminated with Versatill™ treatments providing more selectivity (Champion 2000). Grasses, sedges and rushes were not controlled by these treatments.

3.4 CULTIVATION AND RE-ESTABLISHMENT OF ENDANGERED SPECIES

Of the species identified by DOC only *Amphibromus fluitans* was considered a suitable candidate for attempting re-establishment at Lake Whangape as it was the only species classified as Endangered. The status of the other species is discussed in Section 4.1.

Nursery-propagated plants of *A. fluitans* were planted in all exclosures and controls in February 1998 and April 1998. Plants were also planted in the exclosure and control of Plot 4 in February 1999. Monitoring in March 1998 reported plants of *A. fluitans* at low covers within the exclosures in Plot 2 (quadrat series 5—closest to the lake) and Plot 3 (quadrat series 5 and 4—closest to the lake and adjacent to these). In May 1998 plants were recorded at low covers from Plots 1 (exclosure), 2 (control) and 4 (both exclosure and control). No plants of this species were found during the January 1999 monitoring. Monitoring in April 1999 revealed higher covers (mostly 2 and 3) of *A. fluitans* in Plot 4 in all quadrat series. No plants of this species were found during the two monitoring occasions in 2000. The maximum persistence of *A. fluitans* plants in the field was two months and on no occasion did any of the transplants of this species survive inundation due to high lake levels over the winter months.

3.5 LAKE LEVEL

Lake level records from 1998 to 2000 are shown in Fig. 19. The entire plot areas were submerged over each winter to depth of over 1 m. Waters receded over the summer and plots were exposed from mid to late December in the summers of 1998 and 1999.

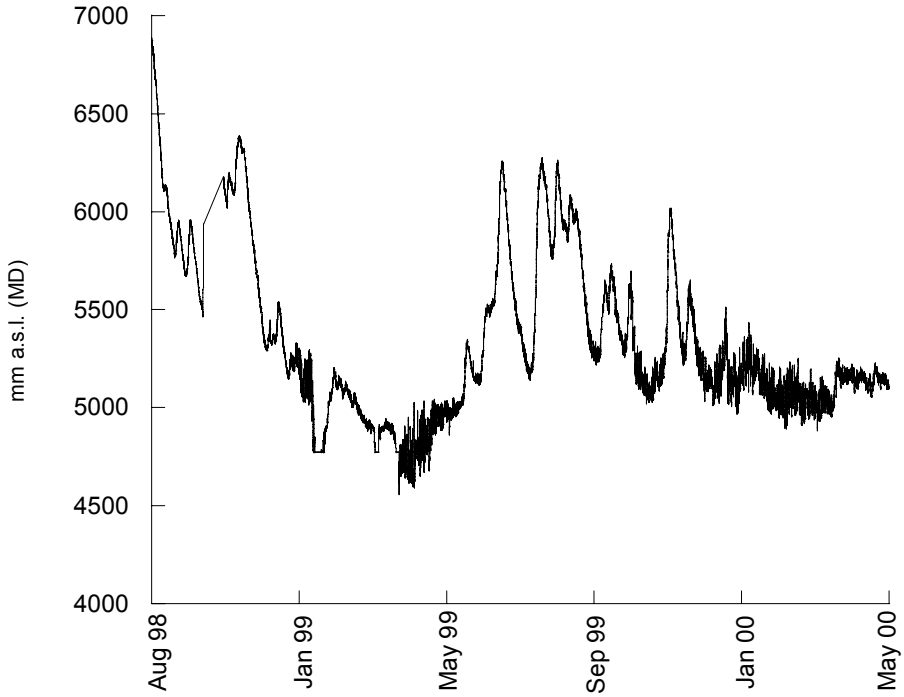

Figure 19. Water level at Lake Whangape from August 1998 to May 2000. Units (mm a.s.l.) are millimetres above sea level at Moturiki Datum.

Between March and April 1999, within the period of this study, a weir was installed at the outlet of Lake Whangape. This increased the base lake water level from 4.9 m to 5.0 m a.s.l. Moturiki Datum. The resulting changes to Lake Whangape water levels are compared in Table 3.

TABLE 3. WATER LEVEL RECORDS FOR LAKE WHANGAPE BEFORE AND AFTER THE INSTALLATION OF THE NEW OUTLET WEIR. LEVEL RECORDS REFER TO MOTURIKI DATUM.

TIME PERIOD	MEAN LEVEL (m a.s.l. MD)	MAXIMUM LEVEL (m a.s.l. MD)	MINIMUM LEVEL (m a.s.l. MD)	DIFFERENCE IN LEVEL (m)
Aug 1998–May 2000	5.32	6.89	4.56	2.33
Aug 1998–May 1999	5.27	6.89	4.56	2.33
June 1999–May 2000	5.35	6.27	4.88	1.39

Minimum lake level was 0.33 m higher during the summer of 1999/2000 compared with the previous year.

These water levels are within a similar range to those monitored on a monthly basis between 1992 and 1996 (Champion et al. 1996) as shown in Table 4.

TABLE 4. WATER LEVEL RECORDS FOR LAKE WHANGAPE BETWEEN 1992 AND 1996.

TIME PERIOD	MEAN LEVEL (m MD)	MAXIMUM LEVEL (m MD)	MINIMUM LEVEL (m MD)	DIFFERENCE IN LEVEL (m)
Oct 1992–Sept 1993	5.01	6.83	4.51	2.32
Oct 1993–Sept 1994	4.93	6.90	4.17	2.73
Oct 1994–Sept 1995	5.26	6.97	4.76	2.21
Oct 1995–Apr 1996	5.46	6.46	5.06	1.40

Lake depth maxima occurred during winter months with minima occurring in late summer/autumn. The mean annual fluctuation was 2.4 m. Lake level was monitored by the Waikato Valley Authority (now Environment Waikato) from 1968 to 1983 by a continuous recorder situated in the Southern Arm. Mean annual fluctuation in lake level was 2.11 (±0.54 SD) m with maxima of 7.10 (±0.52 SD) m (MD) and minima of 5.07 (±0.13 SD) m (MD) (calculated from data presented in Environment Waikato 1993).

The recent (1999) replacement of the outlet sill has resulted in the complete inundation of cattle exclosure Plot 3 and much of the lake edge vegetation within the other three plots. Exposure time for the lower turf communities has been reduced from approximately 4 months in the summer of 1998/99 to around 1 month in 1999/2000.

4. Discussion

4.1 STATUS OF ENDANGERED AND LOCAL SPECIES

Amphibromus fluitans was classified by de Lange et al. (1999) as Critically Endangered. This classification indicates that extinction is considered inevitable unless conservation intervention is undertaken. P.J. de Lange collected this plant in 1990 from the margins of Lake Whangape, at the site of Plot 2. There have been no further finds of *A. fluitans* within similar habitats around this lake or from the three other recently recorded sites of *A. fluitans* in the Waikato (Champion et al. 1993). The plant obtained from Percy Scenic Reserve has been successfully propagated, however transplants of cultivated material have failed to persist for greater than two months within the trial sites, not surviving winter inundation with lake waters (see Section 4.3). The majority of *A. fluitans* plants that did persist at the Plot sites after planting were found in the wettest parts of these plots, or in the seepage area of Plot 4. It would thus appear that this species is not drought tolerant.

In 1990 the sill at the Whangape outlet was removed exposing an average additional 9–13 m width of lake shore over summer (see Section 4.3). Presumably the *A. fluitans* plant found at that time grew from seed banks that were only exposed as a result of removal of the sill, and were therefore likely to have represented vegetation from an earlier time in the lake's history. Presumably current factors such as grazing by cattle, waterfowl and coarse fish are influencing turf vegetation and preventing establishment of *A. fluitans* and it would thus appear that this species could no longer persist in the marginal flora of Lake Whangape.

