Past, present and future vegetation of Waimeha Lagoon, Waikanae, New Zealand, and its relation to management

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ABSTRACT

Situated in Waikanae, North Island, New Zealand, the Waimeha Lagoon, bordered by wetland vegetation, is surrounded by urban housing. In recent years invasive exotic weeds, including aquatics, are increasing their distribution, perhaps at the expense of native plant species. Vegetation patterns and their past, present and future changes were studied, based on a time-series of aerial photos, and in conjunction with field surveys, to assist in identifying future possible changes, with a view to considering appropriate management strategies.

A recent high-resolution aerial photograph from 1996 exhibited distinct vegetation patterns; their reality as communities was confirmed by ground-truthing, and a current vegetation map with ten communities was generated from a cluster analysis. Using these communities, and older aerial photographs, it was possible to create historical plant community maps and thus changes in proportions of plant communities could be evaluated.

A series of 300 random grid points was overlain on each of the three aerial photos (1978, 1986 and 1996). From these, changes in community transitional probabilities were entered into a Markovian model to predict future successional paths. The matrix predicted that: (1) natural successional processes i.e. macrophytes to divaricated plants to lowland forest, will continue into the future; (2) although the invasive weed species would fail to increase greatly in area they will be persistent; (3) when main weed species are removed from the predictive analysis, transitions to later stages of succession was accelerated.

Management should include removal of blackberry, and planting of native macrophyte species along drainage channels to outcompete aquatic exotic weeds. A buffer zone comprising of wetland plants should be created, extending the size of the wetland vegetation. In addition, public education and community involvement are important to stop harmful activities, e.g. weed dumping by residents into the lagoon environs, and to provide support for protecting the integrity of the lagoon's surrounding wetland vegetation.

INTRODUCTION

Over 70% of the world's wetlands have been disturbed by human encroachment and unsound ecological practices (Bildstein 1991), and New Zealand is no exception, with an estimated 8% of its original wetland areas left, or 0.61 % of New Zealand's total land area (Patterson and Cole 1999). Approximately 160,000ha have been lost (Newsome 1987), and many of the remaining areas have also been modified. In the past wetlands have been viewed as a nuisance, although being one of the most productive habitat types on the planet. They also perform many ecosystem services: filtering polluted water, acting as flood reservoirs, controlling erosion, stabilising and retaining sediment, recharging groundwater, purifying water, removing and retaining nutrients/toxins, supporting food chains, providing fish and wildlife habitat, and recreation and heritage values (Kent 1994). The direct and indirect value of these services in New Zealand has been estimated at over $5.5 billion per year (Patterson and Cole 1999).

Dune lakes are a very important, but now rare wetland type (Ogden and Caithness 1981), that were once common on the West Coast of the lower North Island. Smaller dune lakes support several endangered plant species and are of an ephemeral nature; they may persist for several years before disappearing altogether. At Tangimoana, Manawatu, it was found that ephemeral wetlands are incredibly dynamic in relation to water table fluctuations, and to changes in species distributions resulting from these fluctuations (Singers 1997). Larger dune lakes also have a distinct flora, and may develop into lowland coastal forest over time (Robertson *et al.* 1991), such as the remnant at Round Bush Scenic Reserve, Foxton.

The Waikanae plain on which Waimeha Lagoon appears, slowly formed from the receding of the oceans since the Holocene period of ten thousand years ago, and subsequent water infill of depressions in sand dunes. Waimeha Lagoon was part of a wetland system that once extended from Peka Peka in the north, and south to the Waikanae River (about 8 kilometres in distance). As with many other lowland areas in New Zealand, the Waikanae region has developed rapidly over the last century, and most of these wetlands have now been drained or severely disturbed.

STUDY SITE

The Waimeha Lagoon is a freshwater lake on the coast of Waikanae in the Kapiti region (Manawatu Ecological area) of the North Island (Figure 1). It is located at 175° 01' 28" E and 40° 52' 28"S in the Waikanae residential area, approximately 300 metres inland, east of Waikanae Beach (Figure 2). Waikanae receives on average 2043 sunshine hours per year and has an average yearly rainfall of 1054mm (NZMS 1980). The lagoon is mostly sheltered from the prevailing North-Westerly winds.

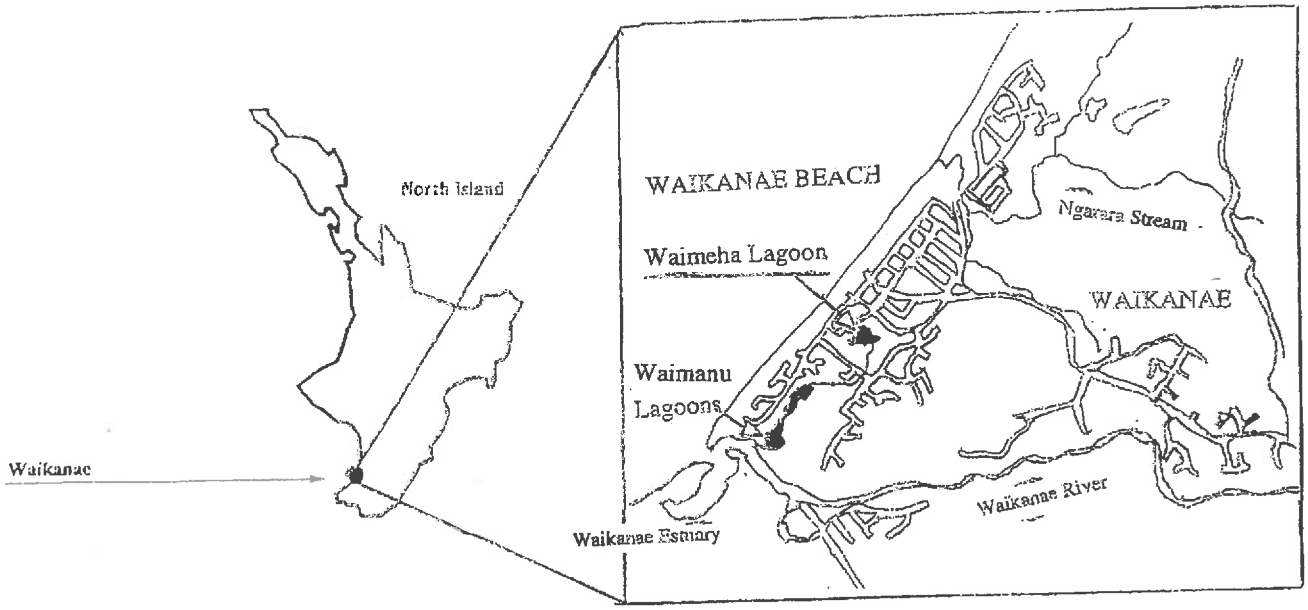

Figure 1: Location of Waimeha Lagoon on the Kapiti Coast, New Zealand

The Waimeha Lagoon drains into a channel, which then feeds the Waimanu Lagoons to the south, the watercourse finally joining the Waikanae River at the Waikanae Estuary (Figure 1). Diversion of the Waimeha Stream in 1924 took away the lagoon's major source of water inflow. The lagoon was dredged in 1974 amid fears that it would dry up completely, and a weir emplaced at the southern end to retain a consistent and higher water level. The lagoon is now currently fed by small streams draining from the coastal hills in the Waikanae Beach area and by stormwater from surrounding residential areas. In the early 1980's a boardwalk was built across the reserve and a stormwater channel was cut running adjacent to the reserve's eastern edge (Figure 3). Current management techniques involve the mowing of the grassed reserve surrounding the wetland vegetation, the periodic spraying of blackberry (***Rubus fruticosus***) and the yearly removal of the exotic weed *Apium nodiflorum* from the drainage channels. The Waimeha Lagoon is currently part of the Conservation estate, gazetted as a recreation reserve, and managed by the Kapiti Coast District Council (KCDC).

Reeds and rushes fringe the waters of the lagoon, and away from the lagoon the vegetation grades into lowland swamp forest. The vegetation of the Waimeha Lagoon covers an area of approximately 4 hectares, the lagoon waters 1.4 hectares and the surrounding grassed reserve about 3 hectares (Figure 2).

Figure 2: Overview of Waimeha Lagoon from above Waikanae Beach (Mclean and McLean 1988).

The aim of this paper is to identify past vegetation changes and attempt to predict future vegetation changes at the Waimeha Lagoon. This involves identifying successional patterns and how these are affected by invasive species at Waimeha Lagoon. By illuminating the ecological processes within the wetland, and related management issues, it should be possible to make informed recommendations concerning the maintanance, management and restoration of the Waimeha Lagoon.

METHODS

Aerial photographs of the Waimeha Lagoon of resolution high enough to use for vegetation mapping (scale 1:500 and 1:100) were obtained for 1978, 1986, and 1996, and these were used in the analysis of past vegetation changes. The vegetation types, based on variation in canopy shape visible in the aerial photos, were distinct, and appeared to represent consistent groupings or communities of plants. The boundaries visible in the aerial photo for 1996 were ground-truthed in May 1999, using distance and bearings along obvious vegetation demarcations. These vegetation types were overlain on the 1996 aerial photograph, and a vegetation map for the Waimeha Lagoon vegetation was produced.

To verify the community designations, and to identify their compositions, a series of 4 transects were laid, parallel, and 60 metres apart running from the eastern edge of the lagoon across the main area of native vegetation. The two central transect lines were sampled at every 15 metres and the two outer transects at 10 metres apart, to give a total of 44 sites (Figure 3). Using a 50 x 50cm quadrat, all species were recorded in June 1999 (see Appendix I for species list). For each species, cover was estimated visually in the following shoot cover classes: (1) less than 1 %; (2) between 1 and 10%; (3) 11-25%; (4) 26-50%; (5) greater than 50% cover. Holes approximately 20cm x 20cm by 50cm deep were dug at each site and soil horizons and quality of drainage were recorded (Appendix II). Five drainage classes were used: (1) standing water; (2) water rushing into the newly dug hole; (3) water rising slowly up from the bottom of the hole; (4) wet to damp soil; (5) well drained soil (see Appendix II for raw data).

