Factors causing dune ephemeral wetlands to be vulnerable to weed invasion

P.D. Champion and P.N. Reeves

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ABSTRACT

Ephemeral wetlands are characterised by seasonal fluctuations in water level, with alternating wet and dry periods. The resulting indigenous vegetation is low in stature, making these wetlands vulnerable to alien weed invasion, and many ephemeral wetland plants are now uncommon or endangered. This study investigated soil nutrients and hydrology as potential influences on the susceptibility of dune ephemeral wetlands to weed invasion. Study sites were selected in dune systems on the Pouto Peninsula, Northland, and at Hawkens Lagoon and Whitiau near Wanganui, North Island, New Zealand. At these sites, soils and vegetation were sampled and water tables measured to establish water level fluctuation patterns. Transects were established and vegetation type and percentage weed cover on them were measured on three occasions from 2002 to 2005. Soil nutrient levels did not appear to influence the distribution of alien weed species. The cover of alien species did not increase at Pouto sites over the three monitoring years. However, the Wanganui sites progressively became weedier, and taller indigenous vegetation displaced low-stature turf communities. Weed invasion appears to be promoted by a combination of altered hydrology reducing both the water level and the extremes of wet-dry fluctuations, along with stabilised dunes that restrict the dynamic sand movement that creates and destroys these ephemeral wetland areas. Management options include maintaining natural dune processes which ensure that the conditions for creating new ephemeral wetland areas continue, surveillance for and removal of invasive weed species and, at sites where dunes have been stabilised, removal of taller alien and indigenous vegetation by mechanical methods, grazing or selective herbicides.

Keywords: ephemeral, wetland, weed invasion, soil and plant nutrient concentrations, hydrology, endangered plants, sand dune, management options

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1. Introduction

Ephemeral wetlands are low-lying areas generally defined as being periodically wet. Johnson & Gerbeaux (2004) recognise them as a distinctive wetland class in New Zealand. They are found mainly in closed depressions where seasonal variation in rainfall and evaporation can lead to ponding. They have water level fluctuations so pronounced that they become completely dry for months and sometimes years at a time. The vegetation in ephemeral wetlands is characterised by tiny turf plants, although other plant growth forms (e.g. rushes, shrubs) are also common.

Ephemeral wetlands are under-represented in the Department of Conservation (DOC) network of protected natural areas. They are particularly hard to manage, as they are dynamic, altering seasonally in response to inundation by water, and their low-stature vegetation has very specific habitat requirements. Recently, it has become clear that a particular threat to ephemeral wetlands is weed invasion. This study addresses the impacts of weeds on dune ephemeral wetlands (a subset of the wider range of ephemeral wetland types), to provide a basis for determining realistic conservation objectives and guidance on what management is needed to maintain their native turf communities.

Endangered species mentioned in this report are classified using the most recent classification, available on the New Zealand Plant Conservation Network (NZPCN) website (www.nzpcn.org.nz/, accessed August 2007).

2. Background

A number of authors (Champion 1998; Ogle 1998; Dopson et al. 1999; Johnson & Rogers 2003) have noted the vulnerability of ephemeral wetlands, and the endangered plants they contain, to weed invasion. Ogle (1998) noted that the endangered turf species *Sebaea ovata* is highly impacted by the invasion of alien plants. The small stature of indigenous ephemeral wetland species predisposes them to be out-competed and displaced by taller and/or faster-growing alien species (Champion 1998). Dopson et al. (1999) listed weed invasion as a severe threat to many of the endangered species that are found in ephemeral turf habitats.

Johnson & Rogers (2003) stated that although some alien plants present in ephemeral turfs appear to co-exist with indigenous species, they could become threats following disturbance, nutrient enrichment or changes in climate. Weed species that replace the natural dominant vegetation, grow taller, and/or alter processes such as nutrient cycling and drainage are the major species of concern. Johnson & Rogers (2003) mention 51 species in this category, including perennial grasses, sedges and rushes, with the largest group comprising dicotyledonous herbs.

The invasion of the Sedgemere Ephemeral Tarn in South Marlborough by the alien sedge *Carex ovalis* is a current example of weed invasion impacts (Jones 2007). Five species considered to be nationally endangered occur in Sedgemere Tarn, including one unnamed taxon (*Craspedia* "tarn") that is apparently endemic to this small tarn. All these plants are threatened by an encroaching dense turf of the alien sedge.

The decision to focus on dune ephemeral wetlands was made following discussions in 2001 with a number of people with ephemeral wetlands expertise. Many of these people described an urgent need to address weeds in dune ephemeral wetlands and lake turfs. Johnson & Rogers (2003) stated that the most pressing research need for ephemeral wetlands is to understand how they function, with improved knowledge of their edaphic (soil) and hydrological processes the most critical requirement.

Dune ephemeral wetlands develop on coasts which are advancing seaward and have a good supply of wind-blown sand. Several different types of dune ephemeral wetlands are recognised, such as dune hollows, deflation hollows, dune slacks, swales and sandplains. The depressions where ephemeral wetlands occur are created when wind erodes sand to the level of the water table. At this level, the sand becomes moist and is no longer prone to removal by wind action (Johnson & Rogers 2003). The substrate in dune ephemeral wetlands is mostly sand, which has a low nutrient content. However, substrate fertility may increase over time as a result of nitrogen-fixing algae (e.g. *Nostoc* and *Anabaena* species) and the accumulation wind-blown silt and organic matter (Singers 1998). Water is predominantly sourced from groundwater and rainfall, so that these are freshwater systems despite their close proximity to the sea (Johnson & Rogers 2003).

3. Objectives

This study had the following objectives:

- Determine whether soil fertility is a factor in weed invasion in dune ephemeral wetlands.
- Determine whether the range and periodicity of water level fluctuations in dune ephemeral wetlands are a factor in weed invasion.
- Monitor weed invasion in selected dune ephemeral wetland sites over 5 years.
- Identify management initiatives that will maintain and enhance native dune ephemeral wetland vegetation communities.

4. Study locations

Dune ephemeral wetlands were studied at three locations (Fig. 1): the broad, low-fertility sand plains of Pouto Peninsula (Northland Conservancy) and two similar areas adjacent to river mouths in the vicinity of Wanganui (Wanganui Conservancy).

4.1 POUTO PENINSULA

The southwestern end of the Pouto Peninsula is composed of mobile, low, sparsely vegetated sand dunes. The area comprises Crown Land, Maori Land and private land (Cromarty 1996).

Dominant indigenous dune plants on the mobile dunes of the Pouto Peninsula are spinifex (*Spinifex sericeus*) and pingao (*Desmoschoenus spiralis*). These dunes are interspersed with seasonally flooded slacks (depressions) and lakes with swamp fringes and inter-connecting swampy arms with oioi (*Apodasmia similis*), *Baumea articulata*, raupo (*Typha orientalis*), *Schoenoplectus tabernaemontani* and kuta (*Eleocharis sphacelata*) (Cromarty 1996).

This list was extended by Cameron et al. (2001), who recorded the following plants (alien species are denoted by an asterisk): *Cortaderia splendens*, *pampas (*Cortaderia selloana* and *C. jubata*), club sedge (*Ficinia nodosa*), tauhinu (*Ozothamnus leptophyllus*), *Lachnagrostis billardierei* and sand carex (*Carex pumila*).

The ephemeral wetland vegetation occurs in the seasonally flooded areas. The open ephemeral wetland areas of the Pouto Peninsula contain the largest population of the chronically threatened sedge *Eleocharis neozelandica* (Gradual Decline) (Forester & Townsend 2004). Cameron et al. (2001) also listed the turf species *Gunnera dentata*, *Spiranthes novae-zelandiae*, *Triglochin striatum*, *Isolepis cernua*, *Lilaeopsis novae-zelandiae*, *Limosella lineata* and *Myriophyllum votschii* in these areas. The acutely threatened *Sebaea ovata* (Critically Endangered) was translocated to two ephemeral wetland areas in 2003 (Forester & Townsend 2004), sourced from the known New Zealand populations of this plant in Wanganui (see sections 4.2 and 4.3). *Sebaea ovata* was historically known from Northland, but these populations are extinct (and all others, with the exception of Whitiau and Waitotara). These translocations were an attempt to establish additional populations of this species in similar habitat to those Wanganui sites. Unfortunately, although germination of *S. ovata* occurred in the following year (Forester & Townsend 2004), these populations have not persisted.

Sites initially investigated in this study were the 'Causeway' linking the west coast with Lake Mokeno and 'Stick Lake' just east of North Head on the south coast (Fig. 2).

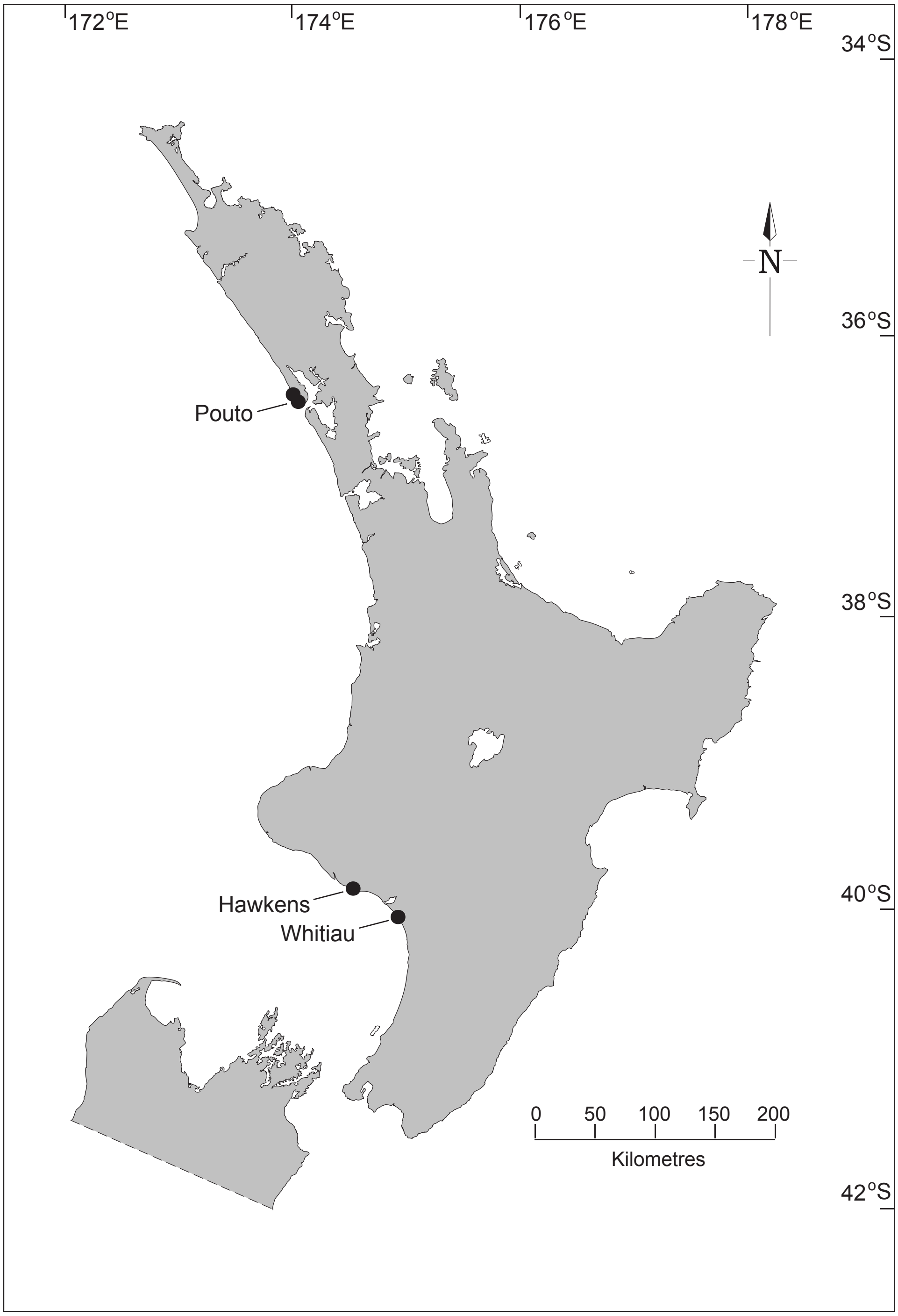


Figure 1. Map of North Island showing dune ephemeral wetland study locations.

4.2 HAWKENS LAGOON

Hawkens Lagoon Conservation Area is located at the mouth of the Waitotara River (Fig. 3), near the settlement of Waitotara, northwest of Wanganui. It is managed by DOC as a Stewardship Area under the Conservation Act 1987. The area is 100% fenced; however, a grazing license covers 18 ha of the area and cattle have been observed grazing in the study area on several occasions. Other threats to the vegetation communities include possum browsing and weeds. Surrounding land use is predominantly stock grazing.

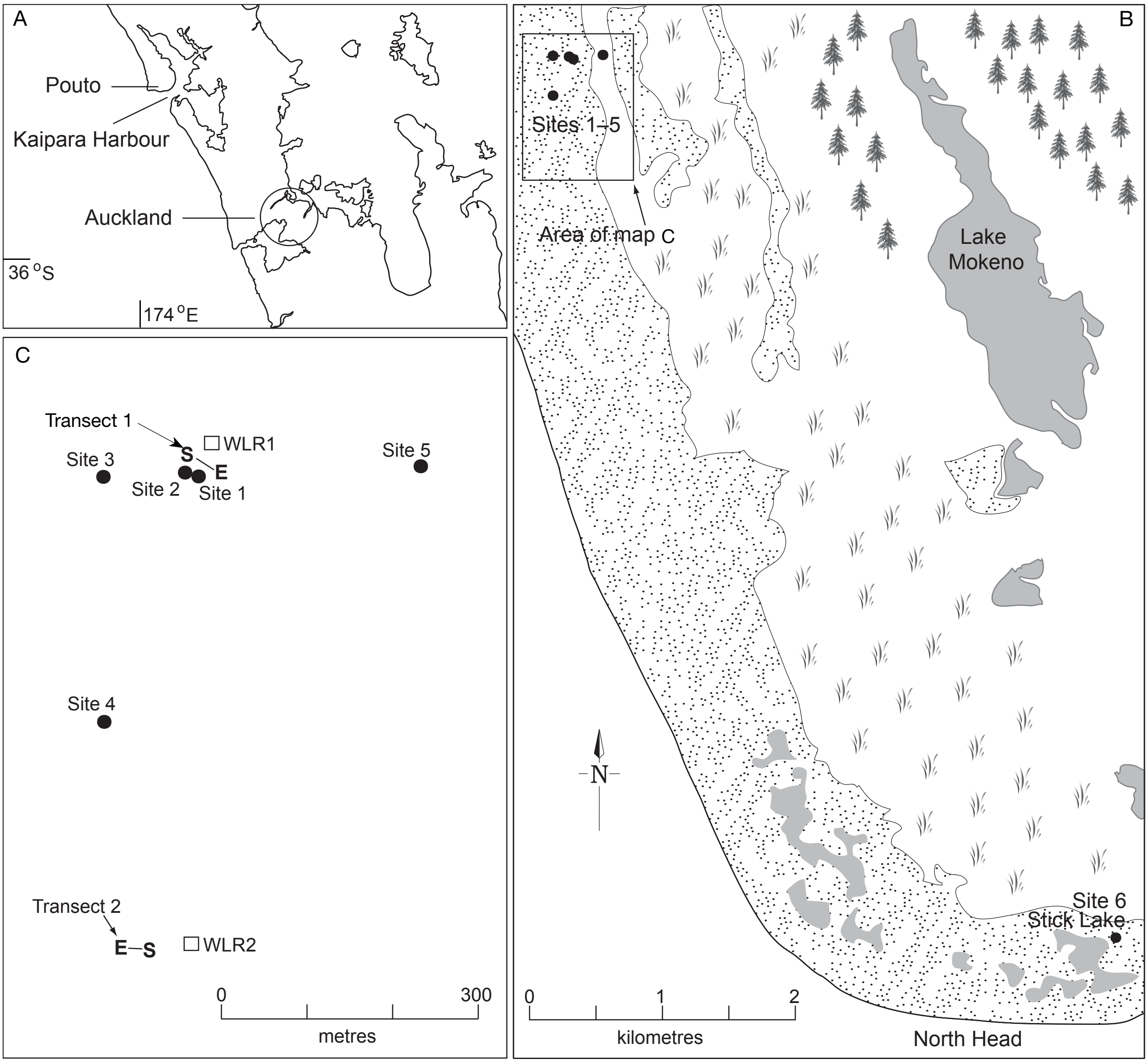


Figure 2. A—Map showing Pouto Peninsula study area. B—General location of sites. C—Map showing the 'Causeway' sites (1–5) in greater detail. Vegetation plots were established at each of these sites. Transects 1 and 2 are also shown, along with the locations of their associated water level recorders. Note, S = start of transect, E = end of transect.

Hawkins Lagoon and Whitiau Scientific Reserve (see section 4.3) have some of the best remaining examples of dune ephemeral wetlands in the Wanganui Conservancy. Hawkins Lagoon contains a complex of vegetation types. The following description is from Ogle (2002) with vegetation classification based on Atkinson 1985 (see hyperlink in the reference section) (alien species are denoted by an asterisk):

- Foredunes were dominated by spinifex – *marram (*Ammophila arenaria*) – (pingao) grassland.
- Hind dunes were dominated by (dead *tree lupin (*Lupinus arboreus*))/*marram – *tall fescue (*Schedonorus phoenix*) – *cocksfoot (*Dactylis glomerata*) grassland. Other pasture grasses were present, along with occasional shrubs including tauhinu, *boxthorn (*Lycium ferocissimum*), *gorse (*Ulex europaeus*) and *evening primrose (*Oenothera stricta*).