A. Rebergen (DOC Wairarapa) has been attempting to manage a small population of *A. fluitans* in an ephemeral wetland between Lake Wairarapa and Boggy Pond. Because of the high water table this wetland is normally flooded to a depth of 0.5 m by clear water from June to February. When the site was first discovered in 1997 (Rebergen 1998), only a few plants were found in the mostly bare wetland area. Cattle had grazed and trampled the area for many years. Removal of cattle resulted in an increase of the dominant grass species *Paspalum distichum* from 5 to 95% cover in the wettest parts, along with an increase in *A. fluitans* in drier areas, so that it formed a sward over several hundred square metres. After two years without grazing, *P. distichum* densities started to decline, and bare areas which were previously colonised by weedy alien annual species supported increased numbers of the native amphibious species *Myriophyllum propinquum, M. triphyllum, Lilaeopsis novae-zelandiae, Pratia perpusilla* and *Gratiola sexdentata* (A. Rebergen pers. comm.). Trials on the continued protection of *A. fluitans* are planned for upcoming years (A. Rebergen pers. comm.).

As a result of this study, Lake Whangape is now considered to be supporting the largest known population of the indigenous annual sedge *Fimbristylis velata* in New Zealand. *Fimbristylis velata* was classed as Local by Cameron et al. (1995), but following communication of the results of this project to members of the New Zealand Threatened Plant Committee, this species is no longer considered

threatened (de Lange et al. 1999). *F. velata* was locally abundant in most of the turf communities around the lake and colonising exposed lake shores during summer. The Waikato Basin is apparently the national stronghold of the species, and the best New Zealand populations of *F. velata* occur around lakes Whangape and Rotongaroiti. Material cultured from plants collected at Lake Whangape persisted throughout the study period. It appeared to be a strict annual, dying off over winter with seedlings germinating during late spring/ early summer, flowering and seeding from February onwards.

Juncus holoschoenus was classified as Insufficiently Known by Cameron et al. (1995) in their assessment of endangered plants in New Zealand. However our study and other investigations of wetlands by the authors have shown this plant to be very common in wetlands within the Waikato Basin and it was not considered endangered by de Lange et al. (1999). *J. holoschoenus* has two forms in New Zealand. One is a small form, which is the form of *J. holoschoenus* found at Lake Whangape. This form may prove to be a recent introduction into New Zealand (P.J. de Lange pers. comm.). The other form, a much larger indigenous variety, has only been collected recently by S.M. Beadel in the Kaingaroa Ecological District. The large variety, *J. holoschoenus* var. *holoschoenus* is ranked as Endangered by de Lange et al. (1999).

P.J. de Lange collected *Carex cirrhosa* at Lake Whangape in 1990 from the turf area on the northern shore adjacent to the outlet. This plant was not found during the 1997 survey, or in subsequent searches for it. Lake Whangape was the northern limit for this species and it is not known from elsewhere in the Waikato Basin. Other populations in the North Island occur at Lake Rerewhakaaitu, Lake Waikaremoana and Lake Wairarapa. *C. cirrhosa* was not classed as endangered by Cameron et al. (1995) or by de Lange et al. (1999), however, it is uncommon in the central North Island and its national status is uncertain. Material cultivated from the original Whangape collection could not be sourced and has, therefore, not been propagated as part of this study.

Carex gaudichaniana is a common component of vegetation fringing ephemeral turf communities at Lake Whangape, occurring as a dominant species in turf types 4–6 (Section 3.1.1), and forming pure sedgelands merging into pasture in several areas around the lake. It is not considered to be nationally or regionally threatened.

Lachnagrostis striata was recorded from several sites around the lake, often occupying the tops of mudstone outcrops as found at Plot 4. It is not nationally threatened (de Lange et al. 1999), but is uncommon in the Waikato Basin. It becomes more frequent at higher altitudes south of the Waikato Basin.

Pratia perpusilla reaches its northern limit at Lake Whangape. The Lake Whangape population is one of only two populations in the Waikato Basin. The status of *P. perpusilla* at the lake is complicated by the presence of a hybrid, *P. angulata* × *perpusilla* (20-ploid *angulata* crossed with hexaploid *perpusilla*) (Murray & Cameron 1990), which is common around the lake shore. There also appears to be a stable hybrid also present, *P. perpusilla* (11-ploid) (Murray & Cameron, 1990). The 11-ploid plant has only been collected at Lake Whangape where it is common in various turf communities. *P. perpusilla* (hexaploid) was restricted to two sites including Plot 4.

Triglochin striata is an amphibious species recorded at two sites (including Plot 4). *Triglochin striata* is uncommon in the Waikato Basin but is not considered to be nationally threatened or regionally uncommon. The presence of this species was not recorded in Champion et al. (1993) but it was found at four other lakes within the Waikato Basin during that study.

Hydrocotyle hydrophila occurs at a few sites around Lake Whangape including Plot 4 where it is locally abundant. This population is near the northern limit for the species (the northern limit is the Hunua Range). It is not nationally threatened; however, it is regionally uncommon, with this being the only known population in the Waikato Basin.

The annual turf species *Alternanthera sessilis* and *Centipeda cunninghamii* have been recently considered as alien plants in New Zealand (Webb et al. 1988). *Alternanthera sessilis* appears to differ from other collections of that species from other countries seen by P.D. Champion. Further studies are required to determine its taxonomy. *Centipeda cunninghamii* is a common Australian plant (as is *C. minima*). It is conceivable that it has been naturally introduced into New Zealand by migratory waterfowl (e.g. grey teal, *Anas gracilis*) which regularly fly between the two countries. Both species were abundant in various turf communities around Lake Whangape.

Several amphibious turf species were recorded at Lake Whangape by Kirk (1871), but have not been recorded since. These are discussed below.

- *Pilularia novae-zelandiae* was recorded by Kirk (1871), however, it has not been seen recently in the area and is probably extinct from the lake. *Pilularia novae-zelandiae* is not nationally threatened (de Lange et al. 1999), however, it is only known from one site in the Waikato Basin at Lake Waahi (Champion et al. 1993).
- *Ranunculus limosella* was recorded by Kirk (1871); however, it has not been seen in the area recently and is probably extinct. *Ranunculus. limosella* is not considered nationally threatened by de Lange et al. (1999), but is not known from any other sites in the Waikato Basin. It is present in the Waikato River near Lake Taupo.
- *Crassula sinclairii* was collected by Kirk (1871) from Lake Whangape. It has not been seen in the lake since. *Crassula sinclairii* is not classed as nationally threatened. It was reported from Lake Waahi within the Waikato Basin (Champion et al. 1993) and occurs in marginal habitat along parts of the Waikato River.
- Kirk (1871) also reported *Isolepis fluitans*, *Galium perpusillum* and *Chenopodium ambiguum* as present on lakeshore margins at Lake Whangape. None of these species has been reported in the Waikato Basin since that time.

The submerged species recorded as present in Lake Whangape by Kirk (1871) or Cheeseman (1925)—*Isoetes kirkii, Lepilaena bilocularis, Potamogeton pectinatus, Ruppia polycarpa,* and *Zannichellia palustris*—are also now apparently all extinct from this lake.