A canonical correspondence analysis was performed using the CANOCO programme, with the environmental data (e.g. drainage, soils, species diversity) superimposed on the axes, and formed by the integration of such data with the species cover class data. Species cover classes for each community were averaged, using the middle value for each cover class range, providing values for species abundance, and native/exotic species ratios for each community. Environmental variables were also expressed on a per community basis.

The species' cover classes were also entered into the SYSTAT computer programme and a similarity matrix linking every pair of sampling sites was derived using average linkage. Clusters of sample sites were then formed using the Euclidean distance metric (comparing samples on root mean squared distance). This cluster diagram, initially accepted at the 11 community level, was then matched with the communities identified along the path of the transects from the 1996 aerial photographs. Ten communities, recognisable on the aerial photographs as well as in the field, were finally identified (see Results). The finalised communities were then used in the subsequent analysis of the three aerial photographs. The area of each community type was calculated, and changes in areas for each time period (1978-1986, and 1986-1996) were derived.

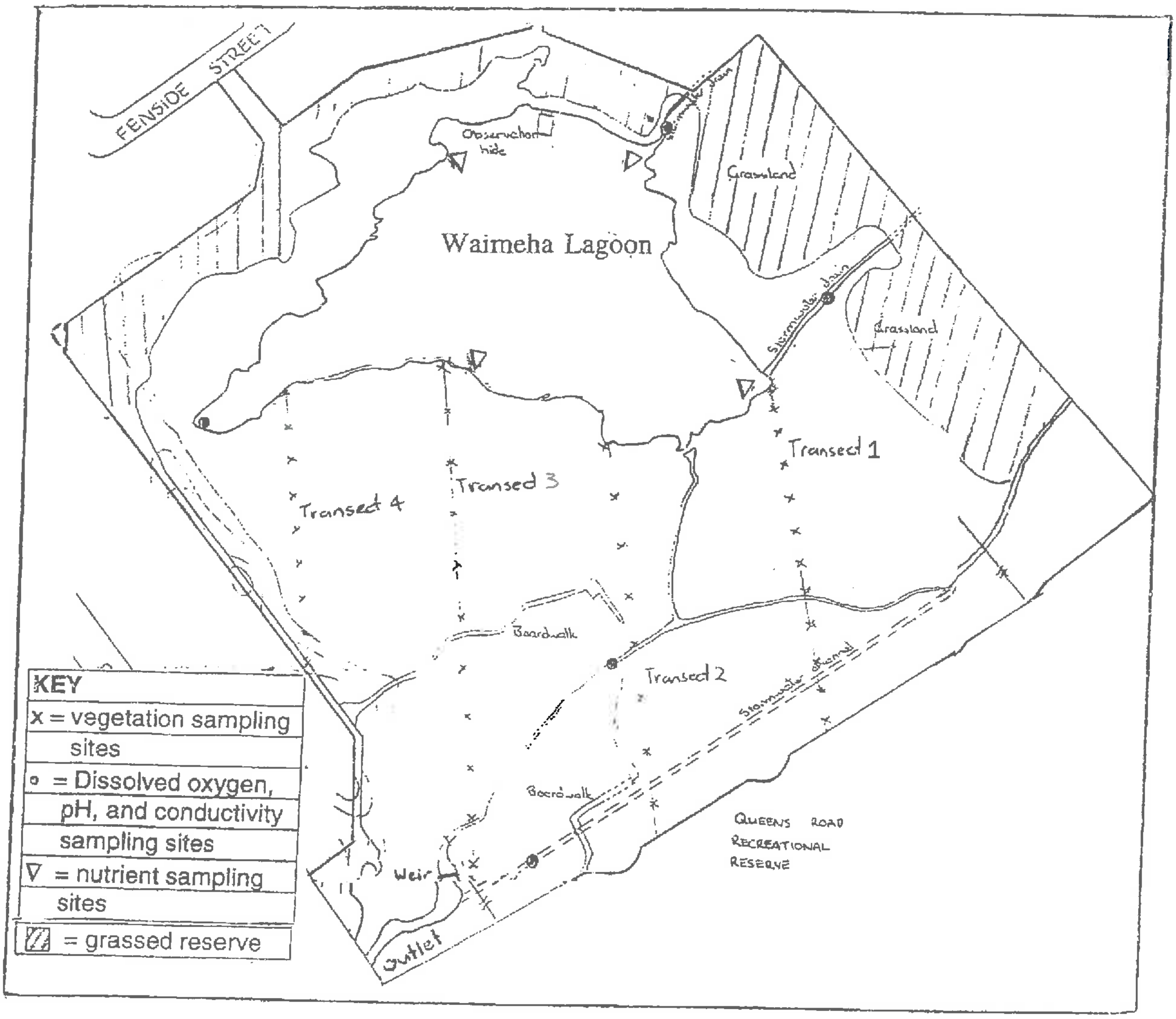

Figure 3: Stylised map of Waimeha Lagoon showing transect lines and various sampling sites

The direction of vegetation change in the main vegetated area of the wetland vegetation was analysed. The north-western perimeter of the lagoon, which is bordered by the managed grass domain abutting onto residential property, and areas of known disturbance such as the boardwalk and recent drainage channel, were not included in the analysis, because these were influenced by human management and disturbance. It appears from the photographs that the lagoon borders had also undergone various management changes, so these areas were also excluded.

A total of 313 points were sampled on grids overlain on each of the aerial photos, and from these points transition values were generated between each community for each time period. These values record the probability that a community present at a particular spot persisted until the next sampling period, or instead, changed into another community (Appendix III). Transition probabilities for each period (1978-1986 and 1986-1996) were entered into a community transition matrix and the values for each period were correlated ($R^2 = 0.489$). The *Apium nodiflorum* invasion event of about 1980 dampens the correlation, and when communities and transitions including *A. nodiflorum* were excluded from the analysis the value is higher ($R^2 = 0.612$).

Multiplying the current proportions of communities (i.e the current state matrix) by the probabilities that these will persist over time generates a model prediction of the proportions of each community at the same designated future time. Then the current state matrix and the transition probability matrix were manipulated to reflect potential management practices such as the elimination of particular weedy species (see Results for details).

RESULTS

General environmental parameters

Most of the soils were wet to very wet in the transect sampling sites, indicating a very high water table in the lagoon area (Appendix II). A rising water table and slight increase in area under water was observed in periods of very high rainfall. Dissolved oxygen was consistently very low in the slow moving channels at Waimeha Lagoon, and pH values ranged around neutral (6.6 to 7.4). Nutrient levels at the Waimanu Lagoons are substantially lower than the levels at Waimeha Lagoon (Table 1). Nitrogen levels are also relatively high in the Waimeha Lagoon.

Environmental Parameters	Waimeha Lagoon	Upper Waimanu	Middle Waimanu	Lower Waimanu
ф Dissolved oxygen (mg/ml)	6.53			
ф Conductivity	517			
ф pH	6.53			
*Ammonia nitrogen (g/m^3)	1.5	0.11	0.08	0.01
*Nitrite (g/m^3)	0.004	0.033	0.012	0.008
*Nitrate (g/m^3)	0.25	0.196	0.074	0.071
*Soluble Reactive Phosphorous (g/m^3)	0.25	0.16	0.03	0.1
*Total P (g/m^3)	0.38	0.28	0.16	0.21
*Total Kjeldahl N (g/m^3)	2.53	0.94	1.03	1.03

Table 1: Nutrients, dissolved oxygen, pH and conductivity at Waimeha and Waimanu Lagoons. ф = mean values of 6 measurements around Waimeha lagoon. * = Means recorded by Keesing (1999). See Figure 3 for location of sampling sites.

Environmental relationships between species

From the results of the CANOCO analysis, *Apium nodiflorum*, *Azolla rubra*, swamp willow weed and *Isolepis nodosa* were all closely associated with organic, peaty and wetter soils (Figure 4). Mahoe, taupata, *Muehlenbeckia* and bracken were all associated with the presence of a distinct leaf litter layer (LFH). Members of the Divaricate community, i.e. flax, bracken, *Olearia solandri* and *Coprosma rhamnoides*, are found in a group associated with blackberry, tall fescue and Japanese honeysuckle, and influenced by dryer soils. Also of note is a large group of exotic grasses and weeds related to the wet soils of the lagoon.

However there was relatively poor distinction between community types, and a cluster analysis was preferred to form clear vegetative groupings.

