Sand-dune vegetation of the Foxtangi region, Manawatu coast, New Zealand


The open wetland W31 and nearby sand plains, January 2010

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Disclaimer

Information contained herein represents a preliminary analysis of the vegetation sampling along this coast. For more details and more refined analyses, consult the senior author, or search for resultant publications.

Note

Some of the detailed maps of rare species presented here may increase their vulnerability to disturbance, and thus should not be widely circulated.

Contents

Abstract

One of the lower North Island's most pristine dunelands, the Manawatu coast is actively prograding, with new foredunes forming regularly. Behind these are parabolic dunes formed by the prevailing wind, between the arms of which depressions form. Some of these contain wetlands, often inhabited by rare turf species to <10cm tall. We examined the vegetation along this coast to understand its ecology and plan for its conservation.

Vegetation surveys were undertaken of the inland and seaward faces of the foredunes, of depressions containing sand plains or wetlands (containing >2 focal turf species), and of the parabolic dune surrounding a wetland, recording both native and exotic plants. Community types were identified from the data, and relations with environmental determinants considered.

The seaward faces of the foredunes are largely comprised of bare sand and the native foredune sand binder, *Spinifex sericeus*, although particularly around settlements and pine plantations, exotic *Ammophila arenaria* is more prevalent. Inland faces of the foredunes are often vegetationally unrelated. Sand plains are scattered, species' poor, and often located close to the coast, but do not offer new wetland habitat. Parabolic dunes, around wetlands, are vegetationally only weakly related to them, and are similar to foredune communities, though more successionally developed.

The small turf species of wetlands are scattered throughout the Foxtangi coast rather haphazardly, with few clear patterns. Most species are extremely rare with low frequencies of occurrence, little contribution to the community structure and with very low coverage by area. Wetlands form 6 community types, reflecting the range of successional stages present in each. Some high-value wetlands are found at Tawhirihoe Scientific Reserve, Department of Conservation, and from Himitangi south to 3-Mile Creek, and medium-quality wetlands are present in the Horowhenua District Council's reserve north of Foxton Beach.

The dynamics of sand dunes along this coast suggest that most of the wetlands are of comparatively recent origin, within the last 5 decades, and that the turfy phases have short life-spans. Construction of new wetlands remains a promising management technique but further consideration needs to be given to the conservation of the rare turf species and protection of natural dune processes.

Introduction

New Zealand (NZ) has a lot of coastline at 15 134 km in length (http://www.nzs.com/about-new-zealand/ - unknown fractal scale), covering a range of latitudes (34º25' - 47º16' Sth) extending over about 1600 km. However due to human settlement, much of the coastline is heavily disturbed. The major areas of duneland in NZ cover 52 000 ha (Newsome 1987), about 39 000 ha of which are active or mobile today (Hilton et al. 2000). Dunes occur in the north of the North Island, along much of the east coast of the South Island, and there are patches of especially native-rich dunes along the West Coast of the South Island, Southland and Stewart Island. Dunes are also extensive along the lower west coast of the North Island, stretching 125km in a smooth curve from Paekakariki to Wanganui, and interrupted only by the three great rivers, Manawatu, Rangitikei and Whanganui, which together drain much of the lower half of the North Island, all entering the Manawatu Bight within 60km of each other (Fig. 1, 2A). As a consequence of their sediment load being deposited along this coast, the Manawatu coast is prograding at a rate of about 1m per year (Cowie 1963; McKelvey 1999; Hesp and Shepherd 2003). Although progradation appears to be constant at the moment, there have been major dune-building phases in the past (Cowie 1963; Muckersie and Shepherd 1995).

Of this coastal strip, about 24km between Paekakariki and Wanganui are occupied by housing, and 50km by pine plantation (chiefly *Pinus radiata*; nomenclature follows Landcare Research's Nga Tipu database, except where noted), with the remainder mostly being farmland. Pine plantations extend to within about 30m of the current high tide mark, and were probably closer when planted (most plantations being about 70 years old; McKelvey 1999).

Fig 1: Aerial of coast just north of Foxton Beach, with typical fore- and rear- dunes, and depressions between trailing dune ridges, backed by pine plantation to the south (right) and pasture to the north (left). The W-shaped wetland W78 is at the right edge, bearing vehicle tracks. Image: Don Ravine, May 2005.

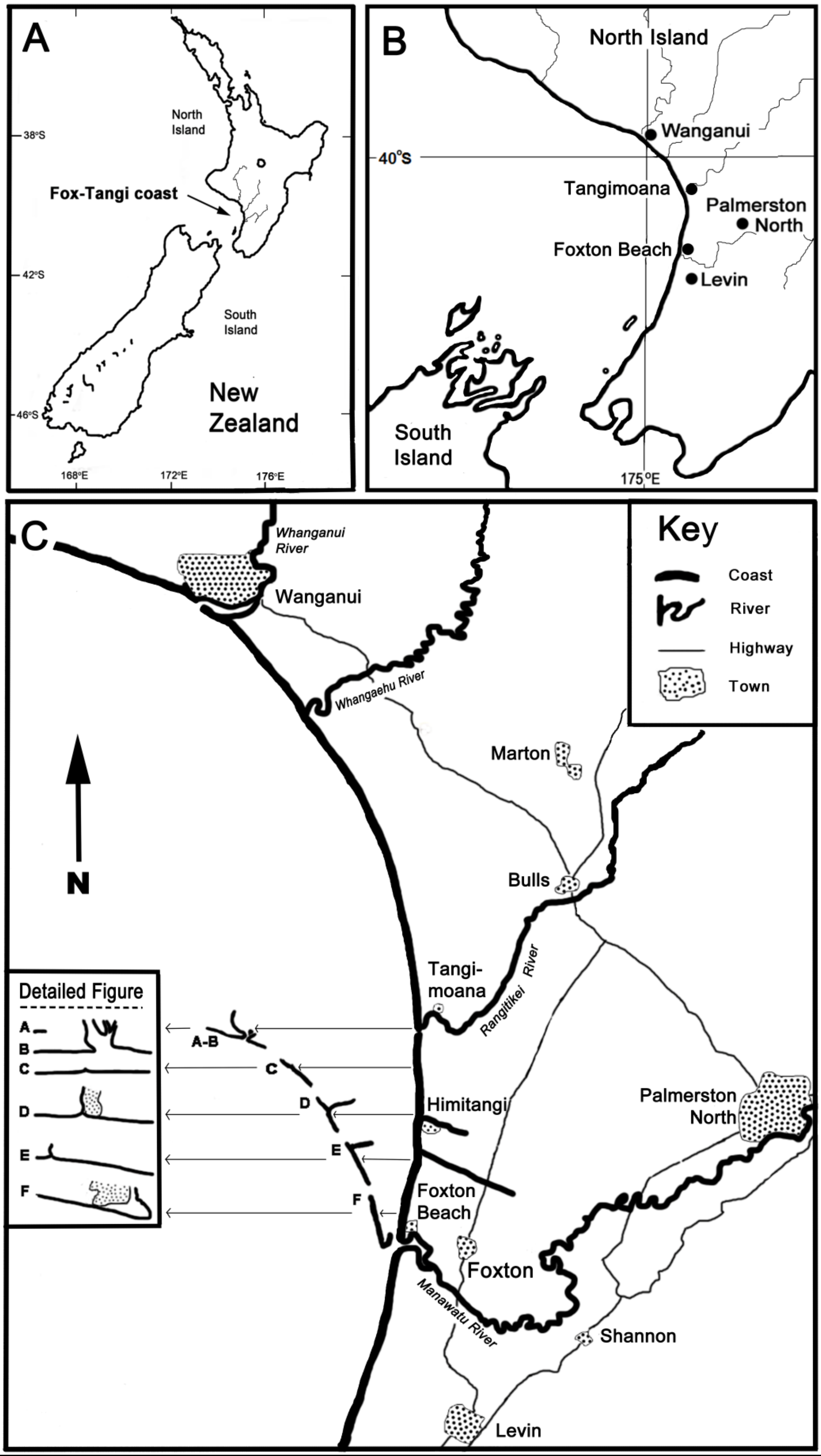


Figure 2: Location of the area surveyed in (A) New Zealand, (B) the western lower North Island coast, and (C) the Foxtangi coast, where the inset ("Detailed") figure shows the method of mapping segments of the coastal vegetation used to display findings.

The dunes in the best natural condition in thihs region occur in a strip of 9km long, from just north of the settlement of Foxton Beach, on the mouth of the Manawatu River, to near the settlement of Himitangi. North of that to the Rangitikei River mouth, which is 1km south of the settlement of Tangimoana (Fig. 1C), is pine plantation, except for the 2km coastal edge of the Tawhirihoe Scientific Reserve, recognised in an earlier survey and “Recommended for Protection” under the Protected Natural Area programme (Ravine 1982). This, called the Foxton-Tangimoana or Foxtangi coast, is the largest strip of native duneland left in the lower North Island (Fig. 2). It is in mixed or indeterminate land tenure, held in private ownership, by various councils or departments, often as coastal accretion. Much of the remaining duneland, particularly areas more than 200m from the coast are in private ownership, with the more inland portions routinely farmed.

The foredune area is usually occupied by sand-binder vegetation, a mix of the aggressive exotic sand binder, marram (*Ammophila arenaria*), planted for sand stabilisation all along the coast from the 1960s (Esler 1969; McKelvey 1999), and spinifex (*Spinifex sericeus*), a native fore dune specialist, with occasional pingao (*Ficinia spiralis*), and in more stable areas the small sand-binder, sand convolvulus *Calystegia soldanella*. Native shrub species such as *Ozothamnus leptophyllus*, *Coprosma acerosa* and *Pimelea villosa* ssp. *arenaria* (Dawson *et al.* 2005) are found mainly on the more inland dunes, and sometimes on the rear of the foredunes.

Foredune of *Spinifex sericeus* with *Ozothamnus leptophyllus*, 3-Mile Creek, December 2009.

Large wetland with pink sward of *Limosella lineata*, Wetland 28, January 2010.

Open and disturbed wetland areas in Wetland W78, Foxton, December 2009.

Small, low value wetland, becoming over-grown, (W27) near Himitangi, January 2010.

Figure 3: Foredune and wetland vegetation.

Parabolic dunes are formed when the foredune ruptures, due to high levels of unstable sand accumulation, or to disturbance by storm episodes or anthropogenic disturbance. The Manawatu region is one of the windiest places in New Zealand, with an average wind speed recorded at Ohakea Airbase of 17km/hr uniformly distributed throughout the year, and similarly distributed gusts of 96 km/hr on 6 days per year (NZMS 1983). When a blowout takes place (Hesp 2002), this involves collapse of the foredune, and destabilisation and movement of the sand inland along the axis of the prevailing wind (Esler 1969). The dune roll-over induces a parabola-like shape as trailing arms are left behind in line with the edges of the blowout, where sand movement is less. The head of the dune continues to migrate inland, stretching out the parabola until there is insufficient sand to feed its movement and it more or less dissipates over whatever land it has rolled onto. Within the parabolic dune a sand plain forms due to sand stripping and this depression may become filled with water and occupied by wetland plants (Esler 1969).

Dune slacks or depressions (hollows between ridges where the ground water is above or close to the sand surface; Tansley 1949; Ranwell 1959) often contain specialist rushland vegetation (Esler 1969). These may be occupied by species such as *Carex pumila* (a curvey-leaved sedge which can also build dunes to 0.5m), *Apodasmia similis*, *Austroderia toetoe*, *Cordyline australis* and

Eleocharis neozelandica

Gunnera dentata

Isolepis basiliaris

Isolepis cernua

Lilaeopsis novae-zelandiae

Limosella lineata

Myriophyllum votschii

Ranunculus acaulis

Selliera rotundifolia

Figure 4: Ephemeral wetland turf species of interest.

Ficinia nodosa, along with an increasing range of exotic weeds, grasses and rushes, and escaped or oversown pasture plants. These reflect a successional sequence from open duneland to wetland or wet forest vegetation (Esler 1988; Singers 1997; Murphy et al. in prep.).

Of more interest is the presence in some depressions of species of short turf less than 10cm high (Fig. 4). Common species are *Selliera rotundifolia*, a species endemic to the Manawatu coast (Ogden 1974; Heenan 1997), but not especially rare there, *Lilaeopsis novae-zelandiae* (locally called tape measure plant) and *Isolepis cernua*, a widespread sedge. Notable rare species are *Eleocharis neozelandica* (Singers 1997), a tiny sedge to 5cm tall, and a primary motivator behind the formation of Tawhirihoe Scientific Reserve (Ravine 1982), and *Isolepis basilaris*, a sedge to 2cm tall, which is listed as nationally vulnerable (de Lange *et al.* 2013).

Wetlands containing short turf represent a very dynamic but increasingly rare habitat is still only poorly documented and understood (Singers 1997, 1998; Murphy *et al.* submitted). We assess the status of the foredunes along the Foxtangi coast, and investigate the many dune depressions along the coast, assessing their wetland and non-wetland (sand-plain) vegetation types. We also investigate the wetlands' relationships to their surrounding parabolic dunes. Our primary focus here is on the rare and specialised wetland turf species, so finally we assess the status of the wetlands, evaluating their importance for the turf species, and consider the conservation and management options of all vegetation types.

Methods

Sampling

A foredune vegetation survey was conducted in conjunction with each depression surveyed or checked (see below) along the lie of the parabolic dunes. Additionally, in areas lacking depressions, a number of foredune sites were spaced haphazardly at intervals along the coast, so that sample points were approximately 160m apart. At each point an approximately 20m wide segment of dune was surveyed. The seaward side of the foredune was evaluated from the seaward-facing toe to the first ridge on the top of the dune, while the rear of the foredune consisted of the same 20 m wide distance along the coast, but went inland to the base of the foredune, or if there was none, for 10 metres. For each site, all species were noted as present and percent cover of individual native species and of *Ammophila arenaria* were recorded, along with the combined percent cover of all other exotic species. Cover was equated to the size the vertical projection of all material onto a horizontal plain ("shadow at high noon" effect), as a percent of the size of the area surveyed. Some cover totals come to more than 100% as material, especially species, form overlapping tiers.