4.2 EXCLOSURE EXPERIMENT

Vegetation increased significantly both in cover and height within the cattle exclosures of Plots 2 and 4, with an increasing divergence from control plots during the three years monitored. After an initial increase, Plot 3 showed a decline in plant cover within the exclosure from winter 1999 onwards, which corresponded to the installation of a sill at the Lake Whangape outlet, which increased minimum lake level. As a consequence of this, the exclosure remained flooded throughout the 1999/2000 summer. A broken rail in the exclosure at Plot 1 allowed stock access to that area from winter 1999 onwards and vegetation was not different from grazed areas in March 2000. The divergence of vegetation within and outside the exclosures continues, with the vegetation within exclosures yet to reach equilibrium.

The major species increasing within the exclosure plots were perennial, with the indigenous *Eleocharis acuta* colonising the wetter zones, and the alien grass *Paspalum distichum* colonising all areas of the plot. Other species increasing in one or more exclosures were *Cynodon dactylon,* and the annuals *Persicaria hydropiper, Aster subulata* and *Ludwigia palustris*, all alien species. No change in turf species diversity or abundance was noted at any site.

The majority of species recorded in the plots (both exclosure and grazed) were ephemeral, occurring in recently exposed lake sediment, persisting during the period of exposure and then dying during winter inundation. This group of species comprised of alien and indigenous plants, all with cover classes of 1 and usually intolerant of waterlogging. These species could be regarded as opportunistic colonisers of bare substrates, but they are unlikely to persist now that the minimum lake water level has been raised.

The herbicide Centurion® did not adequately control either *P. distichum* or *C. dactylon.* No significant change was observed between the treated and untreated sections of the two exclosures. Conversely, Gallant® did initially control both species after application in January 1999, with continued suppression of *P. distichum* within the monitoring period. No significant changes in other vegetation occurred between treated and untreated sections.

The exclosures protected the sites from the effects of grazing by both cattle and horses. It is also unlikely that waterfowl have entered such small areas to graze on vegetation. The construction of the exclosures did not prevent koi carp (*Cyprinus cyprio*) and presumably other fish from entering these areas. However, fence posts were often utilised as roosts by shags which could also influence the incidence of fish impacts. The post and rail construction of the exclosures also provided a more sheltered site than experienced outside of these structures, with protection from wave action and possibly wind.

4.3 FACTORS INFLUENCING THE PERSISTENCE OF TURF COMMUNITIES

The exclosure trial described in Section 2.2 was an attempt to quantify the impacts of cattle grazing and selective removal of weedy grasses on the persistence and health of turf communities around Lake Whangape. Other factors, including shore aspect, wave fetch, water level fluctuation, impacts of waterfowl and coarse fish, must also be considered in any attempt to understand the conditions required to maintain and manage these turfs. Impacts of each factor are discussed below, based on information gained from this trial, additional observations at Lake Whangape, and a review of available literature.

Distribution of turf communities in the absence of biotic influences would be determined by physical features such as exposure of site to wave action, lake level variation and period of exposure, groundwater influences, and also the substrate type (which may also be determined by the sorting action of wave action, with coarser substrates occurring in areas of highest disturbance).

4.3.1 Exposure/wind fetch

Cattle are not present on Motukauere Island, therefore, turf communities present along the island's northern shoreline are not affected by cattle grazing. This vegetation occurs on the lakeward edge of *Bolboschoenus medianus* beds, or *Cynodon dactylon* grassland on a fine sandy substrate. This site would be exposed to a 2.5 km wind fetch from the north west and 2 to 3 km from the west (similar to Plot 4). Other areas with a similar wind fetch from the prevailing wind would include the eastern shoreline and other sites facing either northeast or southeast (e.g. Plot 4 and the eastern side of the peninsula on the northern shore). They are likely to have a similar fine sandy substrate and, therefore, are suitable areas for turf communities to establish

In some more exposed areas a more or less bare, coarser sand substrate occurs which may be too disturbed for turf communities to develop.

Margins of more sheltered sites on Motukauere Island were dominated by emergent vegetation, especially raupo (*Typha orientalis*). This vegetation is rare in other areas unless livestock (especially cattle) are excluded, e.g. the embayment between Plots 1 and 2. In many of the areas where cattle have access to the lake shore a biotic-induced (from cattle grazing) turf community is present (see below). Substrates in these areas range from compacted silty muds/clays to sandy silt.

The exclosures afforded more shelter at all plots, compared with control sites, and the emergent *Eleocharis acuta* increased within exclosures in areas closest to the lake. Absence or decreased abundance of this species outside of the exclosures is possibly an effect of grazing, but is also a feature of Plot 3 where cattle access is restricted.

4.3.2 Lake level variation

All of the turf communities occurred on wind-exposed shores of low aspect (approximately 2–3°) with a maximum width of around 20 m, exposed during late summer/early autumn.

Prior to 1989/90 a natural sill controlled the outflow, and Environment Waikato lake level data from 1968–1983 showed a mean minimum lake level of 5.07 (±0.13 SD) m (Moturiki Datum). Raglan County Council drainage work breached this sill during the 1989/90 summer. Much lower summer lake levels resulted, with mean minimum lake levels of 4.61 (±0.33 SD) m (MD) recorded between 1992 and 1996, and also 1998–99. The Department of Conservation installed a new sill in 1999/2000 to restore water-levels to where they were before the natural sill was breached. During 1999/2000 (after the installation of the new sill, which now sets minimum lake level at around 4.9 m (MD) G. Barnes pers. comm.), minimum lake level was 4.88 m (MD). Winter water levels in the order of 6.8 m (MD) would see the plots totally submerged by more than 1 m for that period.

Presumably from 1990 to 1999 an average additional width of lake shore of 9–13 m was exposed (based on a mean slope of 3° or 2°, and a decrease in lake height of 0.46 m). This may explain why the rare species *Carex cirrhosa, Amphibromus fluitans,* and also *Apium prostratum* (a normally coastal species that was a lake marginal plant reported by Kirk in 1871) were found during the 1990 survey by de Lange (in Champion et al. 1993), but have not been found since. It is presumed these species grew from seed banks that were only exposed as a result of removal of the sill at the Whangape outlet and were, therefore, likely to have represented vegetation from an earlier time in the lake's history.

The increase in minimum lake level as a result of the new sill is likely to decrease available littoral habitat for turf communities by up to 65%, and therefore decrease both the area and time available for the life-cycles of these plants to be completed (especially important for annual species). Decreasing the minimum summer lake level by adjusting the existing sill structure would allow a longer exposure period and therefore a more diverse and denser turf to develop.

4.3.3 Alien plants

Weed threats perceived by DOC were the encroachment of *Paspalum distichum, Centipeda cunninghamii, Myriophyllum aquaticum,* and *Ludwigia palustris* on the turf communities. Of those species only *P. distichum* appeared to threaten to smother this low growing vegetation, where grazing is prevented. *Myriophyllum aquaticum* and *L. palustris* were both present in many of the communities described in Section 3.1, but neither species formed pure stands as occurred in less exposed, low density substrates where cattle could not access these plants. Some local increase of both species occurred in some exclosures, but not at the expense of other vegetation. *Centipeda cunninghamii* does not appear to be invasive typically occurring in turfs where total vegetation cover is in the order of 30–50%.

Small sapling willows (both *Salix fragilis* and *S. cinerea*) were found in several plots, and it is likely that these species would establish more rapidly if areas were protected from grazing. These species already occupy 56% of the lake shore (Champion et al. 1993) and once established, they may form a persistent vegetation, shading turf areas and potentially displacing them. Currently turf communities do not occur adjacent to areas where willow species dominate the lake shore.