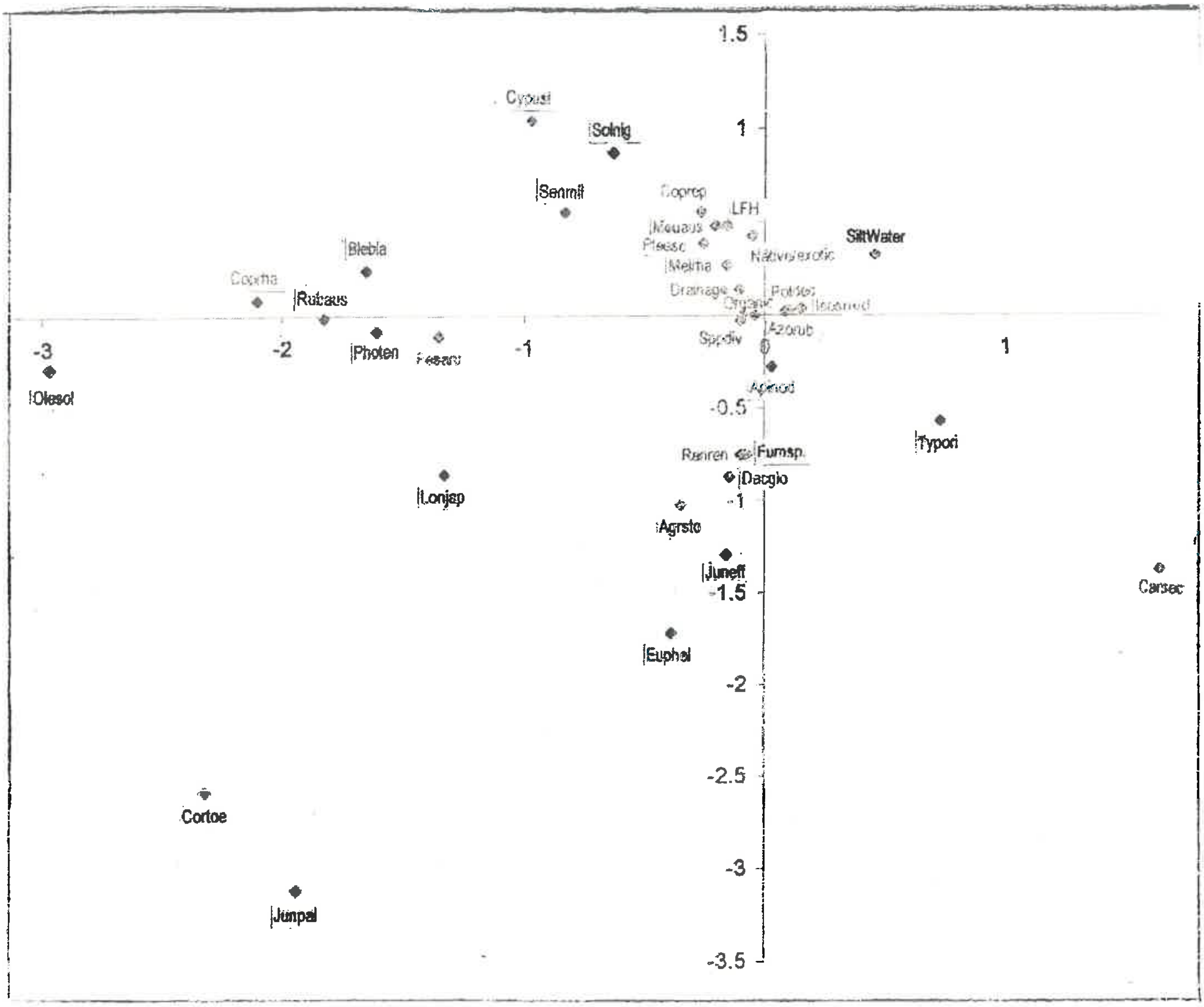

Figure 4: Biplot of plant species in ordinations in space, with vectors depicting influential environmental variables. Species are in six letters codes.

Identification of ground-truthed communities

The SYSTAT dendrogram (Figure 5) linked the quadrats on the basis of the similarities in species and was accepted at a level of 11 vegetation types or 'communities' comparable with the level of differentiation perceived in the aerial photographs.

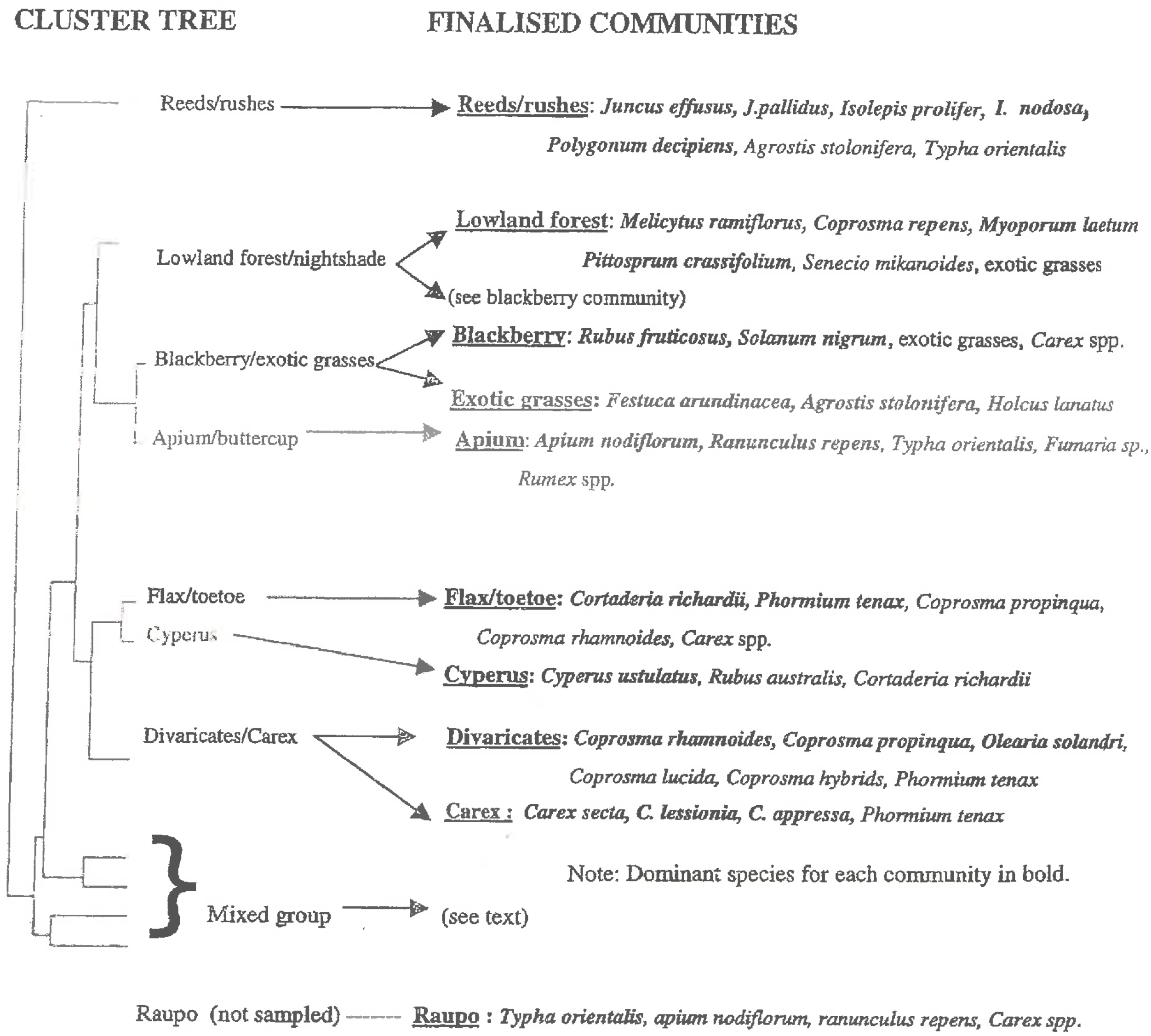

Figure 5: Cluster analysis of quadrats with finalised plant communities. The cluster diagram was generated from field surveys, and finalised communities represent those accepted for use on aerial photographs. The arrows represent relationships between the two based on interpretations of the sites from the aerial photographs.

The Reed/rush community of the water's edge is readily identifiable from the aerial photographs and was verified by ground-truthing. Lowland forest (lowland forest community), including the monocultures of nightshade that appeared in disturbed areas amongst the lowland forest, is also a distinct grouping. Although intermingling with each other, lowland forest and nightshade types are readily distinguishable on the ground and on aerial photographs. The nightshade community represents disturbed areas amongst lowland forest, and so was mapped in the Blackberry community, as nightshade has the habit and ecology of an invasive exotic weed, rather than native lowland forest.

Blackberry and exotic grass dominated vegetation is grouped together by the cluster analysis. The two do in fact grow in close association with one another - although in different abundances. Often there were grasses growing beneath the blackberry (or in association with blackberry), and the cluster analysis would identify both these as co-dominants. But from aerial photographs it is only the canopy species that are visible, and thus individual Exotic grass and Blackberry communities were retained on the vegetation maps (Figure 5).

Figure 6: Blackberry community surrounded by lowland forest.

The exotic Apium/buttercup and Flax/toe communities on the dendrogram retained their integrity in the aerial photographs (Figure 7). The next cluster, Cyperus, also retained its integrity in the photographs (Figure 8)

Figure 7: Apium/ buttercup and Flax/toetoe communities. Note the emerging raupo.

Figure 8: Thick swathes of *Cyperus ustulatus* in front of Lowland forest community

Figure 8: *Carex* at the north-eastern side of the lagoon.

Figure 9: Divaricate community on the left of the 1982 drainage channel. Note the *Olearia solandri* flowering in the foreground. The right side of the channel is where the excavated sand from the drainage project was dumped. It is now dominated by exotic weeds and grasses.

The Carex and Divaricate communities were grouped together as one cluster in the analysis. *Carex* sedges are often found in close association on the ground, especially with flax (also a large component of the Divaricate community). In a study at Taupo Swamp in Plimmerton, (Bagnall and Ogden 1981), one community also comprised of divaricates and *Carex*. Although the two types do often appear together in Waimeha lagoon there are places where carex clumps appear without divaricates (Figure 9). These are also quite distinct on the aerial photographs, and so were separated in the vegetation mapping process.

The bottom four branches of the dendrogram comprised only 6 sites. These groups had either several dominant species (cover class 1) or no dominant species. On the ground they were identified as 4 different groups (lowland forest, divaricates, exotic grasses and carex). Quadrats in the cluster analysis were grouped into communities according to presence/absence and cover class, regardless of life form. When assessing the vegetation here it was considered sensible to designate the tallest dominant species as being indicative of the community type, as only these species are visible on aerial photographs. Thus sites on this portion of the dendrogram were assigned to previously identified communities. Raupo from the band that runs parallel to the lagoon's edge was not included in the field survey, and so did not figure in the cluster analysis. Raupo community was retained in mapping as it is both distinct on the ground and on aerial photographs (Figure 10). This gives a final total of ten communities.

Figure 10: The band of raupo at the northern end of the lagoon.