Aerial images were used to locate possible wetland habitats in depressions along the Foxtangi coast for assessment between (and including) Scott's Ferry (referring to the prograding sand-plain just north of the Rangitikei River) and Foxton Beach. Two sets were used, a colour run at an oblique angle photographed by Don Ravine for Department of Conservation in May 2005, and a vertical aerial colour run by Terralink (Hastings) in 2005, printed at 1:5000 scale (supplied by Jamie Lambie, Horizons Regional Council). Wet depressions look quite distinctive from the air. Signs were areas with darker areas of water or wet sand, or unvegetated areas disturbed by vehicles, or areas that appeared to have water table marks. For about 80% of the depressions the aerial photo alone proved adequate to distinguish between depressions containing turf species and those without. However, some depressions continued to offer surprises, and so over the early summer of 2010-2011, each was visited and sampled as appropriate.

Each depression had its GPS coordinates recorded and was mapped on the aerial photographs. The distance of each depression from the coastline was measured from aerial photos, at right angles against a reference line drawn along the beach as close to the seaward toe of the foredune as possible. Parabolic dunes are actually oriented at 65º west of true North, and 80º to the coast; Esler 1969), so these distances are minimal. The size of the depression was estimated either in the field or from aerial photos as length along its long axis and width at right angles to the midpoint. Area of each depression was calculated from the length and width using the ellipse formula of 0.25π.length.width. Disturbance signs, such as animal presence, browsed vegetation, vehicle tracks, or litter were also noted.

Depressions were assigned to one of two categories, the first being those which might be or might have been potential habitats for wetland turf species, hereafter called "sand plains". A sand plain was considered to be a deflated area, containing at least 95% sand cover, which was not wet (i.e. did not have standing water) though it may be damp with water close to (<10cm) the surface. Also it could contain, in addition to *Selliera rotundifolia*, only one other wetland turf species, all in very low quantity, i.e. <0.5% cover compared to the wetland size. This criterion was selected since *Selliera rotundifolia* was common along the coast, and found in most depressions, and the other wetland turf species appeared to be scattered, so that any one might occur anywhere, even on very dry sand plains. Note was also taken of the presence of all vascular species on the sand plain.

The second category of depression is that of "wetland". A wetland needed to be wet or damp, and large, or to host the presence of at least two of the characteristic turf species of ephemeral wetlands other than the almost ubiquitous *Selliera rotundifolia*: namely *Eleocharis neozelandica*, *Gunnera arenaria* (name preferred for the coastal form of *Gunnera dentata)*, *Isolepis basilaris, Isolepis cernua*, *Lilaeopsis novae-zelandiae*, *Limosella lineata*, *Myriophyllum votschii* and *Ranunculus acaulis*. We also included the slightly taller (<10 cm when not flowering) wetland herbs, *Epilobium billardierei*, *Lobelia anceps*, *Selliera radicans* and *Triglochin striata*. Wetlands at Scott's Ferry (Fig. 2, Sections A-B) were not really discrete amongst the huge sand plain, and so representative portions were surveyed here and there, often 100 m long, and 5 m wide, with adjacent dunes sampled for the parabolic dunes as best as possible.

Surveys of each of the wetlands included percent covers of wet surface, standing water over sand (though these two are both highly seasonally variable), litter and sand. Wetlands that had standing water in them in December (early summer) were revisited in January when the water had subsided, and were resurveyed as necessary. Cover of each vascular species was recorded individually. In addition, for the densest patch found of each of the turf species, shoot cover (%) was recorded in a 25x25 cm quadrat.

The parabolic dune, when present, around the inland head of each of the ephemeral wetlands was also surveyed. A presence/absence (P/A) species' list was compiled of all species on dune faces visible from the wetland, due to the variable sizes and vague boundaries.

A total of 57 sand plains, 81 wetlands (W8 was excluded because it lacked turf species, being a riverine community), 66 parabolic dunes and 88 pairs of inland and seaward foredunes, with 2 extra seaward foredune sites (lacking inland faces), were recorded. These were mapped onto the aerial photos, which were then used to derive a diagram, in segments, of the coast's sampling sites, against which results were plotted (Fig. 2).

Analysis

Preliminary analyses showed the foredune vegetation was largely distinct from the parabolic dune samples, though less so from the rear dunes. Consequently the analyses were separated. For the foredunes, a Principal Components Analysis (PCA) in Canoco (ter Braak and Smilauer, 2002) was used to examine the floral covers for all species, most of which centralised. A simpler data matrix of species with >10 occurrences was rerun using square-root transformed data. A cluster analysis using SYSTAT (1998; Ward and Euclidean distance) generated a tree of 6 groups, designated communities, for which means for all species with >1% cover in any community were calculated. The community types were mapped onto a diagram of the coast, with communities extrapolated between sampling points.

66 wetlands had parabolic dunes or some portion thereof associated with them. The wetlands lacking them are: W11, W12, W14, W15, W18, W19, W28, W34, W37, W55 and W57 (W8 was not analysed). Of these, three are excavated wetlands and two are surrounded by pine plantation. W16 and W17, and W43-W45 each share a surrounding dune, so the most speciose wetland of each, namely W16 or W44, was taken as representative. For the remaining parabolic dunes, the P/A record of species was analysed using SYSTAT (1998; Simple Matching AKA Jaccard's coefficient for the P/A data, and Ward linkage) to compile a cluster tree.

The locations of the rare and short wetland turf species were individually mapped. Similarly, in categories, their frequency in the various wetlands, their percent coverage of the wetland floor, and their estimated coverage in square metres in terms of the total area of the wetland were mapped.

The 81 wetlands were assessed using PCA (Canoco, ter Braak and Smilauer, 2002) on the cover data after square root transformation. The communities were derived from a dendrogram using Ward metric and Euclidean distance using SYSTAT (1998) and mapped onto the PCA diagram. Important species and characteristics of the flora tabulated. The communities were then mapped onto the coastal diagram.

The relationships between the wetlands and their surrounding parabolic dunes were assessed using correlations. The parabolic dunes were first auto-correlated using Simple Matching coefficient (Jaccard's), suitable for presence/absence data. For the wetlands, with square rooted cover data, we used Pearson's correlation coefficient, and the two matrices compared. The relative frequency of the wetland and foredune community types were also tabulated with respect to each other.

Wetlands were given a score rating their turf species' communities using six criteria. The criteria were presence of the rare species *Eleocharis neozelandica*, presence of *Isolepis basilaris*, number of turf species present, area of turf species present, proportion of the flora as natives, and proportion of the cover as natives. Each criterion was scaled to a 0-1 scale, as higher values were seen as more positive for turf species, and a combined score derived by simple addition, and also scaled 0-1.

Results

Foredune vegetation

178 foredune sites were analysed. Axis 1 of the PCA of the foredune communities explains 57.3% of the variation, and Axis 2, 21.2% (Fig. 5). The first axis separates vegetation dominated by the native fore-dune binder, *Spinifex sericeus*, from that of the exotic marram, *Ammophila arenaria* and a grouped taxon "Other" which includes a small range of herbaceous weeds. The smaller, less effective native fore-dune binder, *Ficinia spiralis* and the tiny dune builder, *Calystegia soldanella*, are also associated with *Spinifex*. Native shrubs are more closely linked with the exotic species.

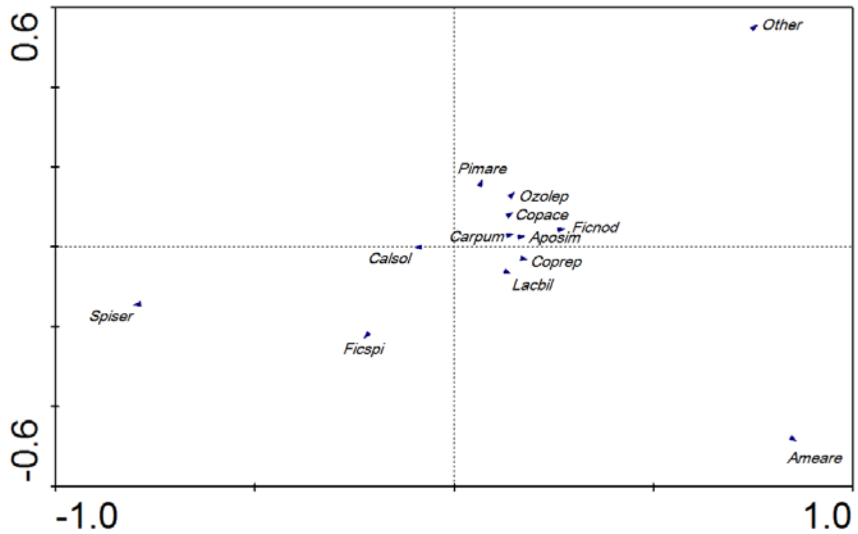


Figure 5: PCA of the square-root transformed cover values for the species of the foredunes. For abbreviations of species' names, see Table 2.

Six foredune community types were defined.

<u>Marram Foredune</u>
This common community is dominated by marram, with many other exotics present, but some *Spinifex sericeus* cover (Table 1). It occurs mainly on the rear of the foredunes in zones with pine plantations (Fig. 6, Section C) and around townships. It has either Mixed Marram or Spinifex Foredunes communities to its seaward side (Table 1).

<u>Mixed Marram Foredune</u>
The community has the second highest cover of marram, mixed with spinifex and both native and exotic shrubs, though at low cover. There are manly other exotics present, and it is more common on the inland side of the foredunes (Table 1). It is found at Tawhirihoe, and scattered south of 3-Mile Creek (Fig. 6, Sections B, E).

<u>Open Spinifex Foredune</u>
Occurring more commonly on the seaward side of the foredunes, *Spinifex sericeus* is the only frequent species, but that at low cover. Bare sand is rarely interspersed by a few exotics. It is found mainly south of 3-Mile Creek (Fig. 6, Sections E, F).

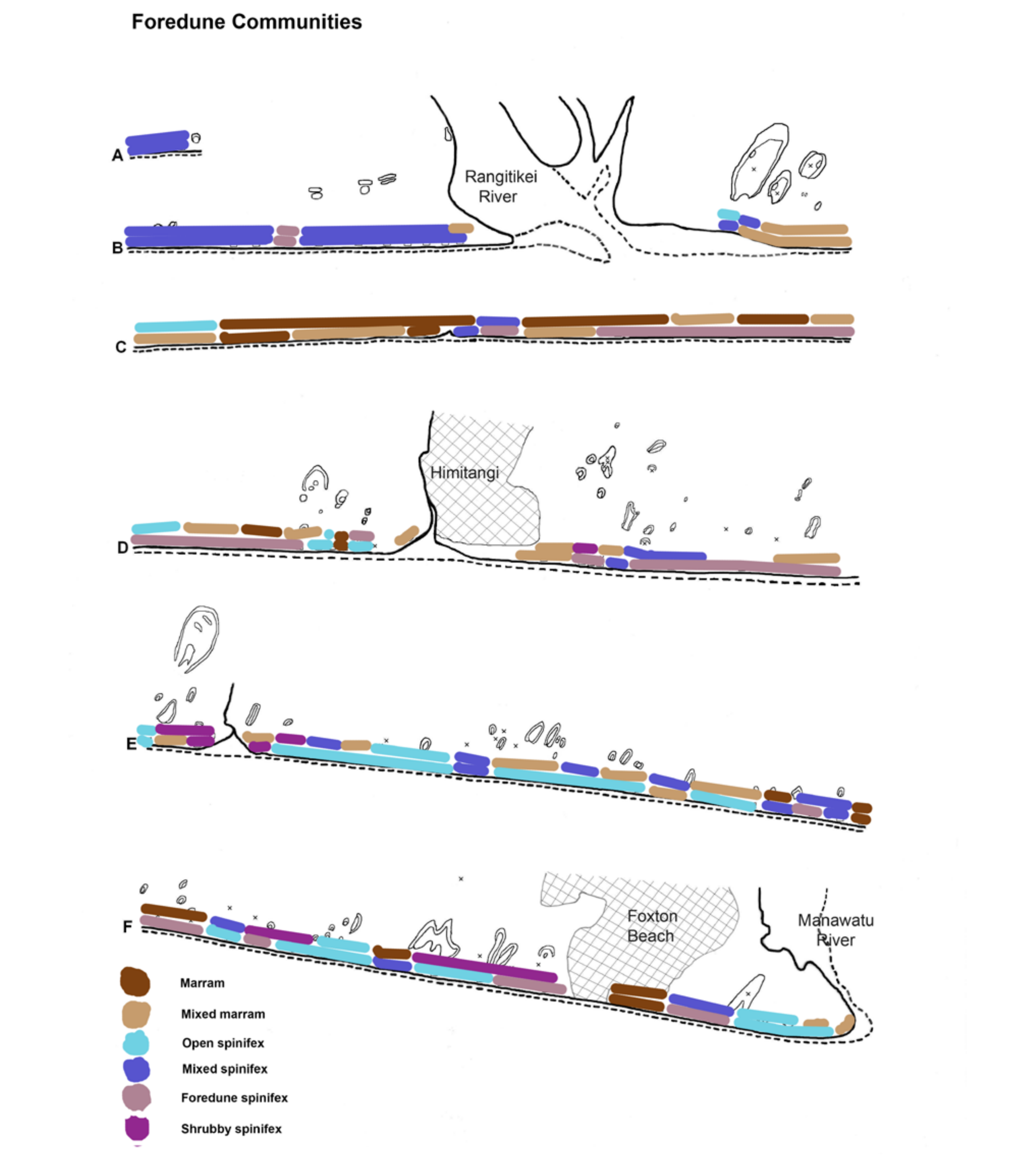


Figure 6: The coastal arrangement (exaggerated vertically) of the six community types of seaward and inland foredunes.

