The dynamics of temporary wetlands in dune slacks at Tangimoana, Manawatu, New Zealand, with special reference to the endangered sand spiked sedge, *Eleocharis neozelandica* Kirk (Cyperaceae).

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Contents

Thesis Abstract

Parabolic dunes are a feature of the Manawatu, New Zealand coastline. Moving inland, the dunes form temporary wetlands in deflation hollows (dune slacks) on their seaward side. One of the few remaining natural dune systems left in the Manawatu is located south of the Rangitikei River mouth at Tangimoana, the "Tangimoana dump dunes", a proposed DoC reserve. The area contains excellent examples of temporary wetlands in dune slacks, with early successional vegetation well represented. This vegetation is being eliminated by larger wetland plants and is unable to colonize new habitat, as dune stabilization prevents its formation.

The vegetation of the proposed reserve was sampled and vegetation patterns were related to environmental factors. Foredune, dune plain, slack, marram dune, shrub dune and grassland communities were identified. A low species diversity was found, which included a high proportion of exotic species in the grassland, shrub and marram dune communities. The low number of communities and species richness may be related to the area's youth and the dune's dynamic nature.

Water table fluctuations were monitored in two temporary wetlands, which contained the endangered sand spiked sedge, *Eleocharis neozelandica*, an early successional species. The water table fluctuations were directly related to rainfall and season. A high winter and spring water table in 1995 resulted in dramatic changes in the distributions of some dune slack plants. Control and exclosure plots were used to assess the effects of rabbit browse on the dune slack vegetation. These plots also provided valuable information of the vegetation change to water table heights. Species more suited to permanently wet locations increased greatly, while species suited to more temporary wet areas moved higher in elevation, to around the winter high water line.

Two endangered plants of the Manawatu dunelands, *Eleocharis neozelandica* and *Pimelea* "Turakina" were cultivated and then established at the Tangimoana dump dunes. *Pimelea* "Turakina" appears to be well adapted to the Manawatu dune lands and produced abundant seedlings at Tangimoana. Creation of deflation hollows for *E. neozelandica* habitat was undertaken. *E. neozelandica* was planted in the constructed hollows at three separate elevations, and survived winter submergence at the medium and high elevation sites, of at least seven months at the medium site, and appears to be a valuable and effective management tool for the conservation of dune slack species. The tolerance and growth of *E. neozelandica* and other dune slack species in relation to sand burial, waterlogging and submergence was studied in controlled experiments. They appear to be generally intolerant of sand burial, but all survived submergence and thrived in waterlogged conditions.

Temporary wetlands in dune slacks at the Tangimoana are incredibly dynamic in relation to the water table fluctuations, and changes in species distributions resulting from them. Management solutions need to be active and address these results in order to maintain the indigenous flora of the area.

Chapter one

Introduction

History of the Manawatu dunes

The Manawatu Ecological region contains a large area of sand country, known as the Foxton Ecological District, encompassing 1,100 km^2 (Ravine 1992). It is the most extensive sand dune system in New Zealand (McEwen, 1987), and was formed (and is still forming) by accretion of sediment onto the coastline, from the region's rivers. The Manawatu coastline has accreted approximately 4 km since the modern sea level was attained 6500 years ago (Muckersie and Shepherd 1994); annual rates of greater than 1 metre have been reported (Hesp pers.comm). The rate of accretion has increased since European occupation, and is thought to be a result of increased erosion from the deforested pastoral hinterland. Sediment carried in these rivers is derived from as far afield as the Taumarunui area (Whanganui River catchment), though the greater part of this sediment is sourced from the Tararua, Ruahine and Kaimanawa mountain ranges, and from the volcanoes of the Tongariro National Park. The topography of the sand country has been shaped by three phases of major sand dune building over 6,500 years, with large mobile parabolic dunes. The oldest phase occurred from 6500 to 4500 BP, the second phase occurred over approximately 3500 to 1300 BP and the last phase (probably initiated by human disturbances) occurred during the last 1000 years (Muckersie and Shepherd 1994). Most of the region now contains stabilized parabolic dunes, though a small area of rapidly accreting and dynamic dunes occur near to the coast.

Dunes of the Foxton Ecological District are naturally dynamic and move inland from the coastline in a predominately south easterly direction, driven by the prevailing north-westerly wind. The dunes are U shaped or parabolic, with the trailing arms running toward the sea in a north-westerly direction. Moving parabolic dunes on the Manawatu coast are arguably the most dynamic and mobile dunes of any in the world with rates of migration recorded at greater than 73 metres per year (Hesp pers com.). Dunes stop moving when the wind speed decreases and the dune runs out of sand.

Parabolic dunes form from an initial disturbance to the fore dune vegetation. The fore dune sand binding vegetation holds most of the sand firmly though a little sand escapes and is blown inland. When the sand binding fore dune vegetation is damaged, the prevailing on-shore north westerly wind further erodes this damage has occurred, creating a hole in the fore dune where the vegetation is unable to hold the sand in place. The hole enlarges as more sand is blown through it and over the fore dune, until eventually a large hole has been created in the foredune down to the water table. The sand blown inland forms a long elliptical sand ridge, running in the direction of the prevailing wind, which later forms into a parabolic dune, with a sand plain between two trailing arms. The fore dune gradually repairs itself as sand binding plants, for example *Spinifex* and *Desmoschoenus spiralis* (pingao) establish and accumulate sand.

On the seaward side behind moving parabolic dunes, a low lying depression or deflation hollow forms, where sand is stripped from the hollow down to the summer (lowest) water table. A sand of small undulating deflation hollows and ridges plain forms behind the moving parabolic dune. The newly created deflation hollow is initially completely devoid of vegetation, though it is quickly colonized by a group of specialised plants common to these hollows. An ecological succession occurs, with the youngest vegetation directly behind the land-ward moving dune; the oldest vegetation is furthest from the dune and closer to the sea. These deflation hollows can be covered with water for most of the winter and spring months, though they are often dry in the summer. They are called temporary wetlands, ephemeral wetlands or dune slacks. The first species to colonize these newly created deflation hollows in the Manawatu is the rhizomatous sand sedge *Carex pumila* which follows the moving terminal deflation hollow (Burgess 1984 and Esler 1969). Following *Carex pumila* other plants arrive, including *Selliera radicans, Isolepis cernua, I. basilaris, Triglochin striata, Ranunculus acaulis, Gunnera arenaria, Myriophyllum votschii, Lilaeopsis orbicularis, Limosella lineata, Epilobium billardiereanum* and *Eleocharis neozelandica*, the last classified as endangered (Cameron *et,al.* 1995). As the sand plains age larger wetland-plants invade, and typically develop communities of *Isolepis nodosa, Leptocarpus similis* and *Schoenus nitens.* Gradually other plants invade, including toetoe (*Cortaderia toetoe* and *C. fulvida*), flax (*Phormium tenax*), cabbage trees (*Cordyline australis*), and the shrubs manuka, (*Leptospermum scoparium*), *Coprosma propinqua* subsp. *propinqua* and *Olearia solandri.* If undisturbed these dune plains would eventually become coastal swamp forest of predominantly kahikatea (*Dacrycarpus dacrydioides*) and pukatea (*Laurelia novae-zelandiae*), of which very little remains in the ecological district.

There have been no detailed accounts of the original pre-European vegetation of the sand country. Early references mention open grassy flats and ridges interspersed with areas of manuka, bracken fern (*Pteridium esculentum*), tutu (*Coriaria arborea*), rushes, toetoe and flax. The sand binders spinifex (*Spinifex sericeus*) and pingao (*Desmoschoenus spiralis*) occupied the foredune, with the dune binding shrubs tauhinu (*Ozothamnus leptophylla*, Breitwieser and Ward 1997), sand coprosma (*Coprosma acerosa*) and sand pimelea (*Pimelea arenaria*) on the stabilised lee of the fore dune and the hinterland dune areas. The three endemic nitrogen fixing shrubs tutu (*C. arborea*), *Carmichaelia* spp. and matagouri (*Discaria toumatou*) may have occupied stabilised dunes. All are largely absent from the region.

The vegetation would have been modified even prior to the first European settler's arrival, because of a long history of Maori occupation. Most of the vegetation would have been in an early successional status because of the regularity of Maori fires. The dune land is naturally dry and therefore very prone to fires, and as a consequence when fires were lit, large areas could have been uncontrollably burnt. Very few areas would have been entirely free from modification. It is likely that some plants which were present prior to Maori occupation are not present today because of their relative fire intolerance. It is assumed that the effects of Maori occupation and fires initiated a dune building phase approximately 1000 years BP (Cowie 1963). European occupation drastically modified the dune land vegetation, and to a much greater extent than the Maori. They used beaches and coastal land for travelling and moving stock, resulting in over-grazing and burning of the dunes (Saunders 1968). This damage initiated the last dune building phase. When Cockayne visited the Manawatu dunes in 1909, large areas of wandering dunes were moving inland destroying valuable farmland. This was the result of only fifty to sixty years of occupation. In this time uncontrolled grazing had damaged and in some places eliminated the palatable foredune sand binder, *Spinifex* and other palatable species. It was on Cockayne's advice that large areas of dunes were planted in marram (*Ammophila arenaria*), tree-lupin (*Lupinus arboreus*) and then into exotic forests in order to stabilise them. In addition to direct development of the dunes, European colonization of New Zealand has introduced thousands of exotic plants into the country. Many of these plants have become naturalised in the dune country; some of these are equally at home in other dune areas of the world, most commonly the dunes of Europe and Britain. Plants such as marram, tree lupin, pampas grass (*Cortaderia selloana*), *Melilotus indica*, lotus (*Lotus pedunculatus*) catsear (*Hypochoeris radicata*), hawkbit (*Leontodon taraxacoides*), Yorkshire fog (*Holcus lanatus*) and tall fescue (*Festuca arundinacea*) are more common than many natives.

The study site

The area of coastal dunes between the mouth of the Rangitikei river at Tangimoana and Himatangi was until recently (early 1980's) largely unmodified and in a natural state with predominant native vegetation. Part of this area was suggested to be set aside for the conservation of this unique ecosystem, early as 1975 when a regional park was proposed (Carlin and Turner 1975), with support from the New Zealand Ecological Society and Massey University. Burgess (1984) researched his Ph.D. on *Carex pumila* in this area, in deflation hollows in which the successional process was still occurring behind a moving parabolic dune. Unfortunately the majority and the best examples of dune systems were lost when the New Zealand Forest Service planted most of this area with exotic forests in the Foxtangi dune stabilization scheme (1983-1992). Very little of this area remains in a representative natural state; the largest area is situated at Tangimoana, south of the Rangitikei River mouth, the Tangimoana dump dunes, (Ravine 1992). The least modified areas of the sand country today are the surviving areas of damp dune plains, and foredunes where representative plant communities still occur.

The Tangimoana dump dunes were recommended as a priority area for protection in the Foxton Ecological District, Protected Natural Areas survey report (Ravine 1992). This area is approximately 45 hectares in size and runs from the coastline inland 800 metres at its furthermost point. It is situated approximately 40 km north west of Palmerston North (40°185'S, 175°135'E) directly south of the Rangitikei River mouth. The area was described as "*the least stabilised and the most mobile coastal dunes remaining in the ecological district*". Consequently at the time of survey these dunes were the most representative example of coastal dunes left in the Foxton Ecological District.

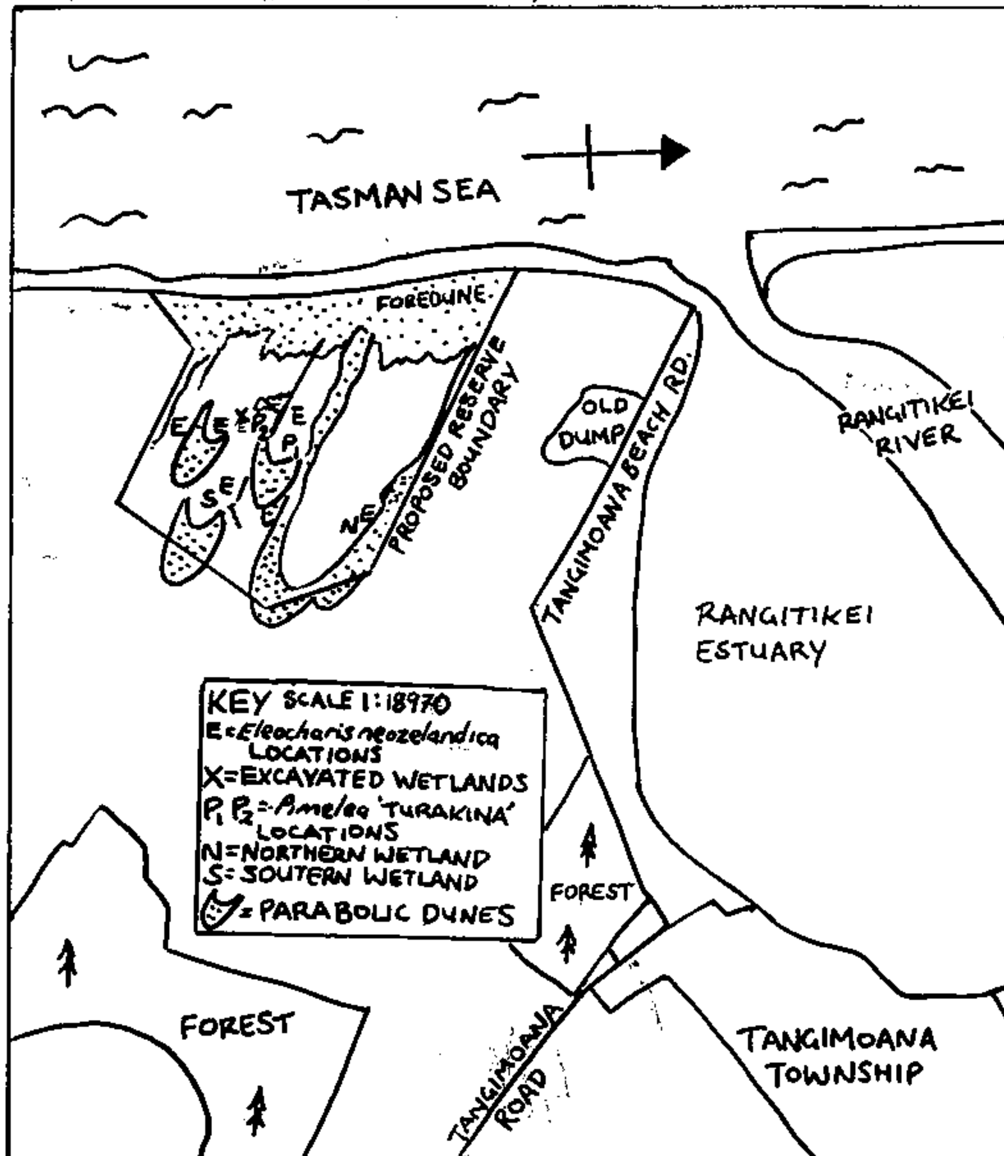
The Tangimoana Dump dunes are currently owned by the Manawatu District council. In 1992 all areas of mobile sand within the Tangimoana dump dunes area were planted in marram, radiata pine and macrocarpa for stabilisation purposes, while stable areas already with a vegetation cover were planted in pines. This stabilization work was the last area planted by the Manawatu-Wanganui Regional Council under contract to the Manawatu District Council, by the Government funded Foxtangi sand stabilisation scheme. However most of the planted pines and macrocarpa in sensitive areas in the proposed reserve area (the Tangimoana dump dunes), were pulled out by conservation activists shortly afterwards. This was undertaken because the area had been identified as a natural area of regional significance (Ravine 1992), and it was assumed that the trees would greatly modify area to the detriment of the native vegetation. Most of the marram was left intact on the mobile dunes resulting in their stabilization, and the cessation of formation of new dune plain and deflation basins. As a result there are very few surviving temporary wetland areas on the dune plains with communities of a early successional status.

This was not the first time marram was extensively planted at the Tangimoana dump dunes (Saunders 1968), as the New Zealand Government first funded stabilisation work at Tangimoana in 1913, following Cockayne's (1911) recommendation. The area of dunes directly south of the Rangitikei river was tackled for stabilisation work as it had been devastated by grazing, presumably as a result moving stock being camped on the southern side of the river when it was in flood. The reclamation work included foredune construction and planting marram, and later afforestation work on dunes further inland (Saunders 1968). It appears from aerial photos that these dunes planted in marram collected large amounts of sand, which later became unstable and started to wander. These wandering dunes became the major parabolic dunes which now surround the

Tangimoana dump dunes. As early as 1949 the foredune was very uneven in places, and some small blowouts and wandering dunes were apparent. However by 1965 there were many large parabolic dunes wandering inland behind the foredune, which were all still very mobile by 1979. It appears that these dunes travelled approximately 500 to 800 metres over 40 years, forming the present day dune plains.

The Tangimoana Dump dunes include areas of foredune, relict foredune, sand plains with temporary wetlands in deflation hollows, sand ridges, stone fields formed from old storm beaches from the Rangitikei River, and several parabolic dunes (Figure 1). Vegetation structural classes (Atkinson, 1985) include, grassland, sedgeland, rushland, shrubland, stonefield, and herbfield classes. The foredune community is primarily composed of *Spinifex*, with some pingao and marram. Older dunes contain the sand binding shrubs tauhinu, sand *Coprosma* and sand *Pimelea*, especially on the lee side of the foredune. The area has very significant sand plains with associated dune slacks species. There are three main dune plains with dune slacks or temporary wetlands. In these temporary wetlands the vegetation is very small and low lying, being referred to as a turf communities. Plants which commonly occur here are *Carex pumila*, *Epilobium billardierianum*, *Isolepis basilaris*, *I. cernua*, *Lilaeopsis orbicularis*, *Limosella lineata*, *Lobelia anceps*, *Myriophyllum votschii*, *Selliera radicans* and *S. rotundifolia* (Heenan 1997), and *Triglochin striata*. The older slacks contain larger rushes, sedges and grasses such as *Leptocarpus similis*, *Isolepis nodosa*, *Schoenus nitens*, *Juncus caespiticius*, and *Cortaderia toetoe*. Some exotic species are present with *Agrostis stolonifera*, *Juncus articulatus*, and *Lotus pedunculatus* common.

Figure 1.1 : Schematic diagram of the proposed reserve with the locations of the northern and southern wetlands, *Eleocharis neozelandica*, *Pimelea* "Turakina" planting areas and the excavated wetlands. Taken from an aerial photo, 23rd June 1995 (Manawatu-Wanganui Regional Council).



One species only occurs in young dune slacks at Tangimoana in the Manawatu. It is nationally classified as an endangered plant (Cameron *et al.* 1995), and is the sand spiked sedge, *Eleocharis neozelandica.* This plant occurs in six temporary wetland areas in the Tangimoana dump dunes (Figure 1.1). In the Manawatu *E. neozelandica* occupies recently formed deflation hollows behind moving parabolic dunes, and deflation hollows along the lateral arms of parabolic dunes. This plant is very small (< 3cm) and occurs in dune slack communities of an early successional status, requiring newly formed hollows to colonise. If new areas are not available it will be eliminated by the larger rushes and sedges in the successional process (Burgess 1984).

The Tangimoana dump dunes are the most significant area of coastal dune vegetation existing between Tangimoana and Himatangi. The vegetation patterns inside the proposed reserve boundary were described and related to the topography and environmental variables present. Investigations into the water table fluctuations of two temporary wetlands containing populations of *Eleocharis neozelandica* were made over a 30 month period, in order to record the dynamics of the water table and relate these to the habitat requirements of *E. neozelandica*. In the dune slack environment waterlogging and submergence of the occupying plants is virtually an annual event, while sand burial can occur in gales. Laboratory experiments of *E. neozelandica*'s and other dune slack species growth in relation to sand burial, waterlogging and submergence were made in order to assess their tolerances to these events. The dunelands are presently stable and virtually no new habitat for *E. neozelandica* and other early succession dune slack species is being made. The population status of *E. neozelandica* was assessed, and the construction of two deflation hollows as habitat creation for *E. neozelandica* and other dune slack plants, was made as a tool for their long term survival and management. *E. neozelandica* and *Isolepis cernua* were planted with at three different elevations in the deflation hollows to assess their tolerances to winter submergence, and whether habitat construction and planting is successful. The construction of permanent plots to exclude rabbits from grazing the dune slack vegetation was made, in order to assess their effect on the vegetation. The sand plain daphne *Pimelea* "Turakina", taxonomically indeterminate - status critical (Cameron *et al.* 1995) only naturally occurs in the coastal dunes between Himatangi and Foxton. Plants were propagated sourced from cuttings from the natural population and planted at the Tangimoana Dump dunes, where their survival and reproduction were monitored.

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Chapter Two

The vegetation of the coastal dune system and associated temporary wetlands at Tangimoana, Manawatu New Zealand.

Abstract

The vegetation of the Tangimoana dump dunes, a proposed coastal DoC reserve was surveyed using randomly placed quadrats along five transects, running from the beach inland. In each quadrat all vascular plant species were recorded, as well as the elevation, overall slope and aspect, percentage sand and stones, disturbance types and levels, and vegetation height. Soil samples were collected at every third quadrat and soil moisture, pH and conductivity were measured. Foredune, dune plain, slack, marram dune, shrub dune and grassland communities were identified by cluster analysis. Mean species diversity was low in all communities, with the dune slack community having the highest diversity of 11.3 species per quadrat. Wind was the most common disturbance type and the low species diversity found was attributed to the Manawatu having a high energy and dynamic coastline.

Introduction

The Manawatu region contains a large area of sand country, known as the Foxton Ecological District, encompassing 1,100 km^2 (Ravine 1992) It is the most extensive sand dune system in New Zealand (Muckersie and Shepherd 1994). The sand country was formed and is still forming by accretion of sand onto the coastline from the region's rivers. In addition three phases of major sand dune building over 6,000 years (Muckersie and Shepherd 1994) have shaped the topography, with large parabolic dunes.

The area of coastal dunes between the mouth of the Rangitikei River at Tangimoana and Himatangi was until recently (early 1980's) predominantly largely in an unmodified and natural state, and supported mostly native vegetation. The New Zealand Ecological Society with support from Massey University suggested as early as 1975 that an area of natural vegetation be set aside for maintenance of this unique ecosystem when a regional park was proposed (Carlin and Turner 1975). Burgess (1984) researched his Ph.D. thesis on *Carex pumila*, in one of the many temporary wetlands in deflation basins shortly before the Foxtangi (between Foxton and Tangimoana) area was developed. His study site was largely in a pristine state considered to be a pre-European phenomenon (Carlin and Turner 1975). Unfortunately the majority and the best examples of dune systems were lost to afforestation in the Foxtangi dune stabilization scheme (1984 -1992) when the New Zealand Forest Service planted most of the area in *Pinus radiata*.

The last remaining area of coastal native vegetation between Tangimoana and Himatangi was recommended for protection in the Foxton Ecological District, Protected Natural Areas Survey Report (Ravine 1992), i.e. the "Tangimoana dump dunes". It is situated approximately 40 km North west of Palmerston North (40°185'S, 175°135'E). This area is approximately 45 hectares in size and runs from the coastline inland 800 metres at its furthermost point. It encompasses foredunes, relict foredunes, sand plains with temporary wetlands in deflation basins and sand ridges, a gravel plain of relict storm beaches, and several parabolic dunes. The area contains good populations of both dune and dune slack communities, including the endangered spiked sand sedge *Eleocharis neozelandica*.

The dunelands were sampled to describe and map the vegetation in the proposed reserve boundaries. In addition the topography and environmental variables were measured to provide an explanation of factors controlling of the distribution of the plant communities.

Methods

The sampling area ran 500 metres south along the beach from the Northern reserve boundary, and up to 800 metres inland (Figure 2.2). Five centre line transects were placed parallel to each other and 100 metres apart running at 110° (compass bearing) from the seaward side of the fore dunes inland, within the reserve boundaries. The transects ran inland until they reached the head of each parabolic dune, which had been planted with Marram (*Ammophila arenaria*) in winter 1992, and were uniform and not representative of the natural state. Two hundred and seventy one quadrats were placed randomly over this area.

In each quadrat (2m X 2m) the shoot presence of all vascular plant species was recorded. Nomenclature follows Connor and Edgar (1987) and references therein, Edgar (1995), Breitwieser and Ward (1997) for native vascular plants, Webb, Sykes and Garnock-Jones (1988) for exotic species. The quadrat information unintentionally lumped closely related species on three occasions. The species *Sonchus asper* may include individuals of *S. kirkii* which were assumed to be varied forms of *S. asper.* The two exotic species of pampas were classified under the name of *Cortaderia selloana* which is the most abundant species in this area. The other exotic species *Cortaderia jubata* was also identified in the area during flowering. *Selliera rotundifolia* has subsequently been separated as a distinct species from *Selliera radicans* (Heenan 1997), though at the time of sampling the two *Selliera* species were classified under the name of *Selliera radicans.*

The maximum vegetation height, the angle of greatest slope, and the aspect, and Percentage cover of sand, stones and wood was estimated. Elevation was measured using a surveyor's level and staff, with respect to the high tide zone at the start of each transect. Disturbance type was recorded (rabbits, vehicles and wind), and placed into a subjective disturbance categories of 1 (none), 2 (low), 3 (medium), 4 (high) and 5 (very high) levels of disturbance. A very high disturbance category(s) was used for quadrats which were located in blowouts or vehicle tracks. The number of rabbit pellets was also counted in each quadrat.

A soil sample was taken from the centre of each quadrat (1300 cm^2) and stored in sealed plastic bags at 4° C until analysis. The soil samples were analyzed for moisture content by loss-on-drying at 90° C for 8 hours (which was sufficient time for the raw sandy soils), pH and conductivity of a 1:5 soil/water solution shaken for 1 hour and then tested with standardized pH and conductivity meters (Rayment and Higginson 1992). Additionally five soil samples were taken for daily moisture content, at the start of each sampling day and again at the end of each day, within a 5 metre radius of a specific location. Daily soil moisture averages were calculated from these samples, and the difference in soil moisture between each sampling day was found. All quadrat soil moisture samples were then standardized to the first sampling day's moisture content.

The quadrats were grouped using species composition with a Cluster analysis (using MVSP, Kovack software), using unweighted pair group clustering method and dissimilarity measured by Jaccard's coefficient. Quadrats which contained no species, and those species which occurred only in a single quadrat were excluded from the analysis, but were mapped as bare sand. Communities were decided at an arbitrary level, and species compositions for each community calculated in percentages.

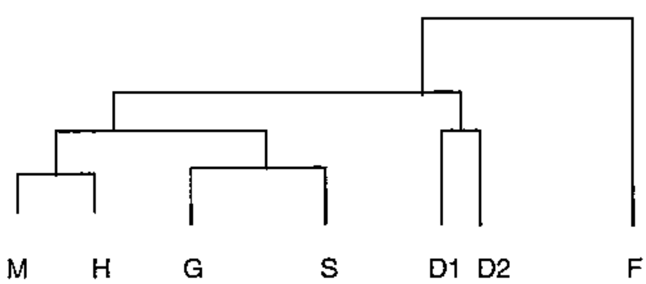
Photo 2.1: An overview of the northern dune plain from the most inland point of the proposed reserve, looking out to sea, approximately along the first transect. The northern wetland (Chapter 5) is the area under water. The red vegetation is predominantly *Leptocarpus similis* and *Isolepis nodosa*, while the green is grassland.

Results

Vegetation analysis

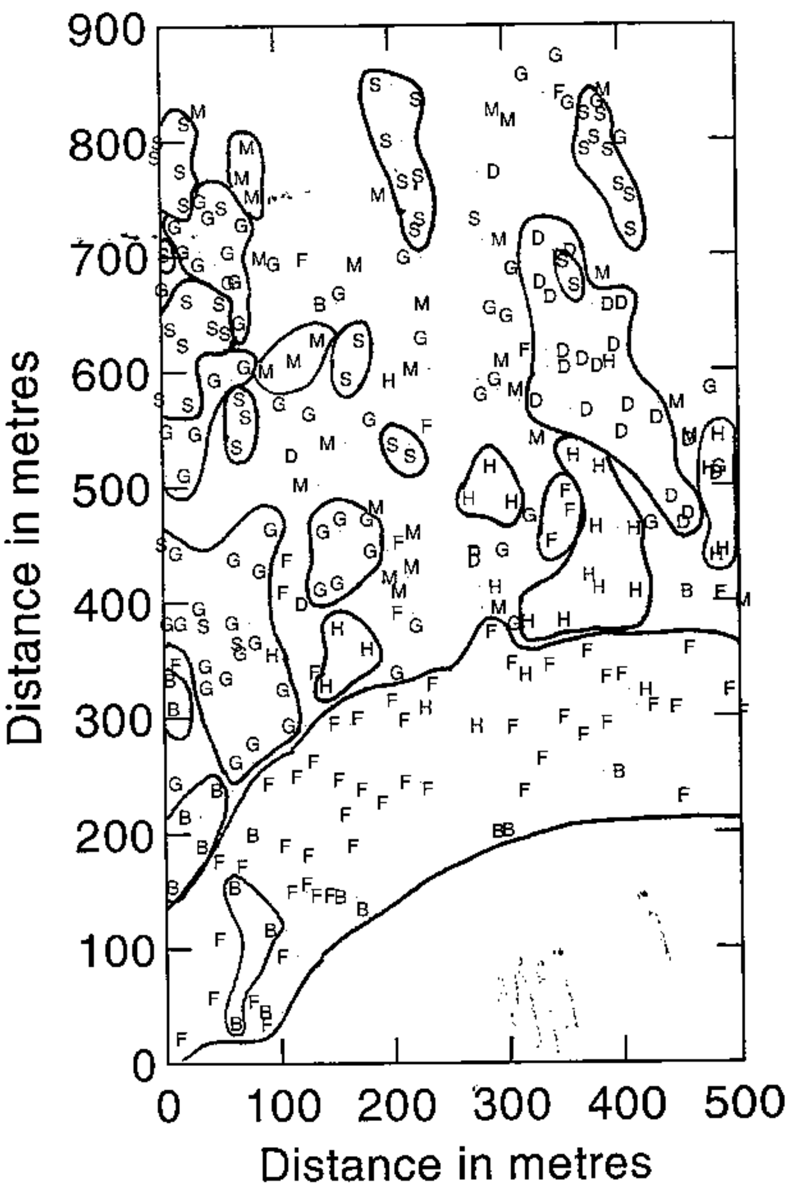
The cluster analysis identified seven major community types: fore dune, (F), two dune plain communities (D), dune slack (S), grassland (G), shrub dune (H) and marram dunes (M). Of the two dune plain communities identified in the cluster analysis, one (D1) consisted of only three quadrats containing few species, some rare. These two dune plain communities were joined together when comparing species compositions, and environmental variables of the communities.

Figure 2.1 : Dendrogram produced by the cluster analysis showing communities at the arbitrary level. The communities are M = Marram dune, H = Shrub dune, G = grassland, S = slack, D = dune plain (1 & 2), F = Fore dune.