Changes in proportions of communities

From the aerial photographs it was possible to estimate the changes in area of each community over time. The subsections (Figure 11) show that the open water areas have increased in size since the emplacement of the weir in the early 1980's. In 1978 the area was largely Exotic grasses and Blackberry, with small patches of Flax/toetoe, and Lowland forest (in the right hand side of the images: Figure 11). By 1986 Lowland forest and Flax/toetoe had increased, while Carex increased its range, and exotic communities diminished. By 1996 there were two new patches of Lowland forest, and the right hand patch has increased in size (Figure 11). In conjunction with the rising water table Carex displaced Exotic grass. The area of the domain (top right corner) has been increasingly enlarged by management between 1978 and 1996, leaving only a narrow strip between the grassed borders and the lagoon's waters.

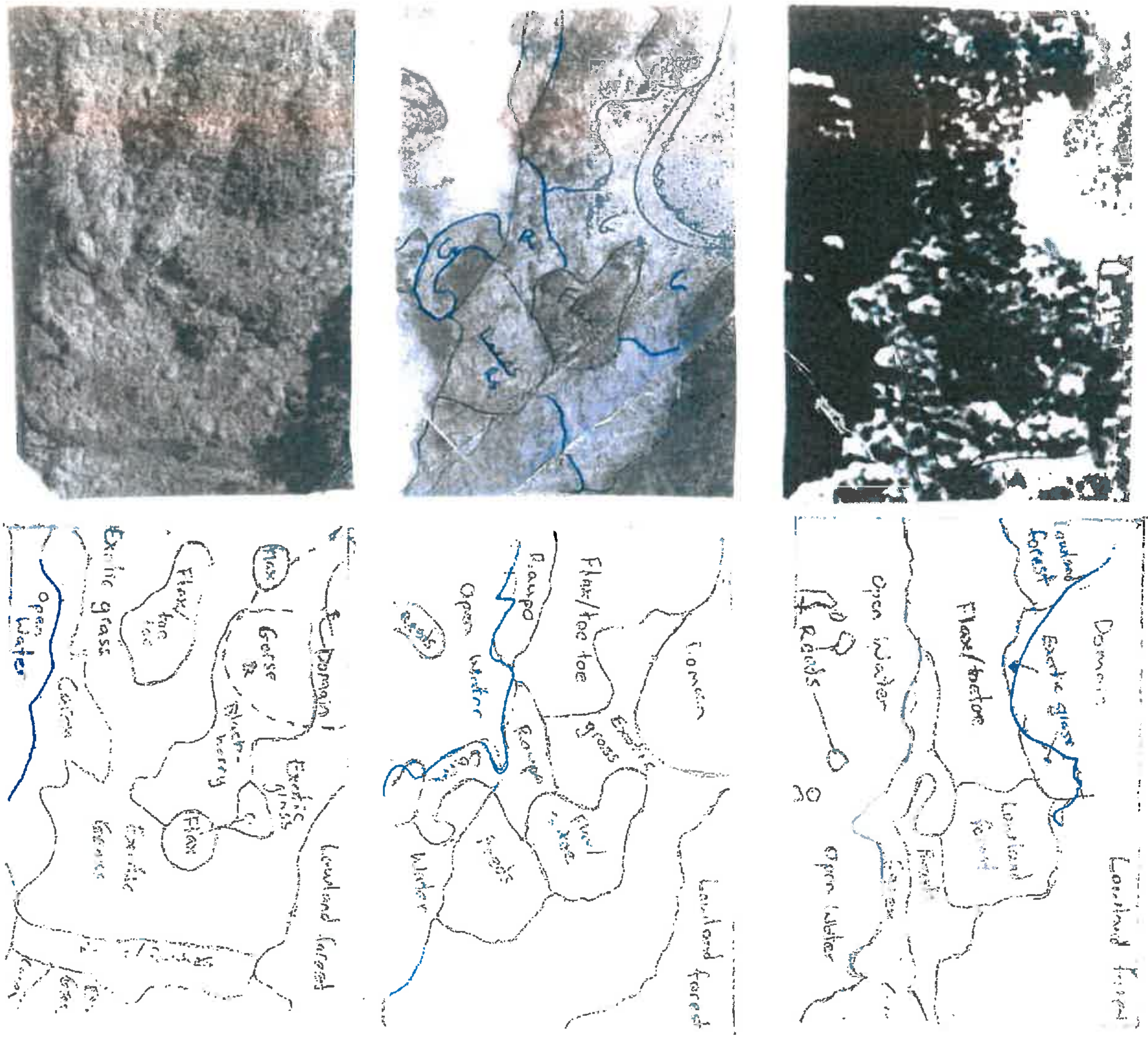

Figure 11: Subsection of the aerial photographs of 1978, 1986, and 1996, with traced communities underneath. Dotted line = current domain boundary

Environmental variables of Communities

The Apium community were always found in peaty soils (Table 2), where drainage ranged from standing water to wet soils. Reeds/rushes were always found in standing silty water. Blackberry inhabits a wide range of drainage as with exotic grasses. These two communities also have the highest diversity per 0.5m x 0.5m sample (5.3 and 4.3 species/quadrat respectively). Lowland forest is found in much drier sites (Table 2), and always occurs in conjunction with a leaf litter layer (LFH). Flax/toetoe and Divaricate communities always occur in organic soils, and their soils ranged from very wet to damp soils. Two random quadrats were taken in the Raupo communities because these were missed in the ground-truthing process; Raupo was found in very wet peaty soils. Exotic dominated communities, e.g. Blackberry, have large drainage ranges. Lowland forest, Divaricate and Flax/toetoe communities are the tallest statured communities, with the shortest vegetation being the exotic dominated communities of Apium and Exotic grasses.

		Soil type (depth in cm)				Drainage classes		Species diversity	
Communities	No. of quadrats	LFH	Organic	Peat	Silt/water	Range	Mode	Average/ Quadrat	Max. veg height (m)
Reeds/rushes	4				**30+**	**1 to 2**	1	4	1
Lowland forest	5	**2 to 10**				**4 to 5**	4	4	5
Blackberry	7	2 to 10	2 to 3			**2 to 5**	4	4.3	2
Exotic grasses	4	5	2 to 5			**2 to 5**	4	5.3	0.5
Apium/buttercup	9		**2 to 10**	**8 to 40**		**1 to 3**	2	3.8	0.8
Flax and toetoe	2		**5 to 7**			**3 to 4**	3	4	2.5
Cyperus	2	5	5			**3 to 4**	4	2.5	1
Divaricates	8		**5 to 10**	8 to 20		**2 to 4**	3	3.8	3
Carex	3		**2 to 7**	**5 to 10**		**2 to 3**	2	5	1.2
Raupo	2		2 to 3	**10**		**1 to 2**	2	4	1.5

Table 3: Summary of community environmental variables. Figures in bold signify where all sampling sites of individual communities fall into the range.

Species cover in communities

For each species in each community the cover classes were averaged using the middle value of each size class (Table 3). *Muehlenbeckia* occurred in low percentages in every community except Apium. Reed community was dominated by Isolepis nodosa, Polygonum decipiens, and to a lesser extent *Carex*. The diverse Exotic grass community has several co-dominant species such as cocksfoot (*Dactylis glomeratus*), creeping bent (*Agrostis stolonifera*), tall fescue (*Festuca arundinacea*) and sun spurge (*Euphorbia helioscopia*). Lowland forest is dominated by mahoe, *Olearia solandri* and taupata, and Divaricate community by toetoe, *Coprosma* divaricates, *Carex* and flax. Cyperus community has a native to exotic species ratio of 1.0 followed by Flax/toetoe (0.75) and Divaricate (0.73). The adventive dominated Apium and Exotic grass communities have lower ratios of around 0.3

	Reeds	Lowland forest	Blackberry	Exotic grasses	Apium	Flax/toetoe	Cyperus	Divaricate	Carex	Raupo
Typha orientalis	19		2	25	6	2		5	1.5	75
Polygonum decipiens	57							2		
Cortaderia toetoe				1		50		33	<1	
Isolepis nodosa	63									
Azolla rubra	4									
Juncus effusus	17			9					1.5	
Juncus pallidus	2				1		8	2		1.5
Carex spp.	25			2.5				21	100	
Apium nodiflorum	1.5		3	<1	63				<1	8
Fumiaria sp.				4	<1				<1	<1
Agrostis stolonifera		20		25	2				1.5	1.5
Dactylis glomeratus				6	4					
Euphorbia helioscopia				20	<1	<1		5		
Phormium tenax			<1	5.5		40		16	1.5	
Blechnum minus				9		18	50	<1	1.5	
Lonicera japonica			11			2.5		7.5		
Coprosma divaricates			11					42	12	
Cyperus ustulatus			2			8	56	5		
Rubus australis		2	55	1						
Festuca arundinacea		4	1	37.5	6			5		
Solanum nigrum		1	21	4						
Pteridium esculentum		7		2.5				<1		
Ranunculus repens			1	1	15					
Muehlenbeckia australis	1	5	<1		<1	8	<1	2	<1	<1
Olearia solandri		20						<1		
Melicytus ramiflorus		52								
Senecio mikanoides		1								
Coprosma repens		15								
Native /exotic ratio	0.66	0.5	0.45	0.31	0.3	0.75	1	0.73	0.64	0.5

Table 3 : Communities and the average cover class of each species. The cover class values are taken from the average of the mid values for each cover class sampled. Also represented for each community is a native versus exotic species ratio.

The plot of community changes over time (Figure 12) shows the rapid increase of the Apium community and decline of Exotic grasses and Raupo over the last 18 years. Lowland forest and Divaricate communities have increased over time, indicating succession. Blackberry has increased slowly steadily over time, whilst Carex and Reed communities have decreased in abundance. Cyperus has maintained a small but constant abundance, while Flax/toetoe has declined slightly in coverage.