<u>Mixed Spinifex Foredune</u>

This is the most common community found along the coast, with *Spinifex* frequent. It has the largest amount of pingao found, along with some marram. It occurs evenly over both faces of the foredune. Common at Scott's Ferry, it is scattered over other sections, especially just south of 3-Mile Creek (Fig. 6, Sections A, B, E).

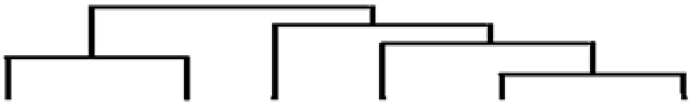
Foredune Spinifex Foredune

This community has the highest cover of *Spinifex*, with many exotics at very low cover. It occurs mainly on the seaward face, along with other communities containing spinifex on the inland face of the foredunes. It is found throughout, but chiefly in the southern half of the Foxtangi coast.

Shrubby Spinifex Foredune

The most uncommon of the communities, this occurs with high cover of spinifex, and many weeds. It is largely on the rear of the foredunes, north of Foxton Beach and around 3-Mile Creek.

Table 1: The 6 foredune communities identified from the cluster analysis, with their characteristic species, and their mean % covers in each community, and community locations with respect to the coastline. The dendrogram is from the cluster analysis. * = exotic species.



Species' cover	Marram	Mixed Marram	Open Spinifex	Mixed Spinifex	Foredune Spinifex	Shrubby Spinifex
*Acacia sophorae**	0.2	2.5	0.0	0.0	0.2	0.0
*Ammophila arenaria**	43.6	11.4	0.3	6.1	0.3	1.2
Coprosma acerosa	0.0	0.7	0.0	0.1	0.0	1.5
Ficinia spiralis	0.2	1.3	0.1	4.1	0.2	0.7
Ficinia nodosa	1.6	0.1	0.0	0.0	0.0	0.4
Ozothamnus leptophyllus	0.3	0.1	0.0	0.2	0.0	3.1
Pimelea villosa ssp. *arenaria*	0.0	2.3	0.0	0.1	0.0	0.7
Spinifex sericeus	12.2	12.1	15.5	32.0	44.4	32.2
Total species no.	25	23	15	21	14	30
No. of native species	8	9	8	9	5	9
Native/exotic cover	0.32	1.12	23.65	5.49	28.06	4.48
Number of samples - inland	18	21	12	22	2	14
Number of samples - seaward	5	9	28	22	24	1

Parabolic dune vegetation

Six communities were selected from the 66 samples of parabolic dunes surrounding wetlands.

Spinifex Parabolic Dune
Spinifex parabolic dunes have high frequencies of *Spinifex* (Table 4), amongst two other dune-builders, *Ammophila arenaria* and *Calystegia soldanella*. The small exotic herb *Senecio elegans* is also common. They are mostly located close to the coast and south of Himitangi (Fig. 13, Sections C-F).

Spinifex Shrub Parabolic Dune
Similar to the Spinifex Community, this community also frequently contains the native dune builder, *Ficinia spiralis*. It also hosts the woody plants *Coprosma acerosa*, *Ozothamnus leptophyllus* and *Pimelea villosa* ssp. *arenaria*, which are native, as well as the exotic *Lupinus arboreus* and the two conifers. These are commonly found around Himitangi township and generally quite close to the coast.

Marram Shrub Parabolic Dune
Exotic dune-builder, *Ammophila arenaria* is found in this community, but *Spinifex sericeus* is rare (Table 4). The two exotic weeds *Lycium ferocissimum* and *Lilium formosanum* are also common. This community is found around wetlands south of 3-Mile Creek (Fig. 13).

Grassy Parabolic Dune
Grassy community frequently contains the exotic pampas, *Cortaderia selloana* as well as the common dune builders and a selection of exotic grasses. Frequency of native species is low. This community is scattered around Himitangi, at medium distances from the sea.

Acacia Parabolic Dune
Acacia sophorae is found in every sample of this community, along with the exotic herbs *Hypochaeris radicata* and *Lagurus ovatus* along with a large range of other exotic herbs. These are all located on the sand plains of Scott's Ferry.

Rich Parabolic Dune
This community has the highest numbers of both native and exotic species present. *Ammophila arenaria*, *Cortaderia selloana* and *Medicago lupulina* are almost always present, along with the native *Ficinia nodosa*. Native shrubs and dune-builders are also often present. This parabolic dune community is scattered along the coast, and are especially common in the two reserves, Tawhirihoe and Foxton.

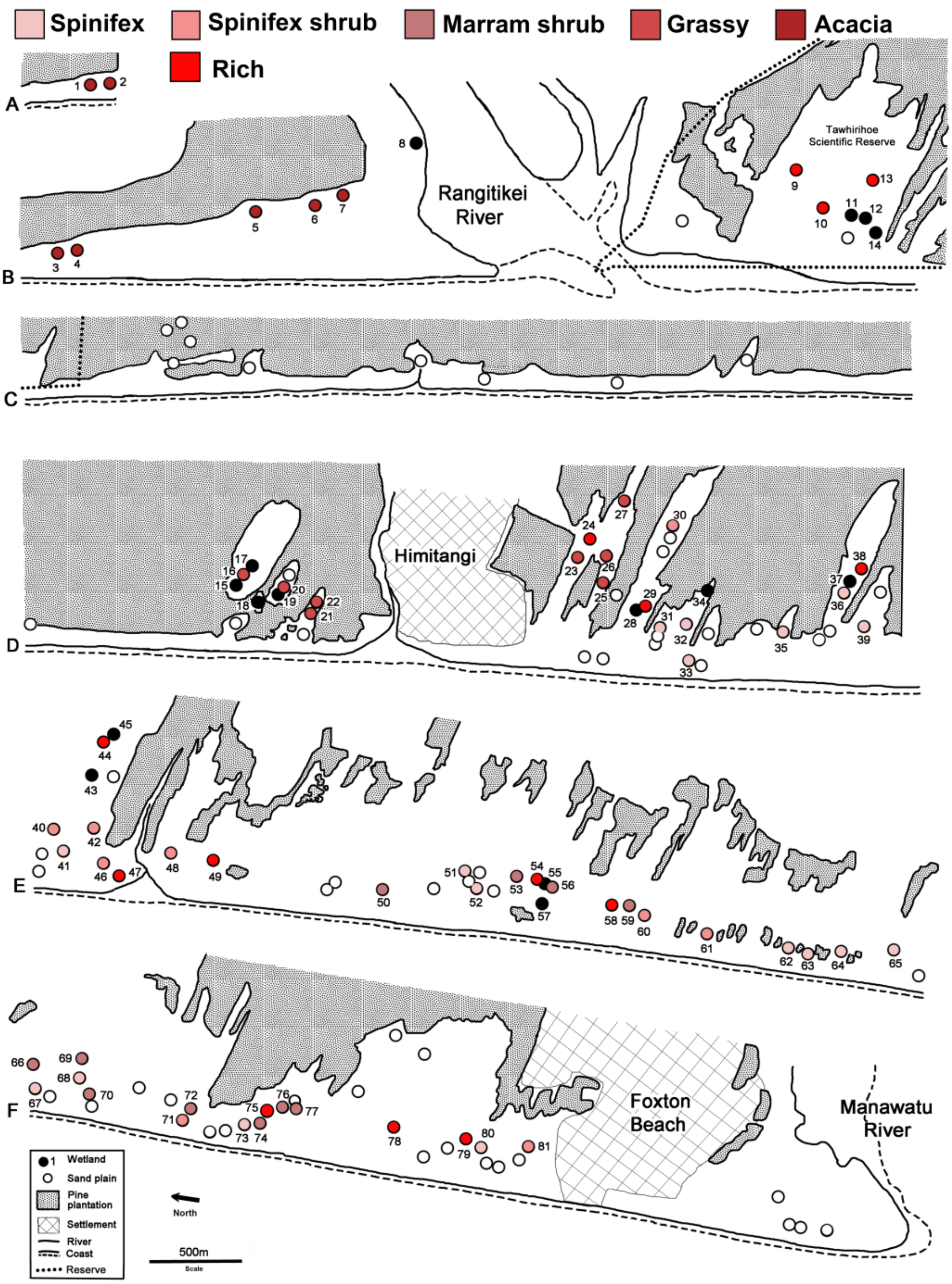
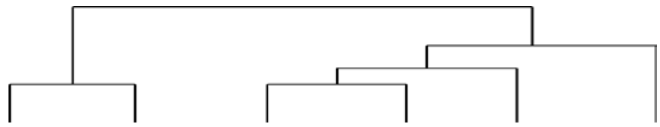


Figure 13: Communities of the parabolic dunes of those wetlands with associated dunes, each mapped onto the location of the wetland. See Figure 6 for the shape and location of those dunes.

Table 4: Important species from the six communities found on the parabolic dunes surrounding wetlands. Values are relative frequency. The dendrogram is from the cluster analysis. * = exotic species.



	Spinifex	Spinifex Shrub	Marram Shrub	Grassy	Acacia	Rich
*Acacia sophorae**	0.00	0.22	0.18	0.63	1.00	0.29
*Ammophila arenaria**	1.00	1.00	1.00	0.88	0.00	1.00
Apodasmia similis	0.06	0.00	0.00	0.25	0.00	0.57
*Arrhenatherum elatius**	0.00	0.11	0.55	0.13	0.29	0.43
Austroderia toetoe	0.00	0.00	0.00	0.00	0.00	0.21
Calystegia soldanella	0.71	0.22	0.27	0.00	0.14	0.21
Carex pumila	0.06	0.11	0.00	0.00	0.00	0.29
Coprosma acerosa	0.12	0.89	0.00	0.00	0.00	0.50
Coprosma repens	0.00	0.11	0.00	0.25	0.14	0.14
Cordyline australis	0.00	0.00	0.00	0.00	0.00	0.14
*Cortaderia selloana**	0.06	0.11	0.09	0.88	0.29	0.86
*Cupressus macrocarpa**	0.18	0.33	0.18	0.00	0.00	0.36
Ficinia nodosa	0.29	0.67	0.73	0.63	0.86	1.00
Ficinia spiralis	0.29	0.56	0.00	0.00	0.29	0.21
*Holcus lanatus**	0.06	0.11	0.45	0.00	0.43	0.79
*Hypochaeris radicata**	0.47	1.00	0.36	0.00	1.00	0.71
Lachnagrostis billardierei	0.18	0.78	0.36	0.13	0.57	0.79
*Lagurus ovatus**	0.65	0.89	0.73	0.88	1.00	0.93
*Lilium formosanum**	0.00	0.00	0.36	0.00	0.00	0.21
*Lupinus arboreus**	0.53	1.00	0.91	0.88	0.14	0.86
*Lycium ferocissimum**	0.00	0.00	0.82	0.00	0.00	0.21
*Medicago lupulina**	0.35	0.11	0.18	0.00	0.43	0.93
*Melilotus indicus**	0.53	0.78	0.55	0.00	0.71	0.57
*Oenothera biennis**	0.00	0.00	0.27	0.38	0.29	0.50
Ozothamnus leptophyllus	0.71	0.89	0.09	0.25	0.00	0.71
Pimelea villosa ssp. *arenaria*	0.12	0.44	0.00	0.13	0.00	0.29
*Pinus radiata**	0.18	0.56	0.18	0.63	0.29	0.79
Schoenus nitens	0.06	0.00	0.27	0.00	0.00	0.43
*Schedonurus phoenix**	0.00	0.00	0.00	0.13	0.29	0.43
*Senecio elegans**	0.71	0.22	0.45	0.25	0.43	0.79
*Senecio glastifolius**	0.00	0.00	0.00	0.13	0.29	0.21
Spinifex sericeus	0.71	0.89	0.18	0.38	0.14	0.71
*Trifolium pratense**	0.00	0.00	0.18	0.00	0.71	0.14
*Trifolium repens**	0.06	0.00	0.00	0.00	0.14	0.21
*Ulex europaeus**	0.00	0.00	0.00	0.00	0.14	0.00
*Yucca americana**	0.00	0.00	0.00	0.00	0.14	0.00
Spp. number	27	28	28	23	39	57
Native spp. number	11	10	6	8	8	17
Native/exotic ratio	0.69	0.56	0.27	0.53	0.26	0.43

Sand plain vegetation

A total of 57 sand plains were encountered in addition to those depressions containing wetlands. SP3, embedded in the pine forest (Fig. 7, Section C) was a species-rich wetland (32 spp.), containing macrophytes, and was probably a highly eutrophic wetland. Since this environment did not present habitat for turf species, similar sites were not further investigated.