Under the current conditions experienced in some existing turf areas, either those bordered by pasture, or on Motukauere Island, alien weeds do not appear to be a major influence on turf vegetation. These sites are submerged for over six months during late autumn–spring, only allowing a narrow window of opportunity for vegetation establishment. Other factors, either natural exposure to wave action or grazing, prevent the establishment of perennial vegetation tolerant of those conditions (either tall emergents, grass swards, or willows).

4.3.4 Cattle grazing

Tanner (1992) reviewed the impacts of cattle on lake margins. These included consumption of vegetation, trampling, pugging, nutrient enrichment through faeces and urine, production of invasion sites for weeds, and increased shore erosion. Cattle may influence the species composition of such areas (Pacala & Crawley 1992), by eating palatable species (e.g. grasses and clovers, but also emergent plants like *Typha orientalis* and *Eleocharis sphacelata*) but leaving unpalatable species like *Mentha pulegium, Axonopus fissifolius,* and *Juncus* spp. Where those palatable species are capable of displacing more desirable shorter plants, i.e. turf communities, then grazing by cattle can be regarded as beneficial. However, if the aim is to protect habitat for endangered palatable species, e.g. *Amphibromus fluitans*, then cattle grazing is undesirable (Section 4.4).

Cattle grazing has undoubtedly increased the area of lake shore occupied by turf communities by reducing the amount of taller species, but it has decreased the quality of turf vegetation and resulted in other negative impacts to the health of Lake Whangape. Heavy trampling and grazing of turfs reduces the cover of such plants, and prevents the establishment of a nutrient buffer of marginal/emergent vegetation to intercept run-off and groundwater sources. Direct entry of cattle into Lake Whangape also leads to direct nutrient addition through excreta and disturbance of lake sediment.

Although turf communities appear to be tolerant of cattle grazing, on balance the prevention of cattle access to Lake Whangape would be desirable in the management of this water body. Other methods of willow control would be needed to prevent further ingress of these species.

4.3.5 Waterfowl grazing

Lake Whangape supports large populations of several birds which could have a major influence on marginal vegetation. The main species would be Canada geese (*Branta canadensis maxima*), black swan (*Cygnus atratus*), and mallard duck (*Anas platyrhynchos*). The browsing of turf communities by waterfowl may be equal to, or more important than cattle browsing (Bakker 1985; Looijen & Bakker 1987). In comparison with cattle, browsing by waterfowl may be preferable because of their minor pugging impact and more selective browsing of palatable species. Detrimental effects of waterfowl are contamination of the lake with excreta and the possibility of selective removal of palatable desirable species.

Exclusion of stock from larger areas of shoreline than the experimental exclosures would allow evaluation of waterfowl grazing impacts in isolation from cattle.

4.3.6 Coarse fish

Large numbers of koi carp were noted foraging along the lake margin (often with dorsal fin sticking above the water's surface) on each sampling occasion. In addition to koi, large populations of rudd (*Scardinius erythrophthalmus*) and bullhead catfish (*Ameiurus nebulosus*) are also present throughout the lakes and rivers of the lower Waikato (Champion 1997), their relative abundance in Lake Whangapae, however, is unknown.

Potential impacts of koi were reviewed by Hanchet (1990). These included removal of submerged vegetation through increased turbidity caused by disturbance of bottom sediments, direct consumption and uprooting of plants during foraging activities. Presumably, because their benthic feeding behaviour, catfish may provide similar impacts. Rudd are herbivorous and may directly consume submerged macrophytes (Lake 1998; Hicks 1994; Wells 1999), however their impact on turf species such as those in Lake Whangapae is undocumented.

No amphibious plant species (e.g. *Lilaeopsis novae-zelandiae, Glossostigma* spp., *Gratiola sexdentata,* or *Ludwigia palustris*) were present under water within Lake Whangape, only occurring in seepages above the lake edge, or germinating on freshly exposed substrates. It is likely that the grazing influences of coarse fish could be removing all turf vegetation during submerged phases. The impact of coarse fish on submerged vegetation is currently being investigated by NIWA.

4.3.7 Submerged macrophytes

The only macrophyte now present in Lake Whangape is hornwort (*Ceratophyllum demersum*) which forms surface-reaching beds over much of the lake (Champion et al. 1996). This species does not produce roots, but the lower branches frequently anchor in soft sediments. It is, therefore, unstable and may be deposited in huge quantities on exposed shores after storm events. Such events have the potential to smother the short turf communities, although this was not observed during the study period.

4.3.8 Conclusions

The minimum summer lake level and duration of lake margin exposure predominantly control the extent of turf communities around Lake Whangape. Where cattle grazing does not influence lake margins, turfs are restricted to areas of moderate wave fetch which typically have fine sandy substrates. The grazing and trampling impacts of cattle have increased the total area of these disturbance-tolerant turfs, but the overall effects of cattle on the health of Lake Whangape are deleterious. Waterfowl grazing is also likely to be important in maintaining these turfs. Coarse fish grazing is likely to be removing submerged amphibious turf species which are effectively excluded from the lake. Weeds do not appear to be a major threat to turf communities, but in the absence of cattle grazing, ingress of willows or taller herbaceous vegetation, e.g. *P. distichum,* may occur and require control.

5. Recommendations

- Investigate the possibility of lowering or modifying the existing outlet structure (sill) to allow a greater exposed surface for turf development during summer. Reducing water levels in Lake Whangape may affect other aspects of the lake's ecology and will need to be considered within an overall management framework for the lake.
- Fence larger areas of turf habitat to prevent cattle access, or attempt to prevent cattle access to the entire Lake Whangape shoreline and monitor changes in turf communities to investigate whether they are eventually displaced by taller perennial vegetation.
- Monitor the impact of waterfowl grazing and actively manage the expansion of willows or other alien weeds into these areas.
- Trial the impact of fish exclosures on turfs and attempt the restoration of amphibious communities in the area around Plot 4.

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Appendix 1

VASCULAR FLORA OF LAKE WHANGAPE

Based on Champion et al. (1993) with additions made from the present study. Vouchers of some specimens have been lodged in the University of Waikato Herbarium (WAIK) with some duplicates lodged in the Auckland Institute and Museum Herbarium (AK) and Landcare Lincoln Herbarium (CHR).

Abbreviations/Formats

(+) = Uncommon or local (Basis: < 10 plants observed)
sdlg = Seedlings (followed by citation)
I = Number of indigenous species
?Ex = Possibly extinct at this locality
A = Number of alien species
1997 = First recorded in 1997
Bold = Bold text denotes indigenous species
1 = Species seen in April 1997
2 = Species recorded in vegetation plots 1998–2000 (N.B. this is not a complete list of species recorded from the plots; species identified to genera level only are not listed; these are *Poa* sp., *Geranium* sp., and *Oxalis* sp.)