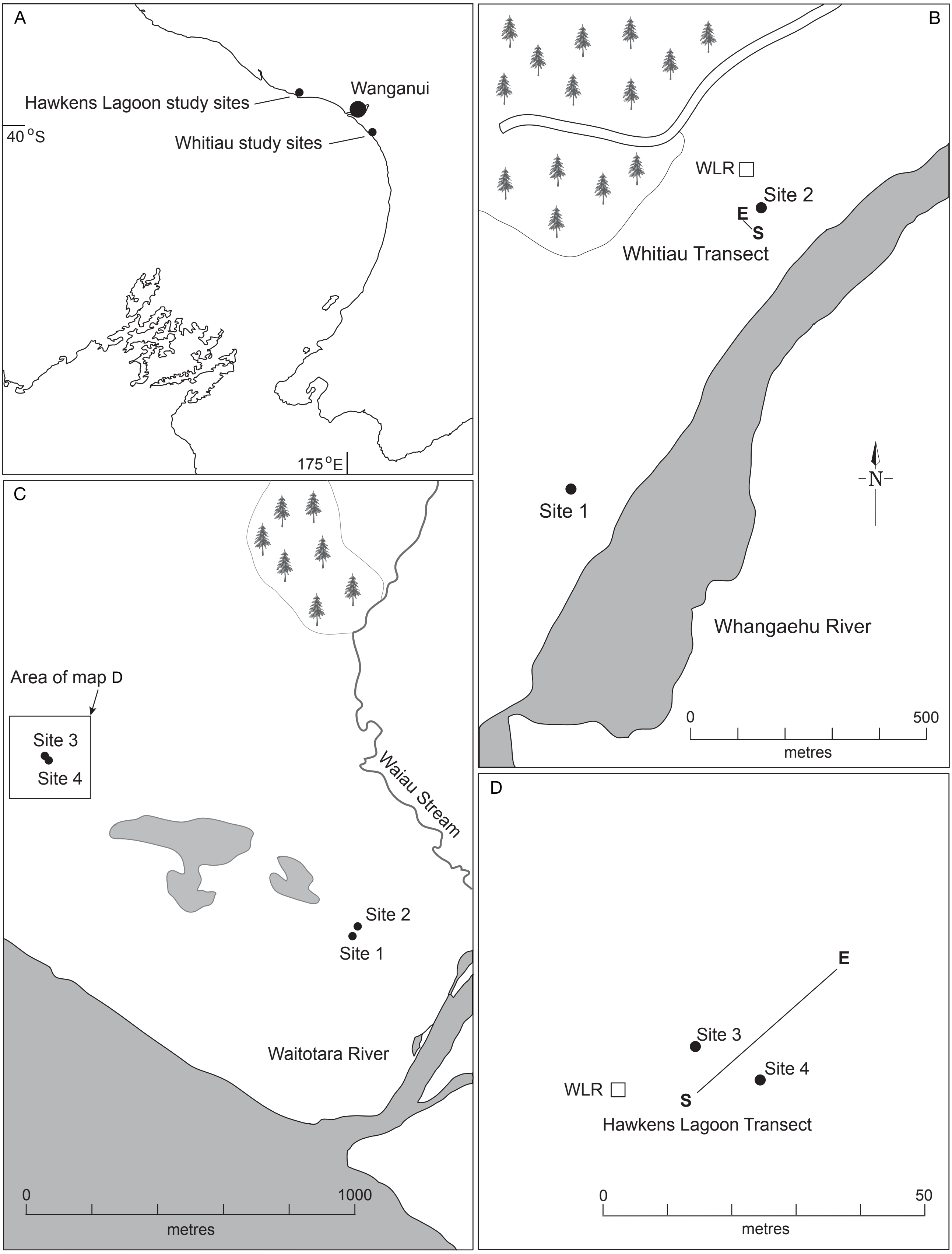


Figure 3. A—Map showing Hawkens Lagoon and Whitiau study sites. B—Whitiau; C—Hawkens Lagoon. D— Sites 3 & 4 and Transect at Hawkens Lagoon in more detail. Note, S = start of transect, E = end of transect.

- Dune flats, where the dune ephemeral wetlands occurred, had several vegetation types, including:
  - — (Club sedge)/*ripgut brome (*Bromus diandrus*) grassland with occasional toetoe (*Cortaderia toetoe*), *pampas, sand willowherb (*Epilobium billardiereanum*), sand carex and three-square (*Schoenoplectus pungens*).
  - — *Gunnera dentata – Myriophyllum votschii – Schoenus nitens* herbfield with *creeping bent (*Agrostis stolonifera*), *Triglochin striatum*, *Potentilla anserinoides*, *hawkbit (*Leontodon taraxacoides*), *Lilaeopsis novae-zelandiae, Isolepis cernua*, and *Eleocharis neozelandica*.
  - — Water milfoil (*Myriophyllum propinquum*) – *Lilaeopsis* herbfield on pond margins.
  - — Other shrub- and alien grass-dominated communities.

In August 2002, a population of the critically endangered *Sebaea ovata* was discovered on the dune flats at Hawkins Lagoon (Ogle 2002). Other threatened species present in this area include half-star (*Selliera rotundifolia*) and *Eleocharis neozelandica* (both classified as chronically threatened 'Gradual Decline').

4.3 WHITIAU SCIENTIFIC RESERVE

Whitiau Scientific Reserve is located south of Wanganui near the mouth of the Whangaehu River (Fig. 3). It is mostly (80%) fenced; however, domestic livestock and other animals (including rabbits and possums) are perceived to be a problem in the area because of their grazing and trampling impacts. Off-road vehicles also have access to the reserve, and cause damage to the dune system. Surrounding land is mostly used for forestry and stock grazing.

The reserve contains a complex of vegetation types, described as follows by Ogle (1997) (alien species are denoted by an asterisk):

- Foredunes were dominated by spinifex – *marram – (pingao) grassland with occasional sand daphne (*Pimelea arenaria*), sand convolvulus (*Calystegia soldanella*) and sand coprosma (*Coprosma acerosa*).
- Hind dunes are dominated by *tree lupin/*marram shrub-grassland with occasional *pampas, sand coprosma and tauhinu.
- The dune ephemeral wetlands occur on the dune flats. Several vegetation types have been described in the dune flats:
  - — Oioi (club sedge)/*ripgut brome rushland with occasional cabbage tree (*Cordyline australis*), toetoe, *pampas, *boxthorn and patches of sand iris (*Libertia peregrinans*) and sand willowherb.
  - — Halfstar (*Selliera rotundifolia*) – *Gunnera dentata – Schoenus nitens* herbfield with *Yorkshire fog (*Holcus lanatus*), *hawkbit and *Sebaea ovata*.
  - — Oioi – sea rush (*Juncus kraussii* subsp. *australiensis*) or three-square rushland with mat-forming halophytes (e.g. *Samolus repens*, *Selliera radicans* and *Sarcocornia quinquenervia*).
  - — Other shrub- and alien grass-dominated communities.

In 1989, *Sebaea ovata* was discovered at this site. At this time, it had not been reported in New Zealand for 17 years (Ogle 1991). Other threatened species that occur in the ephemeral wetlands at Whitiau include the chronically threatened *Isolepis basilaris, Mazus novaezelandiae* var. *impolitus* (both Serious Decline), *Selliera rotundifolia* and *Libertia peregrinans* (both Gradual Decline).

Ogle (1991) reported large areas of shallow standing water overlying much of the low, flat surfaces within the dunes for the six months between July and December, with the area surface-dry for the remaining six months. However, the prevalence of wetland plants at this site indicated that the water table remained high year-round.

Champion et al. (2003) studied the dynamics and ecology of *Sebaea ovata* at this location and Johnson & Rogers (2003) included the vegetation of the surrounding area in their report. Floristic records from both reports and Ogle (1997) are compared with plants recorded during this study in section 6.2.

5. Methods

5.1 DETERMINING SOIL FERTILITY AND PLANT TISSUE NUTRIENTS

5.1.1 Field sampling

Paired samples of vegetation (species composition/cover) and soil were collected during April and May 2002 from 12 sites in the three study areas: six amongst the sandplains on the Pouto Peninsula and six along the Wanganui Coast at Hawkens Lagoon and the Whitiau Scientific Reserve (see Figs 2 & 3). The sites had varying levels of weed invasion.

Vegetation composition and cover were described within two to four randomly placed quadrats (25 cm × 25 cm) at each site. Soil cores were taken from beneath a range of native and weed species using a volumetric soil corer (7 cm diameter × 10 cm deep) following the method described in Clarkson et al. (2003). Soil cores were sent to the Environmental Chemistry Laboratory (Landcare Research, Palmerston North) for analysis of total carbon (C), nitrogen (N) and phosphorus (P), acid-soluble P, % water and pH (methods in Blakemore et al. 1987).

In November 2002, belt transects (1 × 1 m quadrats laid end to end from start to finish of transect) for monitoring weed invasion were set up at, or adjacent to, 4 of the 12 study sites (Figs 2 & 3). Their locations and lengths are given in Table 1.

The fertility of the soils at each transect was determined from two to four soil samples taken at each transect site and analysed as described above. A further soil sample was taken at each site in December 2005 to determine whether there had been any change in soil fertility since 2002.

TABLE 1. LOCATIONS OF BELT TRANSECTS ESTABLISHED AT POUTO, HAWKENS LAGOON AND WHITIAU.

TRANSECT		NZMG COORDINATES		DISTANCE
		E	N	(m)
Pouto 1	Start	2602563	6540562	40
	Finish	2602526	6540579	
Pouto 2	Start	2602481	6539996	30
	Finish	2602458	6539996	
Hawkens	Start	2653240	6150399	30
	Finish	2653262	6150419	
Whitiau	Start	2689599	6128503	50
	Finish	2689563	6128539	

In addition to measuring soil fertility, levels of plant tissue nutrients (especially nitrogen (N) and phosphorus (P)) were also sampled. Plant tissue nutrient content and the ratio of N:P are indicative predictors of nutrient limitation (Clarkson et al. 2003) and there may be differences in the way alien and indigenous species accumulate these resources, perhaps explaining why there is increasing weed incursion in ephemeral wetland habitats.

Small samples (< 5 g) of young foliage were collected from the dominant species at each of the transect sites (see Table 2 for details of species, location and date). Samples were sent to the Environmental Chemistry Laboratory (Landcare Research, Palmerston North) for analysis of total N and P (www.landcareresearch.co.nz/services/laboratories/eclab/eclabmethods_plants.asp#206, viewed August 2007).

5.1.2 Treatment of data

Before analysis, all variables were tested for normality and transformed where necessary. Binary logistic regression was used to determine whether any of the soil variables or a combination of the variables best predicted whether the resulting vegetation would be dominated by indigenous ephemeral wetland species or alien weed species.

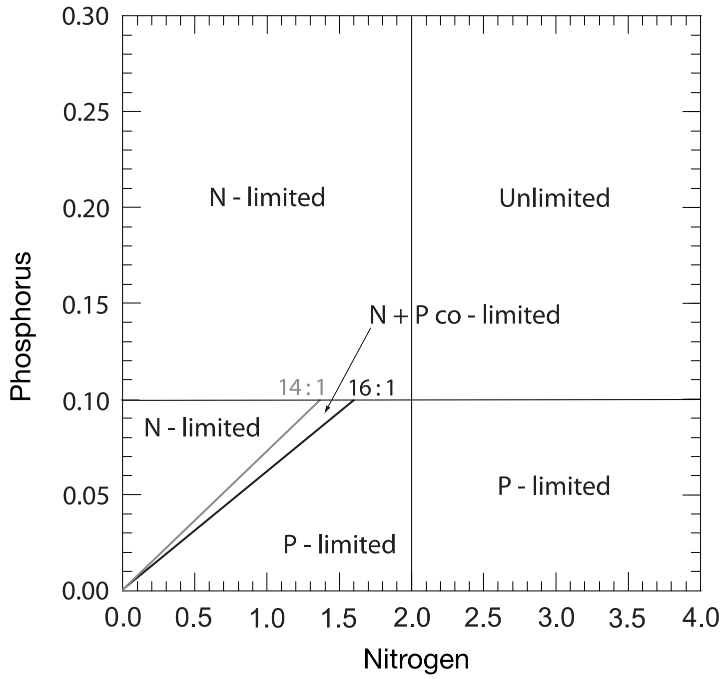
Plots of tissue N and P were made for all species to determine which species were N-limited (N:P < 14), P-limited (N:P > 16), or intermediate between these ratios (N and P co-limited). Where tissue P concentrations were > 0.1 % dry weight and N concentrations > 2%, then the plant would not be nutrient limited (Fig. 4).

TABLE 2. LIST OF DOMINANT SPECIES, THEIR LOCATION, DATE AND NUMBER OF SAMPLES COLLECTED FOR FOLIAR ANALYSIS.

SPECIES	POUTO NORTH		POUTO SOUTH		WHITIAU LAGOON		HAWKENS	
	2002	2005	2002	2005	2002	2005	2002	2005
Apodasmia similis	1		1					
*Blackstonia perfoliata**	1	1						
Carex pumilla			1					
*Cortaderia selloana**					1		1	
Epilobium billardiereanum	1		1					
Gunnera dentata	1		1		1		2	
*Holcus lanatus**	1	1					1	
*Hypochaeris radicata**							1	1
Isolepis cernua			1		1			
*Juncus articulatus**	1	1	1		1		1	
Juncus caespitosa			1	1				
*Leontodon taraxacoides**	1		1		1		1	
*Lotus pedunculatus**					1			
Myriophyllum votschii	1	1					1	
*Parentucellia viscosa**	1	1						
*Schedonorus phoenix**	1		1		1		1	
Schoenus nitens					1		1	
*Trifolium repens**					1		1	

* Alien species.

Figure 4. Plot of plant tissue nutrient concentration (% tissue nitrogen (N) and phosphorus (P)) showing areas representing nutrient limitation (from Clarkson et al. 2003).



5.2 TEMPORAL CHANGE IN HYDROLOGY AND VEGETATION

5.2.1 Hydrology

The height of the water table was monitored over a full year from November 2002 to November 2003 at the four transects. This was done by inserting a plastic pipe into the ground to below the water table at each transect and installing a NIWA Micrologger with a 5-m-range Kainga Pressure transducer to log the water level inside the pipe every 24 hours at midnight.

The topography of each transect was measured in relation to the top of the plastic pipe so that the height of the water table could be monitored in relation to the ground surface along each transect.

Annual rainfall data was obtained for the 1985–2006 period for the Arapohue, Northland and Spriggens Park, Wanganui stations (from NIWA CliFlo database: http://cliflo.niwa.co.nz/, accessed August 2007). This was to determine whether rainfall and, hence, groundwater levels during the monitoring period were typical or atypical.

5.2.2 Vegetation

As described in section 5.1, 12 reconnaissance sites of varying weed invasion status were visited during April and May 2002. At each location, species composition and cover were recorded in two to four randomly selected plots at the sites shown in Figs 2 & 3.

In November 2002, permanent belt transects were established to monitor weed invasion over a 4-year period. These were set up at, or adjacent to, 4 of the 12 reconnaissance sites (Figs 2 & 3). Transects were located to best represent the spectrum of weed invasion observed at the four sites and also to sample sites containing a range of endangered dune ephemeral wetland species. Transects were positioned across each ephemeral wetland to capture variations in ground height and the consequent water table effects and how these influence the distribution of weed species. Map coordinates for the start and end of each transect, and their lengths, are shown in Table 1.

To monitor alien weed invasion of the dune ephemeral wetland vegetation over time, the following variables were recorded in contiguous 1 m × 1 m plots along each transect:

- Cover and composition of all alien species
- Total cover of vegetation for each plot
- Dominant indigenous species
- Vegetation types along the transects were also recorded, based on the Atkinson (1985) classification system

The two transects at Pouto were surveyed on 20 November 2002, 14 November 2003 and 6 December 2005. The Whitiau Scientific Reserve and Hawkens Lagoon transects were surveyed on 6 November 2002, 20 February and 14 November 2003, and 15 December 2005.

A plant species list for the ephemeral wetlands at each location was collated (see Appendix 1).

6. Results

6.1 SOIL FERTILITY

Average total soil C, N, acid soluble P and C:N ratio for samples from the three study areas are shown in Table 3.

All the soils sampled had very low organic carbon and nitrogen content (especially those from Pouto), but there were significant differences in available P content between the three locations. There were no statistically significant differences in the measured parameters between the 2002 and 2005 samples.

There were no significant relationships between particular soil parameters and either alien or indigenous vegetation apart from pH ($P < 0.05$), with weed-dominated sites more commonly associated with lower pH soils. The indigenous *Gunnera dentata* and alien *Schedonorus phoenix* occurred on soils having very similar ranges for all the soil variables measured, including total C and total N. Some alien species grew on soils with low concentrations of all the measured soil nutrients. Only the indigenous *Triglochin striatum*-dominated community grew on soils with lower nitrogen concentrations than the lower limits for the weed communities.

The uptake of nutrients (% tissue N and P) by plants also showed no significant differences between indigenous and alien plants, nor was there any significant difference between sites (Figs 5 & 6) at the whole-community level. Nutrient limitation of four indigenous and four alien species, at one or more of the three locations, are shown in Table 4. In some cases, individual plants collected from the same site showed different nutrient responses in their tissues.