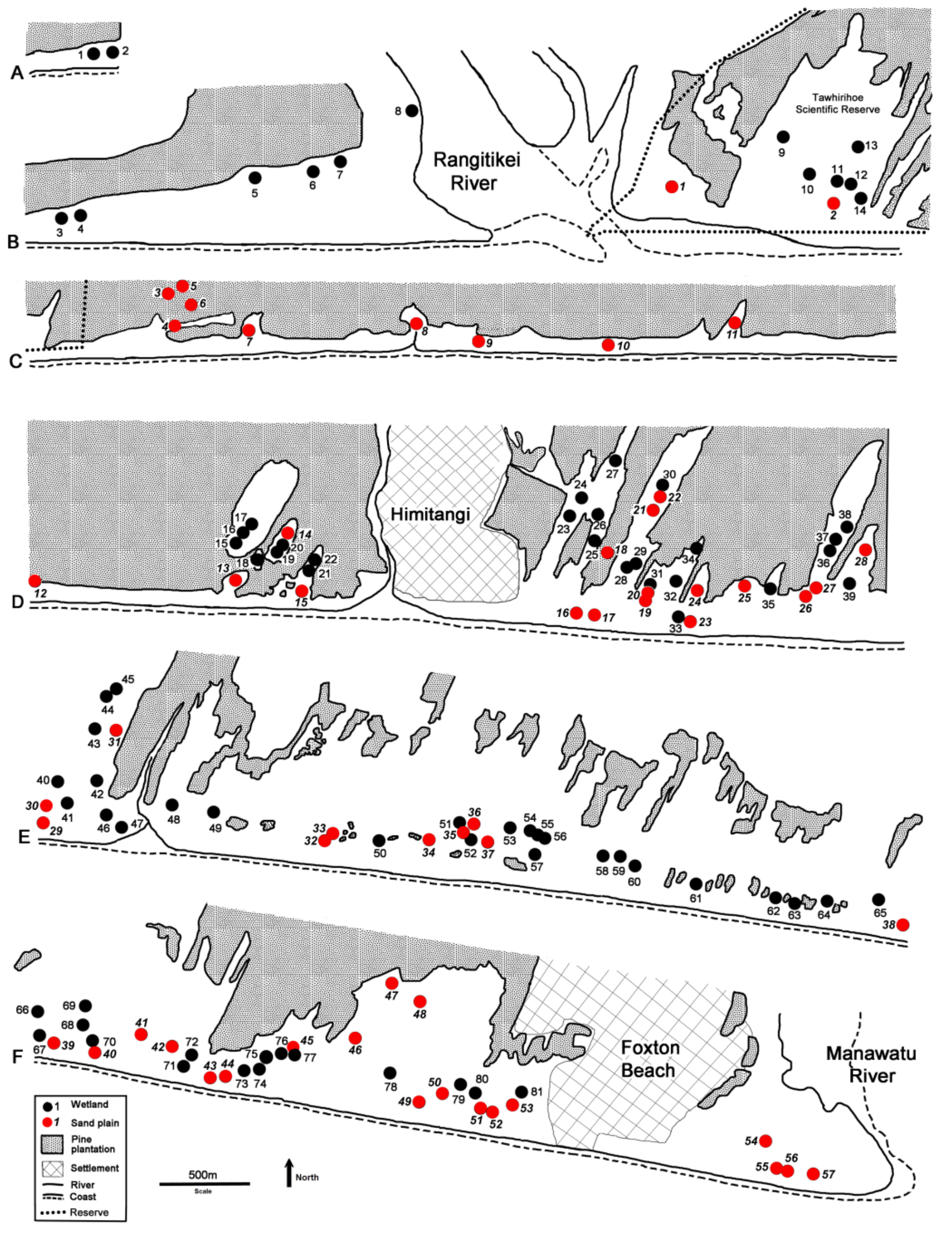


Figure 7: Location of wetlands and sand plains along Sections of the Foxtangi coast. See Fig. 2 for location of Sections.

Sand plains appeared relatively evenly distributed along the coast, except none were found in the southern half of Section E (Fig. 7), perhaps due to extensive nearby agriculture. The huge sand flats of Scott's Ferry (Fig. 7, Section A-B) north of the Rangitikei River were sampled representatively only and reflect most of the open area between the pines and the coast.

The average distance from the coast of sand plains was 197m (Fig. 8), with greater frequency closer to the coast, although 4 were greater than 600m away. The average sand plain, was dry to damp, only 3 having standing water in summer (data not presented).

Of those measured (n = 34) the average sand plain was 80±83 m long by 33±35 m wide, with an ellipsoid area of 3293m^2. Area is non-significantly related to distance from the coast (data not presented). Evidence of presence of people was found in 10 sand plains, and exotic animals in 8.

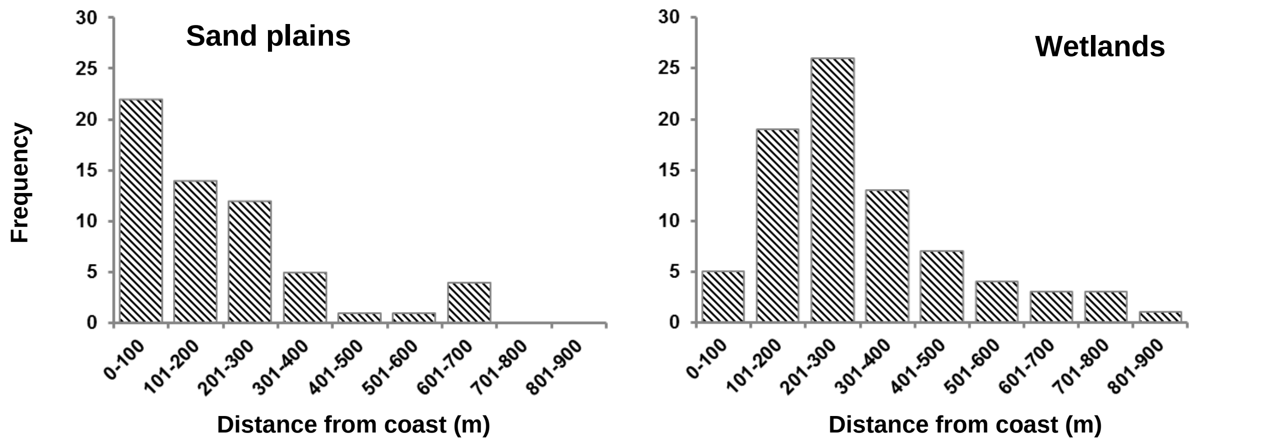


Figure 8: The relative distance from the coast of depressions which are empty sand plains and those containing wetlands.

The mean biodiversity of the sand plains (excluding SP 3) was 3.7, with a total flora of 72 species. *Calystegia soldanella* and *Carex pumila* (natives which are frequent builders of small sand dunes) were the most common occupants of sand plain habitats, occurring in almost half, while *Ammophila arenaria* was present in 20 of 56 sand plain sites. Species found in 12-20% of sand plains were *Ozothamnus leptophyllus*, *Spinifex sericeus, Ficinia spiralis* and and *Ficinia nodosa*, of which the first three are typically dune plants, and only the last a wetland plant, all to >50cm tall, underlining the unsuitability of such sites for turf species. There were 6 occurrences of *Apodasmia similis*, which appears to be a later successional stage for wetlands than turf species, and these were all further from the coast (465 m) compared to other sand plain habitats.

Of the turf species, *Selliera rotundifolia* was found only 7 times, and in 3 cases co-occurred with another wetland turf species, always *Isolepis cernua*, reflecting the basic commonness of these species along the coast. *Gunnera arenaria* was encountered once (SP 28), as was *Lilaeopsis novae-zelandiae* (SP 2), *Myriophyllum votschii* (SP 31), and *Ranunculus acaulis* (SP 41).

Wetland turf species

The most common wetland turf species encountered, in 70 of the 81 wetlands, is *Selliera rotundifolia* (found throughout, and at the edges of its range doubtfully distinguished from *Selliera radicans*, from which it is a recent segregate (Ogden 1974; Heenan 1997; Pilkington 2014; Table 2; Fig. 9). Also common and found throughout is *Isolepis cernua*, the same species most common in Sand Plains (Table 2; Fig. 10). The rarest turf species were *Myriophyllum votschii*, *Gunnera arenaria* (in very localised patches near Himitangi) and *Eleocharis neozelandica* (mostly in the northern sections). *Limosella* is similarly concentrated south of Himitangi (Fig 9). *Ranunculus acaulis* is found mainly in the high value wetland areas, as is *Isolepis basilaris*. Ten wetlands had 4 or more short turf species (W9, W12, W23, W27, W28, W32, W35, W38, W39, W41).

Species' diversity of turf wetland species is greatest at Tawhirihoe, on private land just south of Himitangi, and at the Horowhenua District Council's (HDC) reserve just north of Foxton Beach (Fig. 10). Coverage of turf species as percent of wetland of such species is greatest south of Himitangi, and midway between 3-Mile Creek and Foxton (Fig. 10, Sections D, E). Coverage estimated in square metres of wetland is high, but variable all along the coast (Fig. 10).

The greatest coverage as percent of wetlands is shown by *Myriophyllum votschii*, while *Eleocharis neozelandica*, *Ranunculus acaulis* and the *Isolepis* spp. have the least coverage (Table 2). Per unit area, *Gunnera arenaria* has extensive patches as has *Myriophyllum votschii*, *Limosella lineata* and *Selliera rotundifolia*. Once (very approximately) corrected for the maximum density of shoots per quadrat, then *Gunnera arenaria* has the largest populations along the coast, and *Eleocharis neozelandica* the smallest.

Table 2: Frequency of turf species in the wetlands (n=81), the % cover in a 25x25cm quadrat of the densest patch of each species, the average cover per wetland, and the estimated correct mean surface area of each species (product of max. cover and cover of wetland).

Species	Frequency	Average max. cover (% of quadrat)	Average cover (% of wetland)	Average cover of wetland (m^2)	Corrected surface area of wetland (m^2)
Eleocharis neozelandica	9	5.8	1	21	1.2
Gunnera arenaria	5	86.7	9.8	119	103.2
Isolepis basilaris	10	6.5	1.2	47	3.1
Isolepis cernua	64	12.9	1.5	31	4
Lilaeopsis novae-zelandiae	24	19.4	2.7	60	11.6
Limosella lineata	11	50.7	3.3	140	71
Myriophyllum votschii	6	42	18.9	165	69.3
Ranunculus acaulis	16	7.8	1.2	79	6.2
Selliera rotundifolia	70	34.4	7.6	173	59.5

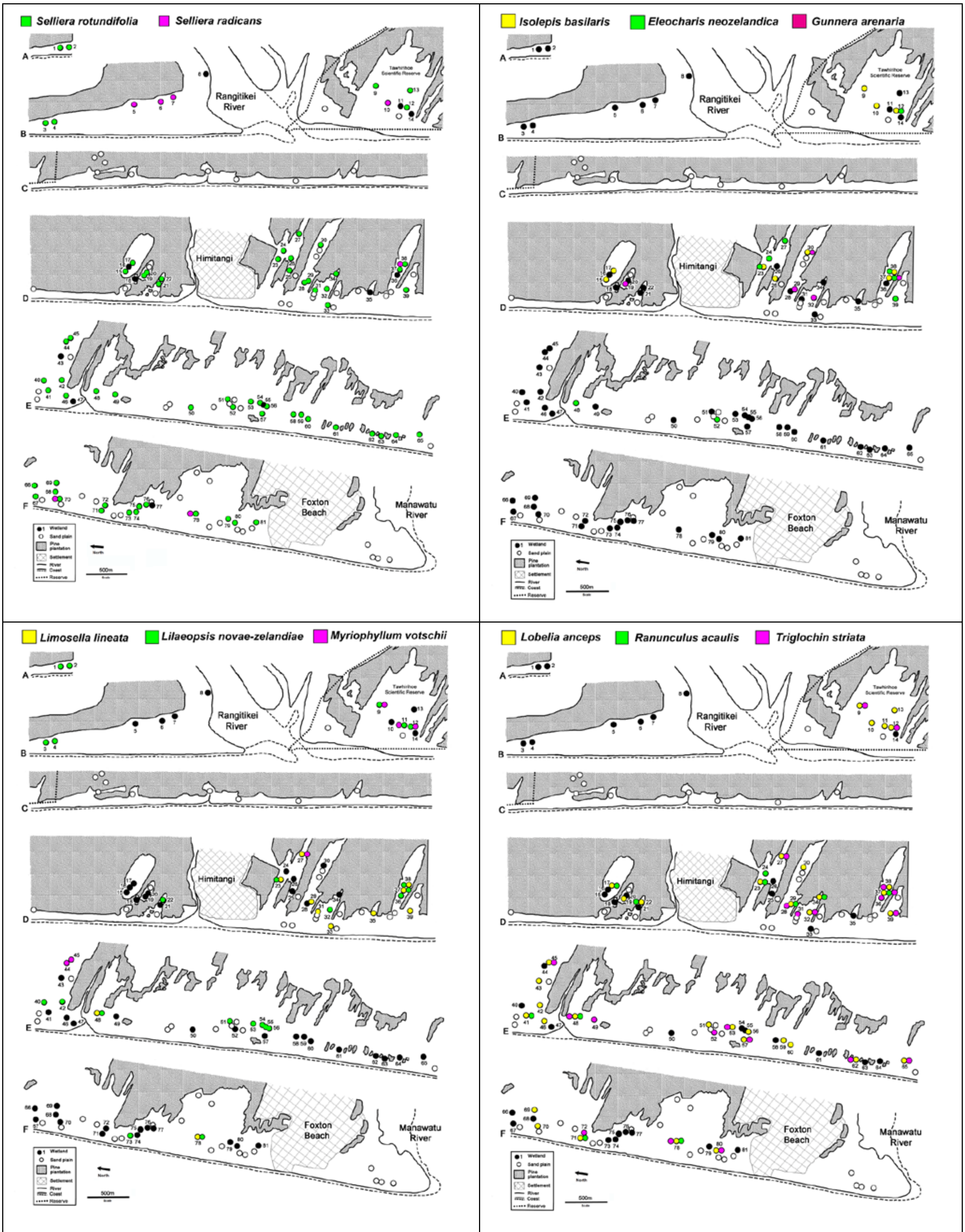


Figure 9: Distribution of wetland turf species along the Foxtangi coast. Adjacent dots of different colours in a row in the same diagram all refer to the same wetland.