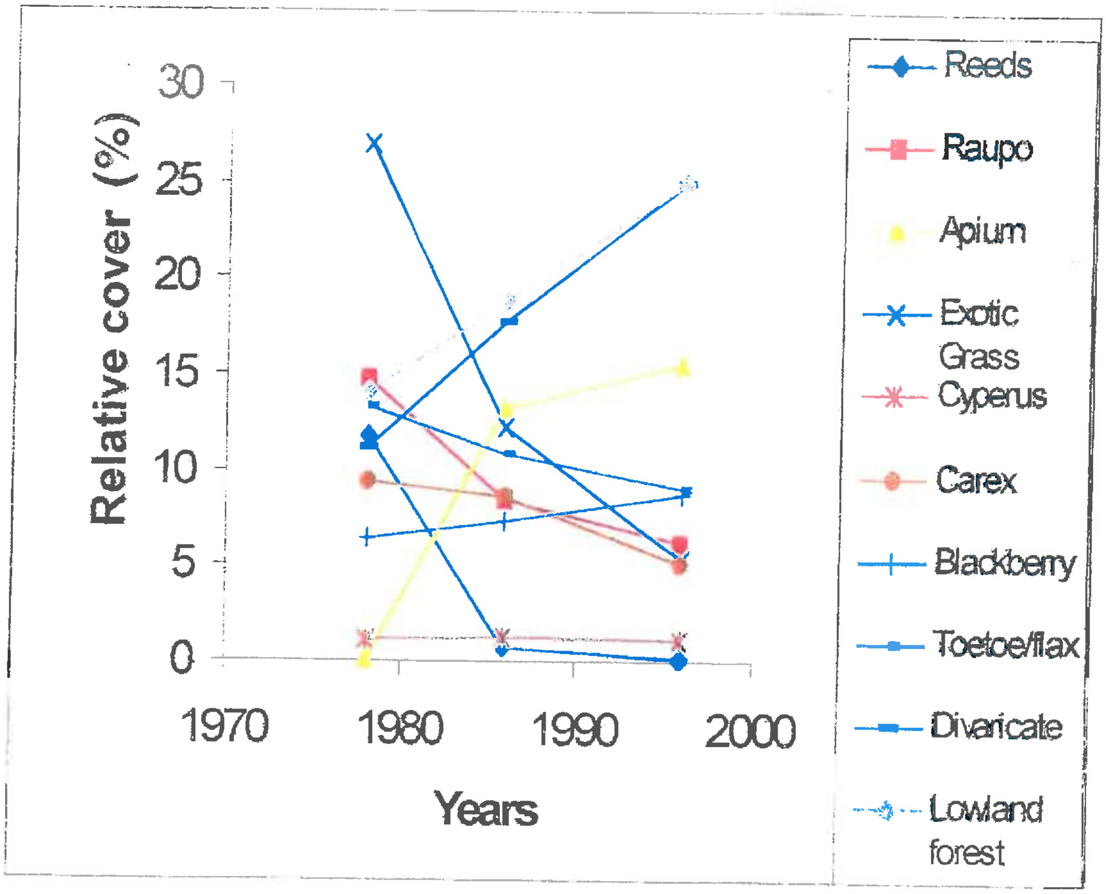

Figure 13:Changes in relative percentage of communities between 1978-1996 (as proportions of the total area of wetland vegetation at Waimeha Lagoon).

Successional trends

The current state matrix for the random point sampling, which gave the current proportions of each community concurred with the current state proportions generated from the aerial photographs ($R^2 = 0.893$), confirming the reliability of the sample size used for its generation. The current state matrix is multiplied by the transition probabilities (appendix III) generated from the Markovian Matrices (see methods). The result is a series of predictive future state matrices. Firstly, using a transition matrix consisting of transition probabilities averaged from the periods 1978-1986 and 1986-1996, the predicted future of the communities was deduced (Figure 13). The Divaricate community is predicted to remain at a high level in the natural vegetated area of the reserve, and lowland forest to increase cover to over 50%, dominating the vegetation. In contrast Raupo, Carex, and Flax/toetoe communities slowly decline. Blackberry persists at a constant level, while Apium declines over the next few decades. The minor components of the lagoon, Cyperus and Exotic grasses, remain in low proportions.

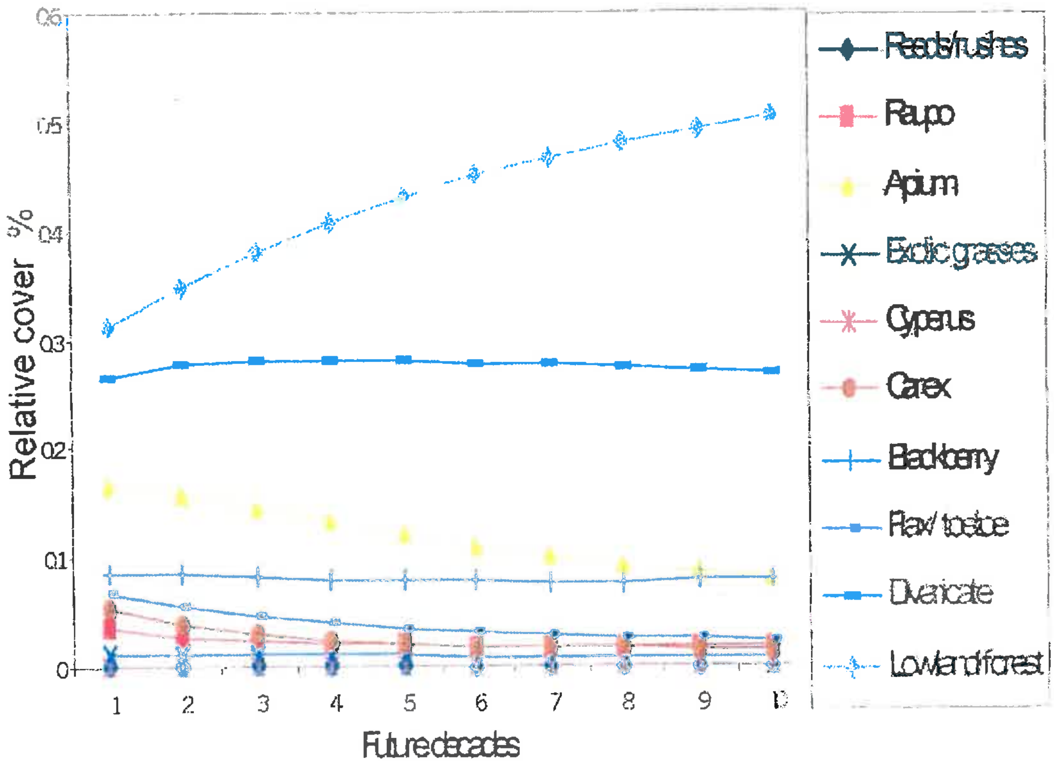

Figure 13. Predicted future changes in all communities using averaged transition probability values for 1978-1986 and 1986-1996 at Waimeha Lagoon.

The second sighting of *Apium nodiflorum* in New Zealand was at the Ngarara Stream in Waikanae in 1981 (only 2km from Waimeha Lagoon). Before the second aerial photograph of 1986 the aquatic weed had arrived into the lagoon. We modelled the changes when it was removed from the analysis. This would identify the past changes which would have occurred in the absence of this aggressive exotic, and predict the consequences of its removal on the future vegetation. To do this the current state proportions were adjusted, Apium community values being distributed proportionately between the different sized communities.

This shows that the Divaricate community remains high, and Lowland forest increases, at similar levels to when Apium is included in the model. Raupo declines, but retains a higher level in all future states compared to when Apium is included in predictions (Figure 14). Smaller communities; Cyperus, Reeds, Exotic grasses, Flax/toetoe, and Carex all decline but remain vegetative components. Blackberry is persistent and increases in distribution when Apium is excluded.

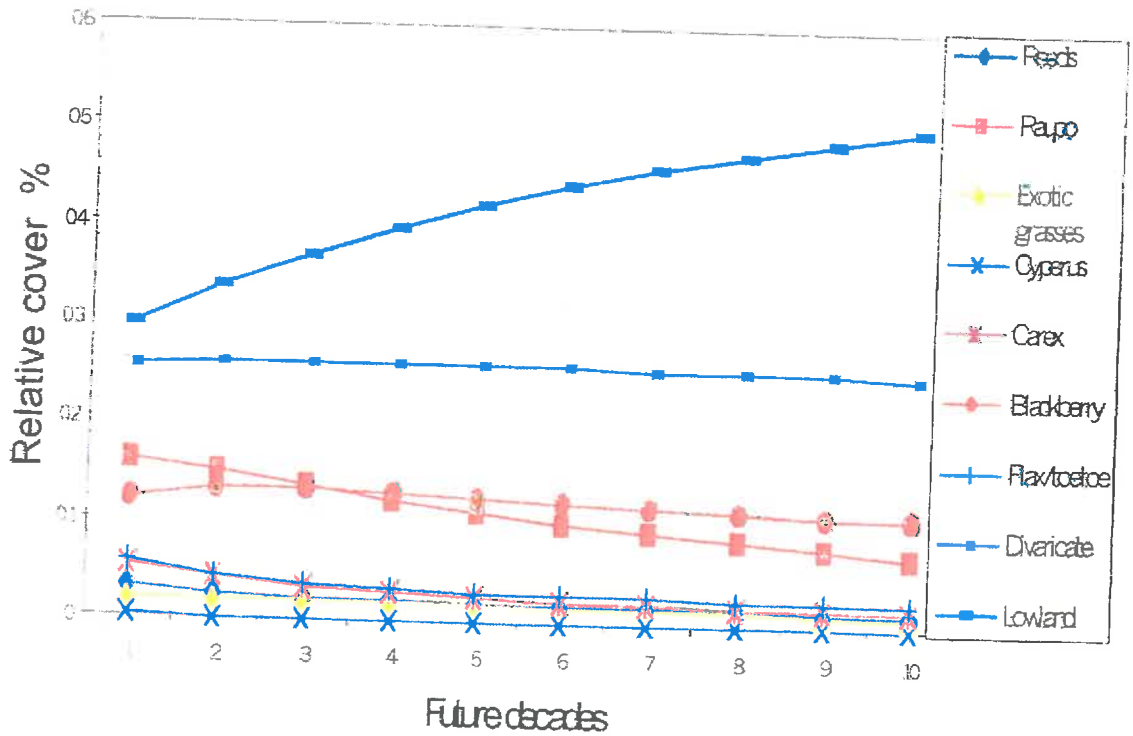

Figure 14: Predicted future change in communities at Waimeha Lagoon excluding *Apium nodiflorum*.