TABLE 3. AVERAGE (± SD) OF TOTAL SOIL CARBON (C), NITROGEN (N), AND ACID SOLUBLE PHOSPHORUS (P) AND C:N RATIO FOR SAMPLE SITES AT POUTO, HAWKENS AND WHITIAU.

	POUTO	HAWKENS	WHITIAU
%C	0.3 (± 0.4)	0.5 (± 0.7)	1.0 (± 0.7)
%N	0.1 (± 0.1)	0.7 (± 0.4)	0.2 (± 0.2)
H_2SO_4 soluble P (ppm)	75 (± 9)	323 (± 18)	698 (± 50)
C:N	18 (± 8)	19 (± 5)	16 (± 5)

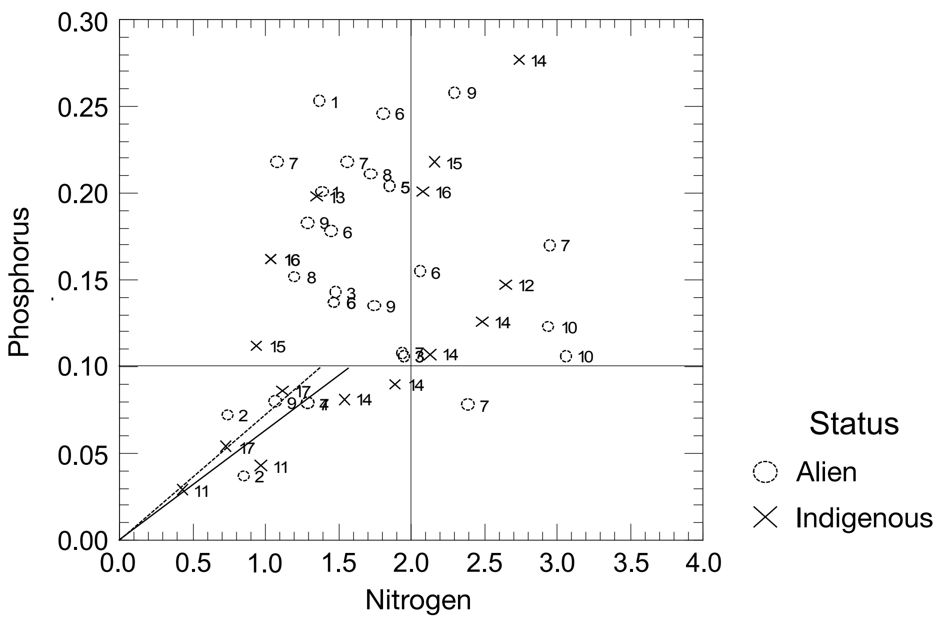


Figure 5. Plot of plant tissue nutrient concentration (refer to Fig. 4). Species labels are as follows: 1. *Blackstonia perfoliata*, 2. *Cortaderia selloana*, 3. *Holcus lanatus*, 4. *Hypochaeris radicata*, 5. *Juncus sonderanus*, 6. *J. articulatus*, 7. *Leontodon taraxacoides*, 8. *Lotus pedunculatus*, 9. *Schedonorus phoenix*, 10. *Trifolium repens*, 11. *Apodasmia similis*, 12. *Carex pumila*, 13. *Epilobium billardiereanum*, 14. *Gunnera dentata*, 15. *Isolepis cernua*, 16. *Myriophyllum votschii*, 17. *Schoenus nitens*.

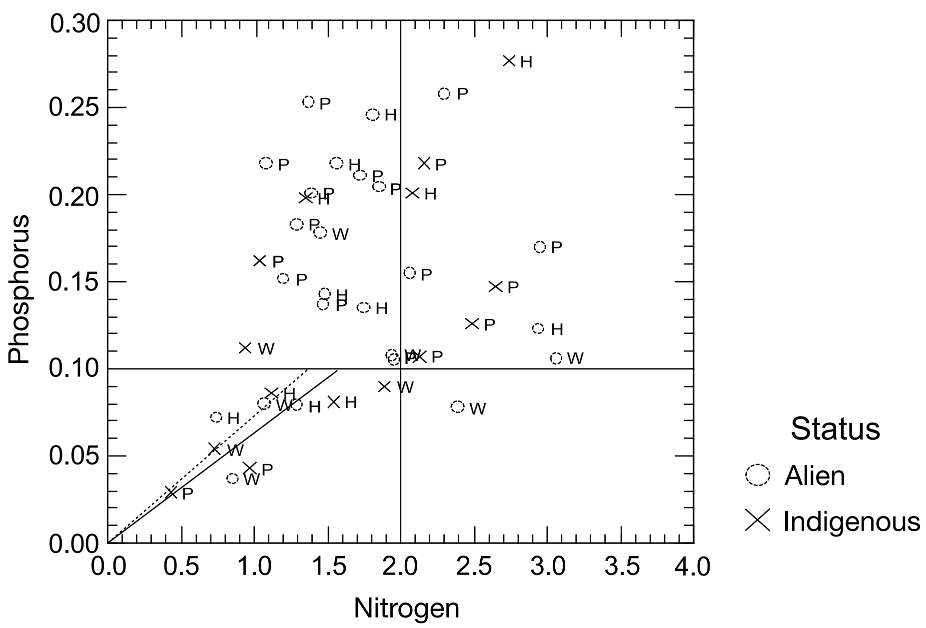


Figure 6. Plot of plant tissue nutrient concentration (refer to Fig. 4) at Pouto (P), Hawkens Lagoon (H) and Whitiau (W).

TABLE 4. DIFFERENCES IN NUTRIENT LIMITATION IN INDIGENOUS AND ALIEN EPHEMERAL WETLAND SPECIES SAMPLES INFERRED FROM VEGETATION NITROGEN:PHOSPHORUS (N:P) RATIOS.

Results are for individual plant samples gathered at Pouto, Hawkens Lagoon and Whitiau (several samples of each species were collected).

SPECIES	NUTRIENT STATUS				
	P - LIMITED	N - LIMITED		N & P CO-LIMITED	UNLIMITED
		P < 0.1%	P > 0.1%		
INDIGENOUS					
Apodasmia similis	Pouto			Pouto	
Gunnera dentata	Pouto, Whitiau				Pouto Hawkens
Myriophyllum votschii			Pouto		Hawkens
Schoenus nitens		Hawkens		Whitiau	
ALIEN					
Cortaderia selloana	Whitiau	Hawkens			
Holcus lanatus		Whitiau	Hawkens		
Schedonorus phoenix		Whitiau	Pouto Hawkens		Pouto
Trifolium repens					Hawkens Whitiau

There appears to be no significant correlation of increased soil fertility (N and P) or soil organic content with the occurrence of alien rather than indigenous plant species (Figs 7 & 8).

6.2 TEMPORAL CHANGE IN HYDROLOGY AND VEGETATION

6.2.1 Hydrology

Unfortunately, we discovered at the end of the monitoring period that the plastic pipe for water level monitoring at Whitiau had been sunk into a perched water table unrelated to the water table along the belt transect. Consequently, water table data cannot be related to the ground surface at this site.

Variations in water table at the two Pouto sites and Hawkens Lagoon are shown in Figs 9, 10 & 11. These figures represent water level relative to the borehole and distances measured along each vegetation transect. Diagrammatic representation of the elevation along each vegetation transect relative to average, minimum and maximum water level are shown in Figs 12, 13, 14 & 15, along with spatial distribution of selected alien plant species.

The ranges in elevation of the four transects are shown in Figs 12 to 15.

Annual rainfall data from the closest meteorological stations to each site is shown in Table 5.

The year 2003 produced the second-highest yearly rainfall for the 20 monitoring years from 1985 to 2006 at Arapohue, Northland, whereas Wanganui in 2003 received the sixth lowest rainfall for the same 20-year period. Thus, during the

Figure 7. Range of A—soil water content, B—pH and C—% total carbon measured for soils collected from beneath indigenous (upper groups) and alien (lower groups) of plants at Pouto, Hawkens Lagoon and Whitiau.

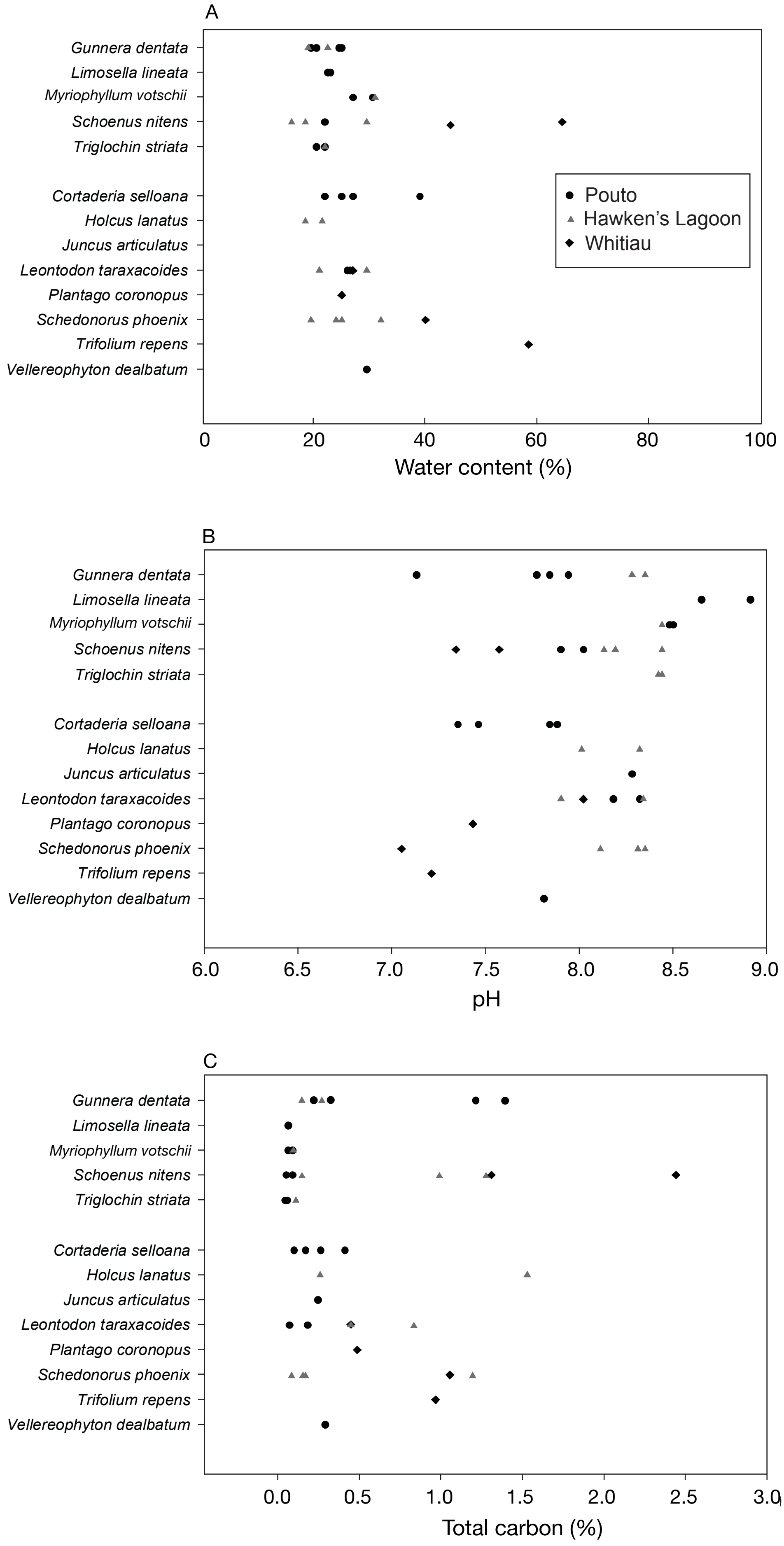


Figure 8. Range of A—soil % total nitrogen, B—C:N ratio and C-acid extractible phosphorus measured for soils collected from beneath indigenous (upper groups) and alien (lower groups) of plants at Pouto, Hawkens Lagoon and Whitiau.

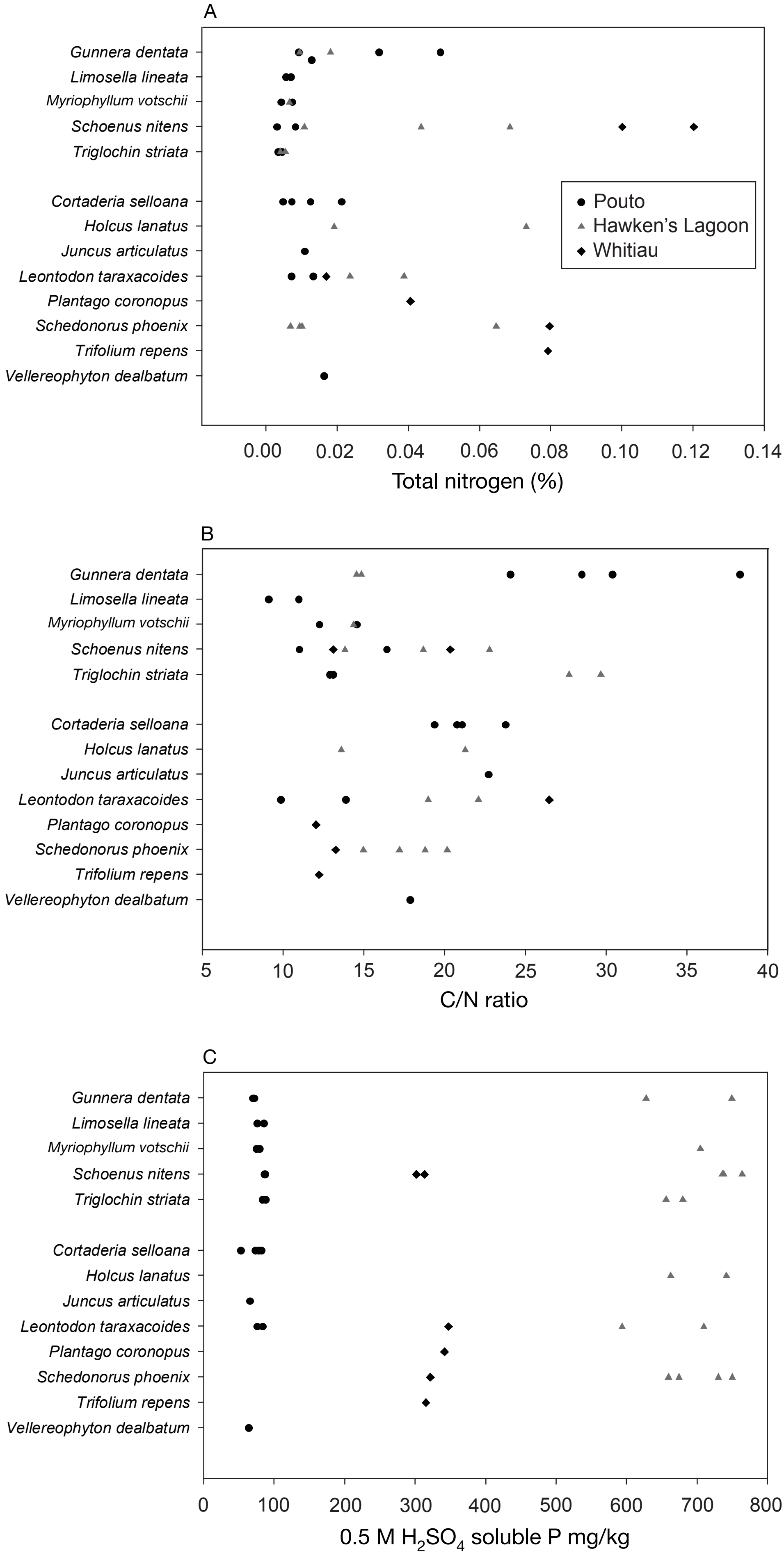


Figure 9. Plot of water table fluctuations from November 2002 to November 2003 at Transect 1, Pouto. Horizontal lines on the figure show the positions of the highest and lowest points on the transect in relation to the height of the water-recording bore and water level. Numbers to the right of the graph refer to the distance along Transect 1 of the highest and lowest points. For example, the lowest point on Transect 1 was 25 m along the transect.

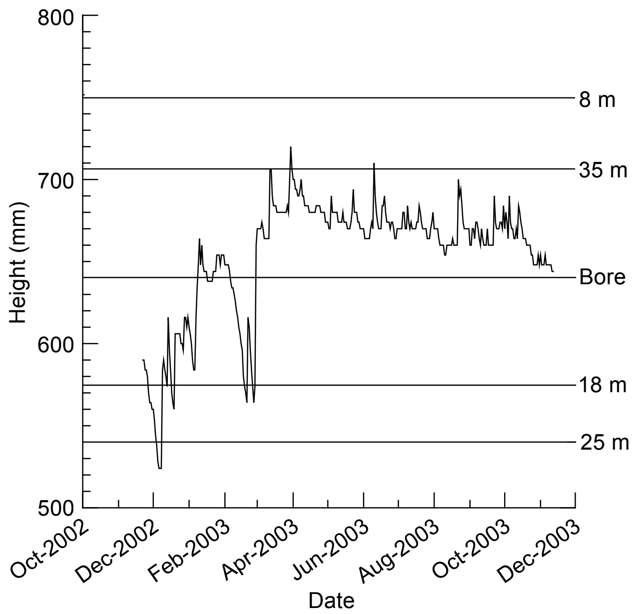


Figure 10. Plot of water table fluctuations from November 2002 to November 2003 at Transect 2, Pouto. Horizontal lines on the figure show the positions of the highest and lowest points on Transect 2 in relation to the height of the water-recording bore and water level. Numbers to the right of the graph refer to the distance along Transect 2 of the highest and lowest points. For example, the lowest point on Transect 2 was 9 m along the transect.