The plot of the communities (Figure 2.2) shows community boundaries. The fore dune community is located along the seaward edge, with the marram, shrub dune, dune plain, grassland and slack communities behind. The majority of the shrub dune community occurs up to five hundred metres inland, on relict foredunes and smaller dunes behind the fore dune. There are three distinct slack regions which correspond to slacks on the northern and southern dune plains, and a long narrow slack on the southern most corner of the reserve. The location of quadrats with only bare sand have been shown, and the small cluster of these between 0 and 100 metres along the X axis is an area where a "blow out" is occurring.

Figure 2.2 : The location of all vegetation communities and bare sand from the quadrat data within the sampling boundary. The communities are M = Marram dune, H= Shrub dune, G= grassland, S= slack, D= dune plain, F= Fore dune and B= bare sand.



Species richness in the six communities range from 1.7 in the fore dune to 9.2 in the grassland communities, with a high proportion of exotic species especially in the grassland, shrub dune and marram dune communities (Table 2.1). The grassland community is the weediest community, and is dominated by grasses, legumes and other herbaceous plants. The fore dune and dune plain communities have the least number of exotic species, though these two communities also have the least amount of species.

Table 2.1 : Mean species richness per quadrat of all species, native and exotic species, and vegetation height for each community. (+/-) indicates standard errors. Values sharing the same letter are not significantly different from one another, by an anova using detectable differences.

COMMUNITY	ALL SPECIES	NATIVE SPECIES	EXOTIC SPECIES	VEGETATION HEIGHT (CM)
Fore dune	1.7 +/-0.13 a	1.1 +/-0.09 a	0.6 +/-0.10 a	64.3 +/-4.43 a
Dune plain	4.5 +/-0.54 b	2.8 +/-0.24 b	1.7 +/-0.35 a	38.3 +/-6.43 b
Slack	11.3 +/-0.48 c	5.8 +/-0.39 c	5.5 +/-0.23 b	102.4 +/-5.75 c
Grassland	9.0 +/-0.36 d	2.5 +/-0.29 b	6.5 +/-0.16 c	104.4 +/-3.32 c
Shrub dune	5.9 +/-0.32 b	2.3 +/-0.25 b	3.6 +/-0.22 d	75.7 +/-6.76 d
Marram dune	5.8 +/-0.41 b	1.4 +/-0.28 a	4.4 +/-0.24 e	83.6 +/-9.04 e

The foredune community has a very low species diversity of 1.7 species per quadrat (Table 2.1). It is very sparsely vegetated with a sand cover of 86.3%, and a mean slope of 13.5° (Table 2.3). It is composed (Table 2.2) of mainly the native sand binder *Spinifex sericeus* (82%) with smaller proportions of the exotic *Ammophila arenaria* and the endemic *Desmoschoenus spiralis* sand binders. The community is located on the incipient fore dune, the fore dunes and the lee of the fore dunes, with occasional patches on isolated dunes further inland.

The dune plain (D1 & D2 together) communities have a low mean vegetation height of 38.3 cm and a sparse vegetation cover with 96.6% of the quadrat area being occupied by sand and stones. These communities are situated on undulating gravely banks (stone fields) and dune plains between arms of parabolic dunes. The gravel was deposited as storm beaches at the mouth of the Rangitikei River, and subsequent accretion of the coastline has meant that it is now located further inland (Shepherd, pers.com.). The low and sparse vegetation is partially the result of high disturbance with numerous vehicle tracks and ruts and damage by vehicular traffic, with a mean disturbance level of 3.2 (Table 2.4). Additionally the high abundance of stones, 29.8% (many larger than a tennis ball) on the surface limits the available space for plants to colonize and establish (Table 2.3). The dune plain community contains species similar to the slack community, though it has a higher elevation than the slack community, and is not temporarily flooded in winter. The vegetation (Table 2.3) consists of predominantly *Carex pumila* (84% of quadrats) and *Isolepis nodosa* (56%) with small deflation areas occupied by *Selliera radicans* (48%), and *Isolepis cernua* (56%). *Ammophila arenaria* is also abundant and is colonizing much of the higher undulating area.

Table 2.2 : The frequency of species (≥5%) in the six communities, F = foredune, D = dune plain, S = slack, G = grassland, H = shrub dune and M = marram dune, and the number of quadrats of each. * indicates exotic species.

SPECIES	F	D	S	G	H	M
Acaena anserinifolia	-	-	-	9	-	-
**Agrostis stolonifera*	-	-	14	-	-	-
**Ammophila arenaria*	40	48	14	38	62	90
Carex pumila	-	84	61	14	-	-
**Centaurium erythraea*	-	-	14	11	-	-
**Conyza albida*	5	32	16	62	17	80
Coprosma acerosa	-	-	-	9	31	-
**Cortadaria selloana*	-	-	33	-	-	-
Cortadaria toetoe	-	-	-	6	-	-
Desmoshoenus spiralis	13	-	-	-	10	-
Epilobium billardierlanum	-	-	19	-	-	-
**Festuca arundinacea*	-	-	37	32	37	-
**Holcus lanatus*	-	8	61	80	-	17
**Hypochoeis radicata*	10	20	77	74	79	47
Isolepis basilaris	-	-	19	-	-	-
Isolepis cernua	-	8	44	-	-	-
Isolepis nodosa	-	56	81	88	14	17
**Juncus articulatus*	-	-	33	-	-	-
**Juncus bufonius*	-	-	7	-	-	-
Juncus caespiticus	-	-	12	-	-	-
Lachnagrostis billardierei	-	40	16	45	48	63
**Lactuca virosa*	-	-	-	8		-
**Lagurus ovatus*	-	-	-	46	14	-
**Leontodon taraxacoides*	-	-	63	76	72	23
Leptocarpus similis	-	-	54	-	-	-
Lobelia anceps	-	20	74	6	-	-
**Lotus pedunculatus*	-	-	49	39	-	13
**Lupinus arboreus*	-	-	-	9	-	7
**Lycium ferocissimum*	-	-	-	-	-	7
**Medicago lupulina*	-	-	33	21	7	7
**Melilotus indicus*	-	-	35	21	10	-
**Oneothera stricta*	-	-	-	14	-	-
**Orobanche minor*	-	-	-	8	21	10
Ozothamnus leptophylla	-	-	-	17	38	-
**Parentucellia viscosa*	-	-	23	21	-	27
Pseudognaphalium luteo-album	-	12	12	6	-	-
Schoenus nitens	-	-	37	8	-	-
Selliera radicans	-	48	81	-	-	-
**Senecio elegans*	-	20	-	23	52	43
**Silene gallica*	-	-	-	9	-	-
**Sonchus asper*	-	36	-	18	21	27
Spinifex sericeus	82	-	-	11	62	-
**Trifolium fragiferum*	-	-	7	8	-	-
Triglochin striata	-	-	37	-	-	-
**Vicia sativa*	-	-	-	8	-	-
Number of quadrats	**61**	**25**	**43**	**66**	**29**	**30**

The dune slack community is situated predominantly in deflation hollows on the dune plains, with the lowest mean elevational height of 0.57 metres. The community is the most diverse with 11.3 species per quadrat ($4m^2$), and is reasonably tall with a mean height of 102 cm, with taller rushes and sedges common. The conductivity is highest indicating, a higher salinity and/or a more developed and weathered status of the soil with a higher nutrient content. *Isolepis nodosa* and *Selliera radicans* are equally common occurring in 81% of the quadrats, with *S. radicans* reaching its peak in abundance in this community. The flat weeds of *Hypochoeris radicata* and *Leontodon taraxacoides* and the dune slack plants of *Lobelia anceps, Carex pumila, Leptocarpus similis* and *Isolepis cernua* are common. Several wetland plants *L. similis, Triglochin striata, J. caespiticus, Isolepis basilaris, Epilobium billardierianum* and the exotics *Agrostis stolonifera, Juncus articulatus, J. bufonius* only occur in this community.

The grassland community is situated on small dunes and hummocks on the dune plain, and on lower slopes of the marram dunes. The vegetation covers the largest percentage of the soil surface with only 22.7% being sand or stones. It has the tallest mean vegetation height of 104 cm. *Isolepis nodosa* (88%), *Holcus lanatus* (80%), *Leontodon taraxacoides* (76%), *Conyza albida* (62%), and *Lagurus ovatus* (46%) reach their peak abundance in this community. This community has the most species (32), the majority (21) being exotic, occurring greater or equal to 5% in abundance. Many species only occur in this community, including *Oneothera stricta, Lupinus arboreus, Silene gallica* and the two natives *Acaena anserinifolia* and *Cortaderia toetoe.*

The shrubland dune community is situated in older dune areas, notably the lee of the foredune, relict fore dunes, and marram dunes further inland. It has the highest mean elevational height of 3.7 metres (Table

2.5). Vegetation is reasonably sparse, with 65.7% of the cover being occupied by sand and stones. The flat weeds *Hypochoeris radicata* (79%) and *Leontodon taraxacoides* (72%) are the two most common species, though they appear not to contribute similarly to percentage cover. The two sand binders *Spinifex sericeus* and *Ammophila arenaria* are equally common occurring in 62% of the quadrats. The shrub species of *Ozothamnus (Cassinia) leptophylla* (38%) and *Coprosma acerosa* (31%), as well as the parasitic plant *Orobanche minor* (20.7%), the native grass *Lachnagrostis billardieri* (48%) and the herb *Senecio elegans* (52%) reach their peak in this community. *O. minor* is predominantly parasitic on *Hypochoeris radicata* (Webb *et al.*, 1988) and owes its abundance the high presence of *H. radicata*. Though *A. arenaria* is common, in the majority of the quadrats it is short and not as thick and tall as the more dominant *A. arenaria* dunes.

The Marram dunes are composed almost entirely of exotic species with only two native species, *Lachnagrostis billardierei* (63%) and *Isolepis nodosa* (17%) occurring in this community of 15 species. This community is principally man-made resulting from the planting of dunes with *Ammophila arenaria*, which occurs in 90% of the quadrats. The other species which occur here are principally species of disturbed habitats, for example *Conyza albida* (80%) reaching its peak abundance, *Hypochoeris radicata* and *Senecio elegans*. The community has a low mean species richness of 5.8 (Table 2.1), which is not surprising as the majority of this community was bare sand in 1992, prior to the planting of marram in the 1992 winter.

Geomorphological variables

The mean quadrat slope clearly shows a difference between dune, grassland and slack communities (Table 2.3). The dune communities have steeper slopes than the grassland, dune plain and slack communities. The shrub dune community has the highest mean slope angle of 23°. This community is commonly found on the steep side slopes of the lateral arms of older parabolic marram dunes.

Though range is great for all communities (Figure 2.3), the mean elevation above high tide mark of the three dune communities (Table 2.3) is higher than the grassland, dune plain and slack communities. The shrub dune community is highest. Figure 2.3 shows the elevation of quadrats by community, type and Table 2.5 shows the mean elevation and standard errors.

Table 2.3 : The mean geomorphological variables for each community. (+/-) indicates standard errors. Values sharing the same letter are not significantly different from one another, by an anova using detectable differences.

COMMUNITY	ELEVATION (M)	SLOPE (°)	% SAND COVER	% STONE COVER
Fore dune	2.4 a +/-0.25	13.5 a +/-1.36	86.3 a +/-2.30	0.9 a +/-0.55
Dune plain	0.7 a +/-0.26	2.7 b +/-1.63	66.8 b +/-5.50	29.8 b +/-9.47
Slack	0.6 a +/-0.20	3.2 b +/-0.64	31.7 c +/-4.96	1.4 a +/-0.97
Grassland	1.1 a +/-0.21	9.4 c +/-1.38	20.8 c +/-3.32	1.9 a +/-1.19
Shrub dune	3.7 a +/-0.38	23.0 a +/-2.67	62.1 b +/-5.20	3.6 a +/-1.63
Marram dune	3.1 a +/-0.58	14.8 a +/-2.44	44.3 cd +/-6.72	10.0 a +/-3.99

Disturbance factors

Three disturbance types, rabbits, vehicles and wind were recorded in categories for each quadrat. Rabbit disturbance was indicated by browsing, digging and scratching, and was not as significant in affecting or stressing the vegetation of the quadrats as the other two disturbance categories, with low disturbance category scores. Rabbit disturbance was least important as a disturbance factor in the foredune community. Rabbit disturbance was most notable in the dune slack and grassland communities with 34.9 % and 31.8 % respectively of the quadrats affected by rabbit browse. These communities had the highest density of rabbit pellets, of 11.9 and 7 per quadrat for dune slack and grassland respectively (Table 2.4).

Vehicular disturbance was a significant factor influencing the dune plain, shrub dune and marram dune communities. In the dune plain community the vegetation was short and a high proportion was damaged as a result of vehicle tracks. The composition of the vegetation may be influenced by the regular disturbance and damage of vehicles, insuring that only small and less sensitive plants, such as *Selliera radicans* survive.

Wind as a disturbance factor was most significant in all dune communities. Wind influenced 76.7% of the quadrats of the foredune community. Wind disturbance is manifested in burying plants with sand or undermining plants, and creating blowouts in dunes. The shrubland and marram dune communities were also moderately affected by wind as a disturbance type with 42.9% and 41.9 % of the quadrats affected.

Table 2.4 : The frequency of disturbance type, mean disturbance category and the mean number of rabbit pellets for each community. Disturbance categories are 1(none), 2(low), 3(medium), 4(high), and 5 (very high). (+/-) indicates standard errors. Values sharing the same letter are not significantly different from one another, by an anova using detectable differences.

	DISTURBANCE TYPE (%)			DISTURBANCE	NUMBER OF
COMMUNITY	RABBIT	VEHICLE	WIND	CATEGORY	RABBIT PELLETS
Fore dune	0.03	0.15	0.77	3.07+/-0.20 a	1.1
Dune plain	0.12	0.72	0.08	3.16+/-0.33 a	4.8
Slack	0.35	0.02	0	0.92+/-3.04 b	11.9
Grassland	0.32	0.05	0.06	1.11+/-0.18 b	7.0
Shrub dune	0.14	0.29	0.43	3.14+/-0.30ac	2.9
Marram dune	0.16	0.22	0.42	2.03+/-0.28 c	11.4

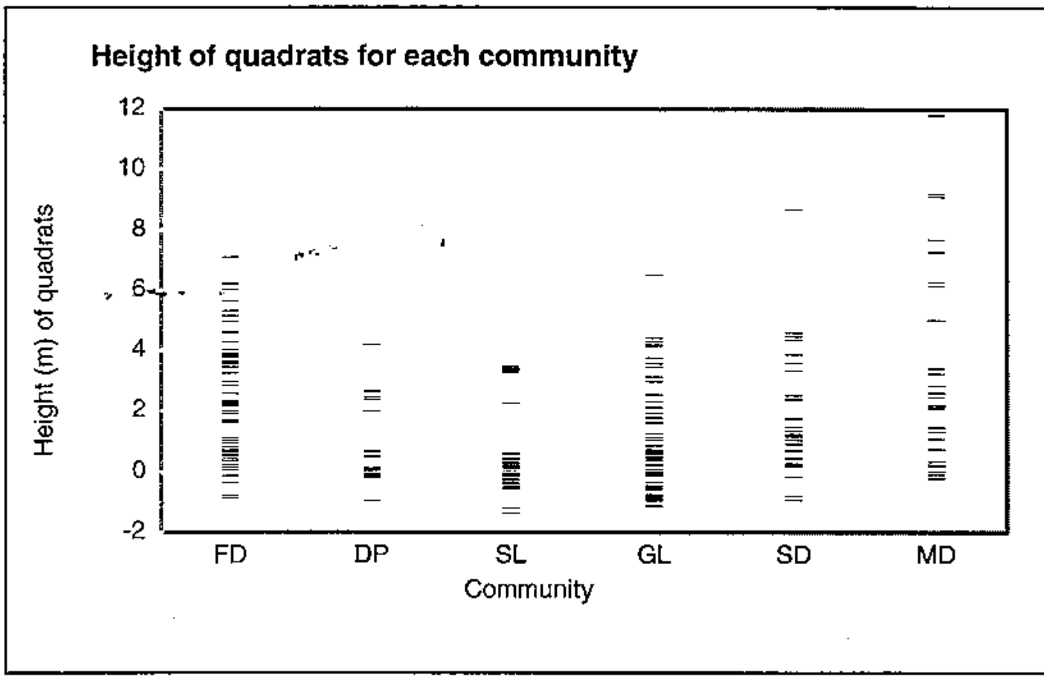
Soil environmental variables

The soils of each community are remarkably similar in respect to pH and conductivity, with only the conductivity in the slack community greater than the rest (Table 2.5). This difference in conductivity may be accounted by the increased fertility in the slack community, a result of organic matter build-up from nitrifying algae (Burgess 1984). The lower lying slack and dune plain communities have higher soil moisture than the dune and grassland communities. The lowest soil water content, were found in the fore dune and marram dune communities.

Table 2.5 : The mean soil environmental variables for each community. Conductivity is measured in micro-siemens (μS/cm^{-1}) and water content is the percentage of water in each sample (wet weight). (+/-) indicates standard errors. Values sharing the same letter in a row are not significantly different from one another, tested with an analysis of variance using detectable differences.

COMMUNITY	pH	CONDUCTIVITY (μS/CM)	MOISTURE CONTENT (%)
Fore dune	7.63+/-0.06 a	45.5 +/-6.96 a	2.25 +/-0.18 a
Dune plain	7.46 +/-0.02 a	48.9 +/-4.45 a	6.47+/-0.72 b
Slack	7.52+/-0.01 a	77.4 +/-2.90 b	17.17+/-1.0 c
Grassland	7.42 +/-0.01 a	40.5 +/-1.35 a	3.31 +/-0.39 ab
Shrub dune	7.45 +/-0.02 a	44.7 +/-1.41 a	3.72 +/-0.28 ab
Marram dune	7.76 +/-0.10 a	40.9 +/-0.62 a	2.17+/-0.37 a

Figure 2.3 : The height of quadrats for each community measured with a surveyors level and staff. . The communities are MD = Marram dune, SD= Shrub dune, GL= grassland, SL= slack, DP= dune plain (1 & 2 together), FD= Fore dune. Every line represents the elevation of a single quadrat.



Discussion

The Tangimoana dune lands are young. In the past one hundred and fifty years they have endured large scale disturbance caused by over-grazing of the fore dune vegetation, and the planting of marram. Tangimoana was the first area where Government-funded sand stabilization occurred in 1913, with fore dune reshaping, and planting of marram and exotic pine plantations (Saunders 1968). It appears that sand collected by these first planted marram dunes became unstable, as early as 1949, resulting in wandering parabolic dunes, which have created most of the present day dune plains (Aerial photos, 1949, 1968 and 1979). The majority of the sand plain vegetation is probably less than 50 years old, because the pre-existing vegetation would have been destroyed by wandering dunes.

The dunes of the Manawatu coast are arguably the most dynamic and mobile dunes anywhere in the world. Rates of downwind migration of parabolic dunes have been recorded at greater than 73 metres per year, which are some of the highest values ever recorded (Hesp pers com.). Clearly the Manawatu has a very high energy and windy coast, with an ample supply of sand from the region's rivers. Sand, when it is not trapped by the fore dune vegetation, is blown inland abrading the vegetation. Additionally, the frequency and velocity of the prevailing onshore wind ensures that high amounts of salt spray are deposited on to the dunes and the dune plants. Salt spray can influence the growth of plants, and therefore influence species composition of communities (Sykes *et al.* 1988). The foredune community has the lowest species diversity, and this may be influenced by regular salt-spray, though was not tested here. The high frequency and velocity of wind, causing almost continual disturbance and salt spray may be a strong influence in the low species diversity of the Manawatu dunelands.

Dunes generally worldwide have a low species diversity, which has been related stress factors that dune species must endure, such as salt spray, drought, nutrient deficiency and specifically burial by sand (Hesp 1991). The Tangimoana dune lands have a dearth of species, in terms of mean species richness per quadrat. The dune communities have very few species (<6), with the dune plain, grassland and slack communities only slightly higher. Pharo and kirkpatrick (1994) used the same size quadrat (2 x 2 m) as the present study, found several dune communities with higher mean species richness than adjoining slack communities, in the alpine sand dune at lake Augusta, Tasmania. This area was not coastal, and therefore was not subjected to salt-spray, which influences species richness (Sykes *et al.* 1988). However these dunes were in pristine condition, and it is likely that without modification the Tangimoana dunes would have had additional dune species which are no longer present.

Dune slacks in contrast, are noted for high species diversity (Ranwell 1972; Hesp 1991). Sykes and Wilson (1987) found a mean of 9.9 species per $0.25m^2$ quadrat, at Mason Bay, Stewart Island, a low number in comparison with other studies, and concluded that there is a lack of dune slack species in New Zealand. The present study used a quadrat size of $4m^2$, sixteen times larger than theirs and only found a mean maximum species richness of 11.1, with 19 species the highest value found, in the dune slack community. This result included many exotic species and the result would have been much lower without them. This study adds further evidence that there is a paucity of species in New Zealand dune slack communities.

Many exotic species have acclimatized and flourished in dune land areas of New Zealand and include legumes, grasses, rushes, sedges, herbaceous annuals, biennials and perennials. The majority of the species occur in other dune land areas of the world, and specifically the dunes of Britain and Europe, where they are natives (Crawford and

Wishart 1966; Noest 1994). Species richness would be significantly less if these exotics were not present, though these exotics may have excluded native species. New Zealand's dune and dune slack flora contains few legumes (*Carmichaelia* species are and were present in some locations, for example Kaitorete spit), no herbaceous legumes and few annuals. Herbaceous legumes such as *Lotus pedunculatus*, *Medicago lupulina*, *Melilotus indicus* and *Trifolium fragiferum* and the small shrub *Lupinus arboreus* are widespread and abundant on the raw sandy soils at Tangimoana. These legumes increase the amount of nitrogen into the area, which is likely to have flow-on effects in changing species compositions. In the Netherlands nitrification of dune slacks resulted in large areas dominated by a few nitrophilous ruderals (Van der Laan 1985). The grassland community has the largest amount of legumes and other exotic species, and areas of it have the appearance of rank pasture with tall thick grasses. Few native species occur in this community, with the robust *Isolepis nodosa* the only significant exception.

Marram (*Ammophila arenaria*) is present in all communities, partially a result of being widely planted throughout in 1992. However it was naturalized prior to the 1992 planting, a result of the first planting in 1913. It is present in the slack community, and would have naturally been absent if not planted. The marram planting has other insidious effects, in that where marram was planted in lower lying areas, taller rushes and sedges, e.g. *Isolepis nodosa*, quickly colonized around it (pers.obs.). The marram planting was fertilized with Ammonium nitrate (pers.com. Lockie Grant, soil conservator, Manawatu/Wanganui Regional Council) increasing the nutrient availability in the soil. This may have resulted in a proliferation of nitrophilous weeds e.g. *Juncus articulatus*, and other plants more usually associated with higher fertility areas. These modifications would have influenced the species abundance and composition of some of the communities especially in the grassland, and slack.

Over the period of the study numerous plant arrivals (native and exotic) were noted in the study area, including *Apium prostratum*, *Asparagus officinalis*, *Eleocharis acuta*, *Sisyrinchium iridifolium* and *Typhae orientalis* at single locations. It appears that the dunelands are being slowly colonized with more species and as such, communities may become richer. Further, some species will inevitably be lost as communities age, as taller and more vigorous species colonize; many losses will be the shorter natives of the dune slacks.

Rabbits are widespread in the dunelands and the loose and dry soils provide ideal substrate for their burrows. Rabbit grazing can have a considerable effect on the vegetation (Chapter 5 and Boorman 1977), and may influence community composition through preferential grazing (Bhadresa 1977). Grazing tends to be restricted to around their burrows, which creates a mosaic of areas with different intensities of rabbit grazing (Boorman 1977). This was found to be the case at the dunes at Tangimoana, where grazing was highest in the slack and grassland communities. These communities also had the highest species richness values (Table 2.1), and at low densities rabbits may help to maintain species diversity (Boorman 1977).

Seven communities were identified in the cluster analysis, a smaller number in comparison with other studies, (Partridge 1992; Sykes and Wilson 1987, 1991). This paucity was probably a consequence of the quadrat size of 4 m^2, which may have lumped several vegetation types together, particularly in the dune slacks, in which a small variation in topography (therefore water table height) can have a dramatic influence on the species composition. Here the quadrat size however was adequate for the majority of dune communities, in which species composition changes less as a result of the micro-topography.

The elevation of the Tangimoana dune lands gradually decreases in height when moving towards the sea. The elevation above the mean tide level is only an approximation of water table height, as the water table follows the topography gradually sloping towards the sea. Thus, the sloping topography creates slack vegetation, with the same water table heights though different elevational heights, and slack and dune vegetation with the same elevational heights but different water table heights, because of being situated some distance from one another. For example, two distinct groupings of slack communities are separated approximately by two metres in elevation (Figure 2.3), and relate to the sloping topography.

The mean slope angles of the foredune and marram dune communities are very similar to the maximum slope angles that *Spinifex* and marram build (Esler 1970). *Spinifex* builds dunes with angles up to 14°, and marram builds dunes of up to 23°. The mean slope of the shrub dune community had the steepest angle, higher than any sand binder. This may indicate that stability of dunes with shrubs is greater than those without, enabling dunes with steeper angles to build.

The Tangimoana dunelands have endured considerably modifications since European colonization, yet native species predominate throughout most of the area. Native vegetation appears to be well adapted to this highly disturbed environment and predominates in newly created habitat areas, for example in deflation hollows. Disturbance may be an important factor in allowing natural vegetation to persist, and it is likely that native vegetation predominate, being located on arguably one of the most high energy and disturbed coastlines in the world. The area contains excellent temporary wetland, sand plain and dune communities and deserves to be protected for the maintenance of its native flora and fauna.

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Chapter Three

Eleocharis neozelandica (Cyperaceae) Kirk, an endangered sedge: habitat and cultivation.

Abstract

Eleocharis neozelandica seeds were collected from plants in natural habitat and from glasshouse grown plants obtained from the natural habitat at the Tangimoana dump dunes. The seeds were weighed and sown into seed trays. Seed number per seed head and seed weight were compared between plants grown in the same glasshouse obtained from two populations, one from Ninety-Mile beach, and the other from Tangimoana. There were significant differences between the two populations. The mean seed weight of the Tangimoana glasshouse grown plants was almost double the size of the seed from the natural population. The mean germination percentage was 61% and 12% for the glasshouse and the field collected seed respectively. The difference was attributed to the glasshouse plants having less competition and more resources as they grew in better conditions, than the plants from the natural habitat.

Introduction

Eleocharis neozelandica Kirk is a small sedge endemic to New Zealand. It is strictly coastal and grows in sandy margins of dune lakes and tidal creeks, damp sandy flats or hollows amongst sand dunes (Wilson and Given 1989). It is a very inconspicuous plant, often camouflaged against a damp sandy surface, with its rhizomes producing small rosettes of thin stems no longer than 8 cm and a reddish brown to dark green in colour (Photo 3.1). It is found in newly created or periodically disturbed areas, along with other colonizing plants. For example in the dunes of the Manawatu, it typically occupies deflation hollows behind a moving parabolic dune, an area of early successional stage.

Photo 3.1 : Rosettes of *Eleocharis neozelandica* on damp sand in centre, with *Carex pumila* (green) left.

Recorded history of Eleocharis neozelandica

Eleocharis neozelandica was unlikely to have ever been very common even before human occupation of New Zealand, because of its very specific habitat requirements in coastal and dune areas. At the turn of the century it probably was still locally common in places as Cockayne (1909) commented in a description of moist sand plains of the dune plant associations of western Wellington:

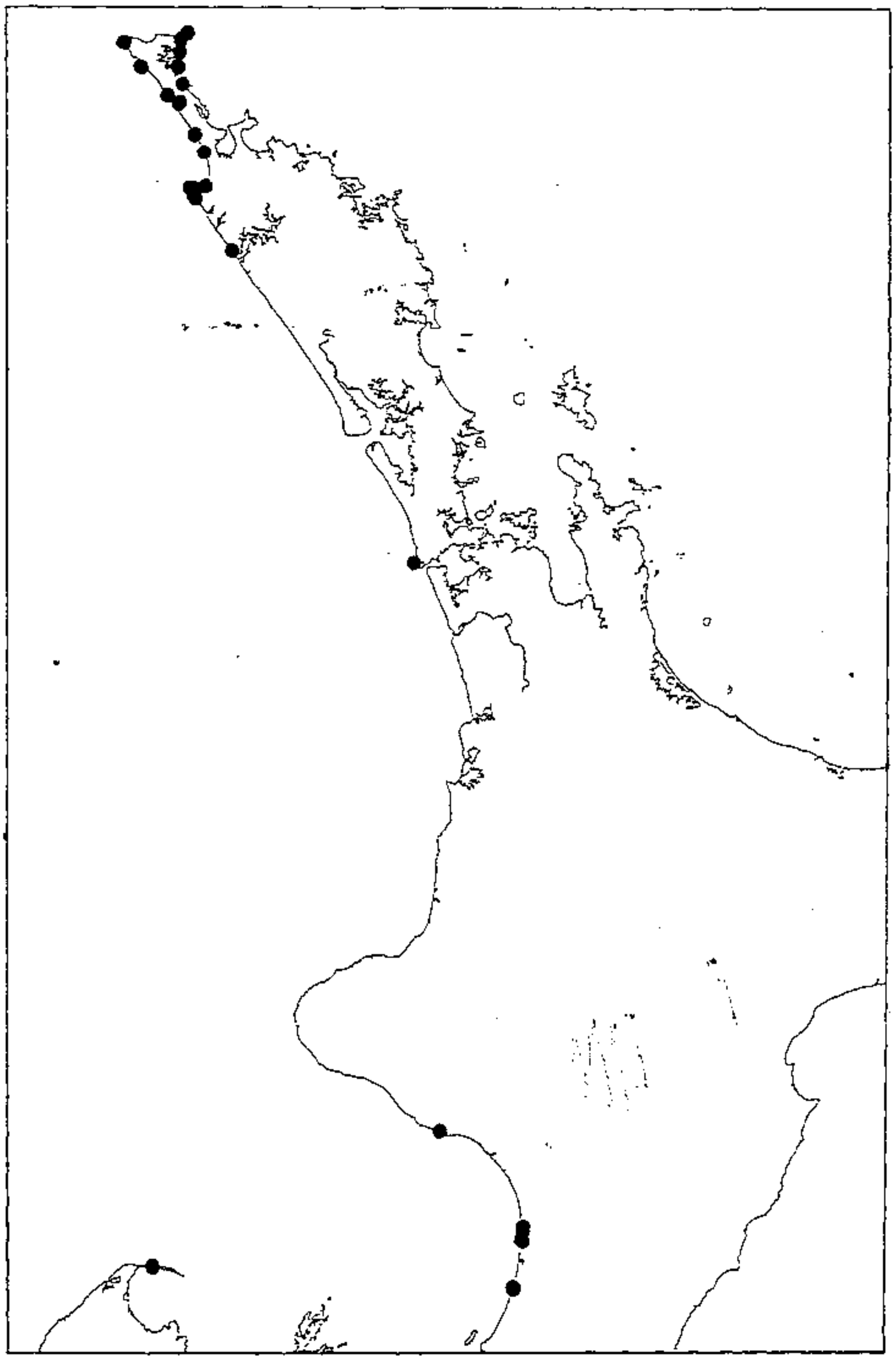
> "The small brownish-coloured *Elaeocharis novo-zelandica* is common in places, catching a certain amount of sand".