Blackberry was also removed from the original model to predict future vegetation changes (Figure 15). The Divaricate community again retained a high level of abundance, with Lowland forest increasing significantly when blackberry was removed. Other communities declined in a similar fashion to the other analyses, where Blackberry was included. The model predicts that nearly 90% of the wetland vegetation at Waimeha Lagoon will be either Divaricate or Lowland forest communities in 100 years, which indicates latter successional stages develop at a faster pace in the absence of the Blackberry community.

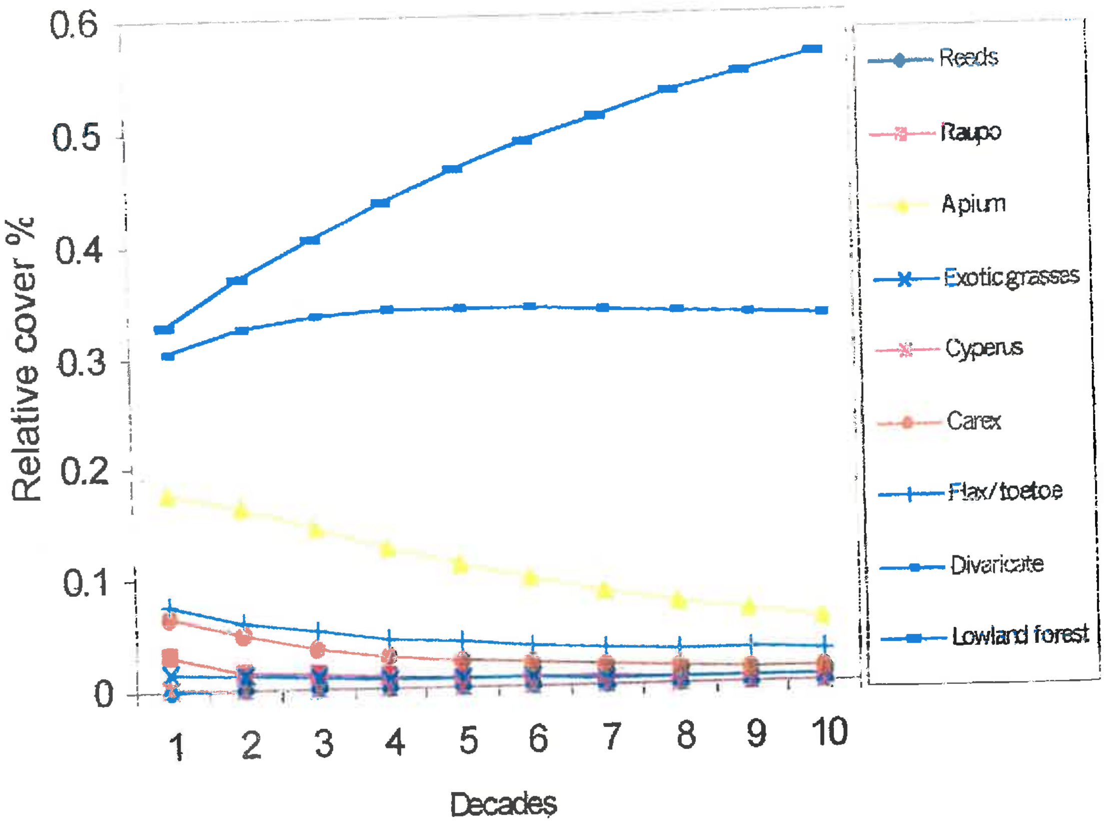

Figure 15: Predicted change in communities at Waimeha Lagoon excluding blackberry.

DISCUSSION

Wetlands have great natural beauty and perform a wide array of ecological services. As an environmental type they have suffered enormously under human exploitation in the last two centuries in New Zealand. There is now widespread public concern regarding the loss of species in wetlands. Of the more than 90% of wetlands that have been lost in this country, dune lakes and coastal wetlands have probably fared worst, due to their coastal location where there is a high density of human settlement.

Dune lakes support a wide array of distinct native animal and plant associations, and some species are dependent on these wetlands for their survival. Many coastal wetlands that have persisted have done so in the presence of disturbance, and an increasing number of exotic plant invaders have become part of their respective floras. One such dune lake is the Waimeha Lagoon, one of just a few surviving sizeable wetlands on the Kapiti Coast, North Island. A current vegetation map was produced and typical successional patterns were illuminated by assessing the past changes in vegetation structure, as well as predicting future changes from Markovian matrices. By simulating the removal of exotic species, using Markovian models, in conjunction with knowledge of their ecology, it is possible to make a prediction about the successional trends of the wetland vegetation, both in the presence and absence of problem adventive species.

Hydrological impacts

The size of the water bodies may fluctuate over time, in response to hydrological change, such as small changes in groundwater level (Ciaocetto 1996). At the Waimeha Lagoon, a body of water that has been altered by dredging and regulated by a weir, I observed large fluctuations in water level and soil saturation in times of heavy rainfall. Since the weir was emplaced in the early 1980's the water body at Waimeha Lagoon has increased in surface area by more than 10%. Bagnall and Ogle (1981) noted an increase in the water table had initiated a reversal in seral direction, with *Carex* proportions increasing in wetter areas, and flax declining. In the Waimeha Lagoon the increase in water area over 18 years, representing a rising of the water table, may have allowed for the increase in Carex community in the wetter areas proximal to the open water of the lagoon. Around 20% of the Exotic grass community transitioned to Carex community over each sampling period (1978-86 and 1986-96).

Hydrology also influences the soils of a wetland. In a South Island coastal lagoon it was found that the dune hollow sequence is highly correlated with water depth and soil organic content (Robertson *et al.* 1991). In my Waimeha study the CANOCO multivariate analysis also showed the closeness of the relationship between many water loving plants, peat soils and hydrology (e.g. *Apium nodiflorum*, *Azolla rubra* and *Isolepis nodosa*). The soils of the Waimeha Lagoon were mostly organic (O horizons). O horizons have accumulated under wet conditions, and are saturated with water for at least 30 consecutive days per year (Clayden and Hewitt 1994). Organic LFH layers, comprising of litter, fibrous and humic material were also recorded at the lagoon. These horizons are found on elevated sites and typically occur with lowland forest.

Several authors emphasize the importance of hydrology as the driving force behind wetland dynamics, including succession. Hydrological variables such as mean water level, seasonal fluctuation and surface water levels may all control vegetation structure. Dickinson and Mark (1994) found that drainage is the major determinant of vegetation distribution in a south westland bog. Water depth has also been identified altering macrophyte phenology, e.g. ramet emergence, new leaf growth and seed production (Froend and McComb 1994). Hydrological processes are important in creating spatially and temporally highly variable conditions which favour specific plant associations (Kent, 1994). Singer (1997) noted that wetland species in dune slacks occur at specific elevations, and respond to changes in the water table. At the Waimeha Lagoon Lowland forest is found at sites elevated above the water table, whereas the Reeds/rush community is always found in standing water. Cyperus is found at slightly raised microsites within the wetland vegetation, and Apium community in very wet soils, just above the water table level.

Rates of succession may rapidly increase with a lowering of the water table, such as occurred in the Murray River, Australia, due to anthropogenic siphoning of the water table (Bren 1992). Even short-term changes in hydrology are likely to have substantial and long lasting effects on wetland vegetation (van der Valk *et al.* 1994). Changes in hydrology have even been shown to reverse the direction of succession (Bagnall and Ogle 1981). In a wetland experiment in Delta Marsh, Manitoba, the number of vegetation types and species richness increased significantly in the drained wetland treatments (Thibodeau 1985). At the Waimeha Lagoon the more diverse communities were also found in drier soils, namely Exotic grasses and Lowland forest.

Many of the communities at Waimeha Lagoon, such as Blackberry, Apium, Raupo, Carex, Divaricates, and Flax/toetoe, are found over a wide variety of drainage classes, and may be able to cope with temporal water table fluctuations, and in some cases temporay inundation. Community drainage ranges then may provide flexibility in coping with subtle hydrological changes during successional processes.

Impacts of other environmental variables

The dissolved oxygen levels are very low and may be due to *Apium nodiflorum;* this plant accentuates low dissolved oxygen conditions by slowing flow, and by deoxygenation of water from its sloughed rotting stems (Wilcock *et al.* 1995). Comparing the nutrient levels from the Waimeha and Waimanu Lagoons it appears that the Waimeha Lagoon, which has comparatively higher nutrient levels, may be acting as a nutrient filter or is producing quantities of its own organic material. Stormwater runoff, fed by the surrounding urban area, may also be adding to the high nutrient levels at Waimeha Lagoon. *Apium nodiflorum* responds to nutrification, having been suggested as an indicator of high nutrient conditions (Onainda *et al.* 1986). High nutrient levels may have allowed for its expansion at Waimeha Lagoon. It has also been shown that raupo responds to increases in nutrients (Froend and McComb 1994)

Nutrification may also be internal: i.e. generated from within the lagoon. Higher nitrogen levels could possibly come from birds (Post *et al.* 1998), but low nutrient levels at Waimanu Lagoons, which also support high numbers of waterfowl, do not support this premise.

Succession

Succession may be described as the process whereby the composition of vegetation changes directionally over time (Horn 1981). Aerial photographs are especially useful for assessing successional changes in wetland vegetation as there is often a canopy monolayer, and very little understorey, at least in the early seral stages. Aerial photography is used today as a powerful source for remote sensing in land-use, including wetlands identification, characterisation, and perturbations, as a result of anthropogenic activities (C.E Tammi, in

Kent, 1994). However, there is some error in transferring communities onto past aerial photographs as it is not possible to ground-truth, as for current photographs.