NAME	OCCURRENCE	COMMON NAME	HERBARIUM
1. Gymnosperms (11) (A: 3; I: 8)			
Agathis australis	(+)	kauri	
Cupressus macrocarpa	(+)	macrocarpa	
Dacrycarpus cupressinum		rimu	
Dacrycarpus dacrydioides	1	kahikatea	
Libocedrus plumosa	(+)	kawaka	
Pinus pinaster		maritime pine	
Pinus radiata		radiata pine	
Podocarpus hallii	(+)	Hall's totara	
Podocarpus totara		totara	
Prumnopitys ferruginea	(+)	miro	
Prumnopitys taxifolia	(+)	matai	
2. Monocotyledon Trees & Shrubs (3) (A: 0; I: 3)			
Cordyline australis		ti kouka (cabbage tree)	
Cordyline banksii		ti ngahere (forest cabbage tree)	
Rhopalostylis sapida	(+)	nikau	
3. Dicotyledon Trees & Shrubs (85) (A:19; I: 66)			
Acacia dealbata		silver wattle	
Acacia mearnsii		black wattle	
Alectryon excelsus var. ***excelsus***		titoki	AK
Aristotelia serrata		makomako (wineberry)	
Alnus glutinosa		alder	
Beilschmiedia tarairi	(+)	taraire	AK 170985
Beilschmiedia tawa		tawa	
Berberis glaucophylla		barberry	
Brachyglottis repanda s.s.		rangiora	
Carmichaelia australis		maukoro	WAIK 1767
Carpodetus serratus		putaputaweta	
Coprosma arborea		mamangi	WAIK 7214
Coprosma areolata			WAIK 6223, 6224

NAME	OCCURRENCE	COMMON NAME	HERBARIUM
Coprosma grandifolia		kanono	
Coprosma lucida		shining karamu	
Coprosma rigida		karamu	
Coprosma robusta		karamu	
Coprosma propinqua		mingimingi	
Coprosma rhamnoides			
Coprosma rotundifolia			WAIK 6225
Coprosma spathulata			WAIK 1531
Coprosma tenuicaulis			WAIK 6212, 6220
Coprosma propinqua subsp. ***propinqua*** × ***C. robusta***	1		WAIK 6214
Coprosma areolata × ***C. rotundifolia***			WAIK 6226
Corynocarpus laevigatus		karaka	
Cotoneaster glaucophyllus			WAIK 12354
Crataegus monogyna	1	hawthorn	WAIK 12479
Cyathodes juniperina		prickly mingimingi	
Dodonaea viscosa		akeake	
Dysoxylum spectabile	(+)	kohekohe	
Epacris pauciflora	(+)	tamingi	
Eucalyptus ovata	(+), sdlg	swamp gum	
Fuchsia excorticata		koutukutuku	
Geniostoma ligustrifolium var. ***ligustrifolium***		hangehange	
Hebe stricta var. ***stricta***		koromiko	
Hedycarya arborea		porokaiwhiri, pigeonwood	
Hoheria sexstylosa		houhere	
Knightia excelsa		rewarewa	
Kunzea ericoides var. ***ericoides***		kanuka	
Laurelia novae-zelandiae		pukatea	
Leptospermum scoparium		manuka	WAIK 9188, 9189
Leucopogon fasciculatus		mingimingi	
Leucopogon fraseri			
Leycesteria formosa	(+)	Himalayan honeysuckle	
Ligustrum lucidum		tree privet	
Ligustrum sinense		privet	
Litsea calicaris		mangeao	
Lophomyrtus bullata		ramarama	WAIK 6227
Macropiper excelsum subsp. ***excelsum***		kawakawa	
Malus domestica	(+)	apple	WAIK 12439
Melicytus micranthus			WAIK 4646
Melicytus ramiflorus subsp. ***ramiflorus***		mahoe	WAIK 6236
Metrosideros robusta	(+)	northern rata	
Mida salicifolia		maire-taike	
Myrsine australis		mapou	
Myrsine salicina	(+)	toro	WAIK 7215
Neomyrtus pedunculata	(+)	rohutu	WAIK 7216
Nestegis cunninghamii	(+)	black maire	WAIK 6221
Nestegis lanceolata	(+)	white maire	
Olearia furfuracea		akepiro	
Olearia rani		heketara	
Paraserianthes lophantha	(+)	brush wattle	
Pennantia corymbosa		kaikomako	WAIK 7230
Pittosporum eugenioides		tarata (lemonwood)	
Pittosporum tenuifolium subsp. ***tenuifolium***		kohukohu	WAIK 6216
Plagianthus regius		lowland ribbonwood	WAIK 6228, 6229
Pomaderris kumeraho	(+)	kumeraho	
Pomaderris ericifolia			
Prunus persica	(+)	peach	
Pseudopanax anomalus			WAIK 7218
Pseudopanax arboreus		whauwhaupaku, five finger	
Pseudopanax crassifolius		horoeka, lancewood	WAIK 6375
Rhabdothamnus solandri		taurepo	
Salix babylonica		weeping willow	WAIK 12149
Salix cinerea	1, 2	pussy willow	
Salix fragilis	1, 2	crack willow	
Solanum aviculare	1	poroporo	
Solanum pseudocapsicum		Jerusalem cherry	

NAME	OCCURRENCE	COMMON NAME	HERBARIUM
Solanum mauritianum		woolly nightshade	
Sophora chathamica s.s.	1	kowhai	WAIK 6211, 6215
Streblus heterophylla		taurepo	
Syzygium maire	(+)	maire-tawake	AK 170392
Ulex europaeus	1	gorse	
Vitex lucens		puriri	
Weinmannia racemosa s.s.	(+)	kamahi	
4. Monocotyledon Lianes (2) (A: 0; 1: 2)			
Freycinetia banksii		kiekie	
Ripogonum scandens		supplejack	
5. Dicotyledon Lianes (18) (A:2; 1: 16)			
Calystegia tuguriorum	(+)	pohue	
Calystegia sp. (***C. sepium*** agg.) ('pink flower' of Ogden, 1978)	1, 2	pohue (pink bindweed)	
Clematis foetida			WAIK 7231
Fuchsia perscandens	(+)		
Lonicera japonica		Japanese honeysuckle	
Metrosideros carminea	(+)	carmine rata	
Metrosideros colensoi			
Metrosideros diffusa			
Metrosideros fulgens		rata	
Metrosideros perforata		white rata	
Muehlenbeckia australis	1	pohue	
Muehlenbeckia complexa	(+)		
Parsonsia heterophylla		New Zealand jasmine	WAIK 12170
Passiflora tetrandra		kohia (New Zealand passionfruit)	
Rubus australis		bush lawyer	
Rubus cissoides		bush lawyer	
Rubus sp. (*R. fruticosus* agg.)	1	blackberry	
Rubus schmidelioides var. ***schmidelioides***		bush lawyer	WAIK 6232
6. Quillworts, Psilopods & Lycopods (7) (A:1; I:6)			
Huperzia varia			
Isoetes kirkii	?Ex (Kirk 1871)		
Lycopodium deuterodensum			
Lycopodium volubile			
Selaginella kraussiana			
Tmesipteris elongata			WAIK 12169
Tmesipteris lanceolata			
7. Ferns (46) (A: 4; I: 42)			
Adiantum cunninghamii			
Adiantum diaphanum			WAIK 7217
Adiantum hispidulum	(+)		
Anarthropteris lanceolata			
Arthropteris tenella			WAIK 6222
Asplenium bulbiferum		hen & chicken fern	
Asplenium flaccidum		hanging spleenwort	
Asplenium gracillimum			
Asplenium oblongifolium		shining spleenwort	
Asplenium polyodon			
Azolla filiculioides var. ***rubra***	1		
Azolla pinnata	1		
Blechnum chambersii			
Blechnum discolor	(+)	crown fern	
Blechnum fluviatile			
Blechnum filiforme			
Blechnum membranaceum			
Blechnum novaezelandiae s.s.	1	kiokio	
Blechnum novaezelandiae (wetland form; ***B. minus*** of NZ authors)	1,2	swamp kiokio	
Blechnum vulcanicum	(+)		WAIK 12282