The dune areas have been predominantly modified and developed throughout the length of country since European arrival, and *Eleocharis neozelandica* has become rare as a result. It is now restricted to areas of least modified habitats and is classified as Endangered on New Zealand's rare plant list (Cameron *et al.* 1995).

Figure 3.1 shows the distribution of *Eleocharis neozelandica* from herbarium samples.

Regionally *Eleocharis neozelandica* was reasonably widespread prior to European occupation, and occurred in most major dune areas of New Zealand, north of Canterbury. In the North Island it occupied dune wetland habitat areas of the far north, from North Cape to Whatipu. It is still most common in these areas north of Auckland. Further south it occurred in the dunelands of the west coast from southern Taranaki to Kapiti. In the South Island it was collected at New Brighton near Christchurch and also from Farewell Spit in the early part of this century (the Christchurch record is not presented on the distribution map). It is now presently only known in the South Island from Farewell Spit (Wilson and Given 1989).

Figure 3.1 : The current and historical distribution of *Eleocharis neozelandica* from herbarium samples from Landcare Herbarium, Lincoln (CHR), Auckland museum (AK) and Auckland University (AKU).



The dunelands of Tangimoana to Foxton probably had areas of very good habitat for *Eleocharis neozelandica*; however the majority of the areas have been developed into exotic forest or exotic grassland/shrubland. Burgess (1984) recorded *Eleocharis neozelandica* at his study site (a deflation basin behind a moving parabolic dune) 1 km south of the Pukepuke stream mouth (S60 995947), approximately 3 km from the Tangimoana dump dunes (Ravine 1992). He surveyed the vegetation cover of slacks of different ages behind a moving parabolic dune sampling by point analysis. *Eleocharis neozelandica* was reasonably abundant, and was well represented with scores of 23, 5 and 22% in three slacks. Aerial photos between Tangimoana to Himatangi from 1979 revealed many deflation basins which would have been ideal for *Eleocharis neozelandica* at that time. *Eleocharis neozelandica* now only occurs at the Tangimoana dump dunes (Ravine 1992), where it occupies six separate deflation basins. It has previously been recorded south of Himatangi, at Foxton and at Levin; however recent searches have failed to find any trace (Wilson and Given 1989; Ravine and pers.obs.). Another two populations still occur in Foxton Ecological District at the Hawken's Lagoon Conservation Area (Ogle pers.com.) and at the Waipipi Dunes (Ravine 1992). These areas are north of the Waitotara River mouth.

Methods

Seed Germination and Propagation

In March 1994 two *Eleocharis neozelandica* plants were "rescued" from the northern wetland at Tangimoana (Chapter 5), and taken into cultivation into the glasshouse in the Ecology Department, Massey University, Palmerston North. These plants had been uprooted and damaged by an off-road vehicle, but once potted up, recovered well. From June 1994 onwards both plants started to flower, and they produced an abundant supply of seed. In January and February 1995 seed was collected from these glasshouse plants and from the natural populations at the Tangimoana dune lands. Viability of both seed lots was assessed. The plants generated were later used for laboratory experimental work as well as for field plantings at the Tangimoana dune lands.

On the 16th January 1995, 436 seeds were collected from the two Tangimoana glasshouse plants, and weighed in bulk. They were then placed into a sealed plastic bag which was kept at ambient temperature. In February seed was again collected from both plants, on the 9th and 14th, totaling approximately 800 seeds. This seed was bulked together, and from this 50 seeds were sown into each of 6 seed trays containing beach sand and placed onto the capillary mating in the glasshouse as a germination trial. Eight seed trays were also sown with 50 seeds each from the stored seed collected on the 16th January.

Seeds were also collected from the Tangimoana dunelands on two separate occasions. On the 13th and 17th February 1995 27 seeds and 140 seeds were collected respectively. Seed was collected in the field by rolling each seed head between the thumb and fore-finger, and holding a receptacle underneath. This insured that only mature golden brown seed was collected, as only this seed loosened from the bract. This seed was husked and bulked. All seed from both the cultivated and the field grown plants was given the "squeeze test" in order to determine its viability. Healthy seed was then weighed in groups of 10 seeds, from which 50 seeds were sown onto sand in each of three seed trays, which were placed on capillary mating in the glasshouse adjacent the other seed trays. The deformed, soft seeds were discarded as being nonviable. Slug bait was applied around and on all of the seed trays in order to reduce damage from slugs. The seed germination trial ran for three months with weekly recording of seedling emergence and seedling deaths, which were identified by brown shriveled shoots. The seedlings which appeared dead were removed from the seed trays. All seedlings were left to grow in the seed trays.

Comparisons of Eleocharis neozelandica populations

Eleocharis neozelandica plants were obtained from a population on Ninety Mile beach, Northland in December 1994 (Rapson). These plants were grown in the farthest corner of the glass house away from the Manawatu plants in cultivation, to mitigate the threat of cross pollination between the two populations. It was noted that the glasshouse grown Northland *E. neozelandica* plants had a slightly different morphology than the Tangimoana plants, especially with the seed head size, which was much larger. The stems were thicker, more robust and longer than the Manawatu plants. Mature seed heads were collected from both the Northland (35) and the Manawatu (114) sourced plants, on the 6th September 1995. The seeds in each individual seed head were then sorted from the bracts, and counted. The seeds of each population were then bulked and weighed in groups of 10 seeds, as the most precise scales could not weigh single seeds accurately.

Results

The mean germination percentage was remarkably similar between collections with 61% (Figure 3.2) at the end of the experiment for both groups of glasshouse seed (fresh and stored seed). The stored seed did not follow the same pattern of germination rate as the fresh seed, as it was lower than the fresh seed until 23 days from the start of the experiment, when they were approximately the same. The field seed was different from these two, with only a 12% germination percentage after three

Figure 3.2 : The percentage germination of fresh, stored and field *Eleocharis neozelandica* seed over time, with standard error bars.

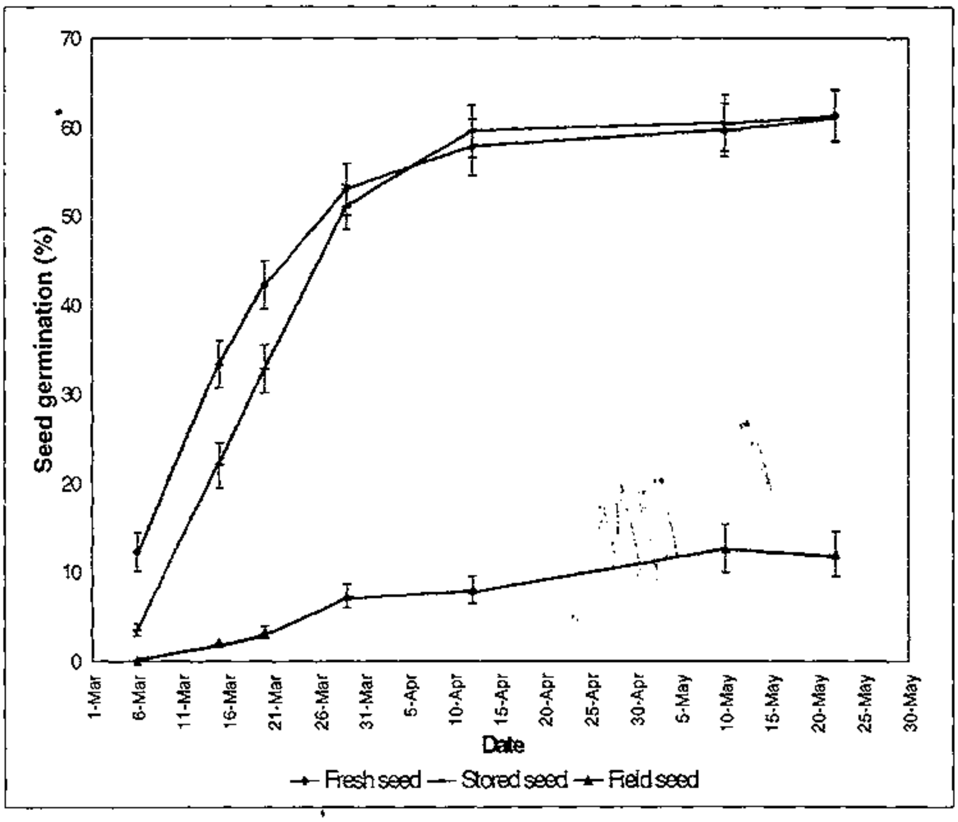
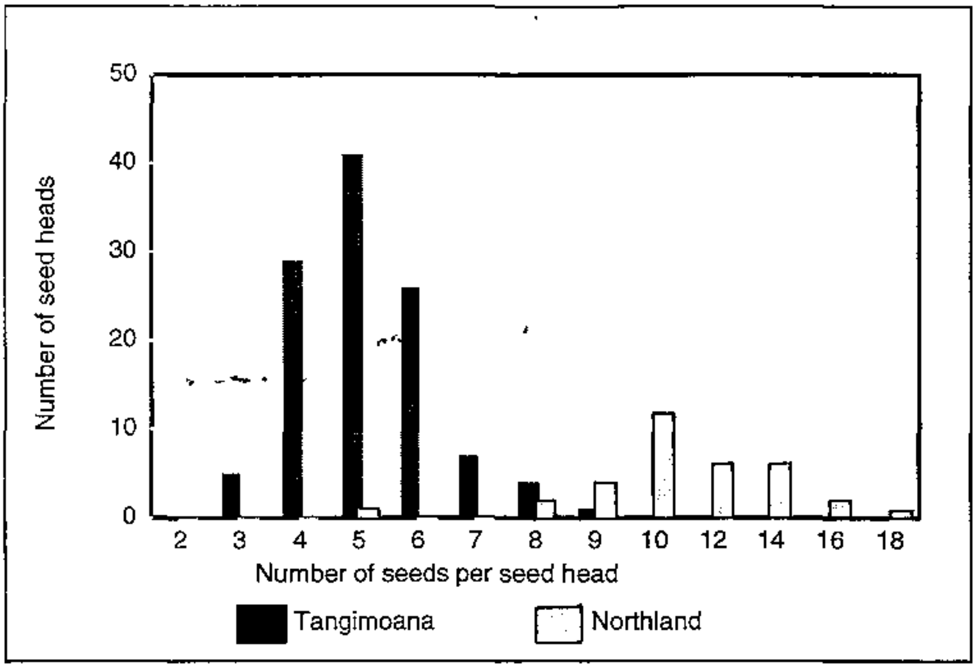
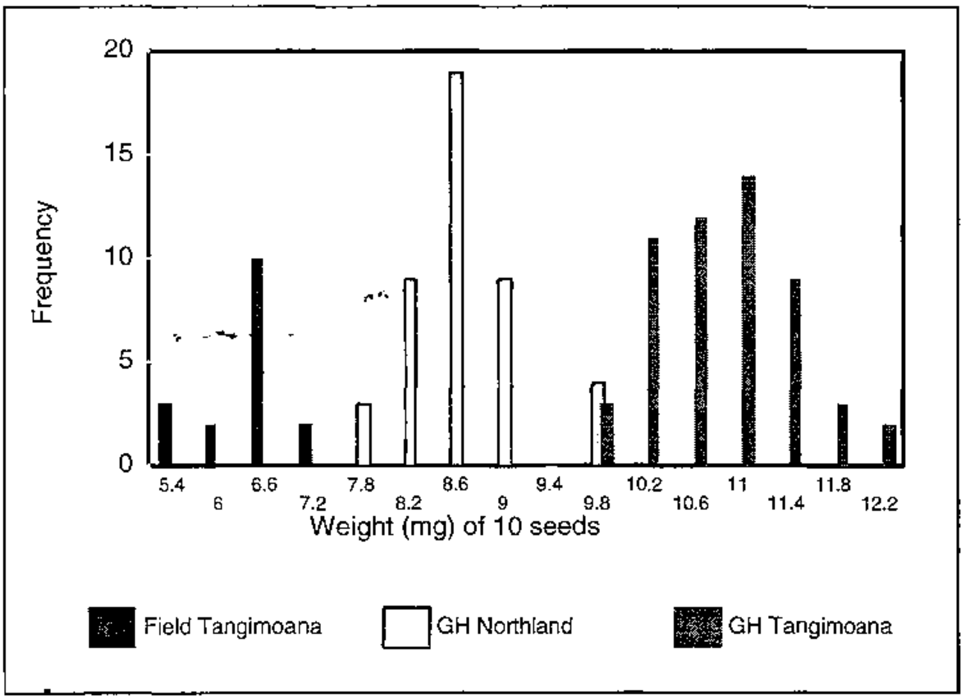


Figure 3.3 : The frequency distribution of the number of *Eleocharis neozelandica* seeds per seed head, for the glasshouse grown Tangimoana and Northland plants.



The number of seeds per seed head differed between the populations growing in the glasshouse with a mean of 5.2 for Tangimoana and 11.7 for Northland (Figure 3.3). The Tangimoana population had minimum of 3 and a maximum of 9 seeds per seed head, while the Northland had a minimum of 5 and a maximum of 19 seeds per seed head. A t-test was performed, and showed that the two samples were discrete (p=0.001). Clearly there are differences between the two populations with respect to number of seeds per seed head.

Figure 3.4 : The frequency distribution of weights of 10 *Eleocharis neozelandica* seeds for the glasshouse (GH) Tangimoana and Northland plants, and the natural population at Tangimoana.



The weight of 10 seeds was compared (Figure 3.4) between the two populations growing in the glasshouse (GH), and those of the plants from a natural habitat (Tangimoana). The three samples are discrete from each other, with the GH Tangimoana seed being the heaviest, then the GH Northland seed followed by the field Tangimoana seed, with means of 0.011, 0.0089, and 0.0065g respectively. The mean weight of the Tangimoana GH seed is almost double the weight of the field seed.

The weight of the average number of seeds per inflorescence for the glasshouse grown Tangimoana and the Northland populations was calculated. The Northland seed weight per head (0.0104g) was approximately twice that of the Tangimoana weight (0.0057g).

Discussion

Eleocharis neozelandica has always been limited in distribution being restricted to the major dune areas of New Zealand. Habitat loss due to European development has resulted in a dramatic decline of the species, and it is even more limited now, than prior to European colonization. Yet there appears to be regional differences in existing populations which are likely to be at the genetic level.

Despite growing in almost identical conditions in the glasshouse the Tangimoana and Northland populations were dissimilar in respect to seed number per seed head or seed weight. The weight of a Northland seed head with an average number of seeds is heavier than the Tangimoana population. The Northland population produces on average twice as many seeds as the Tangimoana population per seed head; however the seed weight is 19% lighter than the Tangimoana weight. This is not unusual as within a single species, populations from communities subjected to different environmental factors show differences in mean seed size (Fenner 1985). The Northland population appears to be investing in producing a greater number of seeds per seed head of a lighter weight, and so the weight of the seeds in the seed head is heavier, while the Tangimoana population produces fewer, heavier seeds per seed head. A variety of reproductive strategies appears to be occurring within the species, with respect to seed number per seed head and seed weight. It is likely that regional environmental differences influence which strategy is most adaptive. Environmental conditions may be less severe or more optimal for seedling survival in Northland compared to Tangimoana, and therefore light seeds with less resources may have a high percentage of survival. Conversely seedlings from heavier seeds may be more likely to survive at Tangimoana than seedlings from light seeds. Generally seed size increases along environmental gradients, for example seed size increases with decreasing environmental moisture as seedlings require greater stored energy to reach moisture (Fenner 1992). Thus, plants carrying genes for light seeds may remain in the Northland population while they do not in the Tangimoana population. Plants which produce light seeds are probably able to produce more of them than those which produce heavier seeds. Though measurements of plant size (e.g. number of leaves, longest leaf length) between the two populations were not made, the two populations appeared slightly different in respect to size of photosynthetic organs (leaves and stems), and this may be contributing to the difference in seed number and weight.

The glasshouse plants were growing in more optimal conditions, compared to the natural population, which may have contributed to the greater seed weight, and seed weight can decrease when resources are limited (Fenner 1992). The greater seed weight in the glasshouse populations was not due to added nutrients as they had been potted up into sand without any additional nutrients added. The glasshouse is warmer, constantly moist, with fewer extremes and with fewer herbivorous pests than the plants in the wetlands at Tangimoana. The plants in the wetlands often experience extremes; they are submerged in winter, reducing light levels and making oxygen unavailable at times, whereas water is readily available on demand through capillary mating in the glasshouse. The glasshouse plants were grown singularly in pots without competition from other species, though there was competition between ramets of the same plant, while the plants in the natural habitat were growing adjacent to other species.

The seed germination experiment ran for 3 months and at this time germination for both stored and fresh G.H. seed had reached a plateau (Figure 3.2). This is probably very representative of the actual percentage of viable seed, as there appeared to be no germination inhibitors or vernalization requirements. Light and moderate temperatures are likely to be important requirements for germination.

Schat (1983) found that the germination of four dune slack species was inhibited by burial, and no germination occurred under 10mm burial; in light conditions germination was very rapid and complete and germination was also inhibited below 15°C.

Season can have a significant effect on the percentage germination of wetland plant seeds. Seed from the seed banks of five Australian wetlands that experienced unpredictable fluctuations in water level (including two temporary wetlands), had higher germination rates in autumn and lower in summer when kept continually moist (Britton 1994). This trend was marked in several species including two species of *Eleocharis*, *E. dietrichiana* and *E. pusilla*. The germination trial of *E. neozelandica* was conducted in autumn, and germination would have been high if it has a similar strategy as the two Australian species.

The field seed did not follow the same pattern as the glasshouse seed; other factors such as seed dormancy, may have contributed to this result. Schat (1983) found only two of four dune slack species them exhibited innate dormancy, which on both occasions was rapidly broken by cold stratification and also decreased over time. All *Eleocharis neozelandica* seeds received ample light and water as they had only been pushed into the sand and not covered. If a proportion of these seeds were dormant at the time of planting, this dormancy was probably broken as a result of exposure to adequate light, temperature and water. Full germination is likely to have occurred. The field seed was on average approximately 40% lighter than the G.H. seed. Small seed are likely to be non-viable, and the result may be representative of the percentage of viable seed in the sample, as only the larger viable seeds may have germinated.

Plants growing in a temporary wetland habitat in dune slacks often have a relatively short period in which to grow and develop. The substrate is sand and quickly loses moisture in hot dry weather, limiting the growing season. Conversely it can quickly become inundated with water, halting growth, and plants such as *Eleocharis neozelandica* must grow and reproduce quickly. A period of rain in summer may be sufficient for a newly released *Eleocharis neozelandica* seed to germinate and grow. *Eleocharis neozelandica* seeds float and new seedling plants are often found around the edge of the maximum winter water height (pers.obs), presumably being dispersed to this location as a result of winter flooding. Conditions in this zone may be adequate for germination and growth during the period of inundation. Seed dormancy in this habitat could be considered to be a disadvantage unless it is easily broken by light and moisture. A seedling's success may be reduced if germination does not occur quickly when times are favorable.

Seed was less readily available for collecting in the field than in the glasshouse. In the field it was often not fully ripe or some seed had been dispersed because of wind etc. and so heads were not full. These factors together with the fact that *Eleocharis neozelandica* is a rare plant, and so only a small amount of seed was collected from the total meant that seed number per seed head was not routinely measured. However on occasions when whole seed heads were collected and the seeds were counted, measurements fell between 3 and 6 seeds, which conforms with the range for the GH seed heads. The seed heads on observation from the field and the G.H. plants were of a comparable size, and more similar to each other than the G.H. Northland heads. It is reasonable therefore to assume that there is not a difference in the number of seeds per seed head for the Tangimoana G.H and field seed.

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Chapter Four

Success of artificial establishment of a rare native sand-plain daphne, *Pimelea* "Turakina" at Tangimoana, Manawatu.

Abstract

Pimelea "Turakina" is a threaten small shrub which is naturally only known from the dune plains between Himatangi and Foxton in the Manawatu. Plants were cultivated from cuttings collected from the natural population, which were planted at the Tangimoana dump dunes. These plants have produced abundant seedlings, though many of the parent plants have died. This species may be a short lived shrub adapted to the dynamic conditions of the Manawatu dunelands.

Introduction

Pimelea "Turakina" (Thymelaeaceae) is presently taxonomically unnamed, though has been classified as "Taxonomically unknown status critical" in the New Zealand rare plants list (Cameron *et al.* 1995). It is a small shrub of dune plains and is currently only known from one area in New Zealand, the dune lands of the Foxton Ecological District (Ravine 1992), between Himatangi and Foxton, on the Manawatu coast. This area is now significantly threatened as habitat for *Pimelea* "Turakina" as the majority of the area has been planted in *Pinus radiata*. It was previously thought to be in another area, the dunes of Turakina (Ogle pers.com.) which is why it has this catch name. However it appears that this population has subsequently become extinct.

Pimelea "Turakina" is generally a prostrate shrub, though when growing amongst taller rushes it has a more upright habit. It has small (4-7 mm) obtuse to ovate glabrous leaves, which are glaucous and are almost succulent when in the open. Its habitat is around temporary wetlands on sand plains, at approximately the edge of the high winter water line. When growing in the open and with a plentiful supply of sand, its branches collect sand, becoming buried, and forming small raised hummocks. The individual shoots protrude from these sand hummocks, each appearing like separate plants. Plants grown from cuttings, flower and set seed from an early age.

This native daphne is vastly different in both its appearance and ecology to *Pimelea arenaria* which also grows in dune lands. *Pimelea arenaria* has 8 -12mm, broadly ovate to elliptic-oblong leaves, which are pubescent on the underside. It can grow to 1 metre tall, and like a true dune shrub collects sand, often having its branches completely buried. *Pimelea arenaria* commonly grows on the lee of the fore dune, as well as in other older established dune areas (Poole and Adams, 1990).

On the 22nd June 1995, Don Ravine (DoC, Palmerston North) and I visited the Himatangi dunes to investigate the habitat of *Pimelea* "Turakina". We found many plants growing amongst *Leptocarpus similis* and *Schoenus nitens*, as well as other plants growing out in the open. The morphology of *Pimelea* "Turakina" varied greatly depending on location. Plants growing with rushes, were tall and appeared to be etiolated having long internode lengths. Conversely the plants growing out in the open were prostrate with short stems and very short internodes. These plants appeared to be growing at a similar location to *Pseudognaphalium luteo-album* with respect to the water table height, which is just above the high winter water line (Esler 1969)

The Tangimoana dunelands, a proposed DoC reserve, not containing a population of *Pimelea* "Turakina", is within its known natural distribution, between Himatangi and Turakina. It was identified as an appropriate area to try to establish a population of *Pimelea* "Turakina" from rooted cuttings sourced from Himatangi, as a refuge.

Methods

In winter 1993 John Barkla (DoC Wanganui) collected cuttings of *Pimelea* "Turakina" from Mr. Basil Sexton's property on the coast at Himatangi, km south of Tangimoana. These cuttings produced 29 plants; however after the plants were propagated many *Pimelea* "Turakina" seedlings germinated in the plant pots, and some were large enough to be monitored individually. These seedlings were not removed from the pots before planting, but were left together with the other plants, in order to reduce the transplanting shock. In 29 plant pots there were 36 individual *Pimelea* plants which were tagged with aluminum tags (Numbers P512 to P547). Another 37 small *Pimelea* seedlings were left untagged.

Planting

All *Pimelea* "Turakina" plants and associated seedlings were planted at the Tangimoana dunelands, at an isolated sand plain on the 20th November 1995. The rationale for planting them is that the parabolic dune at the head of the sand plain was "blowing out", creating a new deflation basin and therefore more potential habitat for future colonization. This site is also isolated from vehicles, which could potentially damage or kill plants, having no accessible tracks around it. The *Pimelea* "Turakina" plants were planted at four places on the sand plain, in groups of between seven to eight pots having between eight to ten tagged plants in each group. Two of the groups were planted close to the end of the sand plain adjacent the newly created deflation basin formed by the dune blowing out. The other two groups were planted closer to the sea. All of the plantings were planted at approximately one metre apart and above the winter high water line, around the edge of the temporary wetland. This elevation was determined by the zonation area between wetland and non-wetland plants, and by the wetland being still very full of water at the time of planting. Photo 4.1 shows one of the planted *Pimelea* "Turakina" flowering.

Photo 4.1 : *Pimelea* "Turakina" flowering.

On the 22nd June 1995 *Pimelea* "Turakina" cuttings were taken from many of the larger plants growing at Himatangi. Some of these were propagated in the Ecology Department glasshouse Massey University, while the rest were sent to Alastair Turnbull of Talisman Native Plant Nursery. In total 25 plants were grown on from the Ecology Department cuttings, from which 22 plants were planted at Tangimoana on the 9th June 1996. Three plants remained at the Ecology Department.

The second planting was the 9th June 1996, on the same dune plain as the southern water table study site (Chapter 1) in an area approximately 150 metres towards the sea, and adjacent to the excavation site (Chapter 1). The plants were tagged with small aluminum tags with numbers from P548 to P569. There was one extra plant, a seedling which was large enough to tag individually from the 21 pots. Two of the plants were carrying many large fruit when planted.

The plants were planted approximately 30 cm above the waterline around a slack (which was full of water at the time of planting) and approximately 1 metre apart in three groups of seven or eight plants. All tagged *Pimelea* "Turakina" plants were monitored at regular intervals.

Results

All plants from the first planting were relocated at the first census, the 10th January 1996, 51 days after planting while two and nine plants had died by the 13th May 1996 and the 27th September respectively (Table 4.1). Over the 1996 - 97 summer, an additional seven plants died, and on the 27th March 1997 the majority of the rest of the planted *Pimelea* were generally unhealthy and may not survive much longer.

All of the tagged plants have flowered and set fruit prolifically from the first year of planting. There are now more plants present at the site of the first planting than were originally planted, as there are numerous seedlings around most tagged plants (Table 4.1). The number of seedlings increased in autumn to spring of 1996 and it appears that most seeds germinate during the winter months. However the number of seedlings declined and fewer seedlings were found in December and March.

Table 4.1: Demographic records of the first planting of *Pimelea* "Turakina", showing the number of tagged plants alive, dead, flowering, fruiting and the number of seedlings around each plant at each monitoring date.

DATE	10/1/96	13/5/96	27/9/96	22/12/96	27/3/97
Plants alive	36	34	27	27	20
Plants dead	0	2	9	9	16
Flowering	29	3	2	13	2
Fruiting	20	4	0	12	4
Number of seedlings	0	192	315	232	189

Some seedlings were up to 20 cm high and appear to be very healthy. Few seedlings occur around the tagged plants in the second planting, which is not surprising considering their age and time of planting and that the planted *Pimelea* have not yet flowered profusely (Table 4.2).

All of the seedlings recorded have only been located around the tagged plants, though there may be other seedlings present in the near vicinity which have not been discovered.

Table 4.2: The demographics of the second planting of *Pimelea* "Turakina", showing the number of tagged plants alive, dead, flowering, fruiting and the number of seedlings around each plant.

DATE	**27/9/97**	**22/12/96**	**27/3/97**
Plants alive	22	22	18
Plants dead	0	0	4
Flowering	10	14	3
Fruiting	0	14	2
Number of seedlings	0	8	3

Discussion

Species in decline may require active management for survival. *Pimelea* "Turakina" is a rare species naturally only known from dune areas, which have now been planted in *Pinus radiata*. Rare species restoration may involve deliberate plantings of populations, or reintroductions to past habitats or even introductions into suitable though apparently previously unoccupied habitat. *Pimelea* "Turakina" is an appropriate candidate for such restoration given its highly modified native habitat.

Pimelea "Turakina" planted at Tangimoana dune lands established well. They have flowered, set seed and many seedlings are present around the parent plants. The aim to establish a viable population at the Tangimoana dune lands appears to be eminently successful. *Pimelea* "Turakina" appears to set seed prolifically, and Alastair Turnbull, (Talisman Native Plant Nursery, pers.com.) stated that this was the most freely seeding *Pimelea* he has ever grown. The plants at

Tangimoana dune lands are presently only located in two areas, which would cover less than 20m^2. It appears that most of the seed is falling from the parent plants and germinating below them. *Pimelea* produces fleshy fruits, and is probably distributed by birds or lizards. However their natural seed dispersers may not be present or may not have located this new food source. Seedlings appear most prolific around plants planted in close proximity to one another. Competition with *Melilotus indicus* (which was extremely thick around the *Pimelea* seedlings, and tagged plants), and a period of dry weather in January 1997, may have caused the seedling mortality. The *Pimelea* planted on the first occasion appeared to be dying on the 27th March 1997, as they had very little green plant tissue left. On this date these plants were only 3 ½ years old, which is a short time for a shrub to live. The *Pimelea* may have been planted at the wrong elevation; however as there are abundant young seedlings at the same location this would seem unlikely as the seedling phase of a plant's life cycle is the most difficult. Further, the *Pimelea* growing at Himatangi were in a variety of elevations, from the sandy edges of temporary wetlands to amongst thick *Leptocarpus similis* and *Schoenus nitens*, at slightly above the elevation where a distinct zonation of wetland and non wetland plants occurs, at the winter high water line.

The *Pimelea* were in plant pots for approximately two years before being planted out and were reasonably root bound at the time of planting. This could have affected the growth of their root systems by causing the roots to grow inwardly and form balls of roots. Thus the *Pimelea* may not have established adequate root systems into the surrounding soil, and have consequently suffered in summer, with a period of dry weather.

Some of the second planting *Pimelea* had been attacked by a leaf rolling insect, which may be the native species of moth *Ericodesma aerodana* which is present in the area (C.Ogle, press release). This moth feeds on the native sand daphne, *Pimelea arenaria* (and closely related species, such as *Pimelea* "Turakina"), which is present adjacent to some of the affected plants. This species of moth could be controlled with an insecticide on these and other young plants in order to help them establish. The insect only seems to have a significant effect in late summer.

It is possible that *Pimelea* "Turakina" are short lived shrubs. They produced a prolific number of seedlings in a relatively short time, and may be adapted to a temporary habitat associated with regular disturbances and a fluctuating water table. Further monitoring should continue in order to identify the longevity of *Pimelea* "Turakina" and at what age they start to reproduce.

Pimelea "Turakina" is most probably a separate species, adapted to the dynamic environment of the Manawatu dunelands. It is extremely threatened in its natural habitat where it occupies small areas around deflation hollows which were not planted with *Pinus radiata*. However it is likely that these plants will be slowly eliminated as the pine trees mature, and out compete the native vegetation. It is advisable that additional plants are planted in other locations within the Tangimoana dunelands to ensure the species survival. The dunelands are naturally dynamic and dunes regularly move inland and cover the existing vegetation. Two small populations are very vulnerable to sand movement on any scale.