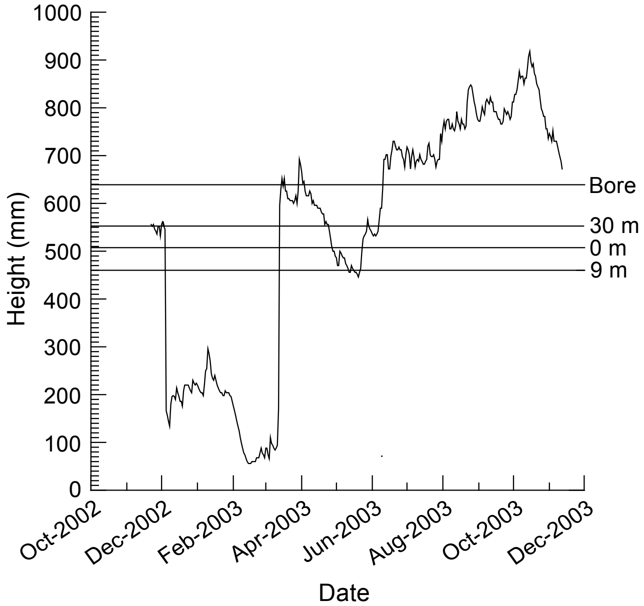
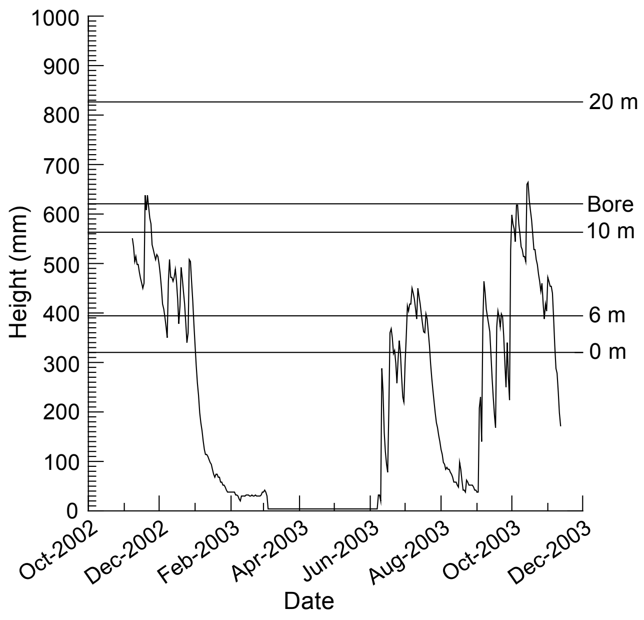


Figure 11. Plot of water table fluctuations from November 2002 to November 2003 at the Hawkens Lagoon transect. Horizontal lines on the figure show the positions of the highest and lowest points on the Hawkens Lagoon transect in relation to the height of the water-recording bore and water level. Numbers to the right of the graph refer to the distance along the transect of the highest and lowest points. For example, the lowest point on the Hawkens Lagoon transect was at the start of the transect (0 m). Note that between early March and the beginning of June 2003, water levels fell below the sensor's range.



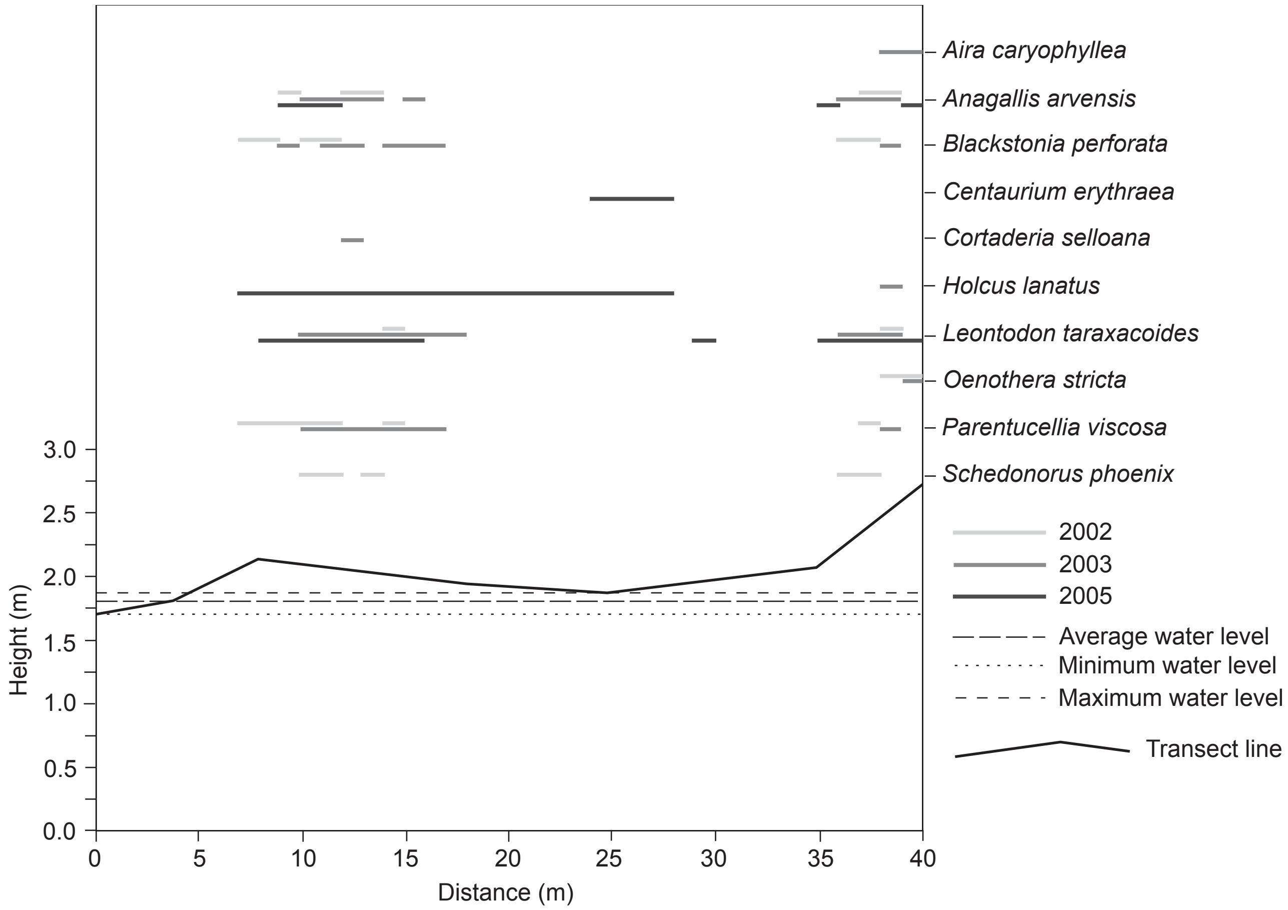


Figure 12. Diagrammatic representation of the elevation along Transect 1 at Pouto (heavy black line), with average, maximum and minimum water levels (straight solid black and hatched lines) recorded from November 2002 to November 2003. Horizontal bars show the distribution of alien plant species recorded in November 2002 (pale grey), November 2003 (mid grey) and December 2005 (dark grey).

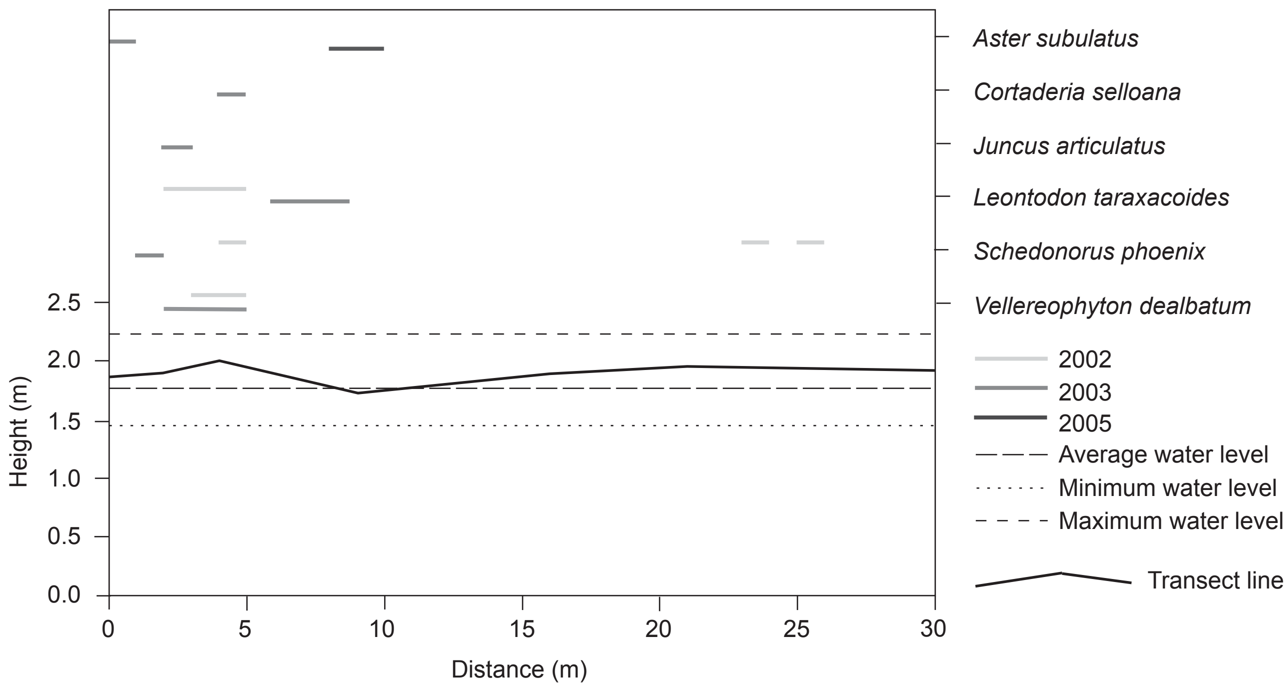


Figure 13. Diagrammatic representation of the elevation along Transect 2 at Pouto (heavy black line), with average, maximum and minimum water levels (straight solid black and hatched lines) recorded from November 2002 to November 2003. Horizontal bars show the distribution of alien plant species recorded in November 2002 (pale grey), November 2003 (mid grey) and December 2005 (dark grey).

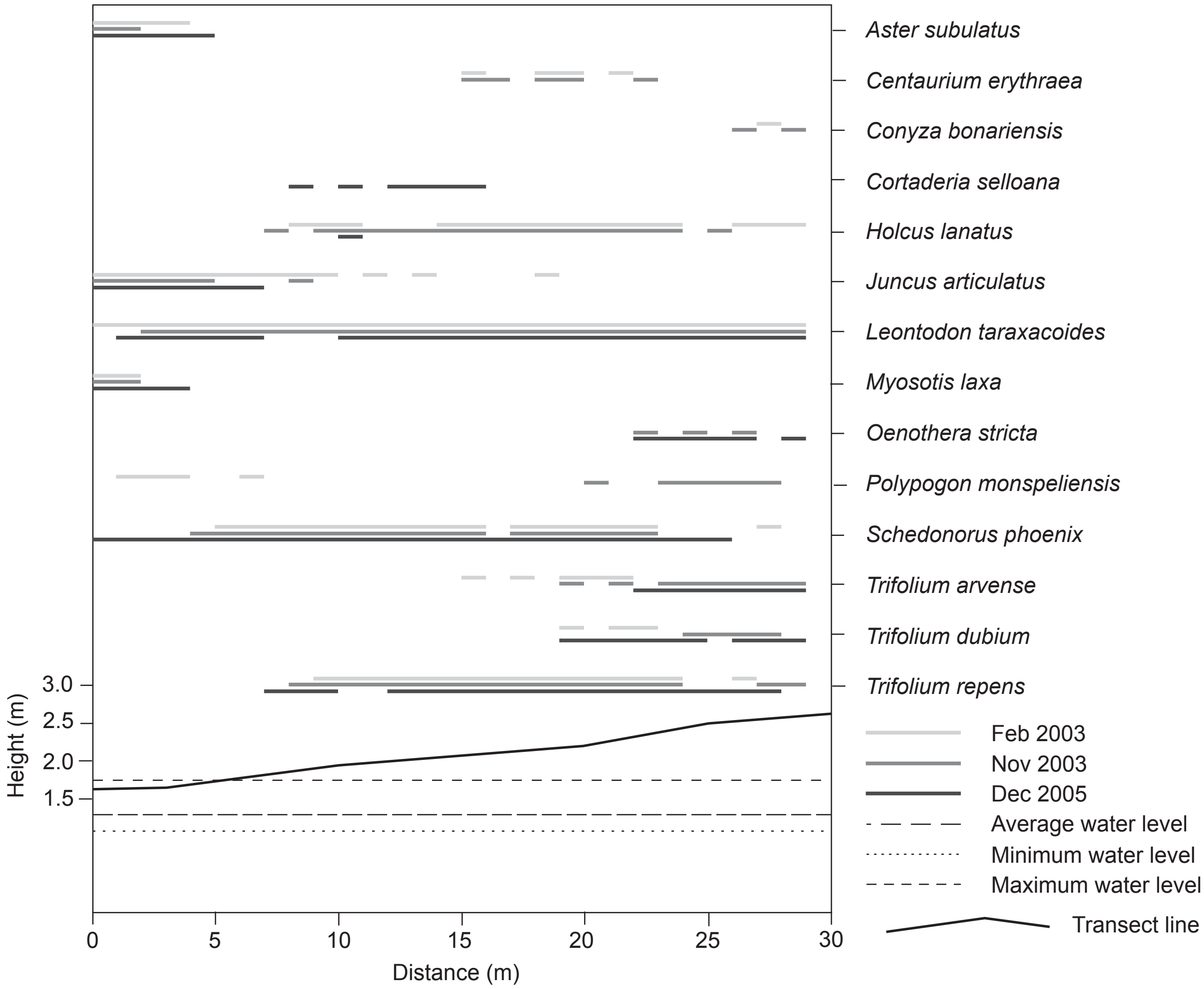


Figure 14. Diagrammatic representation of the elevation along the Hawkens Lagoon transect (heavy black line), with average, maximum and minimum water levels (straight solid black and hatched lines) recorded from November 2002 to November 2003. Horizontal bars show the distribution of alien plant species recorded in February 2003 (pale grey), November 2003 (mid grey) and December 2005 (dark grey).

water level measuring period, Pouto is likely to have received over 200 mm more than the average rainfall, while Hawkens Lagoon and Whitiau received close to 150 mm less than the average. Over the 4 years of vegetation monitoring (2002 to 2005), rainfall was slightly higher than average (13 mm at Arapohue and 34 mm at Wanganui).

6.2.2 Vegetation sampled in 2002

Pouto

Site 1 NZMG 2602541E 6540553N *Gunnera dentata* herbfield (92% cover)

Gunnera dentata formed an average of 85% cover with lesser amounts (in decreasing order of cover) of *Schoenus nitens, Lobelia anceps* and *Ficinia nodosa*. Alien species included *Juncus sonderianus, Leontodon taraxacoides* and *Blackstonia perfoliata*, but alien species collectively only occupied an average of 3% cover of this vegetation.

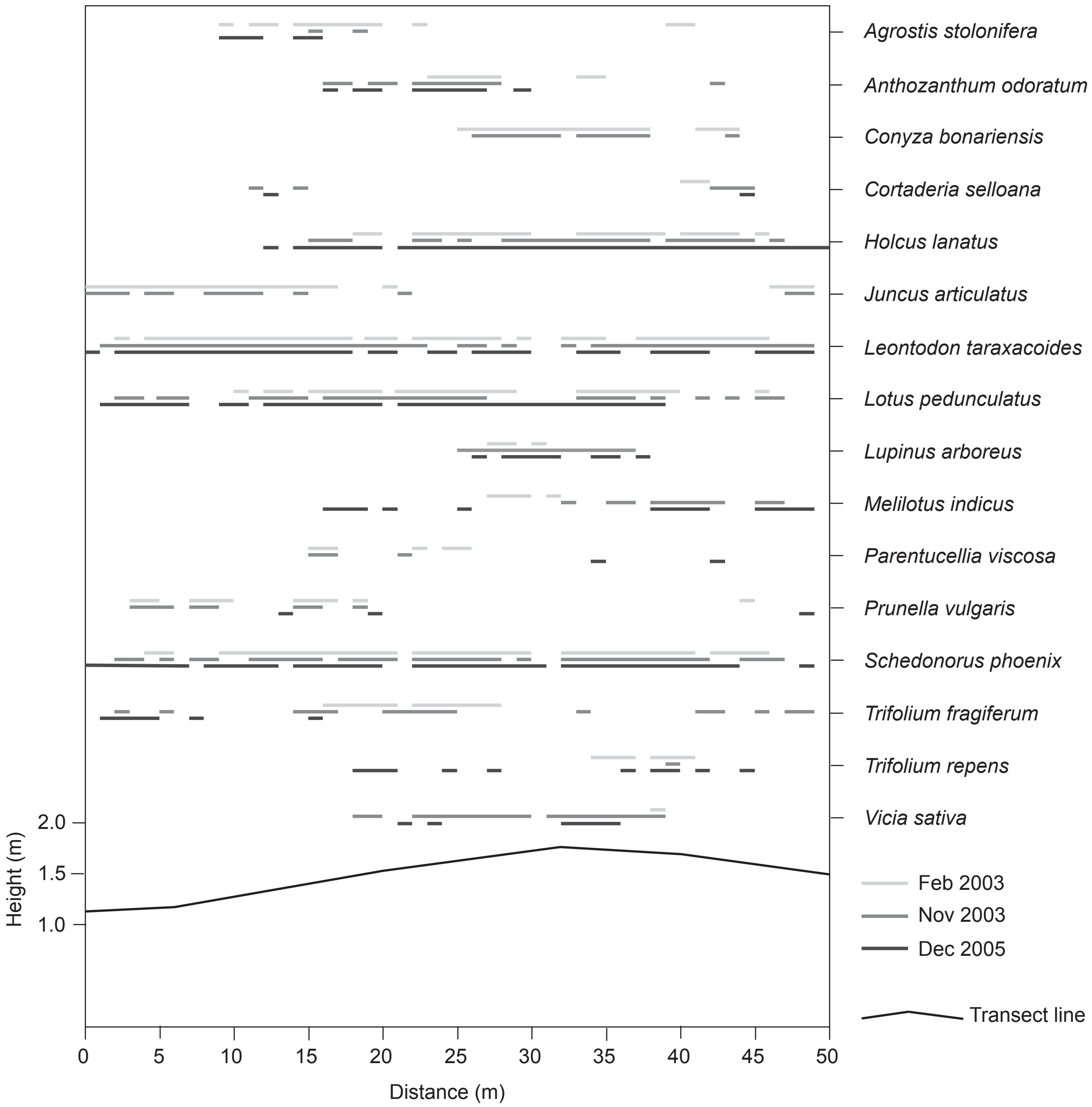


Figure 15. Diagrammatic representation of the elevation along the Whitiau transect (heavy black line). Horizontal bars show the distribution of alien plant species recorded in February 2003 (pale grey), November 2003 (mid grey) and December 2005 (dark grey).