NAME	OCCURRENCE	COMMON NAME	HERBARIUM
Cyathea dealbata		ponga (silver fern)	
Cyathea medullaris		mamaku (black tree fern)	
Deparia petersenii subsp. ***congrua*** (incl. ***D. tenuifolia***)			
Dicksonia fibrosa	(+)	wheki-ponga	
Dicksonia squarrosa		wheki	
Diplazium australe			
Doodia media		pukupuku	WAIK 7212
Doodia squarrosa	(+)		
Gleichenia dicarpa		tangle fern	
Histiopteris incisa		water fern	
Hymenophyllum ferrugineum			
Hymenophyllum flabellatum			
Hymenophyllum flexuosum			
Hymenophyllum sanguinolentum			
Hypolepis ambigua			
Hypolepis distans			
Microsorum pustulatum		hound's tongue fern	
Microsorum scandens		hound's tongue fern	
Osmunda regalis	2	royal fern	
Paesia scaberula		ring fern	
Pellaea rotundifolia			
Pilularia novae-zelandiae	?Ex (Kirk, 1871)	pillwort	
Pteridium esculentum		rarahu, bracken	
Pteris pendula (auct. ***P. macilenta*** of NZ authors)	(+)		
Pyrrosia eleagnifolia		leather-leaf fern	
Rumohra adiantiformis			
8. Orchids (19) (A:0; I: 19)			
Acianthus sinclairii	(+)	heart-leaved orchid	
Bulbophyllum pygmaeum			WAIK 4645
Bulbophyllum tuberculatum	(+)		WAIK 1496, 7580
Caladenia **"green column"**			
Caladenia minor	(+)		
Corybas acuminatus	(+)	spider orchid	
Corybas iridescens		spider orchid	
Corybas macranthus		spider orchid	
Corybas rivularis s.s.	(+)	spider orchid	
Corybas trilobus		spider orchid	
Dendrobium cunninghamii		pekapeka	
Drymoanthus adversus			
Earina autumnalis	(+)	raupeka (easter orchid)	
Earina mucronata			
Microtis unifolia		onion-leaved orchid	WAIK 12159
Orthoceras novae-zeelandiae			
Pterostylis banksii		tutukiwi	
Pterostylis trullifolia			
Pterostylis 'linearis'			
Thelymitra longifolia (autogamous form)			
9. Grasses (58) (A:42; I: 16)			
Agrostis capillaris	1	browntop	
Agrostis stolonifera	1, 2	creeping bent	
Aira caryophyllea	1	silvery hair grass	
Alopecurus geniculatus	1	kneed foxtail	
Amphibromus fluitans	2		WAIK 12136, 12137
Anthoxanthum odoratum	1, 2	sweet vernal grass	
Axonopis fissifolius	(1997) 1, 2	narrow-leaved carpet grass	
Briza minor	(1997) 1	shivery grass	
Bromus hordeaceus		soft brome	
Bromus willdenowii		prairie grass	
Cortaderia fulvida		toetoe	
Cortaderia jubata		pampas	
Cynodon dactylon	1, 2	Indian doab	
Cynosurus cristatus	1	crested dogstail	

NAME	OCCURRENCE	COMMON NAME	HERBARIUM
Dactylis glomerata	1, 2	cocksfoot	
Deyeuxia avenoides	1		
Dichelachne crinita		plume grass	
Digitaria ischaemum		smooth summer grass	
Digitaria sanguinalis	1, 2	summer grass	
Echinochloa crus-galli	1, 2	barnyard grass	
Echinopogon ovatus		hedgehog grass	WAIK 12346
Eleusine indica	1, 2	crowfoot grass	
Eragrostis brownii	1, 2	bay grass	
Glyceria fluitans	1	floating sweet grass	
Glyceria maxima	1	reed sweet grass	
Glyceria striata	(+)	fowl manna grass	WAIK 12290
Holcus lanatus	1, 2	Yorkshire fog	
Hordeum murinum subsp. *leporinum*		barley grass	
Isachne globosa	1	swamp millet	
Lachnagrostis filiformis	1, 2		WAIK 12171
Lachnagrostis striata	1, 2		WAIK 12138
Lolium multiflorum		Italian ryegrass	
Lolium perenne	1, 2	perenial ryegrass	
Microlaena avenacea		bush rice grass	
Microlaena stipoides	1		
Oplismenus hirtellus subsp. ***imbecillis***		bush oat grass	
Panicum capillare	1, 2	old witch grass	
Panicum dichotomiflorum	2	smooth witchgrass	
Panicum sphaerocarpon	(+)		CHR
Paspalum dilatatum	1, 2	paspalum	
Paspalum distichum	1, 2	mercer grass	
Paspalum urvillei		vasey grass	AK 185370
Pennisetum clandestinum		kikuyu grass	
Phalaris arundinaceae		reed canary grass	WAIK 12143
Poa anceps subsp. ***anceps***			
Poa annua	1, 2	annual poa	
Poa trivialis		rough-stalked meadow grass	
Poa pusilla	(+) 1		
Polypogon monspeliensis	(+)	beard-grass	
Rytidosperma racemosa			
Rytidosperma unarede			
Schedonorus phoenix	1	tall fescue	
Setaria verticillata		rough bristle grass	
Sporobolus africanus	1, 2	ratstail	
Stenotaphrum secundatum		buffalo grass	WAIK 12163
Trisetum antarcticum agg. **"ordinary"**	(+)		WAIK 12284
Vulpia bromoides	1	vulpia hair grass	
10. Sedges (58) (A: 8; I: 50)			
Baumea arthrophylla			WAIK 12281
Baumea articulata	1		
Baumea juncea			WAIK 12165
Baumea rubiginosa			
Baumea tenax			
Baumea teretifolia			
Bolboschoenus fluviatilis	1	purua grass	WAIK 12144
Bolboschoenus medianus	1	purua grass	WAIK 12349
Carex cirrhosa			CHR
Carex breviculmis	(2000) 2		
Carex dipsacea			WAIK 1748
Carex dissita			
Carex divulsa			
Carex fascicularis			
Carex flagellifera			
Carex gaudichaudiana	1, 2		WAIK 12166
Carex inversa			WAIK 12280
Carex lambertiana			WAIK 7211
Carex lessoniana			

NAME	OCCURRENCE	COMMON NAME	HERBARIUM
Carex longebrachiata		Australian sedge	WAIK 12147
Carex ochrosaccus			WAIK 7210
Carex maorica			
Carex ovalis	2		
Carex secta	1	pukio (niggerhead)	
Carex solandri			
Carex subdola	1, 2		
Carex virgata		kuawa	
Carex vulpinoidea			
Carex sp. ***geminata*** agg. (common species, leaves >2.5 cm wide)	(+) 2	rautahi (cutty grass)	
Cyperus eragrostis	1, 2	umbrella sedge	
Cyperus tenellus	1		
Cyperus ustulatus	(+) 1, 2	coastal cutty grass	
Eleocharis acuta	1, 2	spikerush	
Eleocharis gracilis	1	spikerush	
Eleocharis sphacelata	1	spikerush	
Fimbristylis velata	1, 2		WAIK 12134
Gahnia lacera			
Gahnia pauciflora			
Gahnia setifolia		mapere	
Gahnia xanthocarpa		mapere	WAIK 7219
Isolepis distigmatosus			
Isolepis fluitans	?Ex (Kirk, in Cheeseman 1925)		
Isolepis inundatus			
Isolepis marginata	1, 2		WAIK 12154
Isolepis nodosa		wiwi	
Isolepis sepulcralis			
Isolepis reticularis	1, 2		
Lepidosperma australe		three square	
Lepidosperma laterale	(+)		
Machaerina sinclairii			
Schoenoplectus tabernaemontani	1, 2	kuawa	WAIK 9179, 12184
Schoenus apogon var. ***apogon***			
Schoenus brevifolius			
Schoenus carsei	(+)		
Schoenus maschalinus	1, 2		
Uncina ferruginea		hook sedge	WAIK 1768
Uncina distans	(+)		
Uncina uncinata		maru, hook sedge	
11. Rushes (16) (A: 10; I: 6)			
Juncus acuminatus	1, 2		
Juncus amabilis			WAIK 12150
Juncus articulatus	1, 2	jointed rush	
Juncus australis	1		
Juncus bufonius	1, 2	toad rush	WAIK 12135
Juncus bulbosus		bulbous rush	
Juncus dichotomus	(1998) 2		
Juncus effusus var. *effusus*	1, 2	soft rush	
Juncus gregiflorus	2		
Juncus holoschoenus	1		
Juncus microcephalus	1		
Juncus pauciflorus			
Juncus planifolius	1		
Juncus prismatocarpus	1		WAIK 9190
Juncus sarophorus	1, 2		
Juncus tenuis	1, 2		
12. Monocotyledon Herbs (other than grasses, orchids, rushes & sedges) (23) (A: 6; I: 17)			
Alisma plantago-aquatica	1	water plantain	
Astelia grandis	(+)	kakaha, swamp lily	
Astelia solandri		kawharawhara, perching lily	
Collospermum hastatum		kawharawhara, perching lily	