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Chapter Five

The water table fluctuations of temporary dune slack wetlands at Tangimoana, Manawatu, New Zealand, with reference to vegetation change in exclosure and control plots.

Abstract

The water table fluctuations were monitored for 30 months in two temporary wetlands in dune slacks at the Tangimoana dump dunes in the Manawatu. These two wetlands contained populations of *Eleocharis neozelandica*. Control and exclosure plots were constructed to assess the effect rabbits have on the temporary wetland vegetation. The water table fluctuations were found to be directly related to rainfall and season. An extreme water table height in the autumn and winter of 1995 resulted in changes in the species distributions in relation to elevation. Species which occupy permanently wet areas increased dramatically, while those species occupying temporarily wet areas moved higher in elevation in the wetlands. Over the study the wetlands were progressively invaded with large rushes and sedges, and they are now less suitable for habitat for *E. neozelandica* and other early successional dune slack species.

Introduction

The dune plains at Tangimoana, New Zealand, contain a number of small temporary wetlands which become inundated with fresh water during the winter and spring months, while often being completely dry over the summer. Heavy rains during the summer and autumn months can also temporary submerge the plants occupying these wetlands. The New Zealand flora contains a group of plants which are well adapted to and predominantly occur these temporary wetlands. Most of these plants reproduce by both seeds and rhizomes, and once established in a suitable habitat, spread quickly. The temporary wetlands at Tangimoana are excellent examples, and contain predominantly native species.

At Tangimoana the wetlands are four hundred to eight hundred metres from the coastline, and are created by parabolic dunes which leave low elevation deflation basins hollows behind them as they move inland. Sand is stripped by wind from these bare deflation hollows down to the summer water table, and blown onto the moving parabolic dunes. Wetlands form in these deflation hollows which have reasonably high water tables. The soils of these deflation basins is predominantly mineral quartz and feldspar sand, deposited on to the coastline by the region's rivers. It weathers easily and provides an ample supply of most plant nutrients; in addition, shell fragments in these sands provide a rich supply of calcium, however the soils are low in potassium and nitrogen which limits plant growth (Cowie *et al.* 1967).

As the parabolic dunes move inland, so does this terminal deflation hollow, along with the primary colonizing vegetation (Cowie 1963). The primary colonizing plants of these basins are well adapted to their low nutrient contents, as well as to the periods of flooding and drought. In the Manawatu the principal colonizer of these hollows is *Carex pumila* (Burgess 1984). As the nutrient content of these wetlands increases most of the primary colonizing plants are eliminated by larger sedges and rushes, for example *Leptocarpus similis* and *Isolepis nodosa* (Esler 1969; Burgess 1984; pers.obs.).

Two temporary wetlands in terminal deflation hollows behind two different parabolic dunes were chosen to study the water table fluctuations (Photos 5.1 and 5.2). They were the best examples of temporary wetlands in the area, and both contained populations of the endangered sand spiked sedge, *Eleocharis neozelandica.* These wetlands are approximately three hundred and fifty metres from each other, and were called northern and southern wetlands respectively.

Photo 5.1 : The northern wetland with a high water table on the 30th December 1995 (Exclosure plots present).

Photo 5.2 : The southern wetland with a high water table on 30th December 1995.

Photo 5.3 : Measuring the water table in the northern wetland, November 1995.

Methods

Water table monitoring

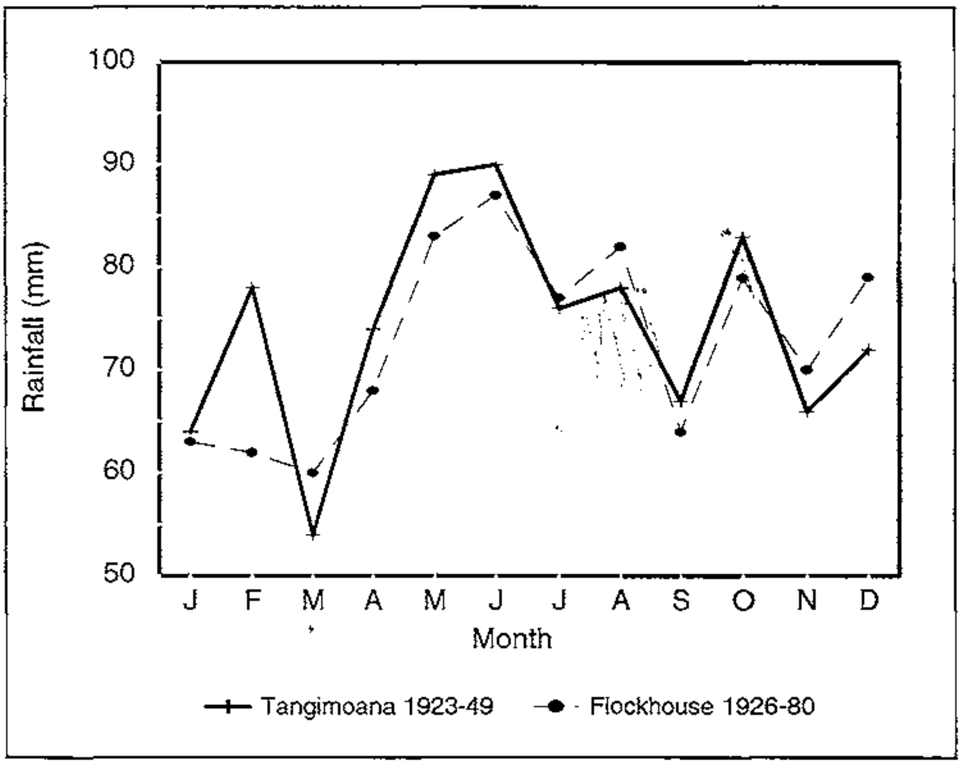
In May and June 1994 two transects which dissected each other at right angles were placed at each of the wetlands. Plastic, polyvinyl chloride (PVC) water table measuring pipes were placed at 10 metre intervals along these transects. At the northern wetland, eight pipes were placed while eleven were placed at the southern wetland. The PVC pipes were 35 mm in diameter and of either one or two metre lengths. The one metre pipes were placed in the hollows within the dune slacks, i.e. where the water table is close to the surface, while the longer pipes were placed at the ends of the transects at higher elevations on small dunes where the water table is further from the surface. These pipes had numerous 3 mm holes along their entire length and were sheathed with a lightweight nylon fabric, which allowed water to penetrate while excluding sand. The pipes were placed in the sand by making a well with a 50 mm diameter PVC down-pipe which was driven into the sand. The sand inside the down-pipe was compacted using a wooden stake, and the down pipe was then pulled out complete with sand. This was repeated numerous times in order to reach the required depth into the slurry of sand. The 35 mm PVC pipes were then placed in these wells, which were back-filled with the excess sand. Approximately 10 to 20 cm of pipe were left protruding above the sand. The nylon sleeves were folded into the top of the pipes and were plugged with corks so sand did not blow in. The elevation of all measuring pipes was measured using a surveyor's level and staff.

At each recording time the height of the water table was measured with a flexible metal tape measure which was placed into the pipe until it touched the water. A measurement was then read at the top of the pipe, from which the length of the pipe above the soil surface was subtracted to give the water table measurement with respect to the soil surface. When the water table was above the surface the tape measure was placed adjacent to the water pipe on northern side. All measures were made to the nearest 0.5 cm.

Rainfall data

Rainfall data from Flock House during the period of the study was obtained from the climate station, Flock House. The Flock House weather station is approximately 7 km directly from the dunelands at Tangimoana. The rainfall data from Tangimoana (1923-49) and Flockhouse (1926-1980) are very similar in comparison, with only February being appreciably different (Figure 5.1). Weather data collection ceased at Tangimoana in 1949, so Flock House rainfall data was used when comparing rainfall and water table.

Figure 5.1 : The mean monthly rainfall for Tangimoana and Flock House for the available data recorded at these two locations. Rainfall was recorded at Tangimoana from 1923-49 and at Flock House from 1926-80.



Vegetation monitoring of the rabbit exclosures.

Four plots (1.5 square x 1 high) were constructed in December 1994 out of 35 mm mesh chicken wire and 1.8 metre steel posts. The two exclosure plots were fenced on all sides, and were designed to exclude rabbits. The chicken wire was inserted 100 mm into the sand to prevent rabbits from digging under it. The two control plots were fenced on only three sides with the open side down wind of the prevailing wind. One plot of each type was placed in each wetland. In January 1995, there was a sparse vegetation cover with the majority of the area bare sand or covered in a turf of *Selliera radicans*. The vegetation cover in the exclosure plots was assessed non-destructively by counting every plant or ramet in one hundred 15 x 15 cm quadrats which covered the entire surface area of each plot. Additionally at the southern wetland the percentage cover of the rhizomatous herb, *Selliera radicans*, was estimated in each of the 15 x 15 cm quadrats, as it is impossible to identify single plants, and it covered a large area of the plots.

The plots were resurveyed in March 1997, over two years after their construction. The cover of many species had increased dramatically to levels where it was impossible to count individual plants, and so percentage cover of each species was estimated in each of the 15 x 15 cm quadrats. These cover estimates were averaged for the hundred quadrats. In order to compare the difference in the vegetation cover of the two measurements, each species was given a percentage cover estimate for an average sized single plant or ramet in a 15 x 15 cm quadrat. These estimates were made in the field and were 4% for *Carex pumila*, 2% for *Leptocarpus similis* and *Leontodon taraxacoides*, 1% for *Eleocharis neozelandica*, *Isolepis cernua*, *Lobelia anceps*, *Myriophyllum votschii*, and *Triglochin striata*. The ramet numbers from the initial recording were then corrected to percentage cover.

Results

Wetland water table shapes

The seasonal range in water table height fluctuated considerably, with a difference of approximately 91cm and 85cm between the highest and lowest heights, for the northern and southern wetlands respectively. The elevation of the northern and southern wetlands along both transects, and the water table heights at the lowest and highest recorded times are shown Figures 5.2a and 5.2b, 5.3a and 5.3b.

The water table is uniform and horizontal in shape when it is above the surface (measured to the nearest 0.5cm). However when the water table falls below the surface, differences in the water table height occur between pipes relative to their location. The lowest water table heights at the southern and northern wetlands are not horizontal, though the southern wetland is more irregular (Figures 5.2a, 5.2b, 5.3a, and 5.3b). Three water table measuring pipes (p7, p8 and p9) in the southern wetland were within 0.5cm of each other in elevation, though the water table height was not horizontal when below the surface (Figure 5.4). The depth to the water table varied considerably over time but also pipes were irregular in respect to the differences between each other. Though pipes 7 and 9 most commonly had the highest water tables, There was up to 15 cm differences between the pipes on occasions.

Figure 5.2a : The elevation along the length of the northern wetland, and the maximum and minimum water table heights at pipes 2 and 4 - 8 over the study period. The zero point relates to the lowest pipe in elevation.

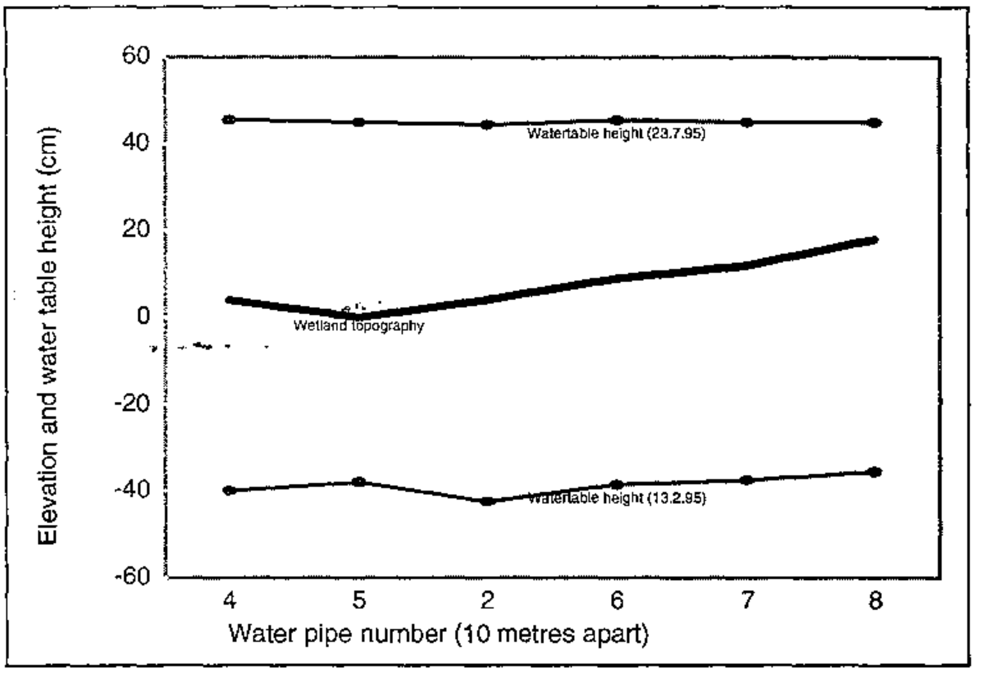


Figure 5.2b : Elevation along the width of the northern wetland, and the maximum and minimum water table heights at pipes 1 to 3 over the study period.

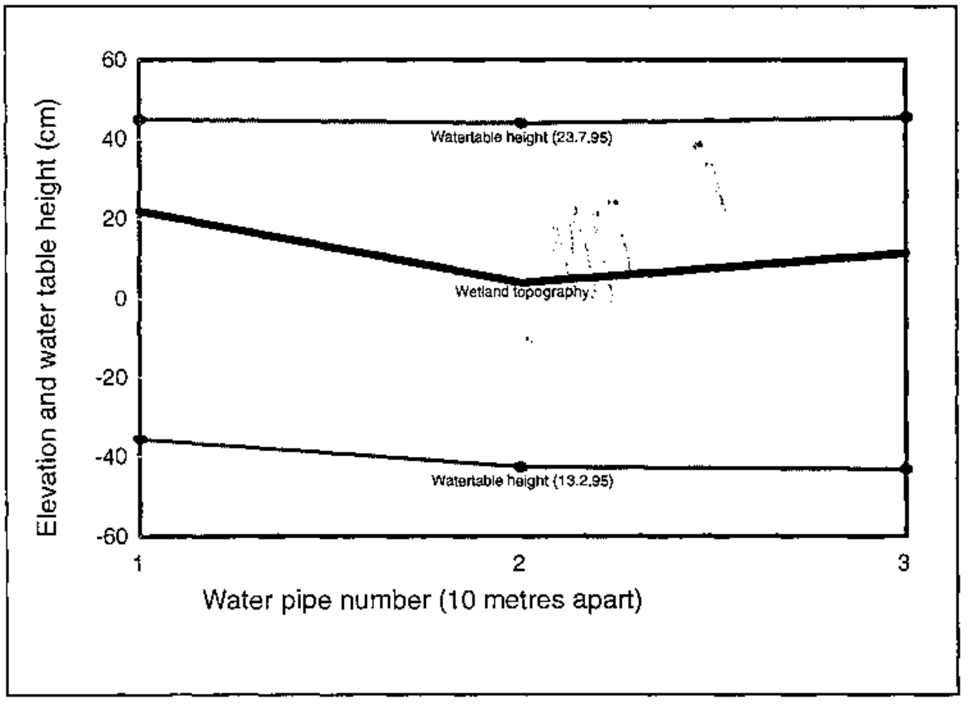


Figure 5.3a : The elevation along the length of the southern wetland, and the maximum and minimum water table heights and pipes 3 and 7 - 11 over the study period.

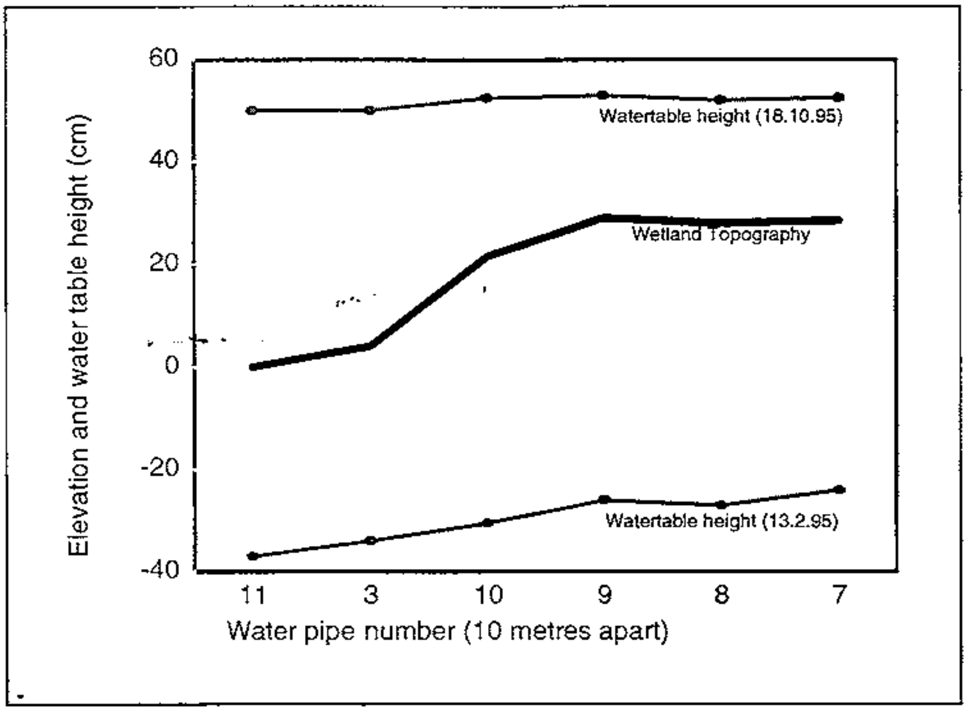


Figure 5.3b : Elevation along the width of the southern wetland, and the maximum and minimum water table heights at pipes 1 to 6 over the study period.

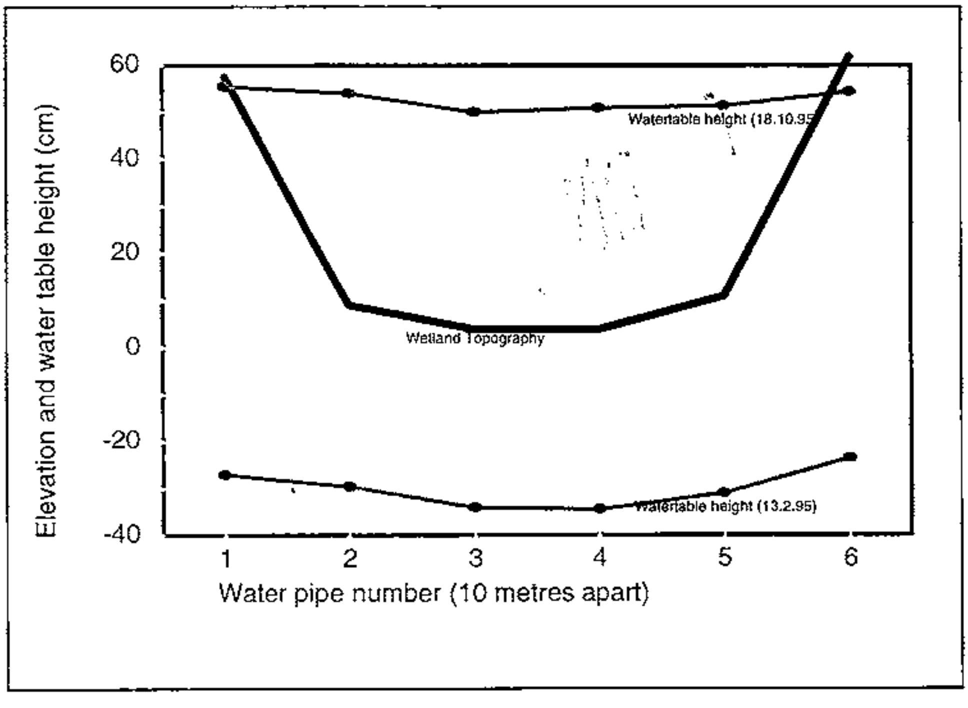
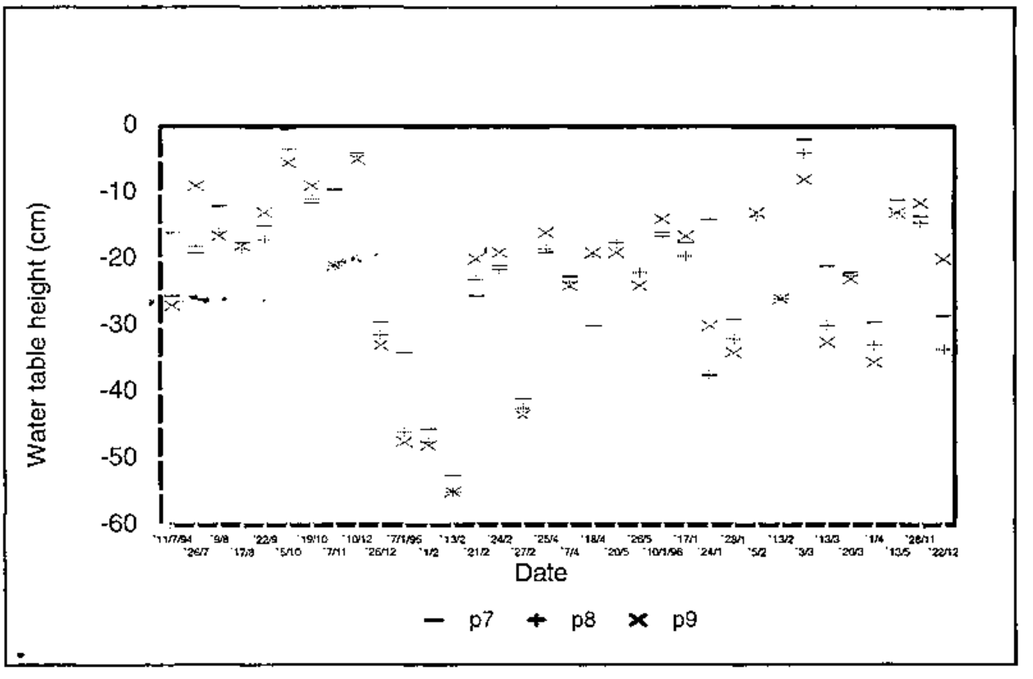


Figure 5.4 : The water table profiles of three pipes (p7, p8 and p9) identical in elevation, at the southern wetland on occasions when the water table was below the surface. All three pipes had the same water table height when the water table was above the surface.



Water table responses to rainfall

Over the study period (July 1994 to December 1996), the rainfall was predominantly above the long term yearly average, with 1994 (July - December) up an extra 19.3%, 1995 an extra 34%, and 1996 an extra 5.7% (Figure 5.4). There were three months, June, August and October in which all readings were both very similar to each other and their monthly means. The months of January, May, and October were also very similar to each other though not similar to their monthly means (Figure 5.5). When the study years were compared with previous years (Figure 5.6), 1995 was the wettest year on record and 1996 was above average from the data shown.

Figure 5.5 : The mean monthly rainfall and monthly rainfall totals for the study period, 1994 to 1996.

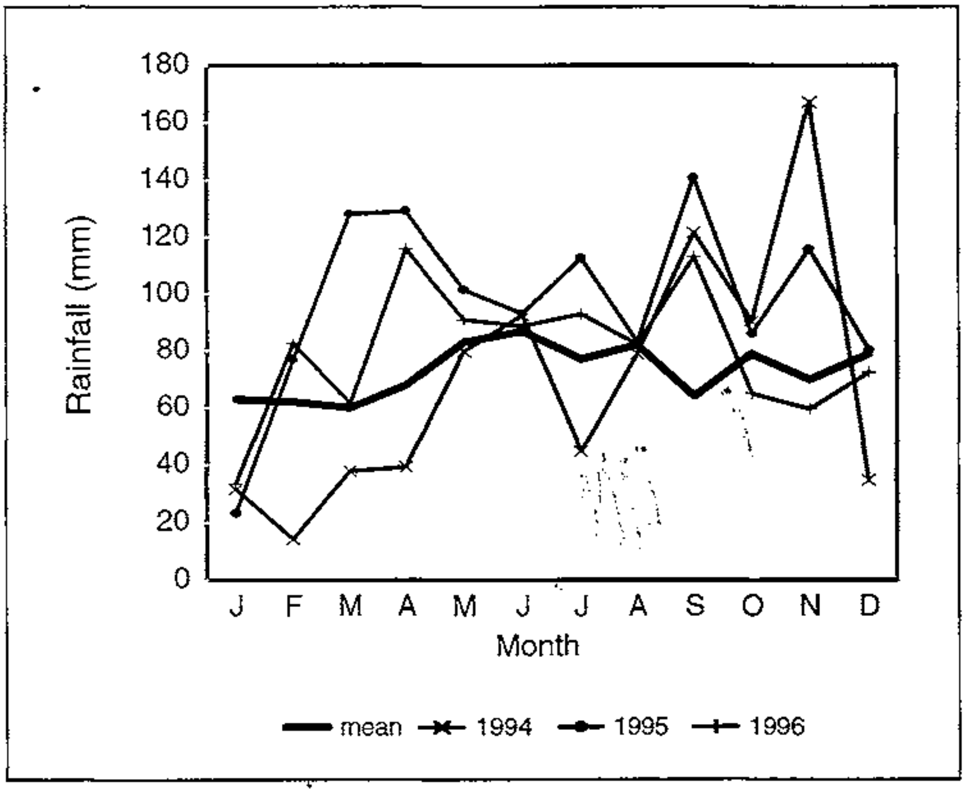
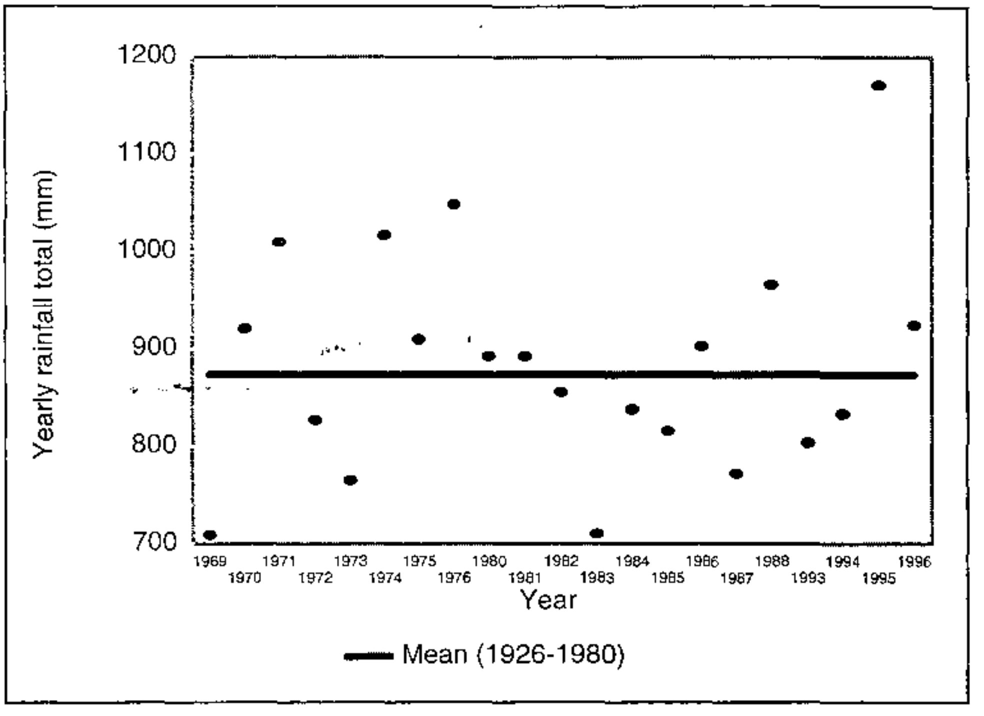


Figure 5.6 : Annual rainfall at flockhouse over 21 recorded years. Some years have been removing because they contain missing data.



The mean water table of the two wetlands were similar in monthly fluctuations and from year to year, as were the maximum and minimum water table heights experienced during winter and summer are closely comparable (Figures 5.7 and 5.8). The northern wetland appeared to respond more quickly to rainfall, and water pooled above the soil surface before the southern wetland. The water table at the two study sites is directly comparable to rainfall, for example, the summer and autumn of 1994 were particularly dry (January to May), when rainfall was 133 mm below average rainfall (Figure 5.5). This deficit correspondingly resulted in the wetlands at Tangimoana being dry until mid winter in July (pers.obs.), when they partially filled with water (Figure 5.7 and 5.8). During the end of October and throughout November an extra 108.6 mm of rainfall occurred above the average for these two months. This resulted in the water table in the northern wetland rising close to the maximum height recorded, thought the southern wetland was only half full. In the middle of March 1995 above average rainfall fell which resulted in the water table rising dramatically in both wetlands (Figure 5.7 and 5.8). This above average rainfall continued throughout 1995 (Figure 5.5), for all months until November 1995. An extra 320.5 mm or +47.8% of rainfall fell, compared to the monthly means during this period with March, April May, July, September and November recording monthly rainfall totals over 100mm. March, April and September 1995 recorded more than twice than their long term monthly averages (Figure 5.5). The highest water tables were recorded in July 1995 of +35.8 cm at the northern wetland and +36.7cm for October in the southern wetland. These are the approximate maximum obtainable water table heights for both of the wetlands, for above these heights water spills over the small dunes encompassing the wetland into other deflation hollows.

Correspondingly, the water table at the northern wetland remained above the soil surface for nine months, and for five months the water table was close to the maximum water table height (Figure 5.7). The southern wetland was not submerged as long, seven months with five being close to the maximum water table height (Figure 5.8).

The elevation of the soil surface at the lowest pipes were 22 and 29 cm below the highest pipes in elevation, for the northern and southern wetlands respectively. All values of the mean water table heights for the northern wetland were an average of the eight water table pipes at this wetland. However at the southern wetland, two pipes (pipes 1 and 6) were removed from the average as they corresponded to small dunes above the true temporary wetland.

Figure 5.7 : The mean water table height at the northern wetland over the study period (July 1994 - December 1996).