TABLE 5. ANNUAL RAINFALL DATA FOR ARAPOHUE (CLOSEST TO POUTO) AND SPRIGGENS PARK, WANGANUI (CLOSEST TO HAWKENS AND WHITIAU) FOR YEARS 2002–05 COMPARED WITH MEAN ANNUAL RAINFALL FROM 1985 TO 2006.

Data from NIWA CliFlo database.

DATE	ANNUAL RAINFALL (mm)	
	ARAPOHUE	WANGANUI
2002	1094.8	1007.4
2003	1368.1	809.2
2004	1215.9	1131.0
2005	1004.8	965.6
1985–2006 average	1158.1 (±159.4 SD)	944.6 (±138.7 SD)

Site 2 NZMG 2602526E 6540558N *Myriophyllum votschii-Nitella hyalina* herbfield (50% cover)

Myriophyllum votschii formed an average 30% cover, with lesser amounts (in decreasing order of cover) of *Nitella hyalina*, *Carex pumila* and *Apodasmia similis.* The chronically threatened *Eleocharis neozelandica* was rare (< 1% cover) in this vegetation. The sole alien species was *Juncus sonderianus*, present at an average cover of 5%.

Site 3 NZMG 2602430E 6540553N *Triglochin striatum-Eleocharis neozelandica* herbfield (12% cover)

Triglochin striatum and *Eleocharis neozelandica* formed very open vegetation with average percentage covers of 8% and 3% respectively. The only additional species was *Isolepis cernua.*

Site 4 NZMG 2602431E 6540266N *Eleocharis neozelandica-Limosella lineata-Triglochin striatum* herbfield (60% cover)

The three herbs *Eleocharis neozelandica, Limosella lineata* and *Triglochin striatum* occupied an average of 14%, 12% and 10% cover respectively. There were lesser amounts of (in decreasing order of cover) *Isolepis cernua, Schoenus nitens* and *Lilaeopsis novae-zelandiae.* The alien species *Juncus articulatus* was locally abundant, present at a cover of 70% in one quadrat. *Juncus sonderianus* was also present in this vegetation, with alien species comprising an average total cover of 20%.

Site 5 *Apodasmia similis/Gunnera dentata* rushland/herbfield (40% cover)

Apodasmia similis formed an open rushland (25% cover) interspersed with a herfield dominated by *Gunnera dentata* (forming an average cover of 25%). No other indigenous species exceeded an average cover of 1%. Alien species included (in decreasing order of cover) *Cortaderia selloana*, *Aira caryophyllea*, *Blackstonia perfoliata*, *Centaurea erythraea*, *Juncus sonderianus*, *Leontodon taraxacoides*, *Lotus pedunculatus* and *Ornithopus pinnata* but, collectively, only contributed an average of 2% cover.

Site 6 NZMG 2602541E 6540553N *Apodasmia similis* rushland (30% cover)

Apodasmia similis formed an open rushland (20% cover). There were lesser amounts (in decreasing order of cover) of *Carex pumila*, *Isolepis cernua*, *Lobelia anceps* and *Schoenoplectus tabernaemontani*. Alien species included (in decreasing order of cover) *Juncus articulatus*, *Leontodon taraxacoides*, *Aster subulatus*, *Blackstonia perfoliata* and *Ornithopus pinnata* but, collectively, they only occupied an average of 7% cover.

Transects

The two transects were located to the north (Transect 1) and south (Transect 2) of the five vegetation types sampled in April 2002 at the 'Causeway' area (Fig. 2). The vegetation of these transects was sampled in November 2002. Changes in transect vegetation and alien species distribution between 2002 and 2005 are presented in Section 6.2.3.

Transect 1 contained similar vegetation to Sites 1, 2 (wettest), 3 and 5 (driest), and dryland vegetation comprising:

- *Spinifex sericeus* grassland (10% cover):
  Spinifex sericeus formed a sparse cover (5% cover) with lesser amounts of the chronically threatened *Desmoschoenus spiralis* (Gradual Decline) and *Coprosma acerosa*.

Average percentage cover over the entire transect was 40%. Alien species were a minor component of this vegetation with the following species (in decreasing order of cover) recorded in 2002: *Anagallis arvensis*, *Leontodon taraxacoides*, *Parentucellia viscosa*, *Blackstonia perfoliata*, *Juncus sonderianus*, *Schedonorus phoenix*, *Vellereophyton dealbatum* and *Ornithopus pinnata.* Collectively, these species occupied an average 1% cover.

Transect 2 had similar vegetation to Site 3, but was dominated by open *Carex pumila* (average cover of 20%) and also included *Isolepis cernua*, *Lobelia anceps*, *Lilaeopsis novae-zelandiae* and very localised *Gunnera dentata*. Alien species recorded in 2002 included (in decreasing order of cover) *Leontodon taraxacoides*, *Schedonorus phoenix*, *Vellereophyton dealbatum* and *Blackstonia perfoliata*, all associated with *Gunnera dentata* and occupying an average cover of 7.5%; this value predominantly reflecting high (38%) covers of *L. taraxacoides* in two of the transect's 1-m^2 quadrats.

Hawkens Lagoon

Site 1 NZMG 2654181E 6149854N *Triglochin striatum* herbfield (25% cover)

Triglochin striatum dominated very open wet vegetation with average percentage covers of 8%. Other indigenous species present included *Myriophyllum votschii* and *Schoenoplectus pungens*. Alien species were *Juncus articulatus* and *Aster subulatus* which, together, comprised an average 10% cover.

Site 2 NZMG 2654197E 6149884N *Gunnera dentata* herbfield (85% cover)

Gunnera dentata formed an average of 40% cover with lesser amounts of (in decreasing order of cover) *Lobelia anceps* and *Carex pumila*. Alien species included *Holcus lanatus*, *Leontodon taraxacoides*, *Trifolium repens* and *Schedonorus phoenix*. These occupied, collectively, an average 40% cover.

Site 3 NZMG 2653241E 6150406N *Myriophyllum votschii-Schoenus nitens* herbfield (90% cover)

Myriophyllum votschii formed an average 50% cover with lesser amounts of (in decreasing order of cover) *Schoenus nitens, Carex pumila* and *Lobelia anceps.* Alien species included (in decreasing order of cover) *Leontodon taraxacoides* and *Aster subulatus*. Together, these covered an average 13% of each quadrat sampled.

Site 4 NZMG 2653250E 6150401N *Holcus lanatus/Schoenus nitens* grassland (90% cover)

The alien grass *Holcus lanatus* occupied an average cover of 35% in this vegetation, overtopping the indigenous *Schoenus nitens* (20% cover), with lesser amounts of *Gunnera dentata* and *Carex pumila.* The acutely threatened *Sebaea ovata* was found in one quadrat associated with high percentage covers of *Schoenus nitens* and *Gunnera dentata*, but only 2% cover of alien grasses. In addition to *Holcus lanatus*, alien species included (in decreasing order of cover) *Trifolium repens*, *Leontodon taraxacoides*, *Schedonorus phoenix* and *Juncus articulatus.* Total average alien species cover was 60%.

The Hawkens Lagoon Transect was situated adjacent to and contained similar vegetation to Sites 3 and 4, but also included a dryland vegetation:

- *Trifolium* spp. herbfield (70% cover):
  The alien clovers *Trifolium arvense*, *T. dubium* and *T. repens* formed a combined average cover of 45%. The only indigenous components of this vegetation were *Ficinia nodosa* and *Carex pumila* (combined average cover of 7%). Other alien species were (in decreasing order of cover) *Lagurus ovatus*, *Leontodon taraxacoides* and *Oenothera stricta*.

Whitiau

Site 1 NZMG 2689191E 6127939N (*Ficinia nodosa*)/*Schoenus nitens* herbfield (90% cover).

Low covers (average 18%) of *Ficinia nodosa* grew emergent above a herbfield dominated by *Schoenus nitens* which had an average cover of 25%. No other indigenous species contributed > 1% cover. Alien species were abundant with (in decreasing order of cover) *Schedonorus phoenix*, *Leontodon taraxacoides*, *Holcus lanatus*, *Trifolium repens*, *Plantago coronopus* and *Lotus pedunculatus* together comprising an average 45% of each quadrat sampled.

Site 2 NZMG 2689599E 6128503N (*Apodasmia similis*)/*Schoenus nitens* herbfield (90% cover).

Low covers (average 12%) of *Apodasmia similis* grew emergent above a herbfield dominated by *Schoenus nitens* (average cover 30%). No other indigenous species contributed > 1% cover; however, the acutely threatened *Sebaea ovata* and the chronically threatened *Isolepis basilaris*, *Mazus novaezelandiae* var. *impolitus*, *Selliera rotundifolia* and *Libertia peregrinans* were all recorded in this vegetation outside of the sampled quadrats. Alien species included (in decreasing order of cover) *Juncus articulatus*, *Schedonorus phoenix*, *Leontodon taraxacoides* and *Sporobolus africanus*, together comprising an average 5% of each quadrat sampled.

The Whitiau Transect began in the vegetation sampled as Site 2 but also included the following vegetation types:

- *Apodasmia similis* rushland (100% cover):
  Apodasmia similis dominated much of the transect, with average covers ranging from 60% to 100%. Associated indigenous species included *Coprosma acerosa*, *Ficinia nodosa* and *Schoenus nitens,* with low covers of the chronically threatened *Libertia peregrinans.* Alien species included (in decreasing order of cover) *Schedonorus phoenix, Leontodon taraxacoides*, *Lupinus arboreus* and *Holcus lanatus*, together comprising an average 15% of each quadrat sampled.

- (*Apodasmia similis*)/*Paspalum dilatatum-Schedonorus phoenix* grassland (95% cover):
  The alien grasses *Paspalum dilatatum* and *Schedonorus phoenix* occupied an average of 50% of this vegetation, with a further 30% occupied by *Juncus articulatus.* Indigenous species with covers > 1% were *Apodasmia similis* (10% cover) and *Schoenus nitens* (5% cover). Fertiliser was applied to this area by DOC several months prior to the commencement of the trial (J. Campbell pers. comm.).

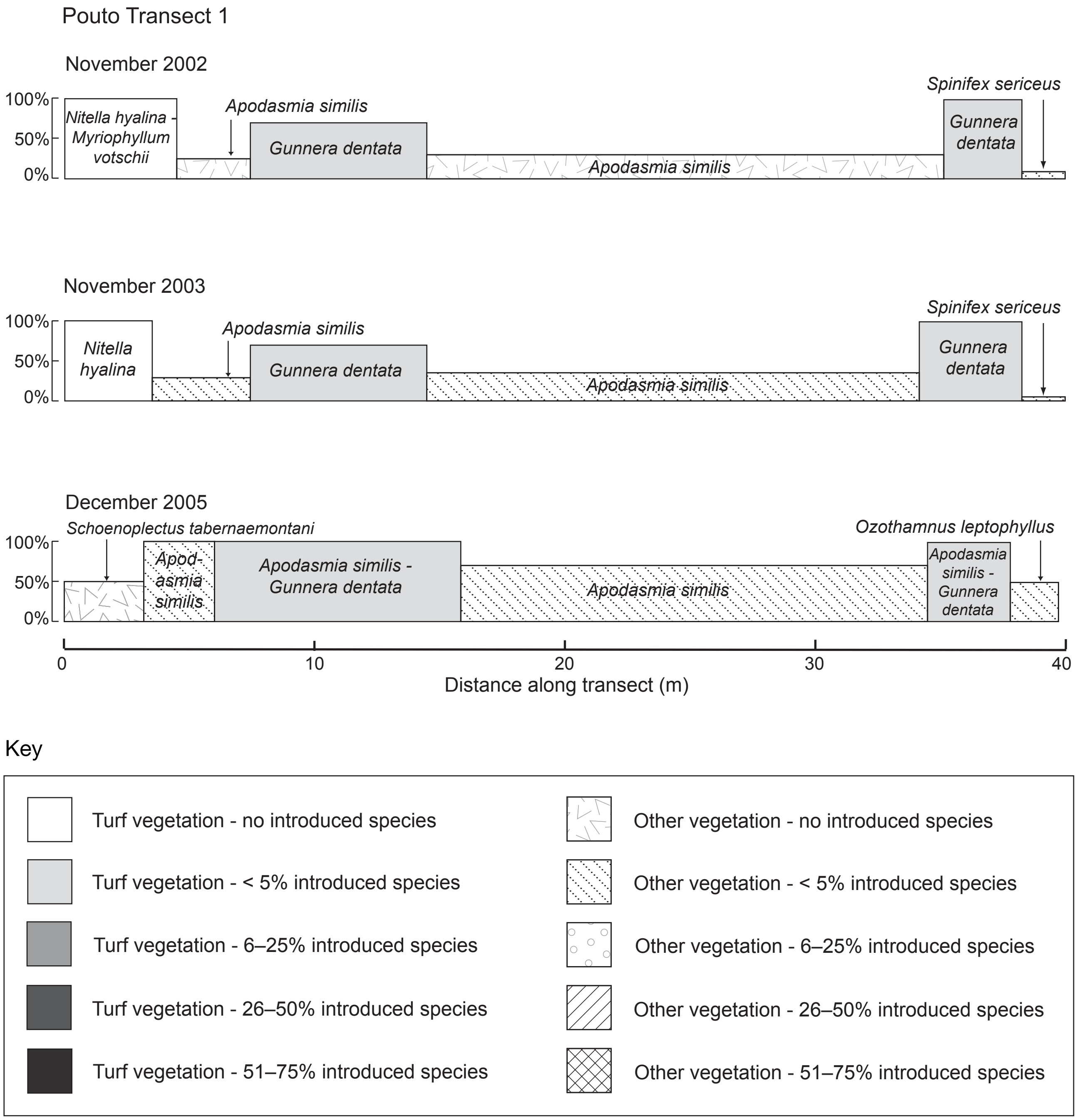


Figure 16. Change in vegetation types on Transect 1 at Pouto monitored in 2002, 2003 and 2005. Vegetation types are based on the dominant species ranked by percentage cover. Height of each box represents total average percentage cover of that vegetation type. Width of each box represents the area of the transect occupied by that vegetation type. Intensity of shade/fill pattern of each box represents proportion of alien species in each vegetation type.