NAME	OCCURRENCE	COMMON NAME	HERBARIUM
Collospermum microspermum			
Dianella nigra		turutu, blueberry	
Egeria densa	(+)	oxygen weed	
Empodisma minus	(+)	wirerush	
Iris foetidissima		stinking iris	
Lemna minor	2	duckweed	
Lepilaena bilocularis	?Ex (Kirk 1871)		
Phormium tenax		harakeke, flax	
Potamogeton cheesemanii	(+)	pondweed	
Potamogeton crispus	(+)	curly pondweed	
Potamogeton ochreatus	?Ex	blunt pondweed	
Potamogeton pectinatus	?Ex (Cheeseman 1925)	fennel-leaved pondweed	
Ruppia polycarpa	?Ex (Kirk, in Cheeseman 1925)	horse's mane weed	
Sisyrinchium iridifolium	(1997) 1	purple-eyed grass	
Spirodela punctata		purple-backed duckweed	
Sporadanthus ferrugineus	?Ex (de Lange 1986)	greater wirerush	WAIK 6468
Triglochin striata	(1997) 1, 2	arrow grass	
Typha orientalis		raupo	
Zannichella palustris	?Ex (Cheeseman 1925)		

13. Composite Herbs (46) (A: 36; I: 10)

Achillea millefolium		yarrow	
Anthemis cotula	2	stinking mayweed	
Aster subulatus	1, 2	sea aster	
Bellis perenis		daisy	
Bidens frondosa	1, 2	beggars ticks	
Carduus nutans	(+)	nodding thistle	
Carduus tenuiflorus	(+)	winged thistle	
Centaurea nigra		knapweed	
Centipeda cunninghammii	1, 2	sneezewort	WAIK 12142
Chamaemelum nobile	2	chamomile	
Chrysanthemum segetum		corn marigold	WAIK 12285
Cichorium intybus		chicory	
Cirsium arvense	1, 2	Californian thistle	
Cirsium vulgare	1, 2	Scotch thistle	
Conyza albida	1, 2	broad-leaved fleabane	
Conyza bilbaoana		Canadian fleabane	
Cotula australis	1	soldier's button	
Cotula coronopifolia	1, 2	bachelor's button	
Crepis capillaris	1, 2	hawksbeard	
Erechtites hieraciifolia	1	American fireweed	WAIK 12350
Euchiton audax	1, 2	creeping cudweed	
Euchiton involucratus	(+) 1, 2	creeping cudweed	
Euchiton limosus	(+) 1	creeping cudweed	
Euchiton sphaericum	2	Japanese cudweed	
Gamochaeta spicata	1, 2	purple cudweed	
Gamochaeta purpureum var. *purpureum*	2		
Hypochoeris radicata	1, 2	catsear	
Lactuca virosa		arid lettuce	
Lapsana communis		nipplewort	
Leontodon taraxacoides	1, 2	hawkbit	
Leucanthemum vulgare		oxeye daisy	
Matricaria dioscoidea		pineapple weed	
Mycelis muralis		wall lettuce	
***Pseudognaphalium luteoalbum* "lowland"**	(1997) 1, 2	Jersey cudweed	
Roldana petasitis	(+) seedling	velvety groundsel	
Senecio bipinnatisectus	1	Australian fireweed	
Senecio glomeratus		fireweed	
Senecio hispidulus		fireweed	
Senecio jacobaea	1, 2	ragwort	
Senecio minimus	1	fireweed	
Senecio quadridentatus	(+)	cotton fireweed	
Senecio skirrhodon	1	gravel groundsel	WAIK 12472
Senecio sylvaticus		wood groundsel	

NAME	OCCURRENCE	COMMON NAME	HERBARIUM
Senecio vulgaris		groundsel	
Sonchus asper	1, 2	puha (prickly sow thistle)	
Sonchus olearceus	1, 2	puha (sow thistle)	
Taraxacum officinale	1, 2	dandelion	
Xanthium spinosum	(+) 1	bathurst bur	WAIK 12353
14. Dicotyledon Herbs (other than composites) (179) (A: 120; I: 59)			
Acaena anserinifolia		piripiri	
Acaena novae-zelandiae	1	piripiri	
Alternanthera sessilis[1]	1, 2	nahui	WAIK 12146
Amaranthus powellii	1, 2	redroot	
Amaranthus sp.	1		
Anagallis arvensis var. *arvensis*	1, 2	scarlet pimpernell	
Aphanes inexspectata		parsley piert	
Apium nodiflorum	(+)	water celery	
Apium prostratum	(+)		WAIK 12283
Brassica oleracea		wild cabbage	
Brassica rapa subsp. *sylvestris*		wild turnip	
Callitriche muelleri	1		WAIK 12340
Callitriche petriei subsp. ***petriei***	1, 2		WAIK 12139
Callitriche stagnalis	1	starwort	
Capsella bursa-pastoris		shephard's purse	
Cardamine debilis agg. 'long style' of Pritchard (1957)			
Cardamine corymbosa agg.			
Cardamine flexuosa	(+)	wavy bitter cress	
Cardamine hirsuta		bitter cress	
Cardamine pratense		cuckoo cress	
Centaurium erythraea			
Centella uniflora	1, 2		WAIK 12287
Cerastium glomeratum	2	annual mouse-ear chickweed	
Ceratophyllum demersum	1, 2	hornwort	WAIK 12162
Chenopodium album	2	fathen	
Chenopodium ambiguum subsp. ***glaucum***	?Ex		(Kirk collection, WELT)
Conium maculatum		hemlock	
Coronopus didymus		twin cress	
Coronopus squamatus		wart cress	WAIK 12172
Crassula decumbens	(+) 2	Cape crassula	WAIK 12279
Crassula sinclarii	?Ex		(Kirk collection, WELT)
Cuscuta campestris		dodder	WAIK 12396 a,b,c,d
Cymbalaria muralis		ivy-leaved toadflax WAIK 12357	
Datura ferox		thorn apple	WAIK 12355
Daucus carota		wild carrot	
Dichondra repens agg. "flannel leaf" 1, 2			
Dichondra brevifolia agg. c.f. "slender"			WAIK 12341
Digitalis purpurea		foxglove	
Drosera binata		scented sundew	WAIK 12153
Drosera pettata *subsp.* ***auriculata***		sundew	
Duchesnea indica		Indian strawberry	
Echium plantagineum		Paterson's curse	
Echium vulgare		vipers bugloss	
Elatine gratioloides	(+) 1		
Epilobium alsinoides			
Epilobium ciliatum	1, 2	willow herb	
Epilobium nummularifolium		creeping willow herb	
Epilobium pallidiflorum	(+)		
Epilobium pubens			
Epilobium rotundifolium			
Epilobium nerteroides	(+)		
Galium aparine	(+) 1, 2	cleavers	
Galium divaricatum			
Galium palustre	1, 2	marsh bedstraw	WAIK 9180, 12173

[1] *A. philoxerioides* was recorded in 1982, however this was likely to have been a transcription error, and should be *A. sessilis*. *A. philoxerioides* has recently (2001) been found in the Whangape Stream.