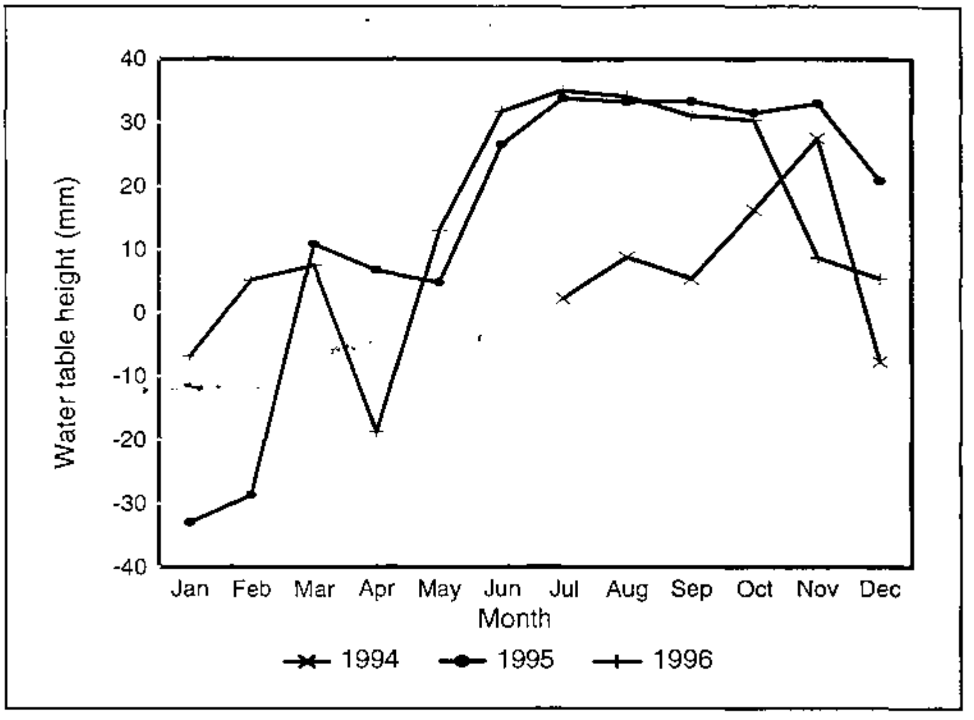


Figure 5.8 : The mean water table height at the southern wetland over the study period (July 1994 - December 1996).

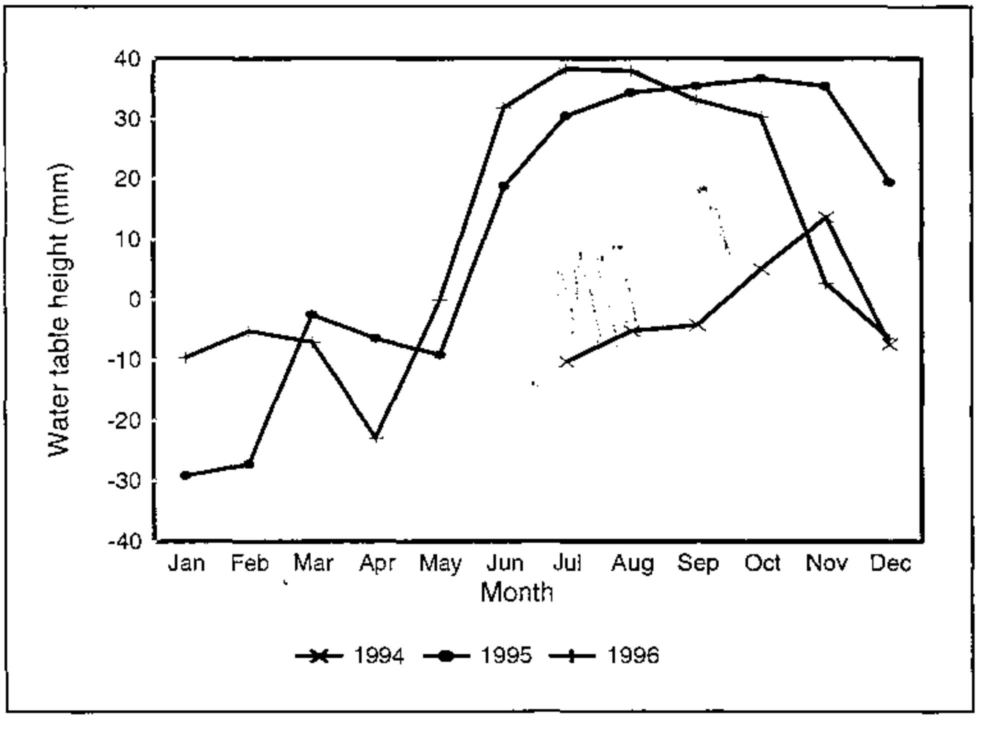
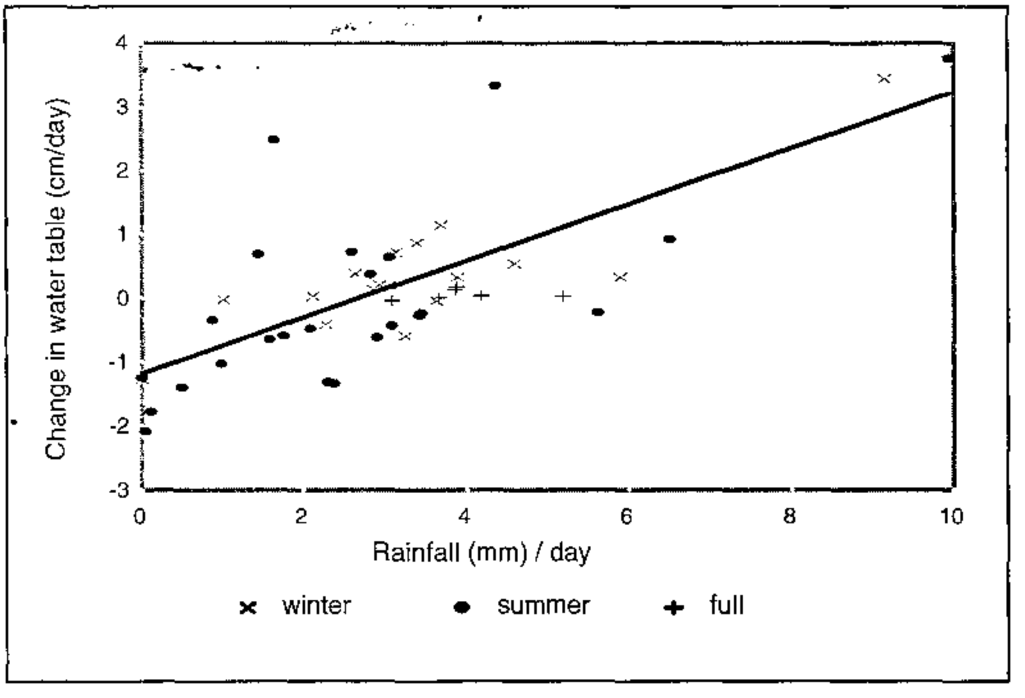


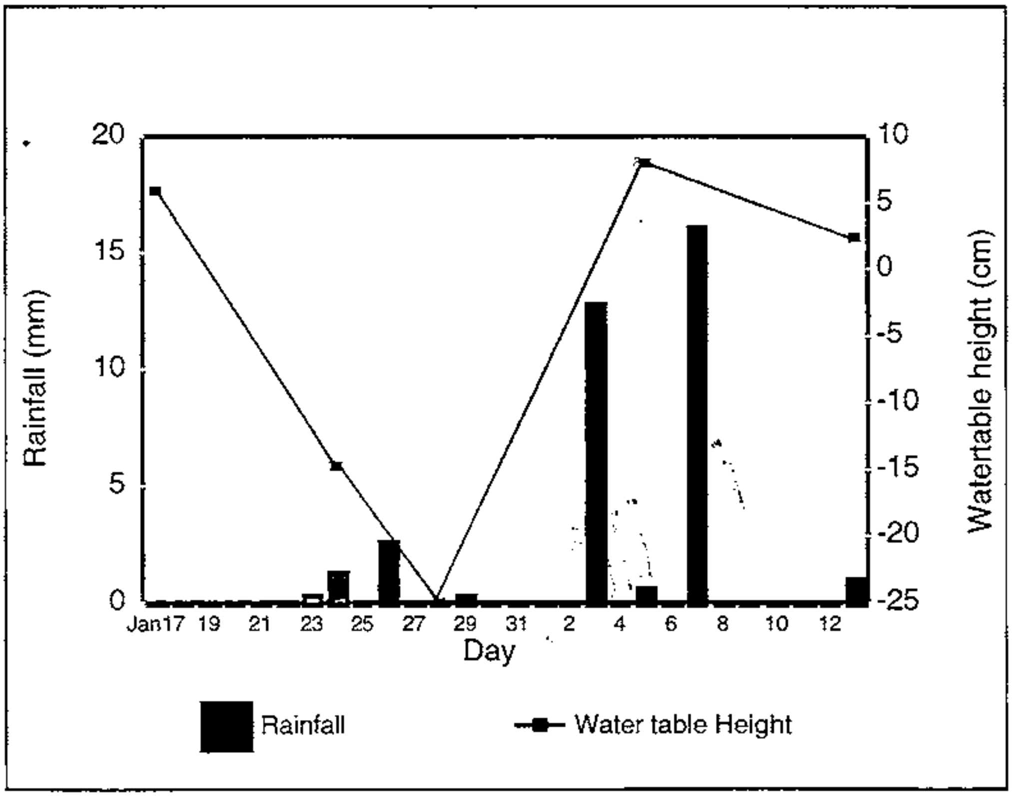
Figure 5.9 : The change in the water table per day against the rainfall experienced per day, for all southern wetland water table records. The majority of the points for the six winter months of the year (April to September) lie above the line, i.e there is a trend of an increase in water table height, while the points for the six summer months of the year (October to March) are below the line, i.e. there is a trend of a decrease in water table height despite rainfall. Several points lie at 0 change in water table even with substantial rainfall (labeled "full") . These points represent when water spills over the sides of the wetland into adjoining areas as the wetland is full of water. They were removed from the line of best fit; correlation coefficient = 0.6524.



The relationship between the water table and rainfall (Figure 5.9) reveals that approximately greater than 3mm of rainfall per day, increases the wetland water table. Temperature and evaporation rate have an effect on water table, and in the summer months (October to March) there is a trend towards a decreasing water table even with a moderate amount of rainfall, as most points lie below the line of best fit. However in the winter months (April to September) this trend is reversed with the change in water table being positive, i.e. rainfall increases the water table height.

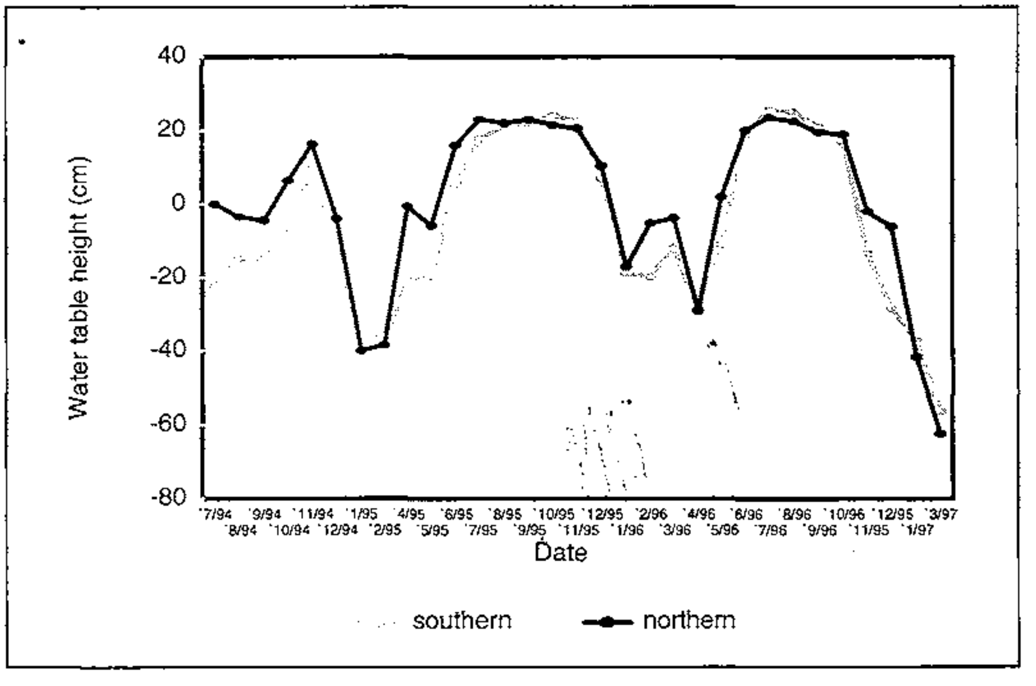
The sand substrate of the wetlands is very porous and as such has a low water retaining capacity. This results in the water table falling quickly in hot and dry weather during summer when the evaporation rate is highest. Conversely, as the wetlands are situated in deflation basins (which are the lowest areas in elevation on the dune plains), and because of their close proximity to tall dunes, they fill with water quickly during periods of heavy rainfall. The wetland species must endure both periods of flooding and times of extreme dryness during their short growing season. In January 1996 (Figure 5.10) measurements were made which show large fluctuations in the water table height, which correspond to heavy rainfall events followed by periods of hot, dry weather.

Figure 5.10 : The mean water table of the northern wetland in relation to the daily rainfall (Flock House), from January 17th to February 13th 1996.



In April 1994 *Eleocharis neozelandica* was widespread in both wetlands, though at certain elevations it was more numerous, and formed small raised mounds where most common. In the northern wetland, a water table measuring pipe was placed in the centre of a mound which was the densest sward of *E. neozelandica* in the entire dune lands. In the southern wetland a pipe was also located in an area where *E. neozelandica* was abundant (Figure 5.11). The two water table profiles for these pipes are alike and follow seasonal trends closely, and are submerged during winter and spring for similar lengths of time. Their average winter maximum water table heights (approximately 25cm) are similar to within a few centimetres, and are the approximate heights at which water spills over into adjoining wetlands. Their summer water tables profiles are more variable (Figure 5.11) with the southern wetland generally having a lower water table, though the northern wetland's water table falls to a lower level during times of extreme dryness.

Figure 5.11 : The water table profile of two water table measuring pipes, one pipe from each wetland (Pipe 1 at the northern wetland and pipe 7 at the southern wetland) where *Eleocharis neozelandica* was abundant.



Vegetation responses to water table and inside rabbit exclosures

The exclosure plots (control and closed) were established prior to the two wet winters of 1995 and 1996, and had been placed at elevations where *Eleocharis neozelandica* was common (Table 5.1). The vegetation growing in the northern wetland was submerged from

March to December 1995. A difference in the total cover occurred between the closed and control plots in both wetlands at the second sampling. In the northern wetland the percentage cover increased over time, and the closed plot had 12.1% more vegetation than the control plot at time 2, compared to 4% at time 1. In the southern wetland the percentage cover fell over time, though the control plot had a greater cover, 12.7% at time 2, compared to the control plot having 3.3% more at time 1. *Selliera radicans* was partly responsible for this dramatic decline in total vegetation cover, as it decreased in all plots over time, and this was especially noticeable at the southern wetland.

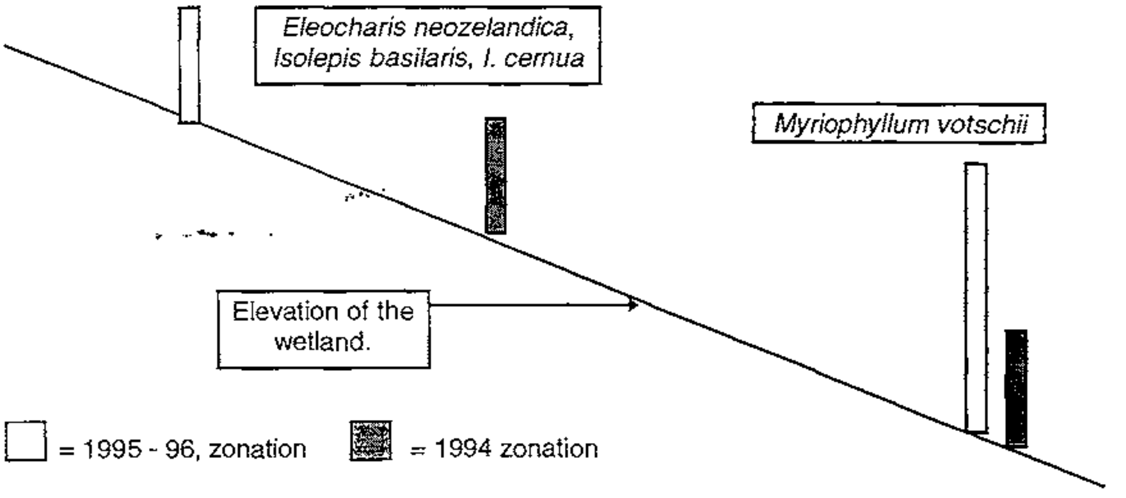
Table 5.1 : The percentage cover of all species >1% cover and the total cover, in the control and closed plots at times 1 (T1, January 1995) and 2 (T2, March 1997) at the southern and northern wetlands.

	NORTHERN WETLAND				SOUTHERN WETLAND			
	CLOSED		CONTROL		CLOSED		CONTROL	
SPECIES	T1	T2	T1	T2	T 1	T 2	T 1	T 2
Carex pumila	4.0	1.2	6.2	12.3	5.6	0.4	14.6	0
Eleocharis neozelandica	2.2	0	0.7	0	3.8	0.4	2.0	0.4
Isolepis cernua	-	-	-	-	10.8	2.2	6.1	0.4
Leontodon taraxacoides	-	-	-	-	0.1	6.8	0.1	2.2
Leptocarpus similis	-	-	-	-	0.3	14.0	0	0.1
Lobelia anceps	0	2.3	0	0	0	3.7	0.1	5.1
Myriophyllum votschii	1.6	26.6	1.2	5.1	-	-	-	-
Selliera radicans	1.7	0	5	1.2	29	6.2	30	10.8
Triglochin striata	2.7	9.5	0.2	8.6	-	-	-	-
Total cover	12.2	39.3	8.3	27.2	49.6	33.7	52.9	19.0

Eleocharis neozelandica was absent from both the control and open plots and the general area of the plots in the northern wetland on March 1997, the date of the second assessment. It appears that all of the *E. neozelandica* at the lower elevations had died, though plants still existed or had colonized areas at higher elevations (pers.obs). This pattern was repeated in the southern wetland, though larger rushes and sedges, for example *Juncus articulatus* and *Schoenoplectus pungens* colonized the areas where *E. neozelandica* had been common (pers.obs). *Carex pumila* followed ~~an~~ a similar trend to *E. neozelandica* at the southern wetland in both plots, though was completely absent at the second assessment (Table 5.1). Similar trends occurred in the vegetation cover of most other species (Table 5.1). Only *Leptocarpus similis* and *Leontodon taraxacoides* had large differences in percentage cover between the closed and open plots in the southern wetland (Table 5.1), with increases in the closed plots. *L. taraxacoides* was the only adventive species with more than 1% cover in any of the plots.

Several species increased their range dramatically in the northern wetland during and following the wet winters of 1995 and 1996. In 1994 *Myriophyllum votschii* was found in the lowest lying area of the wetland, and increased its range to cover the majority of the wetland (Table 5.1 and Figure 5.12). *Triglochin striata* and *Limosella lineata* also increased their ranges, though only *T. striata* occurred in the control and exclosure plots. Neither *T. striata* and *L. lineata* occurred as low in elevation as *Myriophyllum votschii*, but were found below and at the same level in elevational range as *Eleocharis neozelandica*, *Isolepis basilaris* and *I. cernua*.

Figure 5.12 : A representation of the zonation of several wetland plants in the northern wetland over the study period, 1994 to 1996. In 1994 the wetland species were situated lower in elevation, but following the wet winters of 1995 and 1996, *Myriophyllum votschii* increased its range, while *Eleocharis neozelandica*, *Isolepis basilaris*, and *I. cernua* were found higher in elevation.



The extremely high winter water table over the 1995 winter affected other species in the wetlands as well. The two *Isolepis* species, *I. basilaris* and *I. cernua*, were situated at a higher elevation than in 1994, amongst the planted *Ammophila arenaria* while the plants submerged in the wetland had conspicuously died (pers.obs.). *Holcus lanatus* occurs on the edge of the wetlands and it died when submerged with the high water. In the areas which *H. lanatus* had previously occupied many native species colonized, including *E. neozelandica* (pers.obs).

Discussion

Water table fluctuations

The water table fluctuates between seasons with predictably the highest water table in winter and the lowest in summer. Its height is related to both rainfall and respiration, as was found to be the case in other studies (Willis *et al.* 1959). The mean summer and winter water table heights are not static, from year to year, i.e the water table and length of submergence is variable. For much of the year the water table occurred above the surface of the wetlands, while over the summer months it generally lay below the surface. However periodic flooding of the wetlands does occur in summer as a result of extreme rainfall events. At times of high rainfall and water table, water flows from wetland to wetland towards the sea. Over the study period the water table height in the wetlands was probably above the long term average, being the result of above average rainfall.

Burgess (1984) monitored the water table of a series of five dune slacks, from a young primary dune slack to older slacks, from September 1978 to October 1980 at Tangimoana. He recorded the water table above the surface, from May to August 1979, and only to a depth of +10 cm. This water table is low compared to this study where mean winter water table heights reached 30+ cm. Yet during Burgess' measurements, monthly rainfall averages were comparable to this study (New Zealand Meteorological Service, 1981). Burgess' study site may have been higher in elevation and therefore the winter water table height would be lower. The northern and southern wetlands are very alike, and were probably formed during a dry summer and were stripped to a lower elevation than Burgess' deflation hollow.

The water table below ground level was not horizontal across the wetlands, and this was also found to be the case in Fife, Scotland (Studer-Ehrensberger *et al.* 1993), who stated that these differences were due to varied permeability of the soil substrate which creates an uneven water table. The variability was most marked shortly after periods of rainfall. However it may be possible that this variation could be due to the differences in the vegetation which occurs above the pipes. Larger vegetation such as tall rushes and sedges, for example *Isolepis nodosa* and *Leptocarpus similis* may draw the water table higher via capillary action, compared to small herb vegetation. Conversely this larger vegetation may reduce the evaporation rate from the soil surface, compared to the adjacent turf vegetation creating a rise in the water table.

Rain needs to occur in winter and in sufficient quantities to make the dune slacks temporarily wet, creating habitat for dune slack species and limiting the invasion of others into the wetland. In summer rainfall ensures survival of the dune slack species, though in excessive amounts it makes growth and reproduction difficult. Thus, survival in a wetland requires a balancing act between surviving inundation and growing and reproducing in the brief window of opportunity when the habitat is above the water table.

Water table impacts on vegetation

The most striking feature of the temporary wetland community in dune slacks is the zonation and the limited intermingling of some of the species (Esler 1969). Thus, in the temporary wetland habitat there are plants which have narrow habitat ranges, such as obligate water plants, for example *Myriophllum votschii*, plants which require a moist substrate, for example *Eleocharis neozelandica* and *Limosella lineata*, and others which are restricted to dry areas, for example *Pseudognaphalium luteoalbum*. There are still others which have a wide habitat range from seasonally wet deflation hollows to small dunes, for example *Carex pumila* and *Selliera radicans* (Esler 1969).
The zonation of vegetation in dune slacks in Great Britain has been shown to be closely related to the height of the ground water (Willis *et*

al. 1959). The dune slacks at Tangimoana are very similar as species occur at specific elevations, in relation to the water table. However observations made in this study show that the zonation of dune slack plants in the Manawatu are very dynamic and may change as a result of a variable water table. This has been found to be the case with other dune slack situations (van der Laan 1979). As a result of the wet winters of 1995 and 1996 and the relatively wet summer period of 1995 - 96, species which were restricted to wetter areas in the dune slacks increased dramatically in range, for example *Myriophllum votschii.* However, other species not as tolerant to the wetter conditions decreased in range, as plants growing at lower elevations died, for example, *Carex pumila* and *Eleocharis neozelandica.* This may have been the result of the extreme length of the submergence in the wetland during the 1995 winter. *E. neozelandica* can tolerate and grow in periods of submergence of 60 days as shown in the waterlogging experiment (Chapter 6), and survived submerged for 7 months at the excavated wetlands (Chapter 8). Here the plants in the closed and control plots in the northern wetland would have been submerged for up to 10 months, from the 25th March 1995 to 17th January 1996. *E. neozelandica* appears to be unable to tolerate such a long period of anoxia, which is similar to what occurred in the excavation site at the lowest planting quadrats (Chapter 8).

The autumn and winter months of 1995 had a very high rainfall which inundated the deflation hollows in early March. Many of the wetland plants, for example *E. neozelandica* had set seed, some of which had already been released. This seed appears to have been dispersed to the water's edge in the wetlands, which was at a higher elevation in the deflation hollows than the previous year. It was around this elevation that most of the *E. neozelandica* occurred in the summer of 1995-96. On excavation of some of these plants, it was discovered that these plants had arisen from seeds and not from dormant rhizomes.

In addition to the change in zonation, *E. neozelandica* was located in new areas where it had previously been absent. In the winter of 1995 at the northern wetland the water table was so high that it flowed over small dunes (which had previously contained it) towards the sea and into another deflation hollow. This deflation hollow runs parallel with an adjacent dune and had been thoroughly searched for *E. neozelandica* on several previous occasions. In December 1995 several plants were located in this deflation hollow all of which were seedlings. These hollows which *E. neozelandica* was discovered in, are directly into the prevailing north west wind, and so it is unlikely that the seed was blown there. It therefore seems that a high water table in autumn and winter is one mechanism for the dispersal of *E. neozelandica* into adjacent deflation hollows. This process may facilitate seed dispersal from one parabolic dune system to another. Thus the water table both disperses and positions wetland species.

Vegetation change over time

In the wetlands a thick growth of algae, *Nostoc* and *Anabaena* species, occurred especially in the spring months when the water temperature and light intensity increased. This growth may have reduced light reaching *E. neozelandica* in the winter. These two algae species both absorb nitrogen from the atmosphere which therefore increases the nitrogen levels in the wetlands (Burgess, 1984). This then encourages the growth of the larger sedges, rushes and grasses, later successional species, which eventually out-compete the primary colonizing vegetation. The surface of the southern wetland accumulated a layer of organic sludge (decomposed algae and plant matter) which was .5 -10 cm thick in August 1996. Such layers of organic matter may help to hold water in dry periods enabling the wetland to remain moist for longer. In January 1996 the surface of the lowest area of the wetland was still moist even when the water table had dropped to 14 cm below the surface.

At the southern wetland in autumn 1994 the wetland had a sparse vegetation of predominantly *C. pumila* and *S. radicans.* This dominance has subsequently altered and the exotic rush *Juncus articulatus*, has spread rapidly to occupy much of the wetland. The native rushes and sedges, *Leptocarpus similis, Isolepis nodosa, Schoenoplectus pungens* and *Typha orientalis* are also present and becoming more abundant. These plants are characteristic of wetlands with higher nutrients than the primary dune slack wetlands; *T. orientalis* is more associated with permanently wet wetlands. The extreme high water table from October 1994 would have facilitated the establishment of *T. orientalis.*

Rabbit browsing occurs when the water table is below the soil surface, and sufficiently dry, usually during the summer and autumn months. It reduces the standing crop of vegetation by grazing down to a low turf level, and appears to control and limit the spread of *Leptocarpus similis* and the exotic *Leontodon taraxacoides* (Table 5.1). Over the study, it appears that the high water table had a far greater impact on the vegetation change, than the damage cause from rabbit browsing. The length of submergence during the winter of 1995 was probably an extreme event, and if several similar water table years had been encountered the difference between the control and closed plots may have been more marked

In the winter of 1992 the dune areas were planted in *Ammophila arenaria*, which has become well established and covered most of the dune areas with a thickly by the end of the study period. This vegetation cover is likely to affect the amount of water entering the wetlands. Burgess (1984) calculated (for one period of rain over 4 days in which 30.8 mm fell) that direct rainfall onto the deflation hollow only accounted for approximately one half of the observed water table rise of 130 - 135 mm given a soil pore space of 40%. The remaining rise was attributed to the run-off from the surrounding dunes. The vegetation cover on the Tangimoana dump dunes has decreased the solar radiation reaching the sand dunes, reducing the evaporation rate from the dunes. A consequent increase in the water reaching the wetlands may have resulted. However, the thick marram vegetation cover may result in an increase in transpiration, counteracting the decrease in evaporation.

Conclusion

This study measured the water table of temporary wetlands over a period of above average rainfall, which resulted in changes in the zonation of the inhabiting dune slack vegetation. However it is unclear if these vegetational changes were a result of an extended period of a high water table, or anthropogenic effects from planting and fertilizing marram on the surrounding dunes increasing the rate of succession. These changes may have also been partly a result of competition between species, and may be a natural part of the succession process in these temporary wetlands. Monitoring of permanent plots along the elevational gradient over the study period would have helped to accurately understand the changes in height of the dune slack species in the wetlands. Long term monitoring would help to establish if changes in zonation are occasional or regular occurrences. Rabbits reduce the standing crop of dune slack vegetation, grazing it to a low turf, and control the establishment and limit the growth of some plant species. It is unclear if rabbit browsing influences the population dynamics of *Eleocharis neozelandica*.

It appears that *Eleocharis neozelandica* has decreased in abundance in these wetlands since April 1994 as the majority of plants at lower elevations died. Very few plants were found at higher elevations and it is unclear if this trend will reverse in a period of dry years. New plants were found where previously there had been none, adjacent to the northern study site, and near the excavation sites. *Eleocharis* *neozelandica* is clearly successful at finding new sits to colonize if they are available.

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Chapter Six

Dune slack plant growth in response to sand burial, waterlogging and submergence.

Abstract

Dune slack wetland plants are seasonally subjected to waterlogging, submergence and burial by sand in the natural habitat. Controlled experiments investigated the growth responses of several species of dune slack species to three levels of sand burial, and to waterlogging and submergence. All species except for *Selliera radicans* were unable to grow when buried by sand greater to their height. However all species survived submergence and thrived in waterlogged conditions. *Eleocharis neozelandica* was the only species able to continue growing when submerged. It is predicted that *E. neozelandica* can grow at lower elevations in dune slacks which experience longer periods of submergence in winter, than the three other species of dune slacks, *Isolepis basilaris*, *I. cernua* and *Selliera radicans*.

Introduction

Plants of dune slack temporary wetlands in the Manawatu occupy a dynamic environment with a fluctuating water table. They endure prolonged periods of waterlogging and submergence in the winter months, and then must quickly grow and reproduce while the water table rapidly falls during the summer. In dry weather, they suffer periods of drought, and may also be subjected to sand burial during gales and storms.

Anoxia

Soils of dune slacks are often saturated with water (Seliskar 1990). This induces many physical, chemical and microbiological changes in both the soils and plants occupying them (Etherington 1982). Plants are exposed to anoxic soils (creating oxygen deficiency), often with high concentrations of iron and manganese, at levels toxic to many mesophytic plants (Etherington 1982). Some wetland plants overcome the effects of anoxia and toxic concentrations of chemicals with morphological or metabolic adaptations. Transport of oxygen from shoots to roots in well developed intercellular spaces prevents oxygen starvation and damage to submerged tissues (Sorrell 1994). Radial oxygen loss from the roots into the surrounding soil creates an aerobic micro-habitat around the root surface. Aerobic microbial respiration and oxidation of iron can occur (reducing uptake), preventing cellular damage to the roots (Etherington 1982). The roots of *Eleocharis sphacelata* are especially good at this, remaining aerobic and significantly oxidizing anaerobic sediments *in situ*, by transporting oxygen in well developed intercellular spaces (Sorrell 1994). In some species with this type of oxygen transport system, root respiration is never fully aerobic. Other species simply endure the period of anoxia with adaptations at a metabolic level, by accumulating non-toxic fermentation products, such as malic acid, glycerol, shikimic acid and lactic acid, instead of highly toxic ethanol (Schat 1984). The zonation of vegetation in dune slacks has been shown to be closely related to the height of the water table (Willis *et al.* 1959), as plants have varying levels of tolerance to waterlogging and submergence.