- *Gunnera dentata* and *Juncus articulatus* herbfields (25% and 8% cover respectively):
  Two small areas within the transect had been scraped to remove existing vegetation (J. Campbell pers. comm.). One scrape was dominated by *Gunnera dentata* (15%), with smaller amounts of the chronically threatened *Isolepis basilaris* and the alien *Juncus articulatus.* The latter species dominated (5% cover) a sparsely vegetated second scrape that also contained *Schoenus nitens* and the chronically threatened *Selliera rotundifolia.*

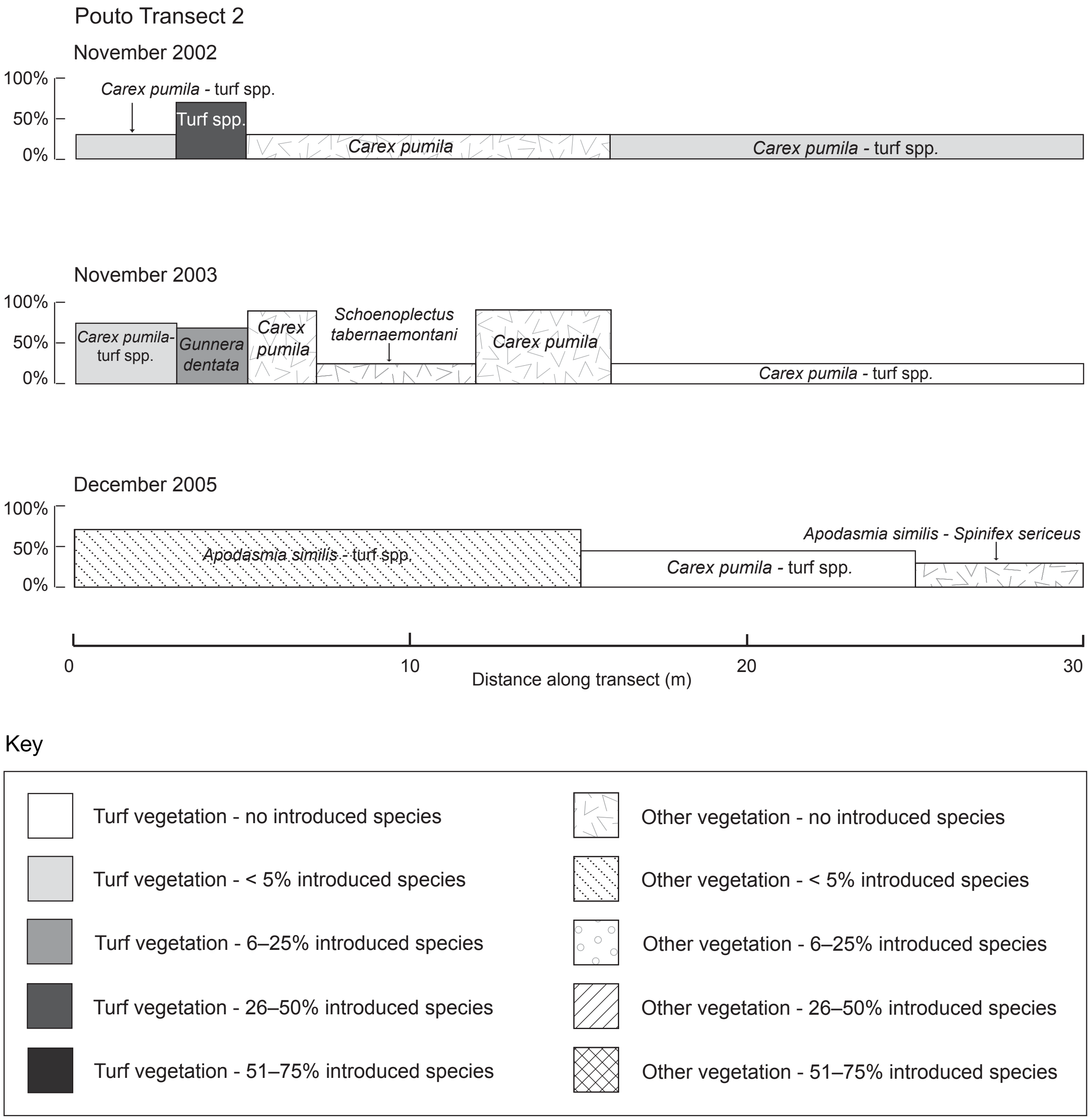


Figure 17. Change in vegetation types on Transect 2 from Pouto monitored in 2002, 2003 and 2005. Vegetation types are based on the dominant species ranked by percentage cover. Height of each box represents total average percentage cover of that vegetation type. Width of each box represents the area of the transect occupied by that vegetation type. Intensity of shade/fill pattern of each box represents proportion of alien species in each vegetation type.

6.2.3 Change in vegetation transects between 2002 and 2005

Figures 12–15 show the change in extent of alien species in the four transects over 3 monitoring periods. Figures 16–19 diagrammatically represent changes to the vegetation types identified and the percentage cover of alien species on these transects. The details of the monitoring carried out at the four transects are provided in Appendices 2, 3, 4 and 5. The changes observed are discussed in section 7.3 below.

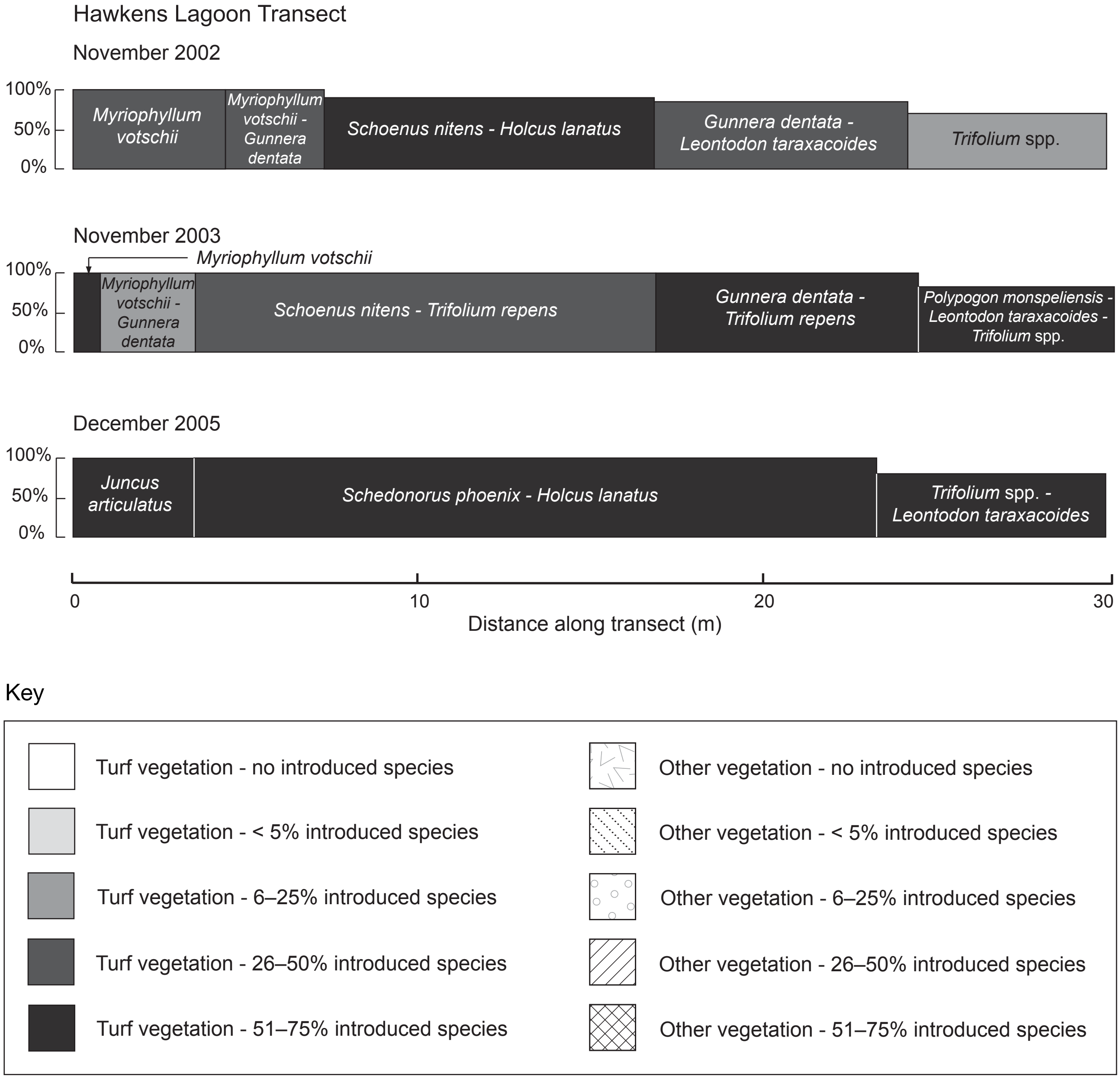


Figure 18. Change in vegetation types on the transect from Hawkens Lagoon monitored in 2002, 2003 and 2005. Vegetation types are based on the dominant species ranked by percentage cover. Height of each box represents total average percentage cover of that vegetation type. Width of each box represents the area of the transect occupied by that vegetation type. Intensity of shade/fill pattern of each box represents proportion of alien species in each vegetation type.

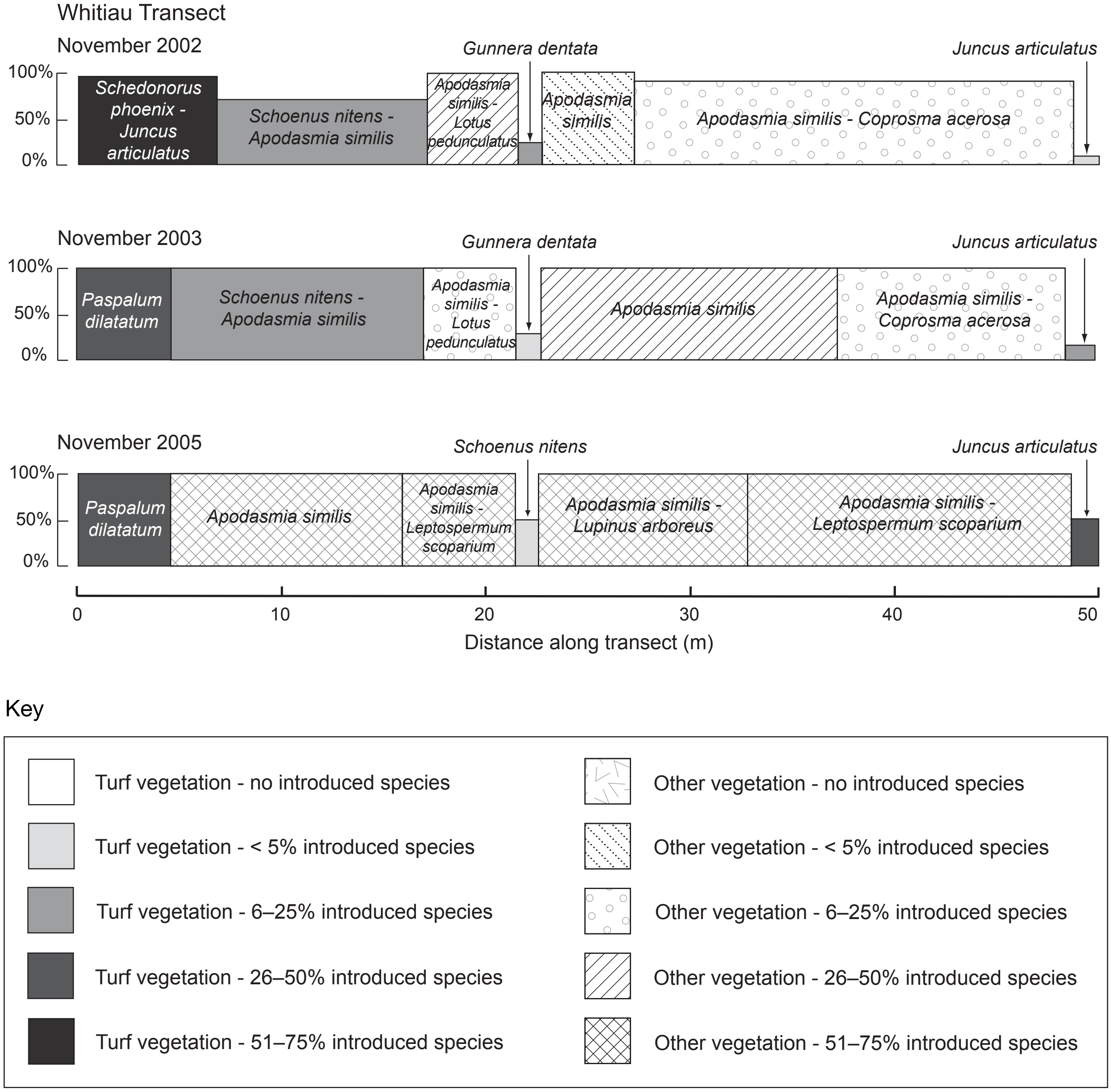


Figure 19. Change in vegetation types on the transect from Whitiau monitored in 2002, 2003 and 2005. Vegetation types are based on the dominant species ranked by percentage cover. Height of each box represents total average percentage cover of that vegetation type. Width of each box represents the area of the transect occupied by that vegetation type. Intensity of shade/fill pattern of each box represents proportion of alien species in each vegetation type.

7. Discussion

7.1 SOIL FERTILITY AND NUTRIENT ASSIMILATION

The sandy soils characteristic of coastal dune ephemeral wetlands were (unsurprisingly) very low in organic matter and nitrogen. Cyanobacteria with the capacity to fix atmospheric N were commonly encountered in wetter soils, including *Nostoc* 'balls'. Available phosphorus levels varied from site to site, with those measured for Whitiau and Hawkens Lagoon soils being 4 × and 9 × greater than levels measured at Pouto. However, the Pouto soils, with acid soluble P of 75 ppm, were still relatively high in P compared with most wetland soils (B. Sorrell, NIWA Christchurch, pers. comm.).

The only soil variable where there was a significant difference was pH. Of the species sampled, indigenous turf species including *Limosella lineata, Myriophyllum votschii* and *Triglochin striatum* grew on soils with a pH range of 8.5 to 9, with only one alien species (*Juncus articulatus*) occurring in this vegetation. These indigenous species were all restricted to the wettest sites and were not apparently threatened by weed incursion, apart from Hawkens Lagoon, where *J. articulatus* increased in area at the apparent expense of *M. votschii*. This change occurred during an unusually dry period (see section 6.1.2).

The indigenous *Gunnera dentata* and *Schoenus nitens* and the alien *Schedonorus phoenix* and *Leontodon taraxacoides* occurred on soils with a wide range of nutrient, pH and C levels. Some alien species (e.g. *Cortaderia selloana*) grew on soils with low concentrations of all the soil nutrients.

Similarly, N:P ratios in plant tissues did not show any significant correlation of weed species assimilation of nutrients compared with those of indigenous plants, neither was there any pattern relating to site (Figs 5–8). Surprisingly, 11 of the 39 samples taken were classified as nutrient unlimited, including 6 indigenous and 5 alien species. Five of these species were N-fixers (either *Rhizobium*-legume or *Nostoc-Gunnera* systems), able to supplement the N supplied by soils. Of the nutrient-limited species, N-limited species were the most abundant, with 18 plants (including 14 alien spp.) occurring where the concentration of P was $>0.1\%$, and 3 (including 2 alien spp.) where concentration of P was $<0.1\%$. Of the 5 P-limited and 2 co-limited species, 5 were indigenous and 2 alien (Table 4). The species with lowest concentrations of both N and P include the indigenous *Apodasmia similis, Schoenus nitens* and the alien *Cortaderia selloana*.

Thus, although the dataset is limited, it does appear that alien weed species are able to grow on the same substrates and utilise nutrient-poor soils as efficiently as indigenous species. Therefore, nutrient availability (or lack of it) does not necessarily influence the distribution of these alien species. However, where localised nutrient inputs were observed (e.g. bird roosting sites at Pouto and the nutrient enrichment area at Whitiau), some alien species were more abundant (e.g. *Juncus articulatus* and *Leontodon taraxacoides* at Pouto) or different alien species occurred (e.g. *Paspalum dilatatum* and *Agrostis stolonifera* rather than *Holcus lanatus* at Whitiau). However, such nutrient enrichment is very localised and, in the case of Pouto, the indigenous *Gunnera dentata* appeared to expand into one such area (Transect 2) at the expense of alien species. Interestingly, the endangered *Mazus novaezelandiae* var. *impolitus* colonised the fertilised area at Whitiau some 3 years after the addition of fertiliser.

7.2 HYDROLOGY AND CHANGES IN TOPOGRAPHY

The distribution of many alien species appears to relate to transect elevation and is therefore likely to be determined by hydrology. Figures 9–11 and 12–14 show the variations in water level experienced over a 12-month monitoring period from November 2002 to November 2003, water height over that time at points along the vegetation transects, and distribution of alien species. The perched water table at Whitiau likely kept the sites with the lowest elevations wet for much of the year, but sites above 1.5 m elevation (Fig. 15) were most unlikely to have experienced inundation (based on distribution of terrestrial plant species). No standing water was recorded on the Whitiau transect during the 2002–05 monitoring periods.

The following alien species were found in all but the permanently wet or permanently dry dune vegetation types: *Leontodon taraxacoides*, *Lotus pedunculatus* (absent from Pouto sites) and *Schedonorus phoenix*. The alien annual grass *Polypogon monspeliensis* was noted amongst both the wettest and driest quadrats at Hawkens Lagoon on different monitoring occasions. This species is probably able to opportunistically colonise the open areas present at those sites when moisture levels permit (i.e. when the wet sites are dewatered during drought, or after sustained rains at the dry sites).

Alien species tolerant of the wettest areas include *Juncus articulatus*, *Agrostis stolonifera*, *Aster subulatus*, *Cyperus congestus* and *Myosotis laxa* (the latter species restricted to the wettest sites). *Juncus articulatus* and *A. stolonifera* were also present in vegetation in seasonally wet areas and *J. articulatus* increased in abundance to displace aquatic vegetation at Hawkens Lagoon after a drier than average year.

Alien species found in other seasonally wet turf vegetation, but rarely in taller vegetation, include *Juncus sonderianus*, *Bromus diandrus*, *Cynosurus cristatus*, *Paspalum dilatatum*, *Sporobolus africanus*, *Conyza* spp., *Vellereophyton dealbatum*, *Trifolium fragiferum*, *Anagallis arvensis*, *Blackstonia perfoliata*, *Centaurium erythraea*, *Lythrum hyssopifolia*, *Parentucellia viscosa* and *Prunella vulgaris.*

Alien species found in both seasonally wet turf and the taller vegetation at less inundated sites include *Anthoxanthum odoratum*, *Cortaderia selloana*, *Holcus lanatus*, *Trifolium dubium* and *T. repens*.

Dryland alien species observed on the transects but rarely in association with turfs include *Dactylis glomerata*, *Lagurus ovatus*, *Lupinus arborea*, *Medicago lupulina*, *Melilotus indica*, *Ornithopus pinnatus*, *Trifolium arvense*, *T. campestre*, *T. glomeratum*, *Vicia sativa*, *V. hirsuta*, *Oenothera stricta* and *Silene gallica*.