NAME	OCCURRENCE	COMMON NAME	HERBARIUM
Galium propinquum	2		WAIK 12278
Galium perpusillum agg.			(Kirk collection, WELT)
Geranium molle			
Geranium solanderi	(2000)		
Glossostigma diandrum	1, 2		
Glossostigma elatinoides	2		WAIK 12158
Glossostigma cleistanthum			
Gonocarpus aggregatus			WAIK 1532
Gonocarpus micranthus subsp. ***micranthus***	1		
Gratiola sexdentata	1, 2		WAIK 12152
Haloragis erecta subsp. ***erecta***	1, 2	toatoa (fireweed)	WAIK 9185
Hydrocotyle dissecta			
Hydrocotyle elongata			
Hydrocotyle heteromeria		waxweed	
Hydrocotyle hydrophila	1, 2		WAIK 12141, 12160
Hydrocotyle moschata			
Hydrocotyle novaezeelandiae s.s.	2		
Hydrocotyle pterocarpa	1		
Hypericum humifusum		trailing St John's wort	
Hypericum japonicum agg.			WAIK 12157
Hypericum mutilum			WAIK 12347
Hypericum perforatum		St John's wort	
Lamium purpureum		red dead nettle	
Lilaeopsis novae-zelandiae	1, 2		WAIK 12161
Limosella lineata	(+)		
Linaria vulgaris		toad flax	
Linum bienne	2	pale flax	
Lobelia anceps			WAIK 12155
Lotus pedunculatus	1, 2	lotus major	
Lotus suaveolens	2	hairy birdsfoot trefoil	
Lotus tenuis			
Ludwigia palustris	1, 2		
Ludwigia peploides subsp. *montevidensis*	1, 2	primrose willow	
Lycopus europaeus	1, 2	gypsywort	WAIK 12173
Lysimachia nummularia	1	creeping jenny	
Lythrum hyssopifolium	1, 2	loosestrife	
Lythrum juncea		rose loosestrife	
Malva nicaeensis		French mallow	
Malva sylvestris		large-flowered mallow	
Medicago nigra		bur medick	
Mentha x *piperita*		peppermint	WAIK 12148
Mentha pulegium	1, 2	pennyroyal	
Mimulus moschatus		musk	
Modiola caroliniana	1	creeping mallow	
Myosotis arvensis	1, 2	field forget-me-not	
Myosotis laxa subsp. *caespitosa*	1, 2	water forget-me-not	
Myosotis scorpioides	2	water forget-me-not	WAIK 9183
Myriophyllum aquaticum	1, 2	parrot's feather	
Myriophyllum propinquum	1, 2		WAIK 12151
Myriophyllum robustum	(+)		WAIK 1308, 12352
Myriophyllum triphyllum	1, 2		WAIK 12156
Nasturtium officinale	(+) 1	watercress	
Nertera depressa			
Nertera scapanoides			
Ornithopus pinnatus		yellow serradella	
Orobanche minor	1	broomrape	
Oxalis corniculata	1	horned oxalis	
Oxalis exilis	1	creeping oxalis	
Parentucellia viscosa	1, 2	tarweed	
Pelargonium inodorum	(1997) 1, 2	kopati	
Peperomia urvilleana	(+)	wharanui	
Persicaria decipiens	1, 2	tutanawai	
Persicaria hydropiper	1, 2	water pepper	
Persicaria hydropiper × *P. persicaria*	1, 2	WAIK 12397	
Persicaria lapathifolia	(1997) 1, 2		

NAME	OCCURRENCE	COMMON NAME	HERBARIUM
Persicaria persicaria	1, 2	willow weed	
Persicaria persicaria × *P. lapathifolia*	(1997) 1, 2		
Phytolacca octandra	1	inkweed	
Polycarpon tetraphyllum	1	allseed	
Polygonum aviculare	1, 2	wireweed	
Portulacca oleracea	(1997) 1, 2	wild portulaca	
Potentilla anserinoides	(+) 1, 2	silverweed	
Potentilla reptans		creeping cinquefoil	
Potentilla strigosum			WAIK 12167
Plantago australe	1, 2	swamp plantain	
Plantago major	2	broad-leaved plantain	
Plantago lanceolata	1, 2	narrow-leaved plantain	
Pratia angulata	1	panakenake	
Pratia angulata* × *Pratia perpusilla	1		
Pratia perpusilla (7 ploid)	1		
Pratia perpusilla	1, 2		WAIK 12140, 12344
Prunella vulgaris	1, 2	selfheal	
Ranunculus amphitrichus	1	waoriki	
Ranunculus flammula	1, 2	spearwort	
Ranunculus limosella	?Ex (Kirk 1871)		
Ranunculus parviflorus		small-flowered buttercup	WAIK 12351
Ranunculus reflexus	2		
Ranunculus repens	1, 2	creeping buttercup	
Ranunculus sardous	1, 2	hairy buttercup	
Ranunculus urvilleanus	(+)		WAIK 12291
Raphanus raphanistrum subsp. *raphanistrum*		wild radish	
Rorippa amphibia	(+)	marsh-yellow cress	WAIK 4647, 9188, 9189
Rorippa palustris	(+) 1, 2	poniu (marsh-yellow cress)	WAIK 12168
Rorippa sylvestris	(+)	marsh-yellow cress	WAIK 9178
Rumex acetosella		sheep sorrel	
Rumex conglomeratus	1, 2	clustered dock	
Rumex crispus		curled dock	
Rumex pulcher		fiddle dock	
Rumex obtusifolius	1	broad-leaved dock	
Rumex sagittatus		climbing dock	
Sagina procumbens	1, 2	procumbent pearlwort	
Sherardia arvensis		field madder	
Silene gallica	1	catchfly	
Sison amomum		stone parsley	
Sisymbrium officinale		hedge mustard	
Solanum chenopodioides		velvety nightshade	
Solanum nigrum	1, 2	black nightshade	
Solanum tuberosum	(+)	potato	
Spergula arvensis		spurrey	
Spergularia rubra		sand spurrey	
Stachys sylvatica	2	hedge woundwort	
Stellaria alsine		bog stichwort	
Stellaria media		chickweed	
Stellaria parviflora			
Trifolium campestre		hop trefoil	
Trifolium dubium	(1998) 2		
Trifolium pratense	1, 2	red clover	
Trifolium repens	1, 2	white clover	
Verbascum blattaria	(+)	white mullein	WAIK 12395
Verbascum thapsus		woolly mullein	
Verbena bonariense		purple-top	
Verbena officinalis		vervain	WAIK 9181
Veronica americana		American brook lime	
Veronica arvensis		field speedwell	
Veronica persica		scrambling speedwell	
Veronica serpyllifolia		turf speedwell	

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