Sand burial

The dune areas of the Manawatu coastline are highly mobile with a plentiful supply of sand from the region's rivers. They are renowned for moving on both a small scale of everyday accumulation and deflation, and on a larger dramatic scale when whole dunes "blow out" and become mobile. Dune slacks on the Manawatu coastline frequently receive sand deposits. Wind transports sand (predominantly during storms and high winds) from the foredune and smaller inland dunes on to dune slacks. The minimum threshold wind speed for sand transport is $4.5 ms^{-1}$; beyond this speed the rate of sand movement is proportional to the wind speed (Boorman 1977). The mean wind speed at Ohakea (16 km from the Tangimoana dunelands) is 4.72 ms^{-1} (N.Z.Met.Serv. 1981), indicating that the majority of the time sand can be moved.

Sand accumulates on the foredune and the majority is trapped by the foredune vegetation. Perennial plants on the foredune are almost continuously being buried with sand. They must have strategies to either survive and cope with sand movement and burial, or have efficient dispersal mechanisms to colonize other areas. Sand binding species such as the endemic *Desmoschoenus spiralis* and the native *Spinifex sericeus*, as well as the widely planted exotic *Ammophila arenaria* are known to survive large scale sand accumulation (Sykes and Wilson 1990; Disraeli 1984). Less is known about the tolerance to sand burial of other species which occupy habitats in dune areas, particularly plants of dune slacks. Wind blown sand is deposited onto the dune slacks covering plants to varying degrees. The occupants, a group of perennial rhizomatous herbaceous plants, are very low in stature (2 cm to 20cm in height), and are occasionally buried by small sand drifts.

Anecdotal references in the literature point to evidence that some dune slack species can cope with sand accumulation.

Cockayne (1909) said;

> "the small brownish-coloured *Elaeocharis novo-zelandica* is common in places, catching a certain amount of sand".

Later, Esler (1969) expanded this saying;

> "*Eleocharis neozelandica*... thrive(s) on the moist sand... The small amount of sand that accumulates is removed when the surface dries sufficiently to allow mobility. *Eleocharis neozelandica*... almost invariably occur(s) on sites with moving sand...".

Esler also commented of *Carex pumila*;

> " no other plant of the plains has greater ability to gather sand, a feature which leads to own extinction where the sand supply is plentiful".

More recently, Sykes and Wilson (1990) said;

> "even small forbs which never actively form dunes are subject to such deposition of sand, and must grow up to the surface to survive".

Thus, sand burial represents a threat and challenge for dune builders and duneslack plants alike.

Experiments were undertaken to investigate the responses of dune slack plants to burial by various depths of sand, and to waterlogging, and relate these responses to the dune slack environment. Dune slack plants, *Carex pumila*, *Eleocharis neozelandica*, *Selliera radicans*, *Isolepis basilaris*, *I. cernua*, *I. nodosa* plus a species which occurs around the edges of dune slacks, *Pseudognaphalium luteo-album* were tested in the sand burial experiment. Four dune slack plants *Eleocharis neozelandica*, *Isolepis basilaris*, *I. cernua* and *Selliera radicans* were inundated with water.

Methods

Most plants were collected in October 1994, from the dunelands at Tangimoana (NZMS 260 S20 995978), though some *Isolepis cernua* and *Selliera radicans* plants were collected from dune slacks south of Himatangi (NZMS 260 S20 995896). The plants were then propagated in 7x7x7 cm plastic plant pots, into beach sand containing 3 month (1:400) Osmocote™. They were placed onto capillary matting on benches in the glasshouse at the Ecology Department, Massey University, to establish for 1 month before the start of the experiment.

Waterlogging

All plants were measured before the start of the experiment using appropriate size measurements for each species, for example number of rosettes, number of leaves and length of longest leaf. These data were then used to divide each species into 10 size classes of four plants each. The plants of each class for each species were randomly allocated between three treatments and a pre-treatment harvest. The three treatments were a control, and waterlogged and submerged conditions. The pre-treatment harvest, was used to assess the reliability of the size estimation for each species at the start of the experiment. All pre-treatment harvest plants were dissected into roots and shoots, washed in water and air dried at 98ºC for 72 hours and weighed. Water levels were maintained in circular plastic containers (1 litre Yoplait™ yogurt container) of 125 mm in height, taller than the combined plant height of the plant and pot together (Photo 6.1). The control treatment had the holes in the bottom of the container, and so held no water. The waterlogged treatment had holes in the container in line with the top of the plant pot at approximately 70 mm, so the plant roots were waterlogged but the leaves were above the water level and exposed to air. The submerged treatment had no holes, so the plants were fully submerged in water, and no plant part was exposed to air. An automatic watering system maintained the water levels through a 5 mm irrigation pipe in all of the treatment containers, which turned on six times a day for 5 minutes and flooded the pots and replaced all the water. This also helped to reduce the temperature of the water in the containers. A Nitrosol™ (1:200) solution was applied to each plant (10ml/ plant) on a monthly basis to counteract the nutrient leaching from the watering system. When required, usually every week, the containers were cleaned and all algae were removed. The temperature of the water and air was measured, using eight maximum / minimum, thermometers. Two were placed in the air above the experiment while the other six were placed in the treatment containers. These were swapped once randomly to other containers.

The 10 replicates (of 4 species x 3 treatments) were randomly assigned to positions on the bench, and each container was randomized within the group. The waterlogging experiment ran for 61 days and throughout the experiment deaths were recorded. The surviving plants which survived were harvested at the end of the experiment, and measured for their dryweight as for to the first harvest.

Sand Burial

All plants were measured before the start of the experiment using appropriate size measurements for each species, identical to the waterlogging experiment. These data were then used to divide the each species into five size classes of six plants in each. In each group four plants were randomly allocated into the four treatments, while two were allocated to a pre-treatment harvest, which was used to determine the plant weights at the start of the experiment. The four treatments similar to those used by Sykes and Wilson (1990) were a control (not buried), $^1/_3$ (plants were partially buried by $^1/_3$ of their height), 1 (plants were buried their height), and $1^1/_3$ (plants were buried by their full height plus another third of their height).

The experiment was conducted in tall PB 3 plant bags, which were 35 cm tall and with a radius of 11cm; (Photo 6.2). All had 2 cm of gravel in the bottom to facilitate drainage and aeration. The bags were then filled with compacted sand to the required height at which the plant pots were placed. A 3 mm piece of irrigation tube was inserted to the surface of the sand. This was used for directly fertilizing the plants at fortnightly intervals with a complete nutrient solution (Nitrosol™). The bags were then carefully filled with sand trying not to damage the plants, to 1 cm of the top and then watered to compact the sand. The experimental containers were watered lightly on demand, to maintain adequate soil moisture levels. The experiment ran for 90 days. Throughout the experiment records were kept of when plants emerged from sand burial. At the end of the experiment all live plants were removed, and their dry weights measured. If any plants did not emerge from burial they were uncovered and left exposed to sunlight with adequate moisture for 2 months in order to see if they recovered. The rationale for this was that plants may simply become quiescent in complete darkness, waiting for the sand to be excavated by wind, before resprouting.

Analysis

The water table and sand burial results were analyzed using two way analysis of variance statistical tests. All dry weights were transformed with Log_e to normalize the data, before analyzed. Tests were performed on the final root, shoot and total dry weights, and the shoot:root ratios, the relative growth rates (RGR) of the root, shoot, total dry weights between harvest two and harvest one and the RGR shoot/RGR root. Detectable differences ($d = t$ RMS $(^1/_{n1} + {^1/_{n2}})$, where t = the t value (at p = 0.05 or 0.01) of the residual degrees of freedom, RMS = residual (or error) mean square, n = the number in the samples which make up the mean) were used identify significant differences between species grand means and between grand treatments means (Glenday, 1965).

Photo 6.1 : The experimental design of the waterlogging experiment showing irrigation system, experimental containers and thermometers. Note water dripping off during waterlogging.

Photo 6.2 : The experimental design of the sand burial experiment showing the tall PB3 bags in which all plants were buried, feeder tubes and control and $^{1}/_{3}$ buried plants.

Results

Waterlogging

All four dune slack species, (*Eleocharis neozelandica*, *Isolepis basilaris*, *I. cernua* and *Selliera radicans*) increased in weight in the control and waterlogged treatments, compared to harvest one (p=0.01), (Table 6.1). Growth was almost equally rapid in these two treatments and were not significantly different from one another, in respect to overall treatment differences in all analyses. However, little or no growth occurred in the submerged treatment, which was significantly different (p=0.01) for all analyses (except RGR shoot/ RGR root) from the control and waterlogged treatments (Table 6.3).

Table 6.1 : The mean root and shoot weights of the four species at harvest one, and after treatment. Measurements are in grams

		TREATMENT		
SPECIES	Harvest one	Control	Waterlogged	Submerged
Eleocharis neozelandica -root	0.025	0.240	0.443	0.022
-shoot	0.129	0.932	1.135	0.187
Isolepis basilaris-root	0.0264	0.297	0.339	0.0153
-shoot	0.625	1.461	1.552	0.4141
Isolepis cernua -root	0.042	0.318	0.279	0.019
-shoot	0.189	1.010	0.773	0.156
Selliera radicans -root	0.026	0.297	0.339	0.015
-shoot	0.191	1.311	1.374	0.103

The general trends for the shoot and total relative growth rates (RGR) were very similar to each other for the three treatments. *Eleocharis neozelandica* had the highest mean RGR for root, shoot and total weights for the three treatments (Table 6.2 shows the RGR of the total weights). *E. neozelandica* was significantly different from the other species, *Isolepis basilaris* and *I. cernua* (p=0.01) and *Selliera radicans* (p=0.05). *S. radicans* had higher shoot and total RGR (p=0.01) than *I.*

basilaris. All species followed similar trends with respect to the RGR of the roots in the three treatments. The tissue weights of *Isolepis basilaris* were heavier in the waterlogged treatment compared to the control, though only the root weight was significantly (P= 0.05) different.

Table 6.2: Mean total weight relative growth rate (day^{-1}) for all species in the three treatments. Figures carrying the same lower case letter are not significantly different from one another (p=0.05), determined by two way analysis of variance using detectable differences. Species means and treatment means are not directly comparable to the individual species means, as shown by the uppercase characters.

	TREATMENT			
SPECIES	CONTROL	WATERLOGGED	SUBMERGED	MEAN
Eleocharis neozelandica	0.0345 a	0.0374 a	0.0037 d	0.0252 X
Isolepis basilaris	0.0175 c	0.0214 bc	-0.0051 e	0.0112 Z
Isolepis cernua	0.0294 ab	0.0266 b	-0.0053 e	0.0169 Y
• *Selliera radicans*	0.0349 a	0.0360 a	-0.0099 e	0.0203 Y
Mean	0.0291 A	0.030325 A	-0.0041 B	

The three genera in the submerged treatment responded differently from one another. *Isolepis basilaris* and *I. cernua* turned brown and dieback had started to occur within one week of submergence. These two species lost root and shoot weight compared to harvest one, and no new growth was observed throughout the entire experiment. Several plants appeared almost dead; notably *I. cernua* by the end of the experiment, except for a few leaves which were still green. By harvest two *Selliera radicans* suffered similar dieback, though more significantly (p=0.05) than the two *Isolepis* species. *S. radicans* did however produce new green and healthy leaves, though of a smaller mature size than the leaves produced before the start of the experiment. The majority of *Eleocharis neozelandica*'s photosynthetic stems remained green and healthy in appearance throughout the entire experiment in the submerged treatment. It produced new leaves which were longer than the leaves produced in the control. All species except *E. neozelandica* lost weight in the submerged treatment and *E. neozelandica* was significantly different from *I. basilaris* and *I. cernua* (p=0.05) and from *S. radicans* (p=0.01) for total relative growth rate (Table 6.2). The increased weight was only due to an increase in shoot weight, as *E. neozelandica* lost root weight. This loss in root weight however was the least of the four species.

Table 6.3 : Summary of all Analyses of Variance for the waterlogging experiment, showing residual mean square, degrees of freedom and probability values. 0.05 and 0.01 represent effects P < 5 and 1% level.

VARIABLE	RESIDUAL MEAN SQUARE	PROBABILITIES		
		SPECIES	TREATMENT	SPECIES X TREATMENT
Degrees of freedom	108	3	2	6
Root weight	0.497	0.05	0.01	NS
Shoot weight	0.35	0.05	0.01	NS
Total weight	0.349	0.05	0.01	NS
Total increment	0.271	NS	0.05	NS
Shoot : root ratio	16.93	NS	NS	NS
Root RGR	0.853	NS	0.01	NS
Shoot RGR	0.000082	0.05	0.01	NS
Total RGR	0.000084	0.05	0.01	NS
RGR shoot/ RGR root	16.929	NS	NS	NS

Sand burial

Most of the seven species in the sand burial experiment responded very similarly to one another, with respect to survival in the four treatments. All survived in the control treatment, while only one plant of *Isolepis nodosa* died in the third ($^{1}/_{3}$) burial treatment. However in the full burial (1) and full plus a third ($1^{1}/_{3}$) burial treatments, all plants of *Carex pumila*, *Eleocharis neozelandica*, *Isolepis basilaris*, *I. cernua*, *I. nodosa* and all but one plant of *Pseudognaphalium luteo-album* died (Table 6.4). *Selliera radicans* was the only significant exception and most plants survived the 1 and $1^{1}/_{3}$ burial treatments (Table 6.4). *Selliera radicans* was the only species which the majority of plants survived these treatments (Table 6.4). It responded quickly to sand burial, with all of the 1 and the $1^{1}/_{3}$ burial plants which survived to the end of the experiment emerging to the surface within three weeks. For this species, there was a decrease in root, shoot and total weights with increasing burial, though only the full burial and full and $^{1}/_{3}$ burial treatments were significantly different from the control (p=0.01) (Table 6.5). The $1^{1}/_{3}$ and the $^{1}/_{3}$ burial treatments were also significantly different from each other (p=0.01).

Table 6.4 : The survival of all replicates in the four treatments in the sand burial experiment. There were five replicates per treatment.

	BURIAL DEPTH			
SPECIES	**Control**	**1/3**	**1**	**1 1/3**
Carex pumila	5	5	0	0
Eleocharis neozelandica	5	5	0	0
Isolepis basilaris	5	5	0	0
Isolepis cernua	5	5	0	0
Isolepis nodosa	5	4	0	0
Pseudognaphalium luteo-album	5	5	0	1
Selliera radicans	5	5	4	3

The mean root and shoot weights are shown in Table 6.5. Several species increased in root, shoot and total weights in the $^{1}/_{3}$ burial treatment, including *Carex pumila*, *Isolepis cernua* and *Selliera radicans* though no species were significantly different.

6.5 : Mean root and shoot weights of all species at harvest one and after treatment. Weights are in grams.

		TREATMENT			
SPECIES	Harvest one	Control	1/3	1	1 1/3
Carex pumila -root	0.068	2.265	3.803	-	-
-shoot	0.652	6.089	9.783	-	-
Eleocharis neozelandica-root	0.046	0.539	0.445	-	-
-shoot	0.204	1.537	1.671	-	-
Isolepis basilaris-root	0.041	0.389	0.305	-	-
-shoot	0.357	1.453	0.917	-	-
Isolepis cernua-root	0.021	0.301	0.119	-	-
-shoot	0129	0.936	0.423	-	-
Isolepis nodosa-root	0.072	3.554	2.041	-	-
-shoot	0.695	8.489	6.429	-	-
Pseudognaphalium luteo-album -root	0.097	1.013	0.901	-	-
-shoot	0.775	4.491	3.721	-	-
Selliera radicans -root	0.025	0.472	0.772	0.433	0.373
-shoot	0.148	2.051	2.634	1.495	1.087

Table 6.6 : Summary of all analyses of variance for the sand burial experiment, showing residual mean square, degrees of freedom and probability values. The lower degrees of freedom excluding 1 and $1^{1}/_{3}$ are due to deaths in these treatments (Table 6.3), and these analyses were conducted on the surviving treatment weights.

VARIABLE	RESIDUAL MEAN SQUARE	PROBABILITIES		
		SPECIES	TREATMENT	SPECIES X TREATMENT
Degrees of freedom (exc. 1 & $1^{1}/_{3}$ burial)	**56**	**6**	**1**	**6**
Root weight	3.449	NS	NS	NS
Shoot weight	3.039	0.01	NS	NS
Total	0.2674	0.01	NS	NS
Shoot : root ratio	1.10	NS	NS	NS
Root RGR	0.000103	0.05	NS	NS
Shoot RGR	0.000099	NS	NS	NS
Total RGR	0.0000947	NS	NS	NS
Root difference	2.095	0.01	NS	NS
Shoot difference	3.039	0.01	NS	NS
Total difference	2.285	0.05	NS	NS

The plants which did not grow to the surface did not recover when placed in full sunlight with ample water, for 3 months. However shortly after being exposed to air and light, abundant seedlings of *Isolepis cernua*, *I. basilaris*, *Eleocharis neozelandica* and *Pseudognaphalium luteo-album* germinated in many of the plant pots. This seed would have been deposited on the surface before the burial treatment as some plants had flowered and set seed.

Discussion

Waterlogging

Performances of all four species were remarkably similar to each other, with respect to productivity in the three water logging treatments. The shoot weights were greater than the root weights, which is the norm for wetland plants or most plants with sufficient water (Salisbury and Ross 1992). Seliskar (1986) found that an increase in the amount of aerenchymatous tissue resulted from waterlogging. This oxygen transfer system can supply the below ground tissues with an adequate supply of oxygen needed for respiration, and is very common in wetland plants, specifically monocots (Crawford 1992). The four species appear to be able to maintain full root and shoot growth not significantly different than the control when waterlogged. For this to have occurred, the roots can not have suffered damage from the effects of anoxia. The four species must therefore be able to efficiently transport oxygen from tissues above water, to submerged roots and rhizomes, via aerenchyma or intercellular spaces. However the mechanism was not examined in the experiment.

The control and waterlogged treatments were very different from the submerged treatment. The four species did not flourish in the submerged treatment, but appeared to be either growing only very slowly, as shown by *Eleocharis neozelandica*, simply maintaining green photosynthetic plant tissues in the case of *Selliera radicans*, or slowly dying (*Isolepis basilaris* and *I. cernua*). The two *Isolepis* species were flaccid, lying flat by the end of the experiment with the majority of their leaves brown and deçaying, and suffered significant dieback of the roots and shoots. It is possible that this dieback process may facilitate the translocation and storage of carbohydrates and essential elements to the rhizomes, in order to survive long periods of submergence. The length of time that plants can survive in submerged conditions is related to their carbohydrate stores and respiratory activity (Crawford

1992). The rhizomes may have remained healthy, as *I. cernua* can survive long periods of submergence of up to seven months (Chapter 7). The survival of the monocot rhizomes and basal buds in submerged or anoxic conditions is not dependent on the maintenance of an intact root system (Crawford 1992).

Maintaining intact photosynthetic organs during submergence may not optimal if these organs are unable to photosynthesize underwater. *Eleocharis neozelandica* and *Selliera radicans* had photosynthetic tissues which were still green and appeared turgid at the end of the experiment. They seem to have different survival strategies from the two *Isolepis* species as, although some dieback occurred, new tissues were still produced. Leaves of *Selliera radicans* and *Eleocharis neozelandica* which had grown in the air prior to treatment had mostly abscised, and by the end of the experiment were replaced by new leaves, which were much smaller in *S. radicans*, and longer and thinner in *E. neozelandica*. The newly produced leaves and photosynthetic stems may be more resistant to the effects of submergence, than those leaves produced in air before submergence. *S. radicans'* original leaves appeared to become inflated with gases and appeared like miniature balloons, which then abscised, were left floating on the surface. This gas was probably carbon dioxide, resulting from fermentation within the leaves.

In the waterlogged treatment *Isolepis basilaris* and *Eleocharis neozelandica* were the only species which significantly differed from the general treatment trends, *I. basilaris* was significantly heavier compared to the control. Similarly Jones and Etherington (1971) found the dune slack plant *Carex nigra* was slightly stimulated by, or insensitive to waterlogging. *I. basilaris'* root growth did not appear to be limited by waterlogged conditions and it is likely therefore that this species is very efficient at transporting oxygen to its roots, maintaining root growth with a well developed system of aerenchyma or intercellular spaces. This species had a very thick root mat at the surface of the soil, and may have obtained oxygen from it, as it was just below the water level, where the water would have been supersaturated with oxygen (Ponnamperuma 1984).

Eleocharis neozelandica had the highest mean RGR overall and was the only species which continued growth in the submerged treatment. In order to sustain growth when submerged, *E. neozelandica* must be capable of obtaining CO_2 for photosynthesis from the surrounding water. Algae were present in the water and on and around the containers (though these were cleaned when necessary), and would have contributed to the water O_2 content from photosynthesis, and CO_2 content from respiration. The majority of CO_2 in water is in the form of a bicarbonate ion (Ponnamperuma 1984), and *E. neozelandica* may be able to absorb this. It would seem highly likely that this species is able to grow in areas in dune slacks of a lower elevation with a higher water table than the three other species because of this increased tolerance to waterlogging. *E. neozelandica* growing underwater *in situ* has been observed to have a similar appearance to the plants in the submerged treatment.

Many of the *I. cernua* plants growing in the glasshouse before the start of the experiment, had flowered and set seed. In two of the plants subsequently placed in the submerged treatment, seeds had germinated while still attached to the seed heads. These propagules floated on the surface of the water when dislodged and this process may facilitate the dispersal of plants to higher elevations in wetlands where conditions may be more suited for growth and survival. These propagules could quickly start growing at the water's edge as they had already produced small leaves and roots.

These results suggest that *Eleocharis neozelandica* has the greatest tolerance to submerged conditions, though all species survive the period of submergence. All four species appear to be capable of growing in a completely waterlogged soil, with no deleterious effects.

Sand burial

All species were able to grow when buried to $^1/_3$ of their height. The monocots *Carex pumila*, *Eleocharis neozelandica*, *Isolepis basilaris*, *I. cernua*, and *I. nodosa* all responded similarly in elongating their rhizomes so that their apical meristems were just below the soil surface. Many of the leaves of the three *Isolepis* species died when buried to this depth and this was most pronounced in *I. nodosa*. The two dicotyledons, *Selliera radicans* and *Pseudognaphalium luteo-album*, produced new adventitious roots off their buried stems, closer to the soil surface, while many of the older, deeper roots died. *S. radicans* produced new rhizomes parallel to the soil surface.

Only *Selliera radicans* was able to grow in the 1 and $1^1/_3$ burial treatments. *S. radicans* is a low growing herb, less than 2 cm tall, spreading horizontally rather than vertically. Thus, it was buried with the least amount of sand out of the seven species, often being buried only with 2 to 2.5 cm in the full and $1^1/_3$ burial treatments. At this depth of burial, light may still penetrate through the sand to the plant's leaves. This may have aided *S. radicans* in growing to the surface. It also had the smallest distance to grow to the surface of the seven species. Further, in the field *Selliera radicans* appeared to move its leaves to a more vertical position, obtaining its maximum plant height when partially buried by sand, and may be adapted to this situation.

Sykes and Wilson (1990) observed that *Pseudognaphalium luteo-album* was able to grow when buried by full plant height. This differs from the results found in this study, as only one plant grew when buried by 1 or 1 $^1/_3$ plant height. *Carex pumila* and *Isolepis nodosa* follow similar trends; both died when buried by greater than their full plant height in both studies. Overall dune slack plants have low survival rates when buried, compared to fore dune species, such as *Spinifex sericeus* which have high survival rates (Sykes and Wilson 1990). These species occupy a habitat with a constant supply of sand and have thus evolved to compensated with large internode lengths and high growth rates.

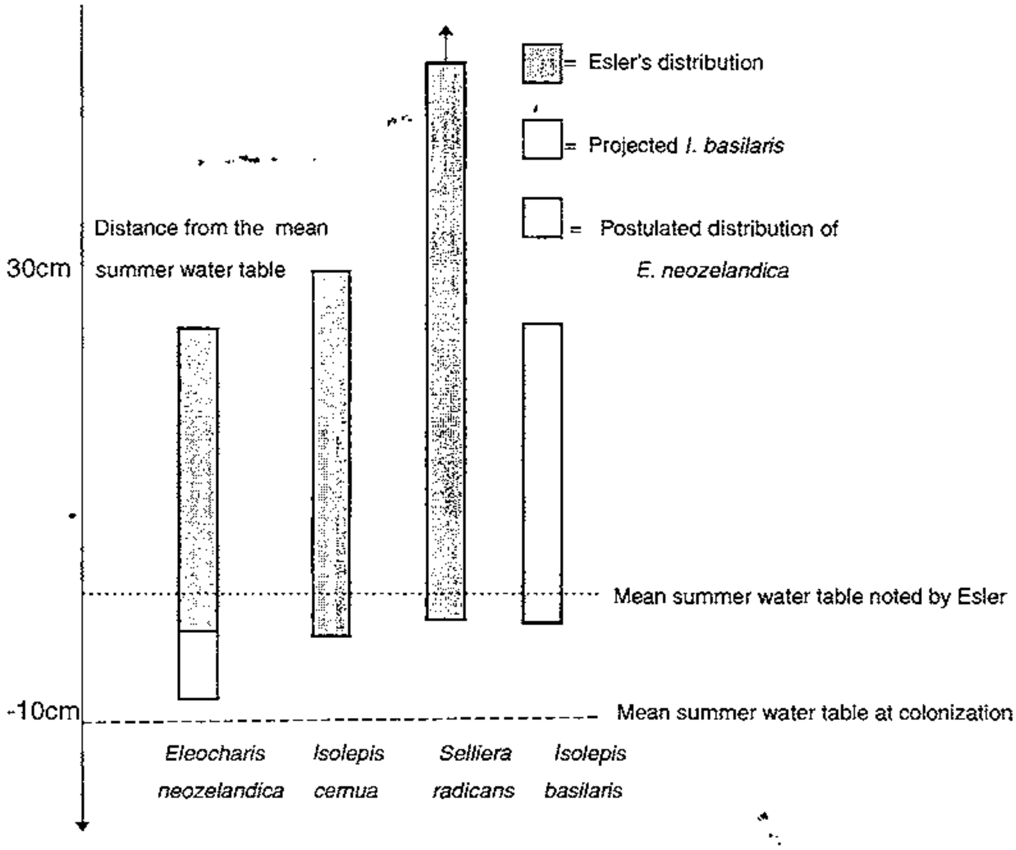
These results suggest that the dune slack plants tested are not adapted to sand burial equal too or greater than their own height, though they are capable of enduring burial to $^1/_3$ of their height. Sand burial of dune slack plants in the natural situation is more likely to occur over a longer period of time, or in several short periods during gales, rather than instantaneously in this study. Dune slack plants may be able to compensate for partial burial in ways which they were unable to implement in this study because of instant burial. *Carex pumila* is a good sand accumulator, building small dunes, by growing vertically, keeping ahead of the sand supply. It is likely that other species can also compensate for gradual sand accumulation.

Waterlogging in relation to the distribution of the four dune slack plants in situ.

The distribution of temporary wetland plants in dune slacks relative to the mean summer water table was described by Esler (1969) at Himatangi in the Manawatu (Figure 6.1). The elevational range of the species recorded by Esler is probably accurate, and would reflect their tolerances to waterlogging, sand accumulation and summer water stress at the time of colonization. *Eleocharis neozelandica* had a distribution centred closest to the mean summer water table in Esler's dune slacks. It did not occur as high above the mean summer water level as *Isolepis cernua* and *Selliera radicans*. *S. radicans* had the largest elevational range occurring at greater than 24" (61cm) above and 2½" (6.25cm) below the mean summer water level. *Isolepis basilaris* was not mentioned in Esler's study and presumably was not present in the study area. *E. neozelandica*, *I. cernua*, and *S. radicans* were all found below the mean summer water table height. They all occurred in the lowest elevation in the wetland, at approximately 2½" (6.25cm) below the mean summer water table. At this height the four plants would have been completely submerged, being less than 3cm in height. It is unlikely that the seeds of the four species in the current study would colonize a dune slack below the water table; the seeds of *E. neozelandica* float (pers.obs.). Barclay and Crawford (1982) found that seedlings of wetland plants were rapidly killed by short periods of anoxia, whereas mature rhizomes were more resistant.

Esler's (1969) results now seem too simplistic as all of these species do not respond well to being submerged, and only *Eleocharis neozelandica* grew when completely submerged. The mean summer water table in Esler's (1969) study was recorded above the surface over the summer, indicating that this level was unusually high, a result of a high summer rainfall (Chapter 5). Additionally, deflation hollows are formed by the prevailing wind removing sand from the surface down to the water table (or the height at which capillary action ensures the sand surface remains moist). This process only occurs during summer when the water table drops below the surface in deflation basins. Clearly these deflation hollows were formed during a summer period of a lower water table. The vegetation subsequently colonized the dune slacks in relation to lower water tables, which is unlikely to be as high as the one shown. *Eleocharis neozelandica* and *Isolepis cernua* were found at the lowest depth in Esler's wetland, though if the wetland had areas of lower elevation *E. neozelandica* would occur to a lower elevation than *I. cernua*.

Figure 6.1 : The vertical distribution of the four dune slack species and their water table preferences, in relation to the mean summer water table in a dune slack, taken from Esler's (1969) study (grey bars). *Isolepis basilaris* was not present in Esler's (1969) though its likely distribution is shown (white bar). The real distribution of *Eleocharis neozelandica* is shown (light grey bar). The three species would have colonized the wetland during a period of a lower water table, such as that shown and not the one shown by Esler.



Isolepis cernua and *Selliera radicans* appear to grow and reproduce quickly over a large range in elevation in dune slacks, during the summer months. *I. basilaris* is more closely located near the water table than *I. cernua*; this interpretation is supported by its significantly greater growth in the waterlogged treatment than *I. cernua*.

If annual fluctuations in height of the summer and winter water table remained constant each year, a species zonation pattern would form, relating to the waterlogging tolerances of the species present, and their competitive abilities. In this scenario *Eleocharis neozelandica* would be found closer to the mean summer water table than *Isolepis* *basilaris*, *I. cernua* and *Selliera radicans*, all slightly higher in elevation. However this scenario is unlikely to occur, as the water table of dune slacks is directly related to rainfall (Chapter 5), which is different from year to year. Zonation patterns of dune slack species are dependent on the elevation of the wetland, i.e. its maximum depth during formation, and the subsequent water table fluctuations following its colonization. The dune slack zonation pattern is thus as dynamic as the processes of water table maintenance and sand movement influencing the dunes.