The topography of the two Wanganui transects appeared to be stable throughout the monitoring period, probably because the surrounding dunes have been stabilised by planted sand-stabilisers such as the alien marram grass (*Ammophila arenaria*), and also because of the encroachment of alien pasture species (Whitiau was grazed by cattle until the late 1990s). Conversely, the topography at the two Pouto transects changed over the 2002–05 monitoring period, especially at the second transect, where sand accumulated at the end of the transect. In addition, water level apparently increased at both sites between 2003 and 2005, possibly because of sand dune incursion, which may have dammed subterranean water flows and raised the water table locally.

7.3 TEMPORAL CHANGES IN VEGETATION AT TRANSECTS

Figures 16–19 show the changes in vegetation recorded at the four transects over the monitoring period.

The vegetation of Transect 1 at Pouto remained fairly similar over the 3 years of monitoring, with an increase in cover of the indigenous *Apodasmia similis* from an average of 10% in 2002 to 30% in 2003 and 70% in 2005, and a decrease in indigenous turf species associated with those areas. The area covered by the indigenous *Gunnera dentata* expanded over the monitoring period, and a similar expansion of alien species occurred, with cover in one place on the transect increasing from 2% in 2002 to 12% in 2005. Most alien species recorded on Transect 1 were annual, with the exception of *Cortaderia selloana*, *Schedonorus phoenix* and *Leontodon taraxacoides*. In 2005, the indigenous *Spinifex sericeus* vegetation was much more weedy than previously recorded, possibly due to a higher water table. Permanently wet areas on the transect changed from charophyte-dominated vegetation to vegetation dominated by the tall indigenous sedge *Schoenoplectus tabernaemontani*. At Transect 2, changes in hydrology and sand redistribution had modified the transect on each monitoring occasion. Alien species became progressively less abundant at Transect 2 over the monitoring period. Apart from two vegetation types on Transect 1, alien species did not appear to be invading the Pouto dune ephemeral wetlands in this study.

At Hawkens Lagoon, vegetation zones changed over the monitoring period, with the wetter herbfields dominated by the indigenous *Myriophyllum votschii* gradually drying out and being replaced by taller emergent indigenous species (e.g. *S. tabernaemontani*) and increasing cover of alien species. By the end of the monitoring period, turf areas initially dominated by the indigenous *Gunnera dentata* and *Schoenus nitens* had been replaced by the alien perennial grasses *Schedonorus phoenix* and *Holcus lanatus.* Alien species cover increased over the monitoring period in all vegetation types on the Hawkens Lagoon transect.

Similar trends of increasing indigenous vegetation height and and increasing alien species cover were observed at Whitiau, with increasing abundance of tall *A. similis* at all sites, except where it was being displaced at drier sites by taller *Leptospermum scoparium* scrub.

Champion et al. (2003) and Johnson & Rogers (2003) presented vegetation data for an area containing the endangered *Sebaea ovata* at Whitiau, which is equivalent to the vegetation in Quadrats 1–22 on the Whitiau transect. Champion et al. (2003) reported alien species covers in *S. nitens* turf at Whitiau of 25% in March 1999 and 10% in February 2000, while Johnson & Rogers (2003) reported 16% alien species cover in turf areas and 35% in surrounding vegetation at Whitiau. On the Whitiau transect, total alien species cover had increased in turf vegetation to 28% in February 2003, 27% in November 2003 and 41% in December 2005. Invasive alien perennial grasses including *Schedonorus phoenix*, *Holcus lanatus*, *Agrostis stolonifera*, *Anthoxanthum odoratum* and *Paspalum dilatatum* all increased in abundance on the transect over the monitoring period, continuing the trend observed at Whitiau since 2000. Conversely, some shorter alien species (such as *Leontodon taraxacoides*) maintained similar covers, whereas the taller *Juncus articulatus* decreased in abundance, possibly because of drier conditions. In addition to increasing alien species abundance at Whitiau, the cover of the tall (c. 1 m) indigenous restiad *Apodasmia similis* also increased from an average 12% to 30% during the course of the study.

In summary, the ephemeral wetland turf vegetation at the two Pouto transects did not appear to become more influenced by alien species during the 3-year monitoring period. The dynamic nature of sand dunes in the area and subsequent changes in topography and water tables that their movement causes appeared to prevent the establishment of tall perennial vegetation (including alien species), and new surfaces for colonisation by turf species were still being created (as seen on Transect 2). Some endangered species such as *Eleocharis neozelandica* appear to require areas with low vegetation covers (e.g. Pouto Vegetation Plots 2 and 3, which had total vegetation covers between 12% and 60%; see section 6.2.2). Similarly, Ogle (1998) suggested that bared areas amongst low-stature vegetation are necessary for the endangered annual *Sebaea ovata* to persist in ephemeral wetland turf vegetation. Unfortunately, the habitat previously occupied by this species at its last two New Zealand locations appears to be increasingly dominated by taller, denser vegetation (both alien and indigenous). The stabilisation of sand dunes and the resulting stable conditions at these sites appears to favour the establishment of taller, denser vegetation, including alien species. Invasion of woody vegetation such as *Acacia sophorae* at Whitiau and the establishment of plantation pine forest may provide an additional impact by reducing water tables and thus reducing the extremes of the wet-dry cycles that undoubtedly maintain the diversity of dune ephemeral wetland habitats (Johnson & Rogers 2003).

Weed invasion appears, therefore, to be promoted by a combination of altered hydrology (which reduces both the water levels and the extremes of wet-dry fluctuations) and stabilised dunes (which restrict the dynamic sand movements that create and destroy ephemeral wetland areas).

7.4 INVASIVE ALIEN SPECIES IN DUNE EPHEMERAL WETLANDS

Of the 59 alien species recorded at the three study areas, 17 were common to all three areas. Pouto had the lowest total recorded, with 12 annual and 11 perennial alien species (48%), including 6 species confined to the northern North Island, while Whitiau and Hawkens Lagoon had 48 and 43 species respectively. At both of these sites, 58% of the recorded alien species were perennials. Several of these species have been recorded as alien species in ephemeral wetland communities in other countries, including *Lythrum hyssopifolia*, *Leontodon taraxacoides* and *Trifolium dubium* which are found in vernal pools in California, USA (Barbour et al. 2005).

Many of the alien species recorded in the transects and other vegetation plots (see Appendix 1) did not appear to be aggressively displacing indigenous turf vegetation, despite being classified by Johnson & Rogers (2003) as aggressive weeds in ephemeral wetland vegetation. The following alien species recorded during the study were listed as aggressive weeds by Johnson & Rogers: *Agrostis stolonifera*, *Anthoxanthum odoratum*, *Holcus lanatus*, *Schedonorus phoenix*, *Cyperus congestus*, *Juncus articulatus*, *Aster subulatus*, *Conyza* spp., *Lotus pedunculatus*, *Lythrum hyssopifolia*, *Myosotis laxa* and *Parentucellia viscosa.*

In the dune ephemeral wetlands studied, only the four alien perennial grasses *Agrostis stolonifera, Anthoxanthum odoratum, Holcus lanatus* and *Schedonorus phoenix*, the rush *Juncus articulatus* and the legume *Lotus pedunculatus* were abundant or markedly increased in cover over the study period. Other abundant alien species were *Cortaderia selloana, Paspalum dilatatum, Leontodon taraxacoides* and the clovers *Trifolium fragiferum* (at Whitiau only) and *T. repens*. Pampas (*Cortaderia selloana*) was found in all three study areas. We pulled out *C. selloana plants* whenever we found them. Tall tussocks of this species were noted in the area surrounding Vegetation Site 5 at Pouto (section 6.2.2) and this species can survive on the most nutrient-limited sites (section 6.2.1). The invasive alien sand country weed sharp rush (*Juncus acutus*) was found adjacent to Transect 1 along the four-wheel drive track accessing the Pouto Causeway. These plants were also removed by hand. All of these species are perennial and, apart from *L. taraxacoides*, have a growth form that can smother and overtop the short-stature turf communities.

Overall, it is likely that the low number of alien species sampled in the three areas is due not only to the fluctuating wet/dry regime of these wetlands, but also to their relatively isolated locations. This isolation means that the pool of neighbouring potential weeds is restricted, so the ability of weeds to colonise the areas is limited. There are other potentially invasive species that are likely to be problematic for ephemeral wetlands in the future. For example, Bakker et al. (2007) list several species adapted to European ephemeral dune wetlands. These include *Carex flacca*, *Calamagrostis epigejos* and *Samolus valerandi*, all of which are only sparingly naturalised in New Zealand at present.

7.5 SUGGESTED MANAGEMENT INITIATIVES

The ephemeral wetlands near Wanganui (Hawkens Lagoon and Whitiau) deteriorated in condition over the course of this study and from conditions reported in earlier studies of this area. The likely cause of this is loss of dynamic changes in topography resulting from restriction of sand movement and a possibly reduced water table. The increase in abundance of alien weed species is, in most cases, symptomatic of these changes, although some species (such as pampas and sharp rush) are likely to be able to colonise both impacted and relatively unimpacted ephemeral sites. Taller indigenous vegetation is also increasing in the modified Wanganui sites, probably also because of more stable conditions. Conversely, the ephemeral wetland sites at Pouto do not currently appear to be threatened by weed invasion, with natural fluctuations in water table and unrestrained sand movement maintaining dynamic systems where wetland areas are continually being created and destroyed.

Control of invasive alien species such as sharp rush and pampas should continue at all the studied sites and surveillance for new weed species incursions (especially perennial flood-tolerant species) is required to prevent further species establishment and impacts.

At the Wanganui sites, management intervention is needed or the turf species—including several endangered plants—are likely to be displaced. For example, *Sebaea ovata* may be lost from the New Zealand flora unless there is significant management intervention (see Champion et al. 2003); in particular, the removal or control of tall competitive species (both alien and indigenous) is needed.

Removal of tall competitive species to allow the persistence or re-establishment of low-stature herbfields or turfs can be achieved in several ways:

- Mechanically remove taller vegetation, leaving a bared surface which can then be recolonised**.** The periodicity of flooding and soil waterlogging can be increased by deepening scrapes and low-lying areas (Ogle 1998; Singers 1998). Singers (1998) successfully translocated the endangered species *Eleocharis neozelandica* to an artificial scrape near Wanganui, but found rabbit grazing was a major threat to these plants' survival. Ogle (1998) suggested using a rake to scarify existing vegetation at Whitiau, but scrapes similar to those used by Singers were eventually created. By the time this study commenced, the scrapes at Whitiau had been colonised by a number of endangered species, all having spread naturally to the bared areas from surrounding vegetation (see Appendices).
- Lightly graze areas to remove tall vegetation. Cattle grazed the Whitiau site up until the late 1990s. Reeves & Champion (2004) reported that the direct impacts of grazing on wetlands included consumption of plant biomass, trampling of plants, soil compaction, nutrient inputs and contamination by both faecal bacteria and weed seeds. The impacts of grazing on plant species appeared to vary depending on species palatability, habitat growth and reproductive output response under grazing. Many of the alien species occurring within ephemeral wetlands are northern hemisphere species which are adapted to mammalian grazing (e.g. perennial grasses and clovers). Therefore, grazing alone as a method of encouraging turf vegetation in ephemeral wetlands may not be particularly successful in controlling these weeds, but grazing may have a role in preventing succession to woody vegetation.
- Use herbicides to remove unwanted plants. Application of non-selective herbicides such as glyphosate has been recommended (e.g. Ogle 1998) to remove all vegetation and allow the recolonisation of the resultant bare patches by turf species. Herbicides have been used to control swards of *Carex ovalis* that have colonised turf areas at Sedgemere Ephemeral Tarn in South Marlborough (Champion 1999). A pot-based trial found that some *Crassula* species and *Isolepis basilaris* survived applications of 3.6 mg/L of glyphosate (Champion 1998). Application of this herbicide to taller vegetation using a weed wiper or other targeted application methods could enable remnant turf vegetation to recolonise areas where taller plants are killed, although mechanical removal of dead plant material might be required before recolonisation can occur.
- Selective herbicides such as the grass-specific haloxyfop or the broadleaf-specific clopyralid offer the opportunity to target problem weed species while leaving non-susceptible plants unaffected. Champion (1998) found

that haloxyfop killed all grasses but no other plants in a pot-based trial and significantly reduced grass covers in eight ephemeral vegetation types (a maximum cover of 60% was reduced to 1% after one year). Corresponding increases in non-grass species were recorded, presumably through colonisation of the gaps left by dying grass (Champion 1999). Clopyralid controlled clovers in pot trials and in the field, but did not affect many other indigenous species including *Isolepis basilaris* and *Mazus novaezelandiae* (Champion 1998, 1999).

The current study is one of only a few that have monitored hydrological regime (water level fluctuations) in ephemeral wetlands (Johnson & Rogers 2003). The relative contributions of water sources for such wetlands and the functioning of perched water tables in dunelands need quantification before recommendations on managing hydrology can be made.

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9. References

Atkinson, I.A.E. 1985: Derivation of vegetation mapping units for an ecological survey of Tongariro National Park, North Island, New Zealand. *New Zealand Journal of Botany 23*: 361–378. www.rsnz.org/publish/nzjb/1985/39.pfd, accessed August 2008).

Bakker, C.; van Bodegom, P.M.; Nelissen, H.J.M.; Aerts, R.; Ernst, W.H.O. 2007: Preference of wet dune species for waterlogged conditions can be explained by adaptations and specific recruitment requirements. *Aquatic Botany 86*: 37–45.

Barbour, M.G.; Solomeshch, A.I.; Holland, R.F.; Witham, C.; MacDonald, R.L.; Cilliers, S.S.; Molina, J.A.; Buck, J.J.; Hillman, J.M. 2005: Vernal pool vegetation of California: communities of long-inundated deep habitats. *Phytocoenologia 35*: 177–200.

Blackmore, L.C.; Searle, P.L.; Daly, B.K. 1987: Methods for chemical analysis of soils. *New Zealand Soil Bureau Scientific Report 80*. Department of Scientific and Industrial Research, Lower Hutt.

Cameron, E.K.; Jones, S.; Wilcox, M.D.; Young, M.E. 2001: Flora and vegetation of Pouto Peninsula, North Head, Kaipara, Northland, New Zealand. *Auckland Botanical Society Journal 54*: 38–51.

Champion, P.D. 1998: Selective control of weeds in New Zealand wetlands. Pp. 251–254 in: Proceedings of 51st New Zealand Plant Protection Conference.

Champion, P.D. 1999: Selective control of weeds in New Zealand wetlands using herbicides: interim report on field trials. NIWA Client Report, Hamilton. 20 p.

Champion, P.D.; Hofstra, D.E.; Auger, M.E.; Gemmill, C.E.C. 2003: Growth and habitat of *Sebaea ovata* (Gentianaceae) in New Zealand and Australia. *Science for Conservation 229.* Department of Conservation, Wellington. 32 p.

Clarkson, B.R.; Sorrell, B.K.; Reeves, P.N.; Champion, P.D.; Partridge, T.R.; Clarkson, B.D. 2003: Handbook for monitoring wetland condition. Co-ordinated monitoring of New Zealand wetlands. A Ministry for the Environment SMF funded project. Ministry for the Environment, Wellington. 74 p.

Cromarty, P. 1996: A directory of wetlands in New Zealand. Compiled for the NZ Department of Conservation, International Waterfowl and Wetlands Research Bureau, and the Ramsar Convention Bureau. Department of Conservation, Wellington. 395 p.

Dopson, S.R.; de Lange, P.J.; Ogle, C.C.; Rance, B.D.; Courtney, S.P.; Molloy, J. 1999: The conservation requirements of New Zealand's nationally threatened vascular plants. *Threatened Species Occasional Publication 13*. Department of Conservation, Wellington. 194 p.

Forester, L; Townsend, A. 2004: Threatened plants of Northland Conservancy. Department of Conservation, Wellington. 80 p.

Johnson, P.; Gerbeaux, P. 2004: Wetland types in New Zealand. Department of Conservation, Wellington. 184 p.

Johnson, P.; Rodgers, G. 2003: Ephemeral wetlands and their turfs in New Zealand. *Science for Conservation 230.* Department of Conservation, Wellington. 109 p.

Jones, C. 2007: Sedgemere ephemeral tarn: possible solutions to *Carex ovalis* invasion problem. Unpublished report, Department of Conservation, Nelson. 4 p.

Ogle, C.C. 1991: When is dryland wetland? *Forest and Bird 22(3)*: 46–49.

Ogle, C.C. 1997: List of vascular plants for Whitiau Scientific Reserve, northwest of Whangaehu River Mouth. Unpublished report, Department of Conservation, Wanganui. 9 p.

Ogle, C.C. 1998: *Sebaea ovata* in Whitiau Scientific Reserve. Unpublished report, Department of Conservation, Wanganui. 4 p.

Ogle, C.C. 2002: List of vascular plants for Hawkens Lagoon Conservation Area on true right bank of Waitotara River Mouth. Unpublished report, Department of Conservation, Wanganui. 6 p.

Reeves, P.N.; Champion, P.D. 2004: Effects of livestock grazing on wetlands: literature review. NIWA Client Report HAM2004-059, Hamilton. 33 p.

Singers, N.J.D. 1998: Rare plant conservation at the Tangimoana dunelands. *Conservancy Advisory Science Notes 199.* Department of Conservation, Wellington. 17 p.

Appendix 1

LIST OF SPECIES RECORDED AT THE POUTO, HAWKENS LAGOON AND WHITIAU STUDY SITES

Note: 'y' indicates plant was recorded. Species recorded by Ogle (1998) but not seen during this study are marked 'o'. Planted species indicated by '!'.