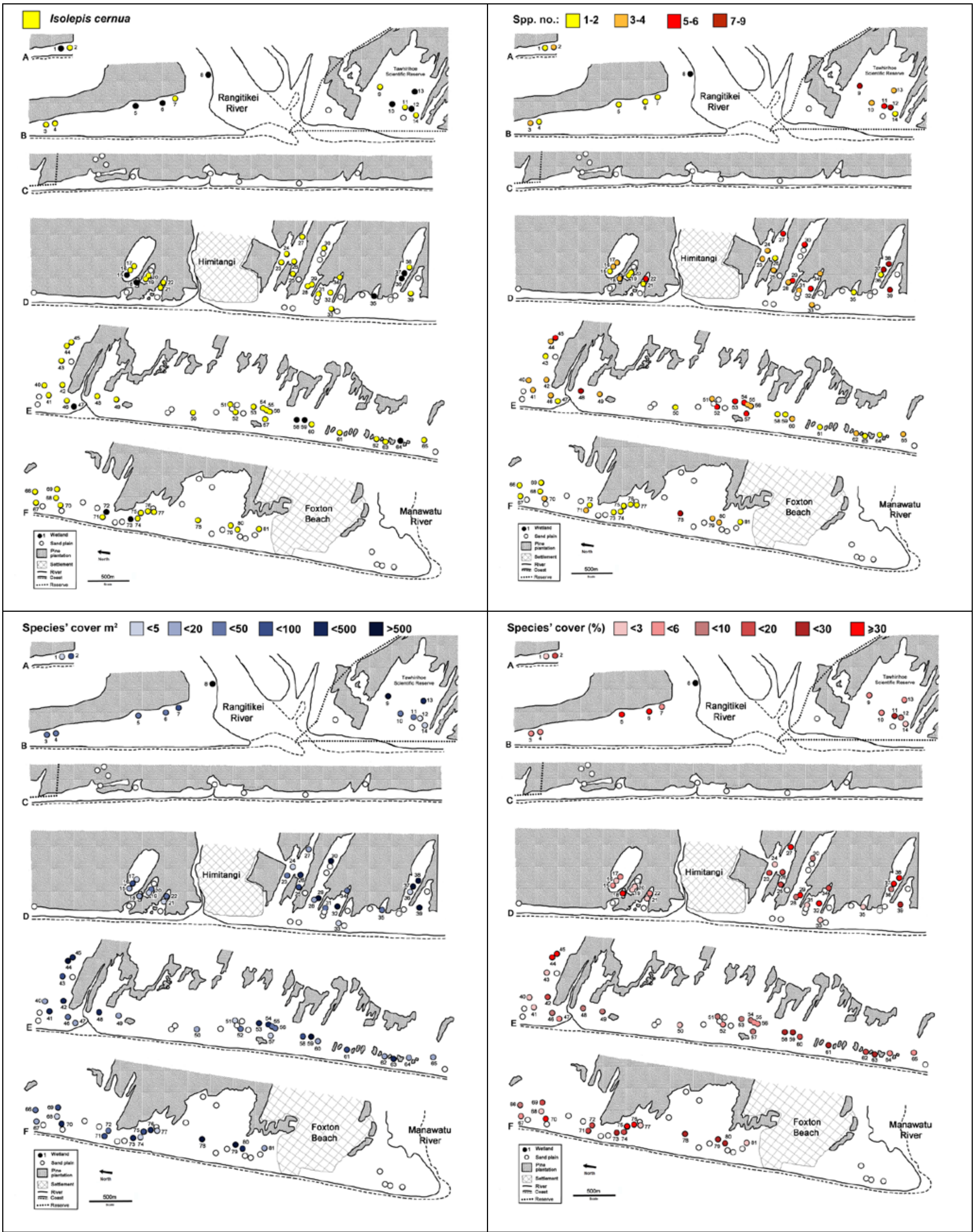


Figure 10: Distribution of *Isolepis cernua* along the Foxtangi coast, and valuation of wetlands by number of turf species, cover of turf (both rare and taller) species in m^2 and by % of wetland size.

Wetland vegetation

A total of 81 ephemeral wetlands (i.e. wetlands containing 3 or more species of turf plants) were found along the Foxtangi coast. There were none from the southern edge of Tawhirihoe Reserve to 1km north of Himitangi, an area with extensive pine plantations close to the coast (Fig. 7, Section C), but otherwise wetlands were scattered along the coast. Wetlands had a mean distance from the coast of 81m, but ranged from 50 to 887 m (Fig. 8).

A total flora of 107 species was found, 64 of them (60%) exotic to the Manawatu. Of the 24 species found only once, 17 were exotic. The average wetland contained 8.1 exotic species, and 20 had more than 10 exotic species present, giving a proportion of exotics in wetlands as 0.47. The most common exotic species were *Hypochaeris radicata*, *Lagurus ovatus*, *Melilotus indicus*, *Holcus lanatus* and *Senecio elegans*, all occurring in more than 50% of wetlands.

The most commonly encountered species of wetlands were *Selliera rotundifolia*, *Carex pumila*, *Ficinia nodosa*, and *Isolepis cernua*, all natives and found more than 82% of the time. Only the two more mature wetlands at Tawhirihoe (W10 and W13) lacked three or more of these common species. The average wetland contained 5.8 non-turf native species. When present, the most abundant species (each occupying more than half of at least one wetland), were *Apodasmia similis*, *Carex pumila*, *Ficinia nodosa*, *Schoenus nitens*, *Myriophyllum votschii* and the exotic *Schedonurus phoenix*, though the last pair occurred in only 6 wetlands each, and the others in 25 or more, with average occurrences of 10-20% cover.

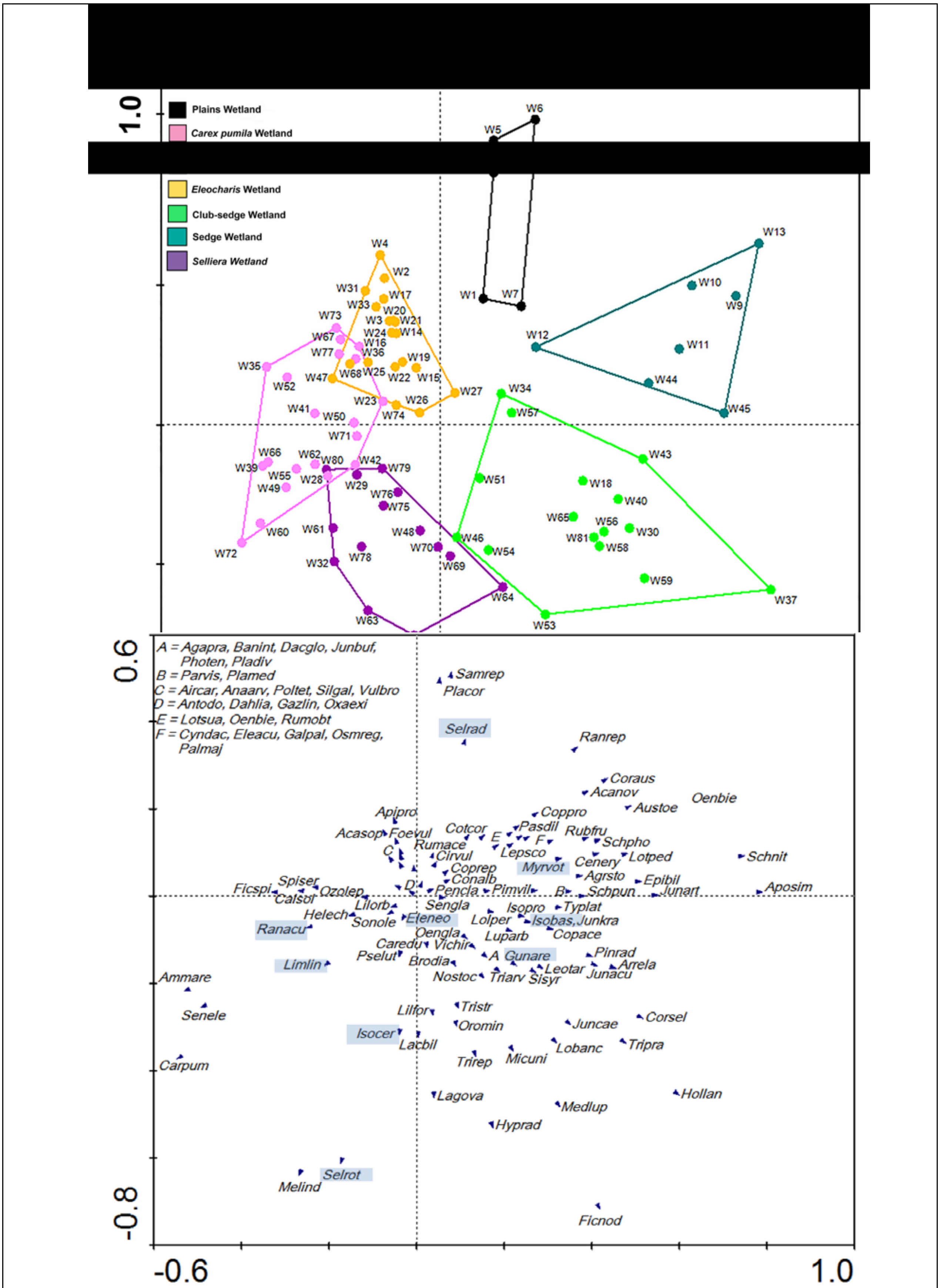


Figure 11: The plant community types of the wetlands in PCA space, using square-root-transformed cover data, and the corresponding species' plot. The 6-letter codes are the first 3 letters of each genus and species. Codes are explained in Table 2 and Appendix 1.

The PCA explained 21.1% of the varation on the first (x) axis, and 14.7% on Axis 2. Six wetland communities were identified.

Eleocharis Wetland
Covers (Table 3) are low in this vegetation-poor but species-rich community, but *Eleocharis neozelandica* is at its commonest. *Schoenoplectus pungens* is the most common species and there are a large range of other small herbs. The community is especially common around the township of Himitangi (Fig. 13, Section D).

Carex pumila Wetland
This type has an average cover of nearly 20% of *Carex pumila* and more than 8% *Ammophila arenaria* of a total vegetation cover of 44% (Table 3). The ephemeral wetland species, *Lilaeopsis novae-zelandiae*, *Limosella lineata* and *Ranunculus acaulis* are also present at their highest cover of any community. The community has some *Ficinia spiralis*, and is common from Himitangi south (Fig. 13, Sections D-F).

Selliera Wetland
Cover of *Selliera rotundifolia* is 20%, with almost as much *Ficinia nodosa*. All short turf wetland species are present here, with their highest total cover of any community. The community is most common just north of Foxton, and also scattered south of Himitangi.

Club-sedge Wetland
Dominated by *Ficinia nodosa*, there is high cover of *Cortaderia selloana*, and *Schoenus nitens* with some *Apodasmia similis*. *Gunnera arenaria* and *Isolepis basilaris* are also at their highest covers, in a very species-rich type, with the highest number of native species. *Hypochaeris radicata* is frequent. The community is most common around 3-Mile Creek.

Plains Wetland
Selliera radicans, *Samolus repens* and *Schoenus nitens* dominate this community, with some *Calystegia soldanella* present. This is the most species-poor of the wetlands, with only 18 species, but cover of natives is high. It is found at Scott's Ferry, north of the Rangitikei River mouth.

Restiad Wetland
Apodasmia similis and *Schoenus nitens* dominate this wetland type, underlain by extensive *Myriophyllum votschii*. This community has the highest total cover, and total number and cover of native species (Table 3). It is the common wetland type at Tawhirihoe Scientific Reserve, and has a range of native shrub species including *Pimelea villosa* ssp. *arenaria*, *Coprosma* spp., and *Leptospermum scoparium*, though *Schedonurus phoenix* and *Arrhenatherum elatius* are very common.

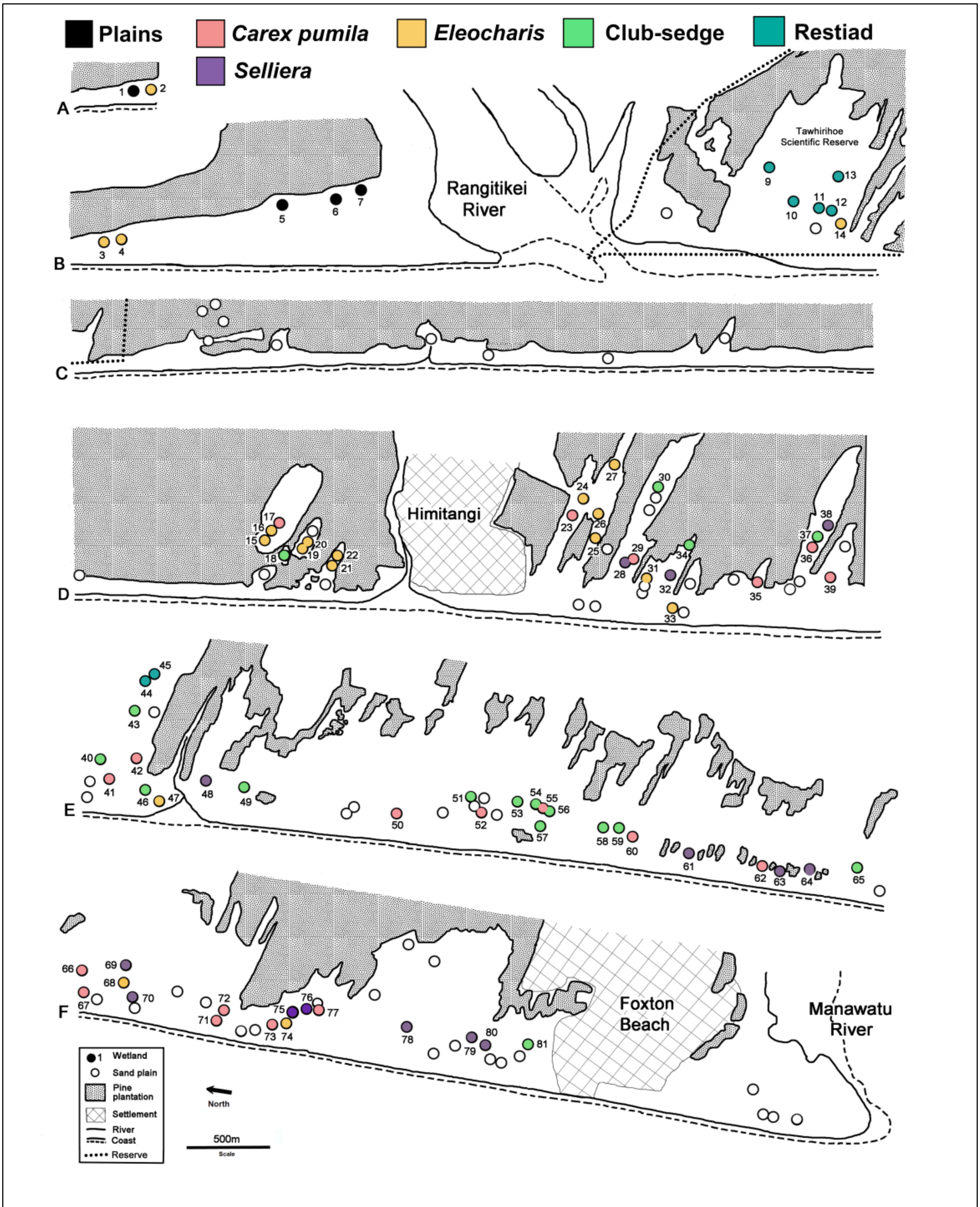


Figure 12: Distribution of the plant communities of wetlands containing at leat 3 turf species.