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Chapter Seven

Habitat creation for the endangered spiked sand sedge, *Eleocharis neozelandica* : construction of a temporary wetland in dune hollows

Abstract

Wandering parabolic dunes of ,the Tangimoana dump dunes were stabilized by marram plantings in 1992. This has resulted in the cessation in the creation of new deflation hollows behind the wandering dunes, the preferred habitat for early successional dune slack species. The experimental construction of two deflation hollows was made to estimate potential habitat for *Eleocharis neozelandica* and other early successional species. These hollows were planted in groups with *E. neozelandica* and *I.cernua* at three elevations, low medium and high. The two species survived the winter submergence at the medium and high location of 7 months of submergence, though died at the low location of 9 months submergence. Colonization of the wetlands occurred quickly in the summer of 1996-97.

Introduction

The Manawatu dune lands are characterized by having parallel parabolic dunes which move inland from the coast. The coastline is prograding, up to 1 metre (Hesp, pers.comm.) each year with sediment deposited by major rivers from the hinterland mountains. Some of this sediment is collected by the foredune vegetation, which acts in an analogous way to a net, collecting small amounts of sand deposited on to the coastline, and holding it in place. When a blowout occurs, sand is driven inland by the prevailing north-westerly winds, to the southeast. The break in the foredune enlarges, creating a larger blowout and the moving sand forms into a long thin elliptical sand ridge. The prevailing wind eventually shapes this sand ridge into a parabolic dune. The head of the parabolic dune moves inland, leaving trailing parallel sand ridges behind, arching back towards the sea. Parabolic dunes stop when they run out of sand and energy (Cowie 1963).

When parabolic dunes move inland they smother all the hinter land vegetation, and create bare sandy deflation hollows behind them. The sand in deflation hollows is stripped down to the water table and blown onto the head of the moving parabolic dunes. As the parabolic dune moves forward, the terminal deflation hollow behind enlarges.

Primary succession occurs in the deflation hollow just behind the moving dune, with the oldest vegetation being closest to the sea and furthest from the moving dune. The first plant to colonize these deflation hollows is *Carex pumila*, a rhizomatous sand sedge which follows the moving terminal deflation hollow (Burgess 1984; Esler 1969). Following *Carex pumila* a group of other plants arrive, including *Epilobium billardiereanum*, *Gunnera arenaria*, *Isolepis basilaris*, *I. cernua*, *Lilaeopsis orbicularis*, *Limosella lineata*, *Myriophyllum votschii*, *Ranunculus acaulis*, *Selliera radicans*, *Triglochin striata*, and *Eleocharis neozelandica* (which is classified as Endangered on the New Zealand plants list, Cameron, *et al.*, 1995). These plants are adapted to this deflation habitat, which is nutrient poor (Burgess 1984) and has extremes with respect to the water table (Chapter 5). They must survive periods of winter flooding and summer droughts.

The nutrient content of these deflation hollows increases with additions from nitrifying algae, e.g. *Nostoc* and *Anabaena* species, atmospheric nitrogen and organic matter buildup. The plants in these deflation hollows also collect wind blown sand particles (*Carex pumila* is a very good sand binder) which raise the soil surface and lower the water table. This in turn enables other larger rushes and sedges to colonize, which eventually eliminate the smaller colonizing plants.

Dunes which are actively moving on the Manawatu coastline are deemed to be a nuisance by land managers, because they cover and destroy productive pasture and forests with metres of sand. As a consequence stabilizing moving dunes with marram grass (*Ammophila arenaria*) and trees and shrubs is encouraged. When moving dunes are stabilized the natural succession is altered because new deflation hollows are not created behind them. As a consequence the colonizing vegetation is slowly eliminated from the region, as it no longer has any where to disperse to. Additionally if bare areas of the dune plains are planted with marram grass they are even more quickly invaded with large sedges and rushes, notably *Isolepis nodosa.*

Sand stabilization creates a problem for conservation managers whose primary function is to retain the diversity and naturalness of conservation areas. One approach in a modified environment, is to assist natural processes in the creation of deflation hollows and their associated temporary wetland vegetation. Here two artificial construction of two deflation hollows were constructed, by excavating an already existing deflation hollow with a 16 ton hydraulic digger. This created deflation hollows with high water tables and a completely barren sandy hollow analogous to the natural ones. The hollows were planted with two species of plants which occur in the young deflation hollows, the endangered spiked sand sedge *Eleocharis neozelandica*, and *Isolepis cernua*, and the natural colonization was monitored over 13 months.

Methods

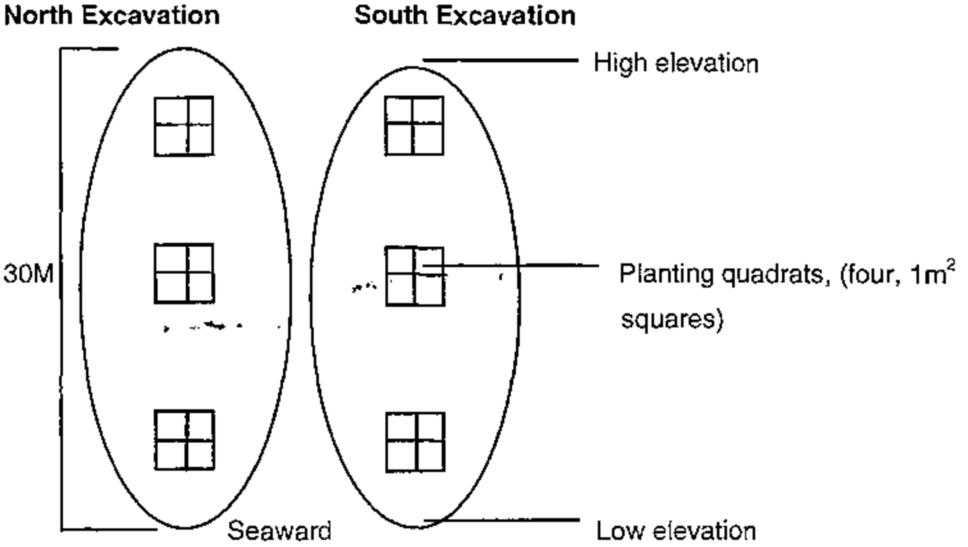
The location of the deflation hollow for the excavated wetlands was chosen firstly to avoid areas that already had significant existing natural values, and secondly its accessibility to roads and tracks, in order to limit damage to the area and plants from the digger. The area was a natural location for a temporary wetland, i.e. on the windward side of a parabolic dune head, which had been stabilized by marram planting. The area consisted of two reasonably large (approximately 25 metres long x 6 metres wide) and low lying parallel hollows with a small raised hummock between them. The location had a sparse vegetation cover of *Selliera radicans*, with occasional *Isolepis cernua* and *Carex pumila*. One *Eleocharis neozelandica* plant with five ramets occurred on the raised hummock between the two wetlands (which was specifically avoided during the excavation process), and another plant occurred on the northern side of the northern wetland. *I. cernua* was widespread throughout the general area.

Excavation took place on the 31st January 1996, using a 16 ton excavator with caterpillar tracks and a two metre wide narrow blade. A small dune was also removed as this was unstable and was moving on to the excavation area. The two hollows were enhanced by excavating the contours of the site, to conform to the surrounding landscape. The deflation hollows were excavated to the greatest depth on the seaward side and gradually tapered off inland. The excavation was carried out to specific water table specifications. The lowest and highest areas of the two wetlands were equivalent to the same elevation as pipe 3 and pipe 7 at study site 2 (Chapter 1), respectively. These heights were chosen as they covered the full range in elevation which *Eleocharis neozelandica* was growing. The water table heights for study site 2 were measured on the same day as the excavation, in order to find out how far the water table was below the surface. The water table was located at both excavation sites, corresponding to where the low, medium and high water table zones were. A surveyor's level and staff was used to measure the water table at each of the holes and adjacent to the holes at the soil surface, and monitor the progress of the excavation, so the exact height was achieved. The soil surface of the hollows was rough and uneven so was smoothed out using the back of the excavating blade. The excavated wetlands were left for two months to weather and stabilize before they were planted. The wetlands were thoroughly surveyed for any plants immediately before the planting took place. Several areas of *Carex pumila* had regenerated from rhizomes; 55 ramets were located over the entire excavated area. It appeared that the *Carex pumila* re-sprouted from rhizomes still present after the excavation took place. Five *Isolepis cernua* and seven *Selliera radicans* plants were also found.

Eleocharis neozelandica and *Isolepis* cernua were glasshouse grown for planting into these temporary wetlands to assess the usefulness of this method of restoration. *E. neozelandica* had been grown from seed (Chapter 3), and *Isolepis cernua* plants had been collected and from the area in September 1995. They had been potted into beach sand with 3 month Osmocote™ (1:400ml) at the Ecology Department glasshouse, Massey University. Three quadrats were placed at the low, medium and high areas of the wetlands (Figure 7.1). The low and high quadrats were located approximately two metres from the edge of the excavation, while the medium quadrat was situated half way between these two, and 10 metres distance from both quadrats. At each area four adjacent 1 m^2 squares were randomly planted with three *Isolepis cernua* and six *Eleocharis neozelandica*, on the 31st March 1996, and at the centre a metal tag was placed. The water table was below the surface at the time of planting.

The water depth at each of these 2 x 2 m quadrats was measured when the water table was above the surface, throughout the winter and spring months, 1996, in order to identify the time that each group of plants were submerged.

Figure 7.1: The location of the planting quadrats in the excavated wetlands.



On the 22nd December 1996, (approximately 9 months after the planting) the quadrats were assessed for survival of all the planted *Eleocharis neozelandica* and *Isolepis cernua*. Six *E. neozelandica* plants out of the plants which survived were randomly selected from each of the medium and high 2 x 2 m quadrats, and tagged at the centre of each plant, with a permanent metal spike. They were assessed for growth, rabbit browse and reproduction. The length and width of each plant was measured with respect to the centre tag. The longest leaf of each plant was measured, giving an indication of rabbit browse. Rabbit browse was also measured with a subjective browse score from no browse (0) to extreme browse (5). Reproduction was measured by counting every flowering or seeding inflorescence. The quadrats were assessed for any additional colonization of other plants, by recording the number of plants, or ramets of each species or subjectively giving a percentage cover of that species. Percentage sand cover was also recorded.

The topography of each wetland was measured on the 22^{nd} on December 1996 along its central axis, at every metre interval. At every 5 metre interval on the central axis additional series of measurements were conducted at 2 m intervals at right angles to the first, to the edges of the site. Colonization of the whole wetlands was recorded by measuring percent cover of species, and the percentage sand cover in a 30 x 30cm quadrat at every metre interval along the same central transect line as for the topography. Colonization also occurred from the edges of the wetlands from clonal spread via rhizomes etc., for example *Carex pumila* and *Selliera radicans*. This inward invasion of the clonal spread was measured at metre intervals along the central transect line, in both wetlands, in January and March 1997.

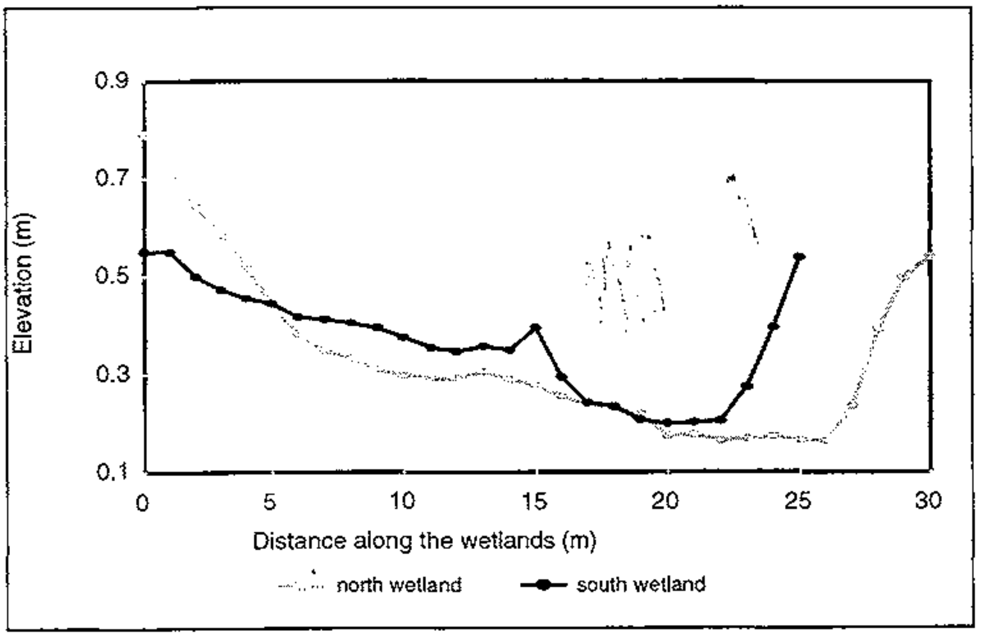
Photo 7.1 : The location and vegetation cover of the two excavated wetlands in the fore ground before construction on the 31st January 1996.

Photo 7.2 : The construction of the temporary wetlands using a 13 ton hydraulic digger with a wide blade.

Results

The lowest area in the North site was excavated to a slighter lower elevation than the southern wetland. The south hollow was 25 metres long, slighter smaller than the north hollow at 30 metres. This length conformed best with the original topography. The two wetlands have a reasonably gradual rise and a range in elevation of 65 cm (Figure 7.2). At the time of planting, approximately two months after excavation, colonization by other plants in both sites had begun. This colonization halted with the onset of the winter rise in water table above the surface in early May 1996. The water table remained above the surface in the lowest areas until late December 1996, resulting in approximately eight months of submergence. It fluctuated in height, and was recorded above and below the highest planted areas throughout these months.

Figure 7.2 : The topography of the two excavated wetlands measured with a surveyor's level and staff. The measurements were made at metre intervals along the central axis of the wetlands.



***Eleocharis neozelandica* and *Isolepis cernua* survival**

On the 22nd December, approximately nine months after planting, the middle elevation set of quadrats had some additional *Eleocharis neozelandica* plants, while the higher elevation quadrats had none. One quadrat had 12 plants, an addition of 6 plants, while another three quadrats each had an additional plant. At the time of planting many of the *E. neozelandica* and *Isolepis cernua* plants had set seed, and would have released much of this seed on to the excavated sites. These additional plants were seedlings and most probably resulted from the previous year's seed set. The low elevation set of quadrats were assessed on the 5th January 1996, when the water table was below the surface. One *E. neozelandica* seedling was found at the south wetland, and another was located on the 30th January (Table 7.1).

Table 7.1 : The total number of *Eleocharis neozelandica* and *Isolepis cernua* plants in all quadrats of high, medium and low elevation quadrats in both wetlands, recorded on the 22nd December. The two *Eleocharis neozelandica* plants at the south low quadrats were found on the 5th and the 30th January, 1997. There were 24 *E. neozelandica* and 12 *I. cernua* planted at quadrats; additional plants are seedlings.

	NORTH WETLAND			SOUTH WETLAND		
SPECIES	**HIGH**	**MEDIUM**	**LOW**	**HIGH**	**MEDIUM**	**LOW**
Eleocharis neozelandica	15	30	0	23	26	2
Isolepis cernua	42	4	0	12	5	0

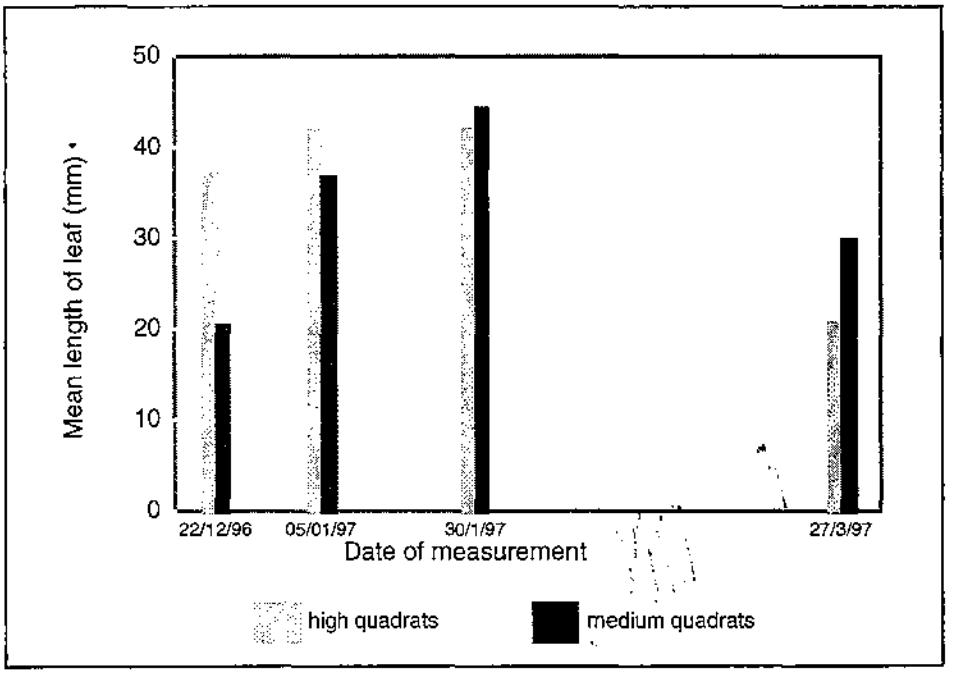
The highest two quadrats on the North excavation site had very low survival rates of all *Eleocharis neozelandica* with only a single plant surviving in one square and two in another. It appears that these plants may have been buried with sand, blown on them from an adjacent area, as the metal tag in the quadrat was buried as well. This sand had been dumped next to this wetland from its construction, and from the removal of the small adjacent dune, and there was more lateral movement than anticipated. The plants in the high elevation quadrats in the south excavation site, (which is of a comparable elevation) survived well with only one plant lost. Additional plants of *Eleocharis neozelandica* only occurred in the medium and low elevation quadrats.

All the planted *Isolepis cernua* plants in the high elevation quadrats were relocated, with additional plants in some of these quadrats. The two quadrats in the high elevation site in the north wetland which had low *Eleocharis neozelandica* survival rates, had high numbers of *Isolepis cernua* plants. Most of these plants were small and probably arrived into the quadrat as seed blown in with sand grains. It appeared that all of the planted *I. cernua*

Rabbit browse of Eleocharis neozelandica

The fall in inflorescence number (Figure 7.4) may be partly due to the increase in rabbit browse (Figure 7.5), as rabbits remove both non-flowering and flowering stems. Rabbit browse increased as the summer progressed with the wetlands drying out. Some individual *Eleocharis neozelandica* plants were significantly affected by rabbit browse, having most of their photosynthetic stems eaten, while others were only slightly affected. Rabbit browse may have significantly reduced the annual seed production considering the degree of the browse.

Figure 7.3 : The mean length of the longest leaf for all tagged *E.neozelandica* plants for medium and high quadrats in both wetlands.



The mean longest leaf size for tagged *Eleocharis neozelandica* (Figure 7.3) was reduced probably by rabbit browse, however this fall in size is less descriptive than the degree of browse score. *E. neozelandica* plants have many photosynthetic stems and though a plant may be heavily browsed it still may have a few stems which are not touched.

Figure 7.4 : The mean inflorescence number for all tagged *Eleocharis neozelandica* plants from the medium and high elevational quadrats in both wetlands. The low quadrats were omitted because of insufficient plants.

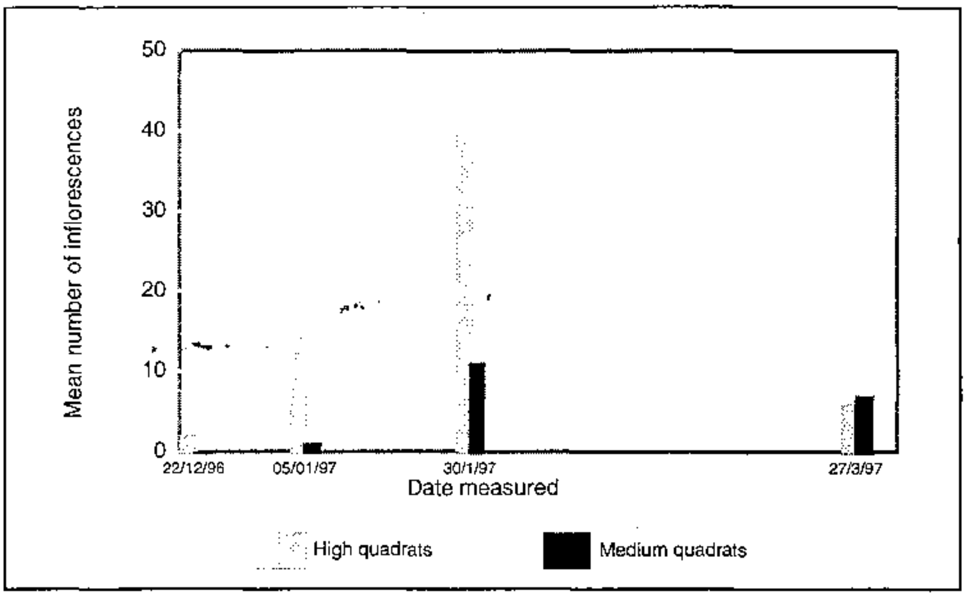
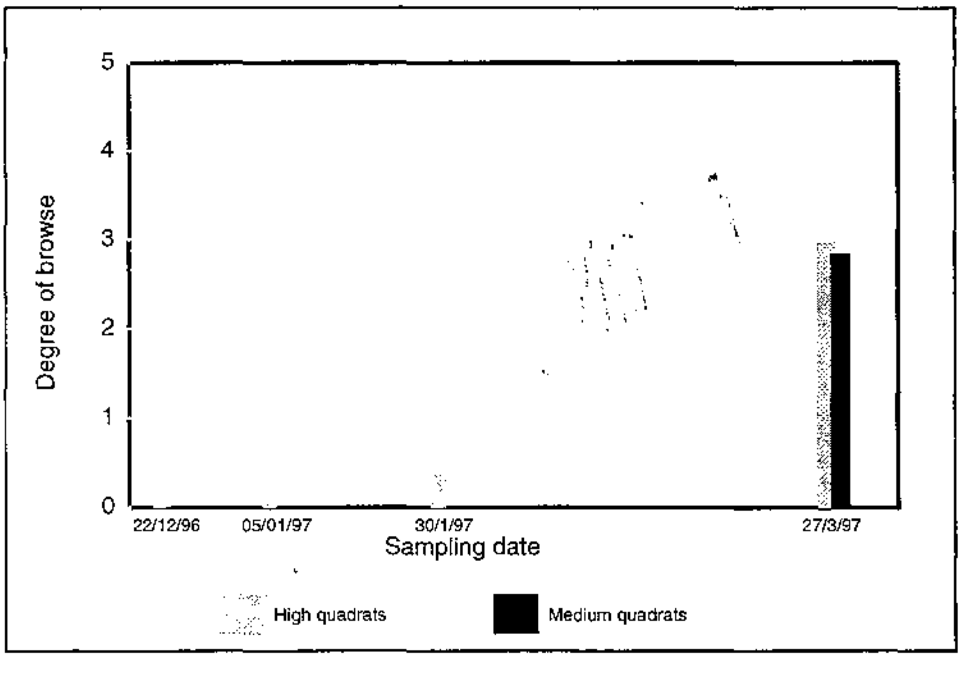


Figure 7.5 : The mean rabbit browse for tagged *E. neozelandica* plants in high and medium quadrats for both wetlands. The degree of browse is 0 = none, 1 = light browse, 2 = moderate browse. 3 = high browse, 4 = very high browse and 5 = extreme browse.



The colonization of the constructed temporary wetlands

The colonization of the wetlands occurred very rapidly, initiated first from damaged rhizomes of *Carex pumila* at the southern wetland, after the excavation in autumn 1996 (pers.obs.). This regeneration quickly halted as the water table rose and covered these plants in winter 1996, though commenced when the water table dropped below the surface in early December. Higher elevations of both wetlands were colonized first, (pers.obs.) followed by lower elevations with the fall in the water table, both by clonal spread and seedling plants. Colonization by *Carex pumila* and *Selliera radicans* spreading from rhizomes from the perimeter occurred in both wetlands (Figures 7.6a & 7.6b). Seedling plants quickly colonized higher elevations, and these seedlings were included with the clonal edge as it was virtually impossible to separate which plants were clonal and which were seedlings, at the second sampling (Figures 7.6a & 7.6b). This separation was distinct at the first sampling. On the 22nd December most of the excavated wetland area was still bare sand (pers.obs.) *Selliera radicans* was abundant around both wetlands, and was present in the wetlands at medium and high elevations (Figures 7.7a and 7.7b). Seedlings of this species quickly colonized the excavated wetlands as the water table retreated. For this to have happened an amply supply of seed must have been dispersed to the area creating a seed bank, after the excavation. Many scattered *Isolepis cernua* seedlings occurred higher elevations. However the majority of the surface in both wetlands was again still bare sand, on 31st March 1997, 14 months after the excavation, with no vegetation present at all at the lowest elevation areas in both wetlands (Figures 7.6 and 7.7).

Figure 7.6a: The colonization edge of clonal plants in the north excavated wetland on the 5/1/97 an 20/3/97. Inside the ring is virtually bare sand apart from planted *E. neozelandica*, *I. cernua* and a few seedling plants.

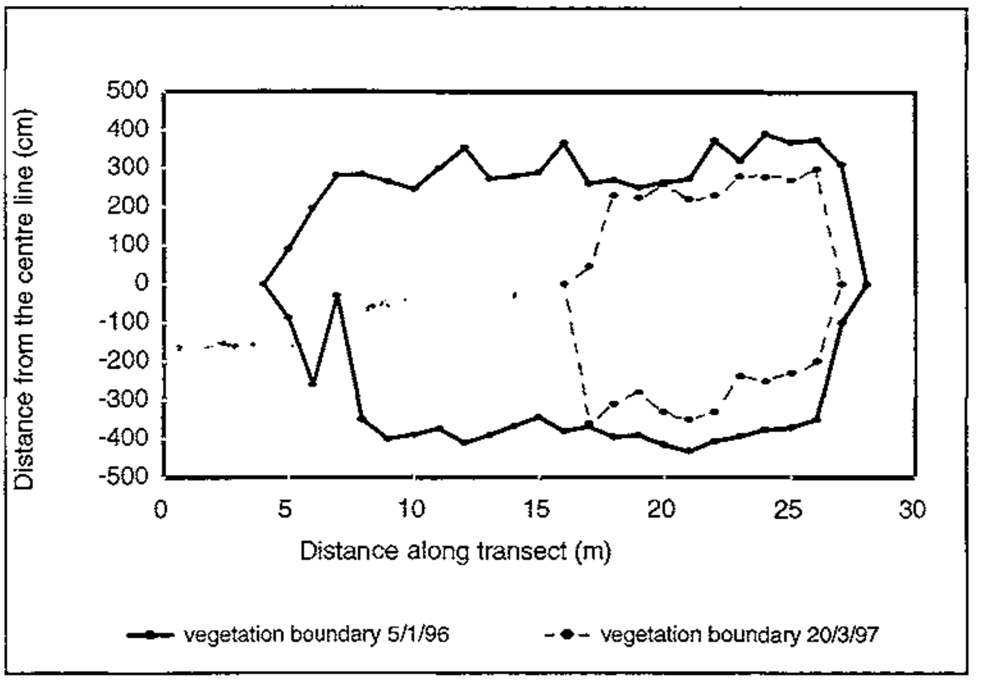


Figure 7. 6b: The colonization edge of clonal plants in the south excavated wetland on the 5/1/97 an 20/3/97. Inside the ring is virtually bare sand apart from planted *E. neozelandica*, *I. cernua* and a few seedling plants.

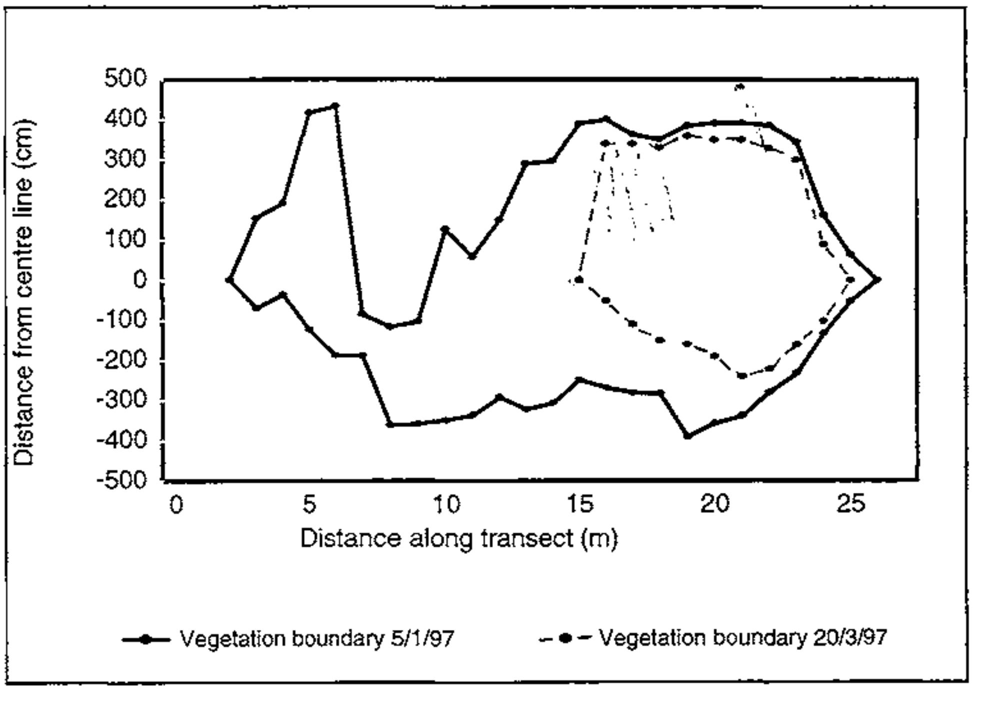


Figure 7.7a: The percent cover of vegetation in 30 x 30 cm quadrats in the north excavated wetland, along the central axis transect on 31/3/97. The lowest elevation is number 25.