Larson (1998) using aerial photographs to evaluate wetland changes in a Massechussets wetland, found that in 20 years nearly half the area changed vegetation class. Although plant community designations may differ in scale and species between sites in different studies, it was interesting to find that at Waimeha 46% of communities had changed in the 18 year sampling interval. This value was derived by assessing changes in communities, using transition points, between the 1978 and 1996 photographs. This rate of change represents a very dynamic environment in wetlands. Singers (1997) at Pukepuke, Manawatu, also found wetland vegetation very dynamic in respect to change.

Ogden and Caithness (1981) suggested the hydrosere in the dune wetland of Lake Pukepuke, was from carex-raupo-flax then to shrub swampland. King *et al.* (1990) found similar successional sequences to Waimeha in a zonation from a marsh to a riverbank, with rushes/reeds transitioning to flax and divaricating plants. Bagnall and Ogle (1981) assessed succession in Taupo swamp, Plimmerton, as the transition from divaricated to lowland forest. Ogden and Caithness (1981) thought that the extensive areas of flax and cabbage trees probably represented yet a later stage in hydroseral development. In a Westland dune hollow sequence it was found that water is initially colonised by rushes and reeds, succeeded by flax and scrub and finally by lowland forest (Robertson *et al.* 1992. Similar successional paths to these Westland wetlands were elucidated from pollen records in several Nelson lakes (Dodson 1978). These representations of succession are in concordance with the direction and process of succession at Waimeha Lagoon.

Thus in the case of a dune wetland a transition from hydrophilic macrophytes (e.g. reeds and rushes), to less water loving macrophytes (eg. flax), to shrubs (eg. divaricates), to lowland forest, is a typical successional pathway. These representations of succession are in concordance with the direction and process of succession at Waimeha Lagoon, where transitions towards lowland forest are accompanied by a decreasing wetness of the soil profiles, and in general in an increased distance away from the open water body of the lagoon. The presence of karaka and kohekohe seedlings implies that the Waimeha lagoon will eventually form a climax community of coastal lowland forest, a forest type severely limited now in New Zealand. Larger dune wetlands such as the Waimeha Lagoon thus not only become establishment sites for this forest type, but also serve as vital refuges for the rare and disparate lowland coastal forest ecosystems of New Zealand.

Disturbance and invasion

Waimeha Lagoon has native/exotic plant ratios comparable to that of other New Zealand wetlands. Of the species at Waimeha Lagoon 79 out of 115 species, or 69% of the species are exotic. This compares with the Lake Wairarapa vascular flora with 63% exotics (Ogle *et al.* 1990), Taupo swamp, Plimmerton, with 50% exotics (Bagnall and Ogle 1981), and Pukepuke Lagoon, Manawatu, with 68% (Ogden and Caithness 1982). Lowland wetlands appear to be vulnerable to invasion, in part due to the high degree of human disturbance. At Waimeha Lagoon there has been much dumping of garden weeds, facilitating the flora's exotic diversity. Wetlands in remote areas of New Zealand have far lower exotic diversity (Robertson 1992). Disturbance then appears to facilitate the aggressive invasions of exotic weeds.

Howard-Williams *et al.* (1987) stated that many adventive macrophytes may have arrived without their natural herbivores, making them more persistent. Many of the weeds are wind pollinated and are thus able to colonise wide areas rapidly. Stockey and Hunt (1994) suggested that initial establishment may be most relevant factor to subsequent vegetation diversity and composition. Thus, the original native vegetation has a profound impact on the vegetative structure and composition at Waimeha Lagoon, but once disturbed, faster colonising exotic weeds establish. These new adventive colonisers will then affect the future structure and composition of the wetland's vegetation.

The disturbance of the drainage channels has provided colonisation sites for blackberry establishment and persistence, especially on riverbanks where sand from excavated drainage channels has been piled. The creation of the drainage channel may also have facilitated the invasion by *Apium nodiflorum.* Other known areas of disturbance, such as the walkway, also have high a ocurrence of rapidly colonising exotics, namely exotic grasses and weeds.

By testing with simulations it is possible to infer how exotic dominated plant communities affect the dynamics of native plant succession in dune wetlands. From the study it was shown that although exotic weed dominated communities will not increase in size, and may in fact decrease slightly, they will be persistent even after 100 years. Simulating management techniques by removing Apium from the predictive model, Carex and Raupo communities increased by up to three times (to 11.5% and 7.7% respectively) after 100 years. These communities, which are the earlier stages of natural succession in wetlands, are thus outcompeted by the Apium community. Later stages of succession, Divaricate and Lowland forest, increase in proportion when the removal of Blackberry is simulated from the original model.

Bagnall and Ogle (1981) found that although exotic species outnumbered natives, the native species dominated the structure of the vegetation. This is also the case at Waimeha Lagoon, where the overall structure is of a native wetland succession, except within the large Apium and Blackberry communities. In a highly disturbed wetland in Bristol County, Massechussets, the processes of natural succession influenced the vegetation more than all the other anthropogenic causes combined (Larson *et al.* 1980). This agrees with the results from Waimeha Lagoon, where in spite of substantial disturbance events and weed invasion, the greatest change has been the increase of the Lowland forest community, indicating natural succession.

MANAGEMENT

Identified from the study are several key species of concern that are affecting the ecology of the Waimeha Lagoon. To manage these species in order that the native flora reverts towards a more natural state, the ecology of these pest species needs to be better known.

Apium nodiflorum was first recorded in New Zealand on 9/1/80 in Kirikiri stream in Northland. It was first observed in Ngarara Stream, Waikanae, in 1981. It is also the dominant macrophyte at the Whangamaire Stream, Northland. It is a species characteristic of zones with high nutrient concentrations and is a problem in many drainage channels in the Bay of Biscay in Spain (Onainda *et al.* 1986), and has been shown to return by vegetative regrowth in the nutrient rich canals of Portugal (Ferreira 1990). Regrowth also occurs in the drainage channels at Waimeha Lagoon after annual management clearance. In areas of *Apium nodiflorum* dissolved oxygen drops at night (Ferreira 1990). The Markovian model predicted that Apium will diminish substantially over the next 100 years, by which time the Divaricate and Lowland Forest will have taken over here, perhaps shading out the Apium community.

Rubus fruticosus

Blackberry is still ranked as the fourth worst weed species in New Zealand (Pennycook 1998), but its pest status has now declined due to improved pasture techniques and potent new herbicides. Blackberry tends towards xeromorphic substrates (Dorrington *et al* 1983), but was found in a broad range of drainage classes at Waimeha Lagoon. Williams and Timmins (1990) noted that blackberry permanently alters the structure and successional processes in native communities. Bagnall and Ogle (1981), at Taupo Swamp, Plimmerton, found that blackberry occurs in clumped association and that patches developed slowly over time. This is in concordance with its ecology at Waimeha Lagoon. Its removal in conjunction with native planting would ensure amore rapid transition to native forest.

Salix species

The spread of individual willow trees was evident from aerial photographs, and several clusters of saplings were observed on the ground. Bagnall and Ogle (1981) found this pattern also at Taupo swamp in Plimmerton. At Waimeha Lagoon it appears that where willow occurs raupo is excluded from the water's edge. The Lowland forest community has a substantial willow element. These trees may inhibit the complete transition to native lowland forest, and should be removed.

Lonicera japonica

Japanese honeysuckle was identified as increasing in distribution at Taupo swamp (Bagnall and Ogle 1981). It is beginning to be a problem at Waimeha Lagoon. In October 1999 it was noted that there had been a large increase from 5 months previously. It has a very low light compensation point (expressed as relative irradiance) of 0.9% compared to Meulhenbeckia with 2% (Barrs and Kelly 1996). This may bestow on it a competitive advantage over native plants, allowing it to grow under low light conditions unsuitable to native plants.

Conclusions and recommendations

Wetlands are developmental stages in a hydrosere and are thus changing with time. They are very dynamic systems. The Waimeha Lagoon should be allowed to continue its path of succession towards lowland forest rather than being maintained artificially in an earlier successional state. The weir prevents the drying up of the lagoon as would happen as a result of natural succession. This allows for the residents' desires to see the open water waterfowl habitat retained, whilst ensuring that the lowland forest development away from the open water will proceed. This may result in a compressing of mid-seral communities e.g. Flax/toetoe, Cyperus, and Divaricate, between the expanding lowland forest and the water's edge.

Effective wetland restoration in both scientific and political dimensions demands data derived from investigation rather than assertation derived from dogma (Wheeler 1995). The Waimeha Lagoon has several overlapping management issues so an adaptive management programme is needed. There is a drastic need for measuring the results and success of wetland restoration projects, especially in urban wetlands (Grayson *et al.* 1999). Rather than manipulating the wetland in an earlier successional state, creation of new wetlands should be considered.

The problem weed species should be removed from Waimeha lagoon so that the natural successional processes can proceed. Native plantings and the installation of a buffer zone can facilitate succession. There is a great need for the establishment of buffers of indigenous vegetation around the margins of lakes, swamps and estuaries (New Zealand Wetland Policy). Buffer zones have already been recommended to filter surrounding runoff and increase the vegetative area at Waimeha Lagoon (Vodder 1992). This would also increase the available habitat for birds and invertebrates. Large trees and shrubs may shelter the water and prevent the growth of problem aquatic plants. Reay and Norton (1999) showed that flax is a useful nurse plant, with over 22 native species and only 1 exotic found in pastoral flax clumps. Flax could then be used as an economic method to revegetate riparian inlet drains, thus shading out aquatic weeds.

Vodder (1992) suggested discouraging walking off designated tracks, and prohibiting the disposing of garden wastes. These acts are currently harming the integrity of the native flora at Waimeha Lagoon, as reflected in the low number of native versus exotic species.