Table 3: Characteristic species of the six wetland communities. Values are mean % cover. Community locations are in Figure 12. * = exotic species.

Spp.		Eleocharis	Carex	Selliera	Club-sedge	Plains	Restiad
	Wetland turf species						
Eleneo	*Eleocharis neozelandica*	0.2	0.2	0.1	0.0	0.0	0.1
Gunare	*Gunnera arenaria*	0.0	0.0	0.0	3.0	0.0	0.0
Isobas	*Isolepis basilaris*	0.1	0.1	0.1	0.2	0.0	0.4
Isocer	*Isolepis cernua*	0.7	0.9	1.9	2.1	0.1	0.4
Lilorb	*Lilaeopsis novae-zelandiae*	0.3	1.8	1.1	0.3	0.1	0.3
Limlin	*Limosella lineata*	0.1	1.2	0.7	0.0	0.0	0.0
Myrvot	*Myriophyllum votschii*	1.5	0.0	0.0	0.0	0.0	11.9
Ranacu	*Ranunculus acaulis*	0.1	0.5	0.3	0.2	0.0	0.0
Selrad	*Selliera radicans*	0.0	0.0	0.2	0.0	17.0	0.1
Selrot	*Selliera rotundifolia*	2.8	5.3	19.8	5.5	0.1	3.0
	Other species						
Ammare	*Ammophila arenaria**	0.7	8.1	2.9	0.0	0.1	0.0
Aposim	*Apodasmia similis*	0.0	0.0	1.1	6.2	0.0	30.7
Arrela	*Arrhenatherum elatius**	0.1	0.1	0.2	1.8	0.0	4.6
Austoe	*Austroderia toetoe*	0.0	0.0	0.0	0.0	0.0	0.9
Calsol	*Calystegia soldanella*	0.1	1.2	0.7	0.0	5.0	0.0
Carpum	*Carex pumila*	1.0	19.5	8.5	4.1	0.3	0.4
Copace	*Coprosma acerosa*	0.0	0.1	0.0	0.3	0.0	0.2
Coppro	*Coprosma propinqua*	0.0	0.0	0.0	0.0	0.0	0.1
Coprep	*Coprosma repens*	0.0	0.0	0.0	0.0	0.0	0.1
Coraus	*Cordyline australis*	0.0	0.0	0.0	0.0	0.0	0.3
Corsel	*Cortaderia selloana*	0.5	0.3	0.1	10.0	0.0	0.6
Epibil	*Epilobium billardierei*	0.0	0.0	0.0	0.2	0.0	0.6
Ficnod	*Ficinia nodosa*	1.0	2.1	13.9	20.1	4.0	4.6
Ficspi	*Ficinia spiralis*	0.0	0.3	0.0	0.0	0.0	0.0
Hollan	*Holcus lanatus**	0.4	0.2	1.4	8.7	0.0	3.6
Hyprad	*Hypochaeris radicata**	0.4	1.2	4.2	7.7	0.1	0.1
Junart	*Juncus articulatus**	0.0	0.1	0.0	2.2	0.0	10.6
Junkra	*Juncus kraussii*	0.0	0.0	0.0	0.0	0.0	0.1
Lacbil	*Lachnagrostis billardierei*	0.2	0.6	0.2	1.0	0.0	0.1
Lepsco	*Leptospermum scoparium*	0.0	0.0	0.0	0.0	0.0	0.1
Lobanc	*Lobelia anceps*	0.1	0.2	0.8	1.3	0.0	0.8
Ozolep	*Ozothamnus leptophyllus*	0.1	0.1	0.0	0.0	0.0	0.1
Pimvil	*Pimelea villosa* ssp. *arenaria*	0.0	0.1	0.0	0.1	0.0	0.1
Placor	*Plantago coronopus**	1.0	0.0	0.0	0.0	9.4	0.0
Samrep	*Samolus repens*	1.0	0.0	0.0	0.0	12.8	0.1
Schpho	*Schedonurus phoenix**	0.0	0.0	0.0	1.0	0.0	12.1
Schpun	*Schoenoplectus pungens*	2.5	0.0	0.0	0.3	0.0	3.1
Schnit	*Schoenus nitens*	0.0	0.0	0.7	10.5	26.8	21.1
Spiser	*Spinifex sericeus*	0.2	0.5	0.3	0.0	0.0	0.0
Tristr	*Triglochin striata*	0.1	0.2	0.3	0.6	0.0	0.2
	Total spp. no.	64	51	51	75	18	65
	Native spp. no.	25	23	27	31	9	31
	Native/exotic spp. ratio	0.6	0.8	1.1	0.7	1.0	0.9
	Total spp. cover (%)	18.0	44.2	71.8	105.0	76.9	115.6
	Native spp. cover (%)	11.9	34.9	51.9	59.3	66.1	82.1
	Turf wetland spp. no.	8	8	9	7	4	7
	Turf wetland spp. cover (%)	5.7	9.9	24.3	11.3	17.4	16.2

Relationships between wetland and parabolic vegetation

There is no correlation between the community patterns of the 66 wetlands and their surrounding parabolic dunes on the basis of their floristics, so the two community types do not appear to be influencing each other's flora.

Two small communities of wetlands, Plains Wetland and Restiad Wetland are each only associated with one type of parabolic dune vegetation, namely Acacia Parabolic Dune and Rich Parabolic Dune (Table 4). Carex pumila Wetland is mostly associated with the two types of Spinifex Parabolic Dunes. Eleocharis Wetland is most frequently associated with Grassy Parabolic Dunes, while Selliera and Club-Sedge Wetlands have variable surroundings.

Table 5: The relative frequency (n=66) of the different combinations of wetland and parabolic vegetation.

	Communities of Parabolic dunes					
Wetland communities	Spinifex	Spinifex Shrub	Marram Shrub	Grassy	Acacia	Rich
Eleocharis	3	0	1	6	3	2
Carex pumila	8	3	4	2	0	1
Selliera	4	3	2	0	0	5
Club-sedge	2	4	3	0	0	2
Plains	0	0	0	0	4	0
Restiad	0	0	0	0	0	4

Valuation of wetlands

The wetlands with a valuation score of >50% were W9, W12, W16, W23, W27, W37, W38, W39 and W48, with the highest value being 74% for Wetland 12, the wetland constructed by Singers (1997) at Tawhirihoe Scientific Reserve. These wetlands were assigned to all communities except Plains Wetlands, but were most common in Carex pumila Wetland.

The community with the highest scores for wetland turf values was Selliera Wetland, with an average score of 0.42, compared with the other communities' average of 0.31 (data not presented).

The wetlands with the highest quality scores for the turf species (>0.46) are mainly located in Tawhirihoe Scientific Reserve, or on private land to the south of Himitangi. The HDC reserve just north of Foxton holds several medium quality wetlands. The quality of the wetlands north of the Rangitikei River mouth is problematical.

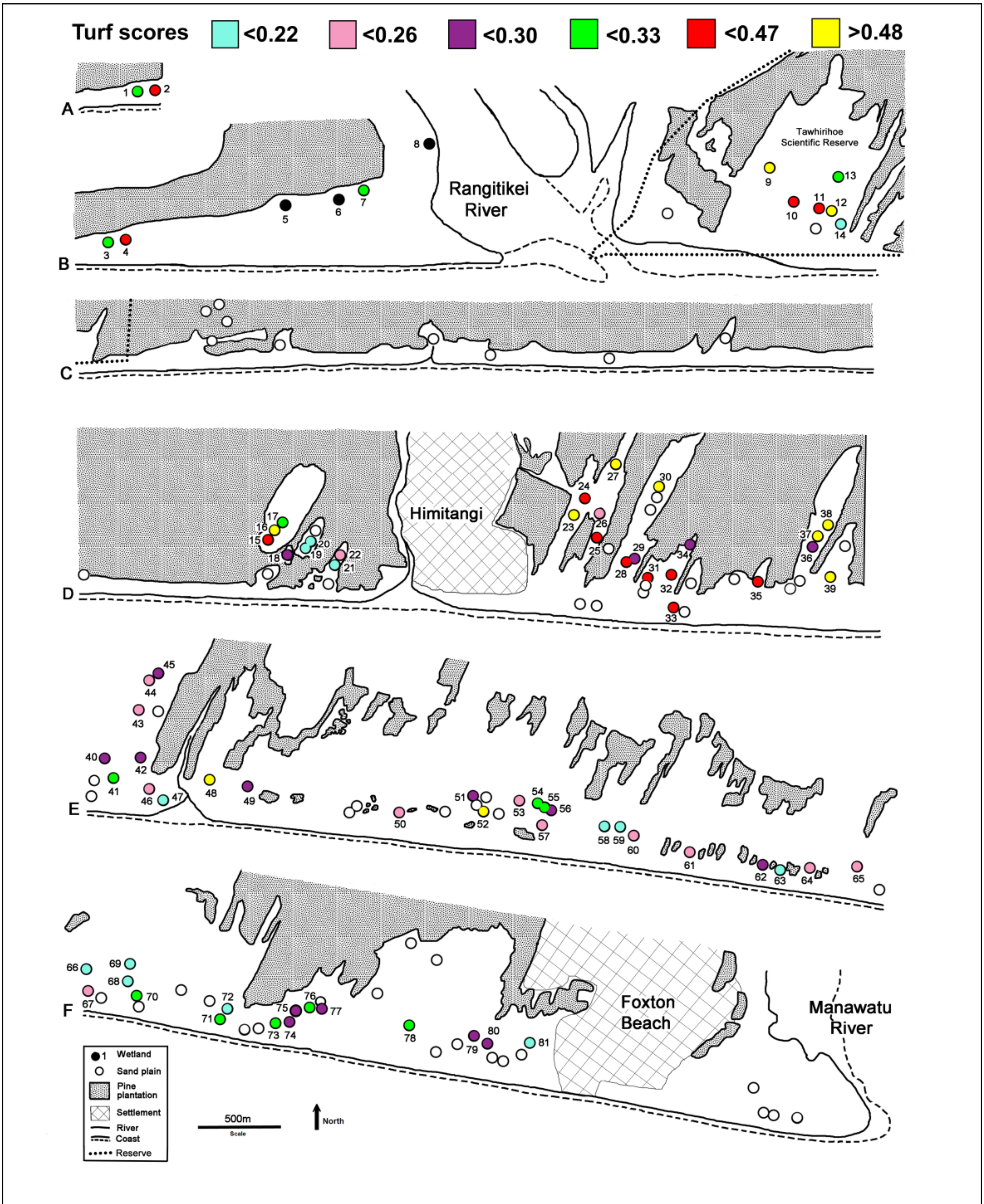


Figure 14: Distribution of the wetlands once divided into 6 approximately equal-sized categories for the summed turf species' quality score.

Discussion

Introduction

Here we try and place our findings briefly in the context of previous research in these dune areas, and using our data and decades of observations, draw deductions about the nature and processes affecting these dunelands and their vegetation. For a more detailed record of the changes in the wetlands of the Tawhirihoe Scientific Reserve in particular, see Singers (1997, 1998) and Murphy et al. (in prep.)

The foredune vegetation

The foredune vegetation along this 9km strip of beach are well-survey in this report, which gives an accurate and detailed picture of its current state.

Coastal stabilisation has been driven by the planting of marram (introduced *Ammophila arenaria*), extensively along the coast over the last 60 years (Cowie 1963; Esler 1970; McKelvey 1999). Marram communities occupy nearly 40% of the coastal strip and dominate the portion of the Foxtangi coast which has its rear-dunes planted in pines, and probably marram was especially favoured here to protect the young plantations.

In recent years there has been increasing criticism of marram's behaviour as a sand-binder (Esler 1970; Hilton et al. 2005). It was originally selected based on its ability to be readily propagated vegetatively (from split clumps in the field), and it does trap large quantities of sand, through which it is capable of growing very quickly, allowing it to trap more sand. Thus it can stabilise large quantities of mobile sand very quickly. However, it has no capacity to grow down or over the face of dunes, and marram dunes exposed to high tides are readily undercut, forming towers known as marram turrets, and leading to total destabilisation of the sand block. By contrast, *Spinifex sericeus*, the native sand-binder most vigorous on this coast, forms long rhizomes which grow downslope and root, thus stabilising the toe of foredunes. Even if undercut, *Spinifex* rapidly repairs the damage. Spinifex communities form more than half of the foredune vegetation, but even these have marram present.

Marram communities dominate the inland portion of the foredunes along much of the coast from Himitangi to close to the HDC reserve at Foxton. It is not clear if these represent a later stage of the foredune development (which is generally based on *Spinifex*-communities along that coastal segment), or if the foredunes have arisen subsequently to the emplacement and vegetative occupation of those dunes. Along the HDC reserve itself, the inland communities of the foredunes are commonly based on *Spinifex*. This suggests some aspect of the relative management of these two areas may be responsible for this difference, which requires explanation if the wish is to support development of more natural duneland vegetation.

The Foxtangi coast is generally considered to be prograding, up to 1m/year (Patrick Hesp, pers. comm.). Certainly evidence such as the recent burial by foredunes of the steamship Hydrabad, grounded at Waitarere to the south of Foxton in 1886, support this interpretation, along with the increasing deposition of dunes coastwards of the Himitangi township.