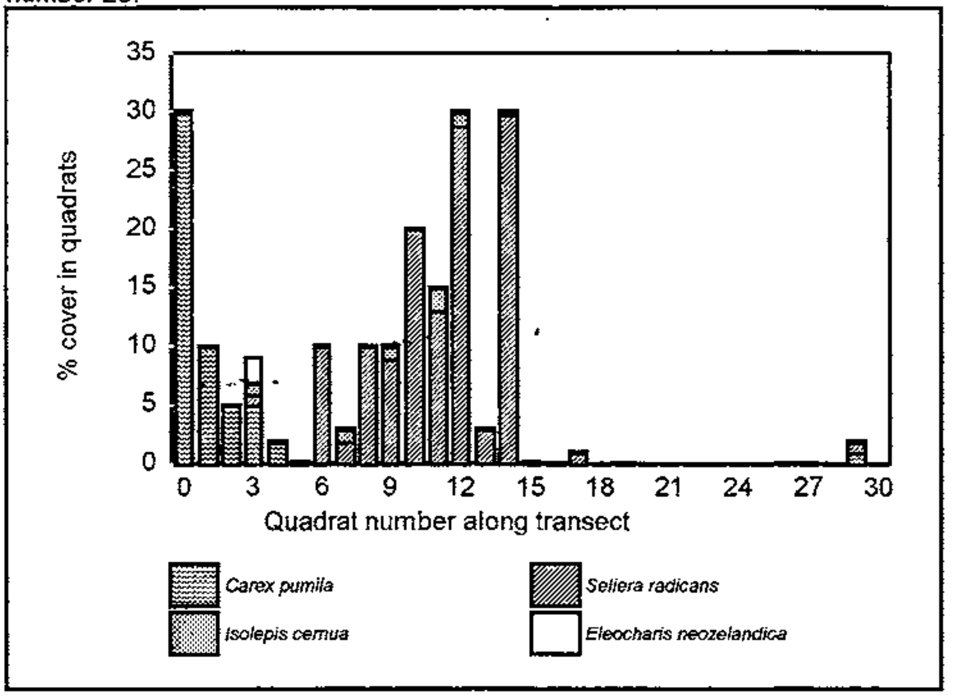
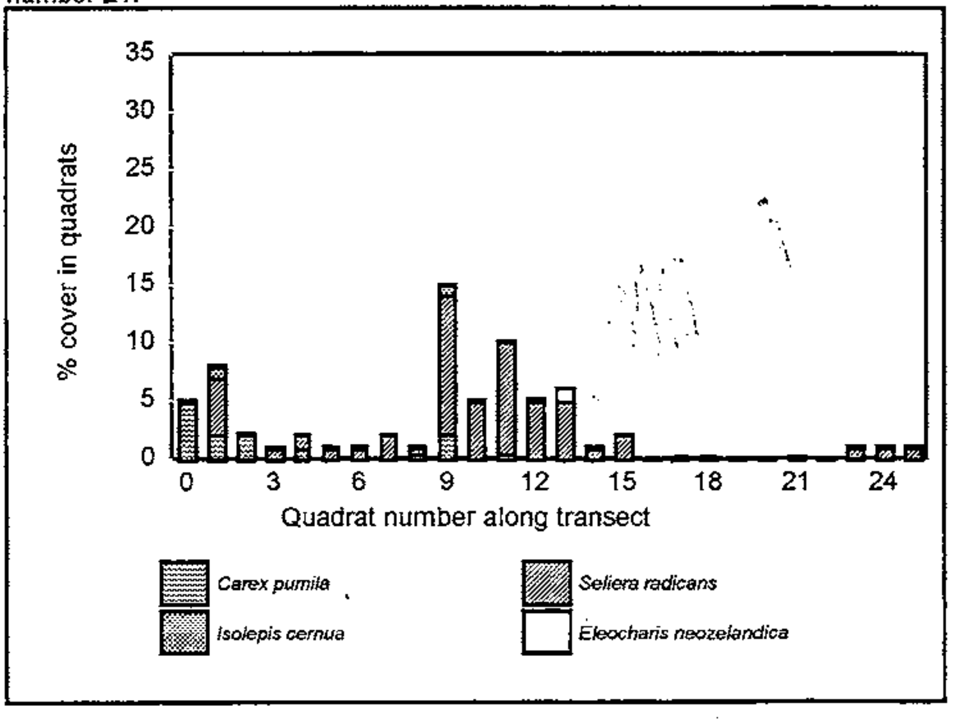


Figure 7.7b: The percent cover of vegetation in 30 x 30 cm quadrats in the south excavated wetland, along the central axis transect on 31/3/97. The lowest elevation is number 21.



Discussion

Wetland creation

Habitat for *Eleocharis neozelandica* and other temporary wetland plants, which colonize newly created sand deflations, is no longer being created naturally in any large extent on the Manawatu coastline. The few small hollows being formed are isolated from seed sources of most of these plants. This lack of habitat was addressed with a trial construction of wetlands as a means to preserve the habitat and the plants which occupy it. It is anticipated that such wetlands would only be temporary due to in-filling of sand, and colonization by larger plants.

Dune slacks have been successfully created for the conservation and management of wetland plant and animal species, notably in the Netherlands (Boorman 1977). A number of small slacks was considered to be more favourable for diversity than a few large ones, as isolation or independence tends to produce diversity. Boorman (1977) recommended that the greater part of the surface should lie between the groundwater level in an average summer and a level of 70-80 cm above the winter water level, for the conservation of temporary wetland plants. This elevation is probably a little large for the Tangimoana dune slack situation, as the higher elevation areas tend to be colonized by exotic species, such as grasses for example *Holcus lanatus* and herbaceous legumes. However the excavated wetlands would fit well into Boorman's recommendation

Temporary wetland plants in newly created dunes slacks occur on raw sandy soils, and the constructed wetlands largely conform to natural hollows in this respect. Colonization is occurring rapidly from plants adjacent to the wetlands. Where disturbance creates hollows (blowouts) in the dunelands at Tangimoana, native species predominate. The constructed hollows as yet contain no exotic species.

Plant survival and colonization

The survival of planted *Eleocharis neozelandica* was very high in both the high and medium elevational quadrats, though no plants survived the winter submergence in the low elevational quadrats. *Isolepis cernua* was less tolerant of submergence than *E. neozelandica*, with only limited survival at the medium elevation, and no plants at the low elevations. *E. neozelandica* was able to grow when submerged for two months during summer, while *I. cernua* was not (Chapter 6). They both appear to be able to tolerate a period of winter flooding, with the survival of most plants in the medium elevational quadrats, which experienced at least seven months of submergence. However they were not able to survive the nine months of submergence, which occurred at the lower elevation quadrats.

Death during prolonged submergence may be due to several causes. Prolonged exposure to anoxic conditions, can result in the accumulation of toxic fermentation products, notably ethanol (Schat, 1984). Nine months of submergence may simply be too long for these plants to endure. Increasing depth of submergence may result in plants may not receiving adequate light in order to photosynthesize and maintain a positive carbon balance, as there is a decrease in the amount of light penetrating a larger layer of water. Temperature can affect whether a plant survives prolonged submergence (Schat 1984).

Eleocharis neozelandica and *Isolepis cernua* may survive submergence in a quiescent state, due to their underground rhizomes and roots abilities to withstand prolonged oxygen deprivation. This has been found to be the case with other temporary wetland plants (Barclay and Crawford 1982). Barclay and Crawford (1982), tested plant growth and survival under strict anaerobiosis, and found that several rhizomatous species can sustain shoot extension and suffer no deleterious after-effects, even with prolonged periods of anoxia. Other species such as *Eleocharis palustris* survived anoxia though no shoot extension occurred. *E. neozelandica* may have a similar strategy, being a close taxonomically related species.

Elevation requirements and consequences

The elevation at which a plant is growing in a temporary wetland can influence the length of its growing season. *Eleocharis neozelandica* and other similar temporary wetland plants, commence growing sooner in spring at higher elevations, with the fall in water table, than those submerged at lower elevations. *E. neozelandica* grows very slowly when it is fully submerged; however it grows as well in waterlogged soils as in soils of field capacity (Chapter 6). *E. neozelandica* growing in the high elevation quadrats were larger, having more inflorescences, and therefore a higher reproductive output, than those at the medium elevational level.

Plants in the temporary wetland habitat need to grow and reproduce quickly. Plants growing at low elevations are more prone to unseasonal high rainfall, which may halt the growing season for period of time or stop it altogether. For example; in 1995 the wetlands (Chapter 1) were inundated in February by unseasonal rain. This flooding remained throughout the winter and spring months and prevented further growth. The annual mean summer and winter heights water table in temporary wetlands is also not static. This height will change over years because of varying amounts of annual rainfall. In dry years the mean water table height will fall while in wet years it will rise. The zonation patterns of temporary wetland plants are directly related to the water table height. Schat (1984) concluded that "the zonation pattern is provoked by differential tolerance of waterlogging and submergence" and "the minimal distance from the average summer water table for a particular species is determined by its ability to survive prolonged submergence during winter". The winter of 1995 was extremely wet and killed many of the temporary wetland plants at low elevations including *E. neozelandica*. This event changed the zonation at which plants were growing in the wetlands.

Rabbit browse

Rabbit browse was more severe at higher elevations, particularly on some individual *Eleocharis neozelandica* plants. Rabbits prefer to graze in areas which are dry and will move down in elevation in dune slacks as they dry out (Willis *et al.* 1959). Higher elevations will be drier for longer and thus are more prone to rabbit grazing. The two *Eleocharis neozelandica* seedlings in the south wetland at the low elevation were never browsed over the period recorded. Here the sand substrate was always moist, and unfavorable for rabbits.

In the long term rabbits may influence the zonation pattern of *E. neozelandica*, as plants at higher elevations will experience a higher degree of rabbit browse. Willis *et al.* 1959 suggested grazing by rabbits affected the distribution of some species in dune slacks at Braunton Burrows. *Festuca* was usually found in damp sites near the lower limits of the range of this grass. Its dominance was attributed to the relative inaccessibility to grazing compared to higher and drier elevational sites. With the spread of Myxomatosis and the resulting reduction in rabbit numbers, *Festuca rubra* increased its range in dune slacks at Newborough Warren, Anglesey, indicating its distribution was limited by grazing pressure (Ranwell 1960). *Festuca rubra* is a highly favored food source by rabbits (Bhadresa1977). The food preferences of rabbits in dunelands are unknown in New Zealand; however new *E.neozelandica* foliage appears to be highly palatable to rabbit grazing.

Conclusion

The colonization of the two wetlands occurred very quickly with the fall in the water table height. The first plants to colonize were those in close proximity to the wetlands, for example *Selliera radicans*, *Carex pumila* and *Isolepis cernua*. These three species were present on the original site before the excavation took place, and an abundant seed source of these species would probably have been present around the excavation sites. These species as well as *Eleocharis neozelandica* are likely to become the dominant species in the wetlands. As the wetlands age gradually more species will colonize from surrounding areas and slowly a zonation pattern in relation to the water table will form. These wetlands are capable of having reasonably diverse communities considering the large range in elevation. The low elevation areas of the wetlands are able to accommodate species more specific to wetter areas, such as *Myriophyllum votschii*, *Limosella lineata* and *Triglochin striata*. A constructed temporary wetland designed for *E. neozelandica* needs to have a large range in elevational height. This range in elevational height accommodates changes in zonation patterns over years. In dry years plants may die as a result of desiccation at higher elevations, while new plants may colonize areas lower down; in wetter years the reverse may happen.

The construction of deflation hollows in dune plains for habitat creation for *Eleocharis neozelandica* and other temporary wetland plants, appears after one year's observation to be a successful way in which to manage these species. Ongoing assessment is required on how long the areas will provide habitat for *E. neozelandica* is not known, as they are clearly temporary. Planting *E. neozelandica* may not be necessary if new habitats are located adjacent to the existing wetlands as natural invasion of the habitat may occur. Dispersing seed may be all that is required in constructed wetlands and newly formed natural ones. The optimum size is not known, clearly a larger wetland will provide more habitat for *E. neozelandica* and other temporary wetland plants, but Boorman (1977), and research on reserve design in terrestrial systems, many smaller wetlands may provide an option less vulnerable to stochastic effects.

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Chapter Eight

Discussion

The dunes and their temporary wetlands

The "Tangimoana dump dunes" (Ravine 1992) are a regionally significant natural area containing excellent dune and temporary wetland communities. Temporary wetlands are one of the most threatened ecosystems in New Zealand, and the majority of dune slack temporary wetlands in the Foxton Ecological District have disappeared, as a result of modification. The area contains several nationally threatened plants, i.e., *Eleocharis neozelandica*, status endangered; *Isolepis basilaris* status endangered; *Pimelea* "Turakina", taxonomically indeterminate-status critical; *Pimelea arenaria* local status (Cameron *et al.* 1995). *Selliera rotundifolia* is a regional endemic only occurring in the coastal dunes of the Foxton Ecological district, and a classification of endangered was suggested (Heenan 1997). Pingao (*Desmoschoenus spiralis*) is present and together with the dune area on the north side of the Rangitikei River, may be the largest population in the Foxton Ecological District. Pingao was previously ranked as "local" status (Cameron *et al.* 1995), as it has significantly reduced its range.

Parabolic dunes in the Manawatu are dynamic in nature and naturally move inland, forming deflation hollows and dune plains behind them. A natural ecological succession occurs behind moving dunes, providing habitat for all dune slack plants from the early to the later stages of this succession (Esler 1969). The flora of young deflation hollows are dependent on the ongoing formation of new habitat, i.e. deflation hollows from moving dunes and small blowouts. Wandering parabolic dunes eventually cease moving, and new deflation hollows tend to form closer to the foredune than older hollows, which may be physically separated by hundreds of metres. Additionally these new hollows form into the prevailing wind from the older hollows.

Dune binding plants e.g. *Spinifex*, pingao, and marram create dunes of different morphologies (Esler, 1970), and in the absence of marram, which creates tall and steep dunes, the dune lands would have had a totally different topography. During times of stability the natural dunes would have been smaller with gentle slopes, and a rolling topography. Dune slack habitat in smaller deflation basins may have been present between these dunes, which now no longer occurs because of the vastly different dune topography. Temporary wetland species may have also occurred along sandy stream edges, which no longer exist because of modifications. Temporary wetland communities along stream margins still exist in the far north, for example Te Paki stream.

Historically, there have been periods when major dune building was not occurring between the dune building phases in the Manawatu dunelands, the inter-dune building periods. The abundance of the flora of young dune slacks may have waxed during periods of increased dune building, and waned during decreased dune building, as habitat became more and less plentiful. Wandering dunes however still occurred during inter-dune building phases, though they were on a much smaller scale, and were later covered by dunes of the larger dune building phases (Shepherd pers.com). Habitats in new deflation hollows would have been less plentiful and at times physically isolated from each other with fewer wandering parabolic dunes. However even with fewer deflation hollows there would have been plenty of habitat in the whole of the Foxton Ecological district, for the survival of young dune slack species during the inter-dune building phases.

Rare species

The rare species of the Tangimoana dump dunes and dune slacks are principally rare as a result of habitat loss and modification, from dune stabilization with marram and forestry. Early references (Chapter 3) indicate that *Eleocharis neozelandica* was reasonably common in places when Cockayne visited these dunes in 1909, and as such the temporary wetland communities were probably well represented. There would have been abundant dune slack habitat, because a high level of instability from wandering parabolic dunes. *Eleocharis neozelandica* occurs in young wetlands with a low and sparse turf vegetation cover, which was found in the two study sites in 1994, and more so prior to the planting of Marram in 1992 (Ravine, 1992). Today *E. neozelandica* occurs in six different locations at Tangimoana, though is far less common now in the northern and southern wetlands when compared to its abundance in April 1994 and in the winter of 1992 (Don Ravine, DoC pers.com). Many *Eleocharis neozelandica* plants probably died as a result of the extreme length of submergence with the high winter water tables during the wet winters of 1995 and 1996 (Chapter 5). However it is likely that the plant is also being eliminated through competition with larger rushes and sedges for example, *Isolepis nodosa*, *Leptocarpus similis* and the exotic rush *Juncus articulatus* as the wetlands are invaded. The two studied wetlands now appear to be less suitable as habitat, and do not resemble the wetlands of April 1994. New habitat adjacent to these wetlands is not being made due to stabilization, and it is inevitable that *Eleocharis neozelandica* will be eliminated from the study areas.

Pimelea "Turakina" has been planted at two areas within the dunelands, and with management could easily become naturalized throughout the area, as it seeds so freely. The plants grown from cuttings flowered and produced fruits from a young age, and within one year of planting seedlings were present around the parent plants (Chapter 4). *Pimelea* "Turakina" appears to be well adapted to the dune plain environment, of raw sandy soils and a fluctuating water table. Additional plants should be propagated from the natural habitat at Himatangi and planted on the most northern and largest dune plain, in dense groups.

Conservation management

The flora of young deflation basins must have efficient seed dispersal mechanisms, either abiotic or biotic, in order to survive, and colonize new habitat, as habitat can be physically isolated from each other. Thus plants with efficient dispersal mechanisms would have been selected for. *Pimelea* "Turakina" and *Eleocharis neozelandica* produce prolific seed from an early age (Chapters 3, 4, & 7), enabling rapid colonization of any newly formed habitat, and ensuring survival during environmental extremes. It appears that the flow of water from wetland to wetland during periods of high water table helps to disperse *E. neozelandica* seed to adjacent wetlands (Chapter 5). Large deposits of seed were present at the high winter water line around the edges of wetlands during the study. The regular prevailing wind would also disperse seed to damp newly formed deflation hollows where they would settle. However the long distance seed dispersal mechanisms of *E. neozelandica* are unknown, though it is possible that wetland birds, for example, ducks, pied stilts and white faced herons which visit these wetlands in winter, are seed dispersal agents. Ducks, especially brown teal (*Anas aucklandica*) would previously have been common on the temporary coastal wetlands in the Manawatu, feeding on seed and insects (Robertson *et al.* 1985); seed could have easily become deposited on their feet and feathers, then dispersed to other wetlands. During the wet winter of 1995, a drain was blocked which drains the "Tangimoana fernbird area", a neighbouring area of temporary wetlands on dune plains of an older age, behind the "Tangimoana dump dunes" (Ravine 1992). Hundreds of ducks (grey, mallard, grey teal, and NZ shoveler) were present on this wetland, and also regularly visited the temporary wetlands in the dune slacks.

The Tangimoana dump dunes are only 45 hectares in size, and little new dune slack habitat is forming adjacent to existing *E. neozelandica* populations, as all parabolic dunes except one are stabilized by the marram planting. However there are several low deflation hollows similar in respect to the water table height of the two studied wetlands (Chapter 5), though these do not contain *E. neozelandica*. Establishing populations of *E. neozelandica* (planting plants, sowing seed, or relocating plants) in these areas is a viable option for the species short term survival. However in the long term, habitat needs to form from wandering dunes and small blowouts for sustainable populations of *E. neozelandica* to occur. Construction of artificial hollows is a valuable tool for habitat creation for *E. neozelandica* and other duneslack species (Chapter 7). These wetlands should ideally be sited next to existing *E. neozelandica* populations for rapid colonization to occur. They should be relatively large 20 x 20 metres and be excavated to a low elevation to ensure a moist substrate is always present during the summer months, even during dry years when plants die at higher elevations because of desiccation. Areas of low conservational value should be chosen as the construction process creates artificial hollows, by scraping the surface layer off to the required level, in doing so destroying the plant cover. Young deflation hollows appear to be excellent habitat for *E. neozelandica*, and other temporary wetlands species. They appear very natural and contain virtually no weeds; it is only as wetlands age and fertility increases that weeds invade.

The succession process appears to have been hastened by the planting of marram, as *Isolepis nodosa* colonized in and around the planted marram on the margins of the wetlands, and is now very thick wherever it was planted close the water table. Fertilization of the marram-planted dunes with ammonium nitrate (NH_4NO_3) which would have added nutrients to the dune slacks via leaching and run off, may have hastened the succession process as well. Additionally this influx of nutrients may be partially responsible for the increase of the exotic rush, *Juncus articulatus*.

There are many naturalized exotic plants within the Tangimoana dunelands, though only a few pose a significant threat to the long term viability of the area. Pampas species (*Cortaderia selloana* and *C. jubata*) are the most significant as they produce a prolific amount of seed, and have the ability to invade and dominate dune slack and dune plain communities. Marram covers the greatest amount of the area through direct planting within the reserve boundaries. It has changed the topography of the dunelands drastically with large steep dunes (Esler 1970). However where it has seeded in sensitive areas such as around the edges of slacks, and on the gravel plain it poses the greatest threat by accumulating sand and altering communities. There are many herbaceous legumes such as *Medicago lupulina*, *Melilotus indicus*, *Lotus pedunculatus*, and *Trifolium fragiferum* which are well adapted to the raw nature of the sandy soils. They fix their own nitrogen increasing the amount in the area, which will be eventually released into the environment. This may have flow-on effects in hastening the succession process and allowing nitrophilous species to dominate.

It appears that rabbits have both positive and negative effects in the Manawatu dunelands, and occur in high numbers, and are a notable presence. They intensely graze certain areas, especially the dune slacks during the summer and autumn months, when the surface dries out. Some plants are more susceptible to rabbit browse; *Eleocharis neozelandica* suffered heavy browse in late summer and autumn at the excavated wetlands (Chapter 7), and this may have reduced its seed production. It would be possible in dry growing seasons for *E. neozelandica* not to produce any seed if rabbits moved on to the wetlands before seed was released. In most years some seed would be produced as the surface of the wetlands remains moist for most of the growing season, and rabbits do not graze in wet areas. Rabbits appear to graze and control the spread of larger sedges and rushes, especially *Leptocarpus similis* and would contribute in slowing the succession of the dune slacks. Additionally, rabbits preferentially graze certain species, for example *Leontodon taraxacoides* (Chapter 5), which may increase available habitat for early successional species for a longer time period.

In 1992, any areas of mobile sand within the Tangimoana dump dunes were planted in marram, radiata pine and macrocarpa for stabilization purposes, while stable areas with a vegetation cover were planted in pine. This work was carried out by the Manawatu-Wanganui Regional Council under contract to the Manawatu District Council. The Ministry for the Environment, somehow inherited the responsibility for the Foxtangi sand stabilisation scheme from the former Ministry of Works. They allocated the money to the Manawatu District Council. This stabilization work was the last area planted by the Government-funded Foxtangi sand stabilization scheme, established under the former Ministry of Works. This scheme was responsible for much of the Rangitikei/Manawatu dune land being converted into forests between 1984 and 1992. The scheme was directly against the aims of resource management act (1991), which aims to protect and sustainable manage natural areas, and the Tangimoana dune lands had been identified as a natural area of regional if not national significance.

Most of the planted pine and macrocarpa in sensitive areas in the proposed reserve area (the Tangimoana dump dunes), were pulled out by conservation activists shortly afterwards. This was undertaken because it is assumed that these trees would greatly modify areas with high conservation values, to the detriment of the native vegetation. The adjoining land next to the 45 hectare proposed reserve area, is covered with young pine trees planted in 1992 and 1994. These trees will out compete any indigenous vegetation left in the area, though more insidiously the water table below the trees will fall as a result of the growing pine forest utilising this resource. Lower volumes of water from catchments planted in pines have been recorded when compared to the previous pasture cover (Maclaren 1996). However it is unclear what effect lowering the water table in the adjoining forest will have on the water table height at the Tangimoana dunelands. If the water table does gradually fall, wetland communities will gradually disappear from parts of the dune lands.

Large scale wandering parabolic dunes are a significant threat to pastures and production forests, and as such the local body councils aim to control their movement with marram planting etc. Moving dunes at the foredune from damage created by off road vehicles and other disturbances. Vehicles are generally deleterious to the dune habitat as they caused considerable damage to plants, animals and dunes. In conservation terms moving dunes are essential for the protection of the early successional stages of the dune slack flora. There is a conflict of interest, as conservation is compromised for the protection of neighbouring productive land.

Recently a dune has become mobile, formed from a blow out at the foredune near the north end of the reserve boundary, which has moved approximately 200 metres since April 1994. This dune may form into a parabolic dune creating valuable habitat for dune slack plants, which may be significant for *Eleocharis neozelandica*. However because of its location it may initiate movement in other adjacent dunes, in doing so forming a larger parabolic dune with a greater threat to neighbouring lands. At some point dune movement will have to be stabilized in order to protect neighbouring land, and maintain amicable relations with the adjacent land owner and the regional council. A management plan needs to address the appropriate time to manage moving dunes in order to maximize the potential duneslack habitat, though still protect adjoining lands. Additionally as the area is environmentally sensitive, stabilization using "eco-sourced" native sand binders *Spinifex* and pingao, as well as the sand binding shrubs *Ozothamnus* (*Cassinia*) *leptophylla, Coprosma acerosa* and *Pimelea* *arenaria* should be used instead of the exotic marram. Trials into the efficacy of such a method should be conducted. The Tangimoana dunelands are realistically too small to allow natural coastal processes to occur unhampered, resulting in compromises in conservation. An agreement with the adjoining land owner to purchase any land smothered by wandering mobile dunes from inside the proposed reserve boundary may be option for their management. This would have an important conservation benefit as it would vastly increase the size of the reserve and allow the natural succession to occur on the dune plain behind the wandering dune. The proposed reserve will naturally increase in size as the coastline is prograding from accretion of sediment at rates of over 1 metre a year (Hesp, pers.com.). The reserve boundary should extend to the mean high spring tide line, to take advantage of this natural accretion. As such the reserve will steadily grow in size and becoming more realistic in size for natural dune processes to occur.

Construction of deflation hollows as habitat for *Eleocharis neozelandica* and early successional dune slack species is an effective method for their conservation, when natural habitat not being formed. These hollows should ideally be constructed at five year intervals, adjacent to existing habitat so natural colonization will rapidly occur.

The Tangimoana dunelands are incredibly dynamic with respect to the water table, which results in dynamic communities. Species colonize at various elevations in the wetlands, as a direct consequence of water table heights, and are dispersed by high water tables when water flows from wetland to wetland. Over the period of this study dramatic changes in species distributions and compositions in the wetlands were observed. Dune slacks as habitat for species of an early successional status appear to be very short lived, requiring and approach to management as dynamic as the environment.

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Appendix

Tangimoana Dump dunes species list

Abundance Ratings

a = abundant

c = common

o = occasional

u = uncommon

l = local (species in small area, but can be common or abundant there)

* = exotic sp.

Gymnosperm tree

*Cupressus macrocarpa (planted)	(macrocarpa)	u
*Pinus pinaster	(maritime pine)	u
*Pinus radiata (planted)	(Monterey pine)	o

Dicot trees, shrubs and lianes

Calystegia soldanella	(shore bindweed)	l
Ozothamnus (Cassinia) leptophylla	(tauhinu)	a
Coprosma acerosa	(sand coprosma)	a
Leptospermum scoparium	(manuka)	u
*Lupinus arboreus	(lupin)	c
*Lycium ferocissimum	(boxthorn)	c
Muehlenbeckia complexa	(pohuehue)	o
Olearia solandri	(shrub daisy)	u
Pimelea arenaria	(sand daphne)	o
Pimelea "Turakina" (planted)	(sand plain daphne)	u
*Racosperma (Acacia) sophorae	(sand wattle)	u
*Rubus fruticosus	(blackberry)	u
*Rumex sagittatus	(climbing dock)	u
*Ulex europaeus	(gorse)	u
*Vicia sativa	(common vetch)	o

Monocot tree

Cordyline australis	(cabbage tree)	o

Fern ally

*Equisetum arvense	(field horse tail)	u

Ferns

Pteridium esculentum	(bracken)	u

Herbaceous monocots

*Agrostis stololnifera	(creeping bent)	lc
*Asparagus officinalis	(asparagus)	u
*Ammophila arenaria	(marram grass)	a
Carex pumila	(sand carex)	a
Carex testacea		u
Cortaderia fulvida	(toetoe)	c
*Cortaderia selloana	(pampas grass)	c
Cortaderia toetoe	(toetoe)	c
*Cyperus congestus	(purple umbrella sedge)	u
Desmoschoenus spiralis	(pingao)	o
Eleocharis acuta	(sharp spike-sedge)	u
Eleocharis neozelandica	(sand spike-sedge)	lc
*Festuca arundinacea	(tall fescue)	c
*Holcus lanatus	(Yorkshire fog)	a
Isolepis basilaris		u
Isolepis cernua		lc
*Isolepis marginata		o
Isolepis nodosa	(club sedge)	a
*Juncus acutus	(sharp rush)	u
*Juncus articulatus	(jointed rush)	lc
*Juncus bufonius	(toad rush)	u
Juncus caespiticius		o

Juncus pallidus		u
Lachnagrostis billardierei	(sand bent)	c
Lagurus ovatus	(harestail)	c
Lilaeopsis orbicularis		u
Limosella lineata		u
Leptocarpus similis	(jointed wire-rush)	a
Microtis unifolia	(onion-leaved orchid)	o
Phormium tenax	(NZ flax)	u
*Polypogon monspeliensis	(beard grass)	u
Schoenoplectus pungens	(three square)	lc
Schoenoplectus validus	(lake clubrush)	o
Schoenus nitens		a
*Sisyrinchium iridifolium	(blue-eyed grass)	u
Spinifex sericeus	(spinifex)	a
Triglochin striata	(arrow grass)	lc
Typhae orientalis	(raupo)	u

Herbaceous dicots

Acaena anserinifolia	(piripiri)	u
*Achillea millefolium	(yarrow)	u
*Anagallis arvensis	(scarlet pimpernel)	o
Apium prostratum	(tutaekoau)	u
*Aster subulatus	(sea aster)	u
*Carpobrotus edulis	(ice plant)	o
*Centaurium erythraea	(centaury)	o
*Cerastium glomeratum	(annual mouse-ear chickweed)	o
*Cirsium arvense	(Californian thistle)	u
*Cirsium vulgare	(Scotch thistle)	u
*Conyza albida	(fleabane)	c
Cotula coronopifolia	(batchelor's button)	o
Epilobium billardiereanum	(sand willow herb)	lc
*Foeniculum vulgare	(fennel)	u
*Hypochoeris glabra	(smooth catsear)	u

*H.radicata	(catsear)	c
*Gnaphalium spicatum	(purple cudweed)	u
*Lactuca serriola	(prickly lettuce)	lc
*Leontodon taraxacoides	(lesser hawkbit)	c
Lobelia anceps	(NZ lobelia)	lc
*Lotus pedunculatus	(lotus major)	o
*Lythrum hyssopifolia	(hyssop loosestrife)	u
*Medicago lupulina	(black medick)	c
*Melilotus indica	(King Island melilot)	lc
*Myosotis sylvatica	(garden forget-me-not)	u
Myriophyllum votschii		lc
*Oenothera stricta	(sand primrose)	c
*Orobanche minor	(broomrape)	o
*Oxalis corniculata	(horned oxalis)	u
*Parentucellia viscosa	(tarweed)	lc
*Plantago lanceolata	(narrow-leaved plantain)	u
*Plantago major	(broad-leaved plantain)	l
*Polygonum hydropiper	(water pepper)	u
*Portulaca oleracea	(purslane)	u
Potentilla anserinoides	(native cinquefoil)	l
Pseudognaphalium luteo-album	(cudweed)	lc
Ranunculus acaulis	(sand buttercup)	u
*Rumex acetosella	(sheep's sorrel)	lc
*Rumex crispus	(curled dock)	o
*Sagina procumbens	(procumbent pearlwort)	u
Samolus repens	(sea primrose)	u
Selliera radicans	(halfstar)	lc
Selliera rotundifolia	round-leaved halfstar	lc
*Senecio elegans	(purple groundsel)	c
*Senecio glastifolius	(holly-leaved senecio)	l
*Senecio jacobaea	(ragwort)	o
*Silene gallica	(catchfly)	o
*Sonchus asper	(prickly sow thistle)	o

Sonchus kirkii	(shore puha)	u
*Sonchus oleraceus	(sow thistle)	c
*Solanum chenopodioides	(velvety nightshade)	u
*Taraxacum officinale	(dandelion)	u
*Trifolium fragiferum	(strawberry clover)	c
*Verbascum thapsus	(woolly mullein)	u

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