Summary of reccomendations

- Removal of problem weed species (Blackberry, willows, pampas grass, Japanese honeysuckle). Monitor results.
- Native planting of riparian inlet drains to shade out *Apium nodiflorum.* Monitor results.
- Increase the size of the vegetation by planting a buffer zone around the lagoon.
- Public education and community involvement to aid in planting and to prevent garden. escapees, walking off designated tracks etc.
- Consider fencing out surrounding residential properties and exclude predatory domestic cats.

Future work

As an adaptive management approach is recommended for the Waimeha Lagoon it would be sensible to monitor any management programmes. This would involve placing a series of permanent quadrats in the lagoon as well as in the areas of resarch.. There is a need to test for the success of restoration and management techniques. For instance, if removing blackberry and planting natives, then mulched versus non-mulched treatments should be created, to measure their relative successes. When planting riparian strips in the drainage channel, small non-treatment areas should be left to illustrate the effectiveness of shading on *Apium nodiflorum.* Concurrent evaluations of the water table should be recorded in conjunction with changes in vegetation, in order to ascertain the relationship between changing vegetation patterns and changes in local hydrology. It would be of scientific interest to obtain a vegetation map in 2006 to see if the predicted changes concur with actual changes on the ground. This would be extremely useful in areas where problem exotic weeds have been removed, in order to demonstrate the effectiveness of the management technique.

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APPENDIX I: **Waimeha Lagoon Vascular Species List** (*= exotics)

Botanical name	Common name
*Achillea millefolium	Yarrow
*Agropyron repens	Couch
*Agrostis stolonifera	Creeping bent
*Allium triquetrum	Three cornered garlic
*Anthoxanthum odoratum	Sweet vernal
*Arctotheca calendula	Cape weed
Azolla rubra	Azolla
*Bellis perennis	Daisy
*Bidens frondosa	Beggars ticks
Blechnum minus	Blechnum blackspot
*Brassica rapa spp. sylvestris	Wild turnip
*Borago officinalis	Borage
*Bromus diandrus	Ripgut brome
*B. willdenownii	Prairie grass
*Callitriche stagnallis	Starwort
*Calystegia sepium	Bindweed
*Canna indica	Canna Lily
*Capsella bursa-pastoralis	Shepherds purse
Carex appressa	Carex
C. lessoniana	Carex
C. secta	Carex
*Chenopodium album	Fathen
*Conyza canadensis	Canadian fleabane
*C. floribunda	Broadleaved fleabane
Coprosma propinqua	Mingimingi
C. repens	Taupata
C. rhamnoides	Coprosma
C. robusta	Karamu
Cortaderia richardii	Toetoe
*C. selloana	Pampas grass
Corynocarpus laevigatus	Karaka
*Crepis capilliaris	Hawksbeard
*Crocosmia x crocosmiifolia	Montbretia
Cyperus ustulatus	Umbrella sedge
*Dactylis glomeratus	Cocksfoot
Dicksonia squarrosa	Wheki
Dysoxylum spectabile	Karaka
*Elytrigia repens	Couch
Entelea arborescens	Whau
*Epilobium sp.	Willow herb
*Euphorbium helioscopa	Sun spurge
*E. peplus	Milkweed
*Festuca arundinacea	Tall fescue
*Ficus sp.	Fig
*Fumaria vulgaria	Fumaria
*Galium aparine	Cleavers
*Geranium dissectum	Cut-leaved cranesbill
*G. molle	Dove's foot cranesbill
*Gnaphalium traversii	Cudweed
*Hedychium flavescens	Wild ginger
Histiopteris incisa	Water fern
*Holcus lanatus	Cocksfoot
Hydrocotyle novae zeelandiae	Hydrocotyle
*Hypochaeris radicata	Catsear
Isolepis nodosa	
*I. prolifer	

*Juncus effusus	Soft rush
J. pallidus	Large rush
*Lactuca virosa	Acrid lettuce
*Lagarus ovatus	Harestail
Lemna minor	Duckweed
*Leontodon taraxacoides	Hawkbit
*Lepidium sp.	Narrow-leaved cress
*Lolium perenne	Ryegrass
*Lonicera japonica	Japanese honeysuckle
*Lotus pedunculatus	Lotus
*Lupinus arboreus	Tree lupin
*Lycium ferocissimum	Box thorn
*Malva sylvestris	Large flowered mallow
Macropiper excelsum	Kawakawa
*Medicago lupulina	Black medick
Melicytus ramiflorus	Mahoe
*Mentha sp.	Mint
Microsorum pustulatum	Hound's tongue fern
Muehlenbeckia australis	Large leaved muehlenbeckia
M. complexa	Wireweed
*Nasturtium microphyllum	Watercress
Olearia solandri	Shrub daisy
*Oxalis sp.	Oxalis
*Paraserianthes lophantha	Brush wattle
Passiflora mollisima	NZ banana passionfruit
Phymatosorus pustulatus	Hound's tongue fern
*Phytolacca octandra	Inkweed
Pittosporum crassifolium	Karo
P. tenuifolium	Kohuhu
*Plantago lanceolata	Narrow-leaved plantain
*P. major	Broad-leaved plantain
*Plectranthrus ciliatus	Plectranthrus
*Poa annua	Annual poa
*Polygonum decipiens	Swamp willow weed
*Populus alba	Silver poplar
*Potentilla anglica	Creeping cinquefoil
Pseudopanax arboreus	Pseudopanax
Pteridium esculentum	Bracken
*Ranunculus parviflorus	Small-flowered buttercup
*R. repens	Creeping buttercup
*R. scleratus	Celery-leaved buttercup
*Rubus fruticosus	Blackberry
*Rumex conglomeratus	Curled dock
R. flexuosus	Native dock
*R. obtusifolius	Broad-leaved dock
*Salix cinerea	Grey willow
*S. fragilis	Crack willow
*Senecio mikanoides	German ivy
*Silene gallica	Catchfly
*Solanum nigrum	Nightshade
Sophora tetraptera	Kowhai
*Tropaelum majus	Garden nasturtium
*Trifolium dubium	Suckling clover
*T. fragiferum	Strawberry clover
*T. repens	White clover
Typha orientalis	Raupo
*Ulex europaeus	Gorse
*Vicia sativa	Vetch
Wolffia australiana	Watermeal
*Zantedeschia aethiopeca	Arum lily

APPENDIX II

	T1A	T1B	T1C	T1D	T1E	T1F	T1G	T1H	T1I	T1J	T1K	T1L
Silt & Water	30	0	0	0	0	0	0	0	0	0	0	0
Organic	0	10	7	67	17	10	7	7	8	7	10	80
LFH	0	0	0	0	0	0	0	0	0	0	0	0
Peat (Om)	0	10	10	0	0	0	0	0	0	0	0	0
Drainage	1	2	2	3	3	4	3	3	2	4	4	3

	T2A	T2B	T2C	T2D	T2E	T2F	T2G	T2H	T2I
Silt & Water	30	0	0	0	0	0	0	0	0
Organic	0	7	8	2	2	8	5	0	5
LFH	0	0	0	0	0	0	0	4	0
Peat (Om)	0	20	20	10	10	10	10	0	20
Drainage	1	2	2	3	3	2	2	4	3

	T3A	T3B	T3C	T3D	T3E	3F	T3G	T3H	T3I	T3J	T3K	T3L	T3M
Silt & Water	30	0	0	0	0	0	0	0	0	0	0	0	0
Organic	0	2	12	10	10	10	12	16	15	10	15	5	5
LFH	0	0	0	0	0	5	0	0	0	0	0	5	2
Peat (Om)	0	8	6	0	0	0	8	30	30	40	0	0	0
Drainage	1	2	2	2	3	4	3	2	2	2	3	4	4

	T4A	T4B	T4C	T4D	T4E	T4F	T4G	T4H	T4I	T4J
Silt & Water	30	0	0	0	0	0	0	0	0	0
Organic	0	15	15	5	10	5	5	5	5	5
LFH	0	0	2	5	5	10	10	10	10	10
Peat (Om)	0	0	0	0	0	0	0	0	0	0
Drainage	1	3	4	3	4	4	4	4	4	4

APPENDIX III Transition matrices

Transition matrix for changes from 1978 to 1996										
	a	b	c	d	e	f	g	h	i	j	Sum
a	0	0	0.5	0.25	0	0.25	0	0	0	0	1
b	0	0.232	0.196	0.018	0	0.232	0.036	0.196	0.054	0.036	1
c	0	0	0	0	0	0	0	0	0	0	0
d	0	0.143	0.334	0.143	0	0.179	0	0.078	0.041	0.041	1
e	0	0	0	0	0	0	0	0.4	0	0.4	1
f	0	0.034	0.173	0.034	0	0.346	0.034	0.103	0.242	0.034	1
g	0	0	0	0.067	0	0	0.866	0	0	0.067	1
h	0	0.024	0	0	0	0.024	0.049	0.489	0.317	0.073	1
i	0	0	0	0	0	0	0	0.059	0.823	0.118	1
j	0	0	0	0	0	0	0	0	0.057	0.943	1

Transition matrix for changes from 1986 to 1996										
	a	b	c	d	e	f	g	h	i	j	Sum
a	0	0.5	0	0	0	0.5	0	0	0	0	1
b	0	0.192	0.346	0	0	0.231	0.038	0.115	0.078	0	1
c	0	0.04	0.806	0.044	0	0.022	0	0.044	0.044	0	1
d	0	0.125	0.25	0	0	0.198	0.069	0	0	0.358	1
e	0	0	0	0	0	0	0	0	0.333	0.667	1
f	0	0	0.14	0	0	0.461	0.049	0.14	0.14	0.07	1
g	0	0.105	0	0.052	0	0	0.632	0	0.053	0.158	1
h	0	0.022	0.044	0.022	0	0	0.111	0.467	0.178	0.156	1
I	0	0	0	0	0	0	0.018	0.018	0.86	0.104	1
j	0	0	0	0	0	0	0.039	0	0.039	0.922	1

a = Reed/rushes
b = Raupo
c = Apium
d = Exotic grasses
e = Cyperus
f = Carex
g = Blackberry
h = Flax/ toetoe
I = Divaricate
j = Lowland forest