However around the two big river mouths, the Rangitikei and the Manawatu, the situation is more volatile. Here it appears episodes of progradation may be destroyed or simply reset by flood events, and the dynamism of the foredunes at Tawhirihoe demonstrate this. There foredunes can simply disappear overnight during storm events, but much of the displaced sand is then resorted offshore, and over time is redeposited on the plage, where foredune building recommences. The role of these offshore deposits, and of the various dune-builders in creating and protecting these, is unknown for this coast (c.f. Bay of Plenty; Jenks and Brake, 2001), but may be substantial in reducing wave action and protecting the shore, especially during periods of rising sea-levels.

However, the number of "blowouts", foredune collapses due to wind erosion, no longer appears to be as high as the 20/km recorded by Hesp (2002). The consequences of the current trend towards stable foredunes is unknown., since foredune blowouts appear necessary for the formation of parabolic dunes, which are strongly associated with the presence of wetlands.

The parabolic dune vegetation

The dunefields are too complex and extensive to be readily sampled, and to summarise their nature we have sampled 66 parabolic dune areas, albeit only those associated with wetlands. It is conceivable that the dune vegetation in other parts of the Foxtangi dunefield is different, but most field observations suggest that it is most likely to be both poorer in terms of species, and more sparse in terms of cover.

The communities delimited here on the parabolic dunes contain three types which are similar in composition to those of the foredunes, for example, Spinifex Parabolic Dune is similar to Open Spinifex Foredune. Further Mixed Marram Foredune community is similar to the Marram Shrub Parabolic Dune community, while Spinifex Shrub Parabolic Dune is similar to Shrubby Spinifex Foredune, though the rear dune version of the two latter have much more extensive coverage of shrub species, reflecting their probably longer development time. The other communities of parabolic dunes have no coast-edge equivalent, and reflect increased invasion of exotic species.

The more Spinifex-dominated parabolic dune communities are largely scattered from Himitangi to 3-Mile Creek, an area where the foredune vegetation is variable in quality. This suggests some discontinuity between the quality of the foredunes, and the dunes behind them, possibly because of different patterns and times of origin and histories of development, a similar conclusion to that drawn from our study of the foredunes.

The sand plain vegetation

Esler (1969) wrote specifically about the sand plains of the Manawatu coast, but their relations to the sand plains studied here is not clear. His sand plains appear to be at larger spatial scales than any present today, while his floristic compositions make it clear that he did not distinguish between dry and wet sand plains, while we have categorised the latter group as wetlands. Thus his sampling points indicate a more richly vegetated and better-covered vegetation type than we have encountered. This may just be a feature of the dynamics of these dunefields, variable with time, or a consequence of the afforestation and agriculturalisation of much of the rear of the dune fields, or a unique episode in the development of the modern dunefield.

Our sand plain vegetation is all relatively close to the coast, large areas further inland having been all planted in pasture or pines in the last few decades. They are generally small, only one tenth the area of the average wetland, and most sand plains are covered just by barren sand. They have an average of <4 species present each, very few of those turf species, Many of the taller species present are plants associated with the latter stages of wetland development by Murphy et al. (in prep.), such as *Ficinia nodosa* and *Apodasmia similis*, suggesting these areas will not trend towards turfy wetlands in the future, and instead appear to be in the process of "sanding over".

Status of the wetland turf species

The focus on this area of the coast has recently been on the presence of small wetlands with a flora of specialist short turf species. This focus did not exist in the past. Although Esler (1969 1970) does comment on the occasional turf species, this is in conjunction with extensive wet sand plains, the dominant species of which appeared to be *Carex pumila* (e.g., Burgess 1984), whose role in wetland turves is largely discounted by Murphy et al. (in prep.), since it appears to be merely a fringe species to young wetlands.

In more recent times the presence of specialist species has been highlighted (Ravine 1982; Singers 1997, 1998), showing an extensive herb flora of wetland floors, all (vegetatively) under 10cm in height, and forming distinctive and often extensive turves.

Our focus here is on the smallest, most prostrate and most unusual of turf species, particularly since two of them are listed as rare species for New Zealand (de Lange et al. 2013), though possibly due to data deficiency in the case of *Isolepis basilaris* (Melanya Yukhnevich, pers. comm.).

Thus, perhaps unjustifiably, we have excluded from detailed consideration, *Lobelia anceps*, which is widespread in such environments, *Triglochin striata* which is more of an estuarine species, though is occasionally found in the Foxtangi dunelands, and *Epilobium billardierei*, a common species of coastal sands. Also discounted as a focal species is *Selliera radicans*, which is at best occasional along this strip of the coast, though that begs the question of why *Selliera rotundifolia* dominates in this environment, and the extent to which it really is a separate species (Ogden 1974; Heenan 1997; Pilkington 2014). Singers (1997) reported that it behaved rather differently from *Selliera radicans* in various experimental stresses, supporting its distinctiveness, though its origin and persistence at Foxtangi remains problematic, and its competitive relations with its congener should be explored. Suspected to be more widespread than just the Manawatu, though possibly elsewhere of independent origin (Pilkington 2014), *Selliera rotundifolia* is the most common of the turf species studied. It is found in most wetlands, and can occur in sand plains and on the lower edges of dunes as well. It appears to disperse readily, whether from seed or rhizome fragments is unknown (Murphy et al. in prep.) and consequently is under no obvious threat at Foxtangi, subject to the availability of suitable habitats.

The nationally common sedge, *Isolepis cernua*, is almost as widespread, though it is less tolerant of dry habitats, and generally is found in most wetlands. Our other wetland focal species are more problematic. *Myriophyllum votschii* is included even though it is an aquatic, and seldom an emergent, and even then to only 3cm high. It may be much more common and widespread than appears, as it is very cryptic, and frequently found under or amongst other, more conspicuous, turf species. It may have an important role in stabilising the floor of wetlands and further investigations are necessary.

The other three more common turf species are *Limosella lineata, Lilaeopsis novae-zelandiae* and *Ranunculus acaulis*. though none are particularly frequent along the Foxtangi coast, and the first does not even occur in the wetlands of Tawhirihoe Reserve, even though it is a common or even dominant species of some wetlands south of Himitangi. Neither species appears restricted to dune habitats, *Lilaeopsis novae-zelandiae* having even been observed growing in local drainage ditches. *Ranunculus acaulis* is relatively rare at Foxtangi, occurring in only 20% of wetlands, and those rather idiosyncratically, but it is not nationally rare, nor is it restricted to dunelands, also being a common plant of damp coastal rocks.

Of the rare species, *Gunnera arenaria* (distinguished from the related or synonymic taxon *Gunnera dentata*), is nationally widespread, though seldom common, though it may have been more so in the past (Carnahan 1957). At Foxtangi it can form extensive swards of densely packed foliage, even on small dunes to 20 cm high dotted around in wetlands. Despite fruiting prolifically, there are only 5 patches along the coast, and its continued presence is very chancy. *Isolepis basilaris* is categorised as threatened, but appears more common than suspected (Melanya Yukhnevich, pers. comm.) as it too is very cryptic, and at <2cm, most likely to be overlooked, or mistaken for its more common congener. It is found at 10 locations along the Foxtangi coast, and has a reasonable coverage (3.1-47 m^2 depending on the assumptions made about the relative density of shoots amongst sand) at most of these.

The rarest turf species we studied is *Eleocharis neozelandica*, known from only populations in Northland, Farewell Spit and from scattered populations near the Waikato River mouth, and north of Wanganui (Singers 1997). At Foxtangi it is found in only 9 wetlands, despite being once more widespread and common (Burgess 1984). Its decline at Tawhirihoe is documented by Murphy et al. (in prep.), and efforts to relocate populations at some of the wetlands sampled here have failed, suggesting its decline is region-wide. However it is also extremely cryptic, especially when only a few flowering heads are present, and it may reappear in the region in future. Nevertheless, with total coverage ranging from between 1.2 and 21 m^2 along the Foxtangi coast, it is clearly under considerable threat.

Complex patterning of these turf species with respect to each other and to the water table has been described by Esler (1969). However no data reported here allow further exploration of these differences, although the ordination of the wetland communities suggests that some species do tend to co-occur, particularly *Ranunculus acaulis* and *Limosella lineata*, while *Myriophyllum votschii* is frequent in swards of the latter. More detailed analysis of the water table relations and patterning of these species in the field is needed.

Wetland vegetation

Community pattern and succession

We here delimited six communities from the 81 wetlands studied. Given our selection criteria derived from our focus on turfy wetlands, it is not surprising that some communities contain 6-8 turf species, up to three of those being our rare turf species (total frequency of 152 for tall turf species or 81 for short turf species out of 81 wetlands). The only exception is the poor-quality wetlands associated with Scott's Ferry to the north of the Rangitikei River mouth. More surprisingly is how high this number is compared with our minimum of 3 turf species. The other turf species are present in some wetland samples within a community, but not necessarily in others, so that it is the non-turf species which are really defining the nature of the community. This suggests the presence or absence of particular turf species (with the exceptions of *Isolepis cernua* and *Selliera rotundifolia*) is somewhat idiosyncratic, even unpredictable. It is not clear if this is a real feature of the compilation of a wetland's flora or a result of the extremely low frequency of occurrence of most of the turf species.

Although the wetlands studied here are each assigned to a single community, in fact, each wetland can be interpreted as a mix of different communities, following Murphy et al. (in prep.). Succession proceeds from the centre (lowermost point) of a wetland outwards, so the horizontal pattern reflects differing times since exposure of the surface as bare sand. Thus the wetland-wide communities reported here reflect the extent of development of each wetland, with Eleocharis Wetland the youngest, with the greatest number of rare turf species, and the least overall cover. Carex Wetland is the next most developed, with greater cover, but it may be because extensive swards of *Carex pumila* were common around young wetlands in the area south of Himitangi, one of the regions where this community is frequently found. Selliera Wetland and Club-sedge Wetlands are probably slightly later stages of those two types, with their increasing dominance of *Ficinia nodosa*, a sedge to 50cm, which signals the incipient loss of the turf vegetation (Murphy et al. in prep.). Selliera Wetland commonly forms the most high-value wetlands, but this is because the scoring system incorporates the species richness of natives as well as the turf species' values. The Plains Wetland type is quite distinct, and localised to Scott's Ferry, so it could be legitimately considered to be a true estuarine vegetation type, with occasional standing water. This suggests the inclusion of this area in the study was counter-productive. The Restiad Wetland type has a high cover of *Apodasmia similis*, or jointed rush, a member of the Restionaceae family to 1m tall, and *Schoenus nitens*, a smaller rush to 20cm. These species are equated by Murphy et al. (in prep.) with the decline of the short turf communities.

Of course there are later stages of these wetlands present along the Foxtangi coast, which completely lack the small turf species, and come to be dominated by *Apodasmia* swards. These were not studied here, but several were observed, especially adjacent to farmland north of the HDC reserve at Foxton. Over time it is conceivable that these will succeed into shrubland as the cover of native shrubs gradually increases (Murphy et al. in prep.). Dune lakes behind the current dune building phase were not surveyed, but are in need of study too, before they degenerate further. Their origin is also a mystery. Such succession may however be arrested due to the paucity of seed sources from local patches of native rear dune species. The nearest remnant of tall podocarp forest being at Omarapapaku or Round Bush Reserve (DoC; Carnahan 1957; Esler 1988), at least 1km inland, while dry duneland shrubland featuring *Dodonea viscosa* is limited to small patches on the banks of the Manawatu River, and near Waitarere Beach to the south of Foxton Beach. It is very difficult today to speculate about the probable past nature of this inland woody vegetation along the coast, no detailed records existing.

Wetland formation

Debate as long raged about the patterns of origin of wetlands of dune slacks along this coast (Singers 1997; Murphy et al. in prep.), and this study has contributed valuable information towards understanding this issue. The concern arose due to progressive "aging" (infilling by aeolian sand, of the three main wetlands in the Tawhirihoe Scientific Reserve (i.e., Wetlands 9, 10 and 13), so that habitat for the turf communities was diminishing. The apparent failure of new wetlands to arise within the confines of the reserve resulted in the interventionist construction of experimental wetlands (Singers 1997, 1998; Murphy et al. in prep.), two in 1995 and one in 2008, to provide habitat for the rare wetland turf species (i.e., Wetlands 11, 12 and 14 in this study). The success of this strategy is assessed in Murphy et al. (in prep.).

Wetland formation has been subject to several different hypotheses. The first is that formation happens behind the foredunes, when dry sand ablates seawards of a mobile parabolic dune, excavating the floor of the sand plain down to the sand dampened by the summer water table, with the consequence that the area holds standing water during the winter at least. This hypothesis is refuted by the spatial distribution of these wetlands. Though most formation appears to be close to the coast, the average wetland being 288m from the coast, at least some occur >800m from the coast, with others potentially further inland being invisible in the absence of suitable mobile sands.

A second hypothesis is of continuous wetland formation. The evidence here is clearly that, even though they are almost regularly spaced along the Foxtangi coastline, wetlands do not form continuously. If they did a graph of their distances from the coast would follow a normal (bell-shaped curve) distribution, and this does not happen. The majority of wetlands are within 200-300 m of the coast, but some are as far inland as 887 m. Further, spatially suitable habitat occurs at Tawhirihoe, but no wetlands have formed (as above). For many years it was considered that this was probably because the reserve was too small for natural dynamics to occur, and any adjacent habitat which might have been suitable was underneath pine trees or pasture.

A third hypothesis is that there are episodes of wetland formation, depending on the occurrence of a summer of unusual levels of drought and wind, so that ablation occurs to greater depths in the depression, where the lowered water table is still effective at dampening sand. But there is no evidence of episodes of wetland formation, which would appear as two or more peaks of higher frequency with distance from the coast.

Perhaps wetlands closer to the coast are there because they are younger (and the coast has not yet prograded a long way past them). But the accepted rate of progradation is only 1 m/yr, which means that the most inland wetlands would have to be >500 years old to have become isolated from the coast by such a distance. And the floristic evidence here is that some of the high-value wetlands are the least coastal. In any case, Murphy et al. (in prep.) put an estimated maximum age on the turfy phases of a wetland's development of <50 years, so those inland wetlands must be of relatively recent origin. This evidence suggests a fourth hypothesis for wetland formation, that they are all relatively recent, within the last 50 years, since Esler (1969) noted extensive sand plains and mobile dunes along the Foxtangi coast in 1942. Such sand sheets were generated by mobile sand being deposited along the coast after being carried downstream by the Manawatu and Rangitikei Rivers, which were washing out sediment from erosive events in the inland and mountain parts of their catchments (Saunders 1968). Any wetlands in existence at the time would have been readily buried by such sand sheets. A more detailed study, using historic aerial photogrpahs of wetlands would be useful in timing their formation and longevity.

The puzzle here is how any wetland turf species survived such burial. Although New Zealand sand dune species do have considerable tolerance for both the dark and the weight of burial (Sykes and Wilson 1990a,b), no turf species have been tested for such tolerances to date. Alternatively the wetland turf species would need to reinvade the coastal region as suitable sites form. For some at least, such as *Lobelia anceps*, *Lilaeopsis novae-zelandiae*, and *Triglochin striata*, this can readily happen from nearby non-sandy habitats. But it is hard to see the alternative habitats for *Eleocharis neozelandica*, *Isolepis basilaris* and *Gunnera arenaria*. Possibly these are instead readily dispersed on coastal currents already responsible for the spread of *Spinifex sericeus* along the New Zealand coast (with the exception of the far south of the South Island and Stewart Island, potentially due to low temperatures).

This fourth hypothesis is increasingly appearing credible. Since all the wetlands we have recorded are of approximately the same age (from about 2-50 years old vegetationally), then it seems that they might have all arisen at approximately the same time. This fits with the successional rate of development of these wetlands described by Murphy et al. (in prep.), especially the fact that they all have at least some (by definition ≥ 3) wetland turf species remaining. So proximity to the coast is not essential for the formation of high-value turfy wetlands. The haphazard or idiosyncratic nature of the wetlands' turfy floras becomes more understandable too, and as individual wetlands succeed to shrubland vegetation, the future of these turf floras becomes more uncertain.

Management issues

Coastal dynamism

Though it is not necessary to manage coastal dynamism on a non-fragmented, natural coast, it is extremely hard to manage it on a fragmented coast. This is exacerbated at Foxtangi because the proportion of land in reserves is so small that large-scale natural processes cannot be expected to occur with the regularity needed to provide a full range of habitats. Additionally most reserves back onto private land where the land-holders run businesses and do not want to have to contend with natural dune processes invading their land. Seeking a working balance between the competing needs of conservation and human habitation of our coastal zone will be a fraught process.

On the negative side, the number of wetland sites along the Foxtangi coast containing turf species, and the spatial extent of those turf patches suggest the turf species are under considerable threat. In addition, many of the wetlands studied here have declined in value over the subsequent 5 years, and in some cases some of the rare species have been lost altogether. Decisions need to be made as to the acceptable extent of these losses and how to reverse these trends.

On the positive side, the manufacture of the three constructed wetlands at Tawhirihoe Scientific Reserve has been a reasonably successful approach, in that wetland habitat for turf species will probably be available for the next decade or two (Singers 1997, 1998; Murphy et al. in prep.). However the longevity of such wetlands probably depends on the up-wind supply of sand. A destabilised foredune is capable of moving inland and covering existing wetlands. Hence foredune stability is essential to protect existing wetlands. However foredune instability seems necessary to create new wetland habitat, via formation of parabolic dunes and subsequent, possibly on-going deflation of their floors. The location of the balance point between these two situations is critical towards managing wetlands in the future.

Pest plants

There are high levels of occupancy of our native dunelands by exotic plant species, particularly once inland of the foredunes, where at least the native foredune binder, *Spinifex sericeus*, dominates. Most of the wetland, sandplain and parabolic dune communities have a mix of native and exotic species, and many small exotic species do not appear to alter the natural wetland processes, e.g., *Senecio elegans*, which is widespread on the dunes, but seldom abundant. However, with exotic species forming more of the cover in the later stages of community succession, it is no longer clear that natural successional processes will eventually dominate, though many native shrubs do appear competitive in such conditions.

Some exotics are extremely weedy and aggressive and on-going control is probably necessary to facilitate natural succession. Control of pampas, *Cortaderia selloana*, has been extensive in Tawhirihoe Reserve, and should be continued. The presence of conifers such as *Pinus radiata* and Cupressus macrocarpa, as well as the Australian dune acacia, *Acacia sophorae*, has very negative impacts on natural succession, and control around high value wetlands is advised.

Most other weeds are not (currently) particularly aggressive, but two species with considerable potential to alter the way dunes function are *Lilium formosanum*, spreading along the Foxtangi coast from infestations at Foxton, and *Senecio glastifolius*, crossing the sea from the Wanganui region (Beautrais 2013), which has also been the subject of various weeding sessions at Tawhirihoe.

Pest animals and humans

The relatively poor relationships between the foredune vegetation patterns revealed here, and those of the inland parabolic dunes suggest that the coast has undergone different degrees of disturbance or even of management in the past, and natural patterns perpendicular to the coast are not developing. Impacts on plant succession and vegetation development are unknown for the different levels of disturbance of the dunes and of different treatments of the hinterland sites (e.g., farming, pasture, intensive irrigation, afforestation).

Humans walking on the dunes, sand plains and dune wetlands do very little to no detectable damage, and may even play a role in the dispersal of wetland species (though hardly a natural role). However vehicles commonly access the beach, and 4WD vehicles, motorbikes and dune buggies frequently drive onto and over the dunes, and enjoy a spin on the wetlands, while the sand plains (incipient wetland areas?) is treated like natural driving habitat. Unfortunately a single pass of a motor-bike or dune buggie can leave tread marks, compression prints, and gouges in wetland areas, especially during the summer-time when water tables are lower. Some of these marks persist for several years, and alter the floristic patches of the wetland via micro-relief. It is highly desirable to prevent vehicles accessing wetlands, and public education is needed.

Sometimes it appears that vehicles can do some good, especially in the wetland areas. *Selliera basilaris* appears to respond well to areas of track that have been compacted. This could be due to the vehicles killing the taller vegetation reducing light and water competition of this species, or to lowering of the surface closer to the water table. Of course, this is only at low levels of visiting - at higher levels no native turf plants survive.

The role of exotic animals in these environments is poorly studied. Sambar deer (*Cervus unicolor*) do occasionally visit the wetland areas, presumably for water at night, and some land-owners along the coast allow hunting. Most damage to turf species would be by hoof-prints, no fodder being presented. However rabbits and, increasingly hares, present a considerable threat to wetland species. Singers (1997, 1998) reported an exclosure trial which showed quite different growth and successional patterns in the presence of herbivores, and further studies are needed. The most likely role for other exotic animals in the dunes is via predational impact on native fauna, such as lizards, which may play a role in pollination or dispersal of wetland species. The role of exotic animal species in changing the dynamics of these dunelands needs further investigation.

Management recommendations

Pine trees planted close to the coast are inimical to good quality coastal vegetation, such areas (e.g. Figure 7, C segment) having the poorest quality dunes (despite the widespread presence of *Spinifex*), and, of course, no wetlands. Foredune quality and strength can best be maintained by selective removal of clumps of marram from both the inland and seaward side of the prograding foredunes before they have time to develop to any size. This will allow *Spinifex sericeus* and *Ficinia spiralis* to dominate, and the flow-on effect when such areas become rear dunes (due to coastal progradation) may be considerable.

With the frequent movement of sand and the management issue of keeping mobile sand within reserves exactly how these wetlands can be protected is less clear. A rear-dune (but not a foredune) belt of pine trees is efficacious here. Where suitable areas are in private land, discussions should be held with the land managers to protect wetlands, and continue such land management as has allowed wetlands to persist to this day.

Excavation of constructed wetlands is showing signs of being a good approach, though much slower than expected (Murphy et al. in prep.). Indeed, it seems the only active management option available given the small size of the currently protected areas. Further, consideration needs to be given to the strategy of destabilising portions of the foredune to create new parabolic dunefields, and hence potential sites for wetlands. This would require larger-scale management than is current practised.

Formation of new coastal reserves should be considered where possible, as this will allow larger areas for representative natural processes to develop. The rarer species are those from wetland habitats, so it is reasonable to suggest that reserves be built around wetland areas where high-value wetlands currently exist. However it is hard to predict where such areas will be in 2-5 decades time, and those are the primary areas needing reservation.

Conclusions

The Foxtangi dunefields currently form a complex of foredunes, rear dunes, parabolic dunes, sand plains and sandy-bottomed wetlands. The nature of this vegetation is now reasonably well understood. Less clear is its relation to past vegetation, especially that prior to human settlement.

The turf species of the wetlands, especially the rarest seven species, are under especial threat, due to the dynamic nature of their habitat, and the over-arching dynamism of the dunes, as well as the impacts of humans and their recreations and occupations. Conserving these within the Manawatu will probably require interventionist management, sometimes rather creatively, and other times at larger scales than currently practised, all within the context of future research.

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Appendix 1: Species' codes

Code	***Species name***
Acasop	*Acacia sophorae*
Acanov	*Acaena novae-zelandiae*
Agapra	*Agapanthus praecox* ssp. *orientalis*
Agrstol	*Agrostis stolonifera*
Aircar	*Aira caryophyllea*
Ammare	*Ammophila arenaria*
Anaarv	*Anagallis arvensis*
Antodo	*Anthoxanthum odoratum*
Apipro	*Apium prostratum*
Aposim	*Apodasmia similis*
Arrelat	*Arrhenatherum elatius*
Austoe	*Austroderia toetoe*
Banint	*Banksia integrifolia*
Brodia	*Bromus diandrus*
Calsol	*Calystegia soldanella*
Carpum	*Carex pumila*
Caredu	*Carpobrotus edulis*
Ceery	*Centaurium erythraea*
Cirvul	*Cirsium vulgare*
Conabi	*Conyza abida*
Copace	*Coprosma acerosa*
Coppro	*Coprosma propinqua*
Coprep	*Coprosma repens*
Coraus	*Cordyline australis*
Corsel	*Cortaderia selloana*
Cotcor	*Cotula coronopifolia*
Cyndac	*Cynodon dactylon*
Dacglo	*Dactylis glomerata*
Dahliasp.	*Dahlia* sp.
Eleneo	*Eleocharis neozelandica*
Eleacu	*Eleocharis acuta*
Epibil	*Epilobium billardierianum*
Ficnod	*Ficinia nodosa*
Ficspi	*Ficinia spiralis*
Foevul	*Foeniculum vulgare*
Galpal	*Galium palustre*
Gazlin	*Gazania linearis*
Gunare	*Gunnera arenaria*
Helech	*Helminthotheca echioides*
Hollan	*Holcus lanatus*
Hyprad	*Hypochaeris radicata*
Isobas	*Isolepis basilaris*
Isocer	*Isolepis cernua*
Isolpro	*Isolepis prolifer*
Junacu	*Juncus acutus*
Junartic	*Juncus articulatus*
Junbuf	*Juncus bufonius*
Juncae	*Juncus caespiticus*
Junkra	*Juncus krausii* var. *australiensis*
Lacbil	*Lachnagrostis billardierei*
Lagova	*Lagurus ovatus*
Leotar	*Leontodon taraxacoides*
Lepsco	*Leptospermum scoparium*
Lilnov	*Lilaeopsis nove-zelandiae*
Lilfor	*Lilium formosanum*
Limlin	*Limosella lineata*
Lobanc	*Lobelia anceps*
Lolper	*Lolium perenne*
Lotped	*Lotus pedunculatus*
Lotsua	*Lotus suaveolens*
Luparb	*Lupinus arboreus*
Medlup	*Medicago lupulina*
Melind	*Melilotus indicus*
Micuni	*Microtis unifolia*
Myrvot	*Myriophyllum votschii*
Oenbie	*Oenothera biennis*
Oengla	*Oenothera glazoviana*
Oromin	*Orobanche minor*
Osmreg	*Osmunda regalis*
Oxaexi	*Oxalis exilis*
Ozolep	*Ozothamnus leptophyllus*
Parvis	*Parentucellia viscosa*
Pasdil	*Paspalum dilatatum*
Pencla	*Pennisetum clandestinum*
Photen	*Phormium tenax*
Pimare	*Pimelia arenaria*
Pinrad	*Pinus radiata*
Pladiv	*Plagianthus divaricatus*
Placor	*Plantago coronopus*
Plamaj	*Plantago major*
Plamed	*Plantago media*
Poltet	*Polycarpon tetraphyllum*
Pselut	*Pseudognaphalium luteoalbum*
Ranaca	*Ranunculus acaulis*
Ranrep	*Ranunculus repens*
Rubfru	*Rubus fruticosus*

Rumace	*Rumex acetosella*
Rumobt	*Rumex obtusifolius*
Samrep	*Samolus repens*
Schpho	*Schedonurus phoenix*
Schpun	*Schoenoplectus pungens*
Schnit	*Schoenus nitens*
Selrot	*Selliera rotundifolia*
Selrad	*Selliera radicans*
Senele	*Senecio elegans*
Sengla	*Senecio glastifolius*
Silgal	*Silene gallica*
Sisblu	*Sisyrinchium* "blue"
Sonole	*Sonchus oleraceus*
Spiser	*Spinifex sericeus*
Trifarv	*Trifolium arvense*
Trifpra	*Trifolium pratense*
Trifrep	*Trifolium repens*
Trigstr	*Triglochin striata*
Typori	*Typha orientalis*
Vichir	*Vicia hirsuta*
Vulbro	*Vulpia bromoides*