PLANT GROUP	SPECIES	ALIEN (a) OR INDIGENOUS (i)	LOCATION		
			WHITIAU	HAWKENS	POUTO
Charophytes (2 indigenous)	*Chara globularis*	i			y
	Nitella hyalina	i			y
Monocotyledons (26 indigenous, 21 alien)					
Rushes (1 indigenous, 3 alien)	*Juncus acutus*	a			y
	Juncus sonderianus	a			y
	Juncus articulatus	a	y	y	y
	Juncus caespiticius	i	y	y	
Sedges (12 indigenous, 3 alien)	*Baumea juncea*	i	o		y
	Carex pumila	i	y	y	y
	Cyperus congestus	a		y	
	Cyperus polystachyos	a			y
	Desmoschoenus spiralis	i	o	o	y
	Eleocharis acuta	i	o	y	y
	Eleocharis neozelandica	i		y	y
	Ficinia nodosa	i	y	y	y
	Isolepis basilaris	i	y		
	Isolepis cernua	i	y	o	y
	Isolepis sepulcralis	a	o		y
	Schoenoplectus pungens	i	y	y	
	Schoenoplectus tabernaemontani	i	y	y	y
	Schoenus apogon	i			y
	Schoenus nitens	i	y	y	y
Grasses (4 indigenous, 14 alien)	*Aira caryophyllea*	a	o		y
	Agrostis stolonifera	a	y	o	
	Anthoxanthum odoratum	a	y	y	
	Bromus diandrus	a	o	o	
	Cortaderia selloana	a	y	y	y
	Cortaderia splendens	i			y
	Cynosurus cristatus	a	y	o	
	Dactylis glomerata	a	y	o	
	Holcus lanatus	a	y	y	y
	Lachnagrostis billiardierii	i	y	y	y
	Lachnagrostis filiformis	i	y		
	Lagurus ovatus	a	y	y	
	Paspalum dilatatum	a	y	o	
	Paspalum distichum	a	y	o	
	Polypogon monspeliensis	a	o	y	
	Schedonorus phoenix	a	y	y	y
	Spinifex sericeus	i	y	o	y
	Sporobolus africanus	a	y	o	

Continued on next page

Appendix 1—continued

PLANT GROUP	SPECIES	ALIEN (a) OR INDIGENOUS (i)	LOCATION WHITIAU	HAWKENS	POUTO
Other (9 indigenous, 1 alien)	*Apodasmia similis*	i	y	y	y
	Lemna minor	i		o	y
	Libertia peregrinans	i	y		
	Microtis unifolia	i	y	y	
	Ruppia polycarpa	i			y
	Sisyrinchium 'blue'	a	y	y	
	Spiranthes novae-zelandiae	i	y		y
	Triglochin striatum	i	y	y	y
	Thelymitra longifolia	i	y		
	Typha orientalis	i		y	y
Dicotyledons (20 indigenous, 38 alien)					
Asteraceae (2 indigenous, 9 alien)	*Aster subulatus*	a	y	y	y
	Cirsium vulgare	a	y	y	y
	Conyza albida	a	o	y	y
	Conyza bonariensis	a	y		
	Conyza parva	a			y
	Crepis capillaris	a	y		
	Hypochaeris radicata	a	y	y	y
	Leontodon taraxacoides	a	y	y	y
	Ozothamnus leptophyllus	i		y	y
	Pseudognaphalium luteo-album	i	o	o	
	Vellereophyton dealbatum	a			y
Fabaceae (14 alien)	*Lotus pedunculatus*	a	y	y	
	Lupinus arboreus	a	y	y	
	Medicago lupulina	a	y	o	
	Medicago sativa	a	y		
	Melilotus indicus	a	y	o	
	Ornithopus pinnatus	a			y
	Trifolium arvense	a	y	y	
	Trifolium campestre	a		y	
	Trifolium dubium	a	y	y	
	Trifolium fragiferum	a	y		
	Trifolium glomeratum	a		y	
	Trifolium repens	a	y	y	y
	Vicia hirsuta	a	y		
	Vicia sativa	a	y		
Other (18 indigenous, 15 alien)	*Acaena novae-zelandiae*	i	y		
	Anagallis arvensis	a	y	y	y
	Blackstonia perfoliata	a			y
	Centaurium erythraea	a	y	y	
	Cerastium fontanum	a	y	y	
	Coprosma acerosa	i	y	y	y
	Epilobium billardiereanum	i	y	y	
	Gunnera dentata	i	y	y	y
	Leptospermum scoparium	i	y	o	
	Lilaeopsis novae-zelandiae	i		y	y
	Limosella lineata	i	y	y	y
	Lobelia anceps	i	y	y	y
	Lythrum hyssopifolia	a	y	y	y
	Mazus novaezelandiae var. *impolitus*	i	y		
	Myosotis laxa	a	o	y	

Continued on next page

Appendix 1—continued

PLANT GROUP	SPECIES	ALIEN (a) OR INDIGENOUS (i)	LOCATION		
			WHITIAU	HAWKENS	POUTO
	Myriophyllum votschii	i	y	y	y
	Oenothera stricta	a	y	y	y
	Orobanche minor	a	y	y	
	Parentucellia viscosa	a	y	y	y
	Persicaria decipiens	i		o	y
	Persicaria hydropiper	a	o	o	y
	Plantago coronopus	a	y		
	Plantago lanceolata	a	y	o	
	Potentilla anserinoides	i	y	o	
	Prunella vulgaris	a	y	y	
	Ranunculus acaulis	i	y	y	
	Ranunculus repens	a	y	o	
	Samolus repens	i	y	o	
	Sarcocornia quinquenervia	i	y		
	Sebaea ovata	i	y	y	!
	Selliera radicans	i	y		
	Selliera rotundifolia	i	y	y	
	Silene gallica	a	y	y	
Total: 107 (48 indigenous, 59 alien)					

Appendix 2

POUTO TRANSECT 1 MONITORING DATA

November 2002 (see section 6.2.1)

Alien species were restricted to *Gunnera dentata*-dominated vegetation and open dry dunes towards the end of the transect. Alien species recorded included *Anagallis arvensis*, *Leontodon taraxacoides*, *Parentucellia viscosa* and *Blackstonia perfoliata* amongst *G. dentata* and *Vellereophyton dealbatum* in drier spinifex vegetation. *Anagallis arvensis* was the dominant alien species, occupying 10% of one quadrat. Total average alien species cover within the first *G. dentata* patch (Quadrats 8–14) was 2%, in the second *G. dentata* patch (Quadrats 36–38) it was 1% and in the *Spinifex sericeus* area (Quadrats 30–40) it was < 1%.

November 2003

Quadrats 1–3

Myriophyllum votschii was absent, with *Nitella hyalina* forming a complete cover apart from low (< 10%) cover of the tall sedge *Schoenoplectus tabernaemontani*. This vegetation remained totally indigenous.

Quadrats 4–7

The open *Apodasmia similis*-dominated vegetation slightly increased in cover, with small amounts of the alien *Parentucellia viscosa* and *Juncus sonderianus* (< 1% cover).

Quadrats 8–16

The first *Gunnera dentata* patch had expanded in area, with increased cover of *Apodasmia similis* (20%) and similar alien species to 2002, with the addition of *Cortaderia selloana* (removed by hand), *Schedonorus phoenix* and *Vellereophyton dealbatum.* Overall alien species cover had reduced to 1%.

Quadrats 17–34

Apodasmia similis vegetation had became slightly denser (from 30% to 35% cover), with one plant of the alien *Leontodon taraxacoides* found in this part of the transect.

Quadrats 35–38

The second *Gunnera dentata* patch had also increased in extent, with alien species similar to the first *G. dentata* area, also with a 1% average total cover.

Quadrats 39–40

More weedy alien species had colonised the *Spinifex sericeus* grassland with *Ornithopus pinnatus, Crepis capillaris*, *Silene gallica* and *Aira caryophyllea* as well as the species recorded elsewhere on the transect. In this dry vegetation, total alien species cover was still < 1%.

December 2005

Quadrats 1–3

Vegetation remained totally indigenous but was dominated by 1-m-tall *Schoenoplectus tabernaemontani,* which made up 50% of the cover and displaced the previous *Nitella hyalina*-dominant vegetation.

Quadrats 4–6

The *Apodasmia similis*-dominated vegetation increased to 100% indigenous cover.

Quadrats 7–16

The first *Gunnera. dentata* patch had expanded in area, with increased cover of *Apodasmia similis* (30%), so that (based on % cover) this species now was the dominant. Alien species had increased to an average total cover of 12%, with *Leontodon taraxacoides*, *Cortaderia selloana* and *Juncus sonderianus* the most abundant.

Quadrats 17–33

Apodasmia similis vegetation had increased in cover to 70%, but total alien species cover was still < 1%.

Quadrats 34–38

The second *Gunnera dentata* patch had also increased in extent (Quadrats 34–38) and *Apodasmia similis* was also the new dominant, but unlike the other patch, alien species still only accounted for 1% of the total average cover.

Quadrats 39–40

The end of the transect appeared wetter with a much denser vegetation than that previously recorded. Vegetation was dominated by *Ozothamnus leptophyllus*. Alien weeds, including *Ornithopus pinnatus*, *Holcus lanatus* and *Cortaderia selloana* occupied an average of 40% of the cover.

Appendix 3

POUTO TRANSECT 2 MONITORING DATA

In November 2002 (see Section 6.2.2), alien species were mainly restricted to an elevated area (Quadrats 4–5) that appeared to be a roosting site for birds (lots of faeces present). *Leontodon taraxacoides* was the dominant species (25% cover), with *Schedonorus phoenix*, *Vellereophyton dealbatum* and *Blackstonia perfoliata* contributing 3%, 1% and < 1 % cover respectively. Indigenous species included *Carex pumila* (20% cover) and turf species (total cover of 20%) comprising *Gunnera dentata*, *Lobelia anceps*, *Isolepis cernua* and *Myriophyllum votschii.* Outside of these quadrats, alien species were only found in adjacent *C. pumila*/turf (*L. taraxacoides* at 1%) and in similar vegetation near the end of the transect, where *Schedonorus phoenix* occupied < 1% and 2% of Quadrats 24 and 26.

November 2003

Alien species were again sparse, with area and abundance reduced from previous monitoring periods.

Quadrats 1–3

Leontodon taraxacoides, Aster subulatus and *Vellereophyton dealbatum* were present in *Carex pumila* turf vegetation at the start of the transect (3% total average cover).

Quadrats 4–5

The alien species *Leontodon taraxacoides*, *Juncus sonderianus*, *Juncus articulatus* and *Vellereophyton dealbatum* were present at the bird roosting site, but only occupied a total average cover of 8%. The indigenous *Gunnera dentata* apparently had expanded in cover in this area, occupying 50% of the two quadrats.

No other alien species were recorded on the transect, although the following changes in vegetation had occurred since November 2002:

Quadrat 6–16

Carex pumila had increased in abundance to 80% average cover.

Quadrats 8–11

The tall sedge *Schoenoplectus tabernaemontani* formed an open (25%) vegetation type in deeper water associated with the charophyte *Nitella hyalina*.

Quadrats 17–30

Sand appeared to have accumulated (burying the end peg of the transect) and an open (25% cover) vegetation of *Carex pumila*, *Apodasmia similis*, *Spinifex sericeus*, *Lachnagrostis billardierei* and some low-lying areas with turf species (*Gunnera dentata*, *Lilaeopsis novae-zelandiae, Isolepis cernua* and *Myriophyllum votschii*) were recorded.

December 2005

The topography of the site had again altered, with an almost total loss of alien species. Only *Juncus sonderianus* (Quadrat 2 at 4% cover) and *Aster subulatus* (Quadrats 9 and 10, both < 1% cover) were recorded.

Quadrats 1–15

This period was wetter than previous recording periods and the elevated bird roosting site (Quadrats 4 and 5) was lost. *Apodasmia similis* was now the dominant species, with lesser amounts of *Carex pumila*, the turf species *Lilaeopsis novae-zelandiae* and seedling *Typha orientalis* present, with a total average cover of 75%.

Quadrats 16–25

A shallower area, with 45% average cover dominated by *Carex pumila* and smaller amounts of *Apodasmia similis* and *Lachnagrostis billardierei.* Amongst the taller vegetation were well-developed turfs of *Eleocharis neozelandica, Triglochin striatum* and *Myriophyllum votschii.*

Quadrats 26–30

The remaining quadrats were dominated by similar vegetation to that present in 2003, although *Apodasmia similis* was the most abundant species and the shrub *Ozothamnus leptophyllus* was also present for the first time. No turf species were present in this part of the transect.

Appendix 4

HAWKENS LAGOON TRANSECT MONITORING DATA

In November 2002, five different vegetation types were discerned along the 30-m transect (see section 6.2.2), with the start of the transect in wet *Myriophyllum votschii*-dominated turf. The vegetation along the transect changed to *Gunnera dentata*- and *Schoenus nitens*-dominated turf areas then drier *Trifolium* spp. herbfield (described in section 6.2.2).

The vegetation types were assessed visually in November 2002 (see below) to enable direct comparison of this (and the Whitiau Transect) to other vegetation data. A second assessment using 1-m^2 quadrats was carried out in February 2003.

November 2002

0–6 m along transect

The alien species *Leontodon taraxacoides* and *Aster subulatus* together comprised an average cover of 13% amongst dense *Myriophyllum votschii* turf.

6–8 m along transect

The alien species *Leontodon taraxacoides*, *Juncus articulatus* and *Schedonorus phoenix* occupied 30% of the *Myriophyllum votschii-Gunnera dentata* turf.

8–17 m along transect

Schoenus nitens dominated the vegetation, with a 45% cover of alien species including (in decreasing order of cover) *Juncus articulatus, Holcus lanatus, Schedonorus phoenix* and *Leontodon taraxacoides.*

17–24 m along transect

This area comprised a turf dominated by *Gunnera dentata* containing a few individual plants of the acutely endangered *Sebaea ovata*. Alien species were abundant, with just over 50% total average cover. Apart from *Juncus articulatus* (which was not recorded), the alien species were similar to those recorded in the previous survey, but the clovers *Trifolium repens* and *T. dubium* and *Parentucellia viscosa* were also present.

February 2003

Quadrats 1–6

The wet area dominated by *Myriophyllum votschii* in November 2002 was much drier, with a 48% cover of alien species, predominantly *Juncus articulatus*, with lesser amounts of *Aster subulatus*, *Myosotis laxa* and *Leontodon taraxacoides.*

Quadrats 7–8

Similar alien covers to 2002 (25% cover) were noted in the *Myriophyllum votschii-Gunnera dentata* turf, with lesser amounts of *Juncus articulatus*, but *Agrostis stolonifera* was also recorded.

Quadrats 9–15

The *Schoenus nitens*-dominated vegetation was more heavily dominated by alien species, with a total alien vegetation cover of 60%. The previously dominant species *Juncus articulatus* was absent, with *Trifolium repens, Schedonorus phoenix, Leontodon taraxacoides* and *Holcus lanatus* now being the main contributors to the alien component of the vegetation.

Quadrats 18–24

The *Gunnera dentata*-dominated area had a similar suite of weed species to 2002, with an average alien cover of 45%.

Quadrats 25–30

The vegetation at this dry end of the transect was mostly dead, especially the alien annuals *Lagurus ovatus* and *Trifolium arvense*. Total alien cover of living plants averaged 20%, predominantly *Trifolium repens* and *Leontodon taraxacoides.*

November 2003

The wet area dominated by *Myriophyllum votschii* in previous monitoring occasions (Quadrats 1–6) was drier and could be divided into two areas, Quadrat 1 and Quadrats 2–6:

Quadrat 1

Dominated by *Schoenoplectus* spp. with a 48% alien cover of *Juncus articulatus* and *Myosotis laxa*.

Quadrats 2–6

Contained indigenous vegetation comprising *Myriophyllum votschii* and *Gunnera dentata.* Dominant alien species were *Schedonorus phoenix* and *Leontodon taraxacoides*, with total alien cover of 23%.

Quadrats 7–17

The *Gunnera dentata*-dominated vegetation previously recorded from Quadrats 7 and 8 was now replaced by *Schoenus nitens* as the dominant indigenous species. This extended across the formerly *G. dentata*-dominated vegetation. Dominant alien species were *Schoenus phoenix, Trifolium repens, Leontodon taraxacoides* and *Holcus lanatus*, and average total alien cover was 35%.

Quadrats 18–24

The species described for Quadrats 7–17 and *Lotus pedunculatus* were also dominant in the *Gunnera dentata*-dominated vegetation in these quadrants (51% total alien species cover), but *Sebaea ovata* was still common, occupying 1% to 2% of the area in some quadrats.

Quadrats 25–30

The dry vegetation at the end of the transect was dominated by the annuals *Polypogon monspeliensis* and *Trifolium dubium,* with the perennials *Trifolium repens* and *Leontodon taraxacoides* also abundant. Total alien cover averaged 55%.

December 2005

The vegetation of the transect had changed markedly since 2003.

Quadrats 1–6

These quadrats contained a range of indigenous species including *Schoenoplectus* spp., *Epilobium billardiereanum*, *Triglochin striatum* and *Carex pumila*, but the alien *Juncus articulatus* was the most abundant species, occupying an average of 48% cover, with a total average alien cover of 70%.

Quadrats 7–24

The alien perennial grasses *Schoenus phoenix* and *Holcus lanatus* dominated the areas (42% combined cover) previously containing *Gunnera dentata* and *Schoenus nitens* turfs. *Ficinia nodosa* and *S. nitens* were the only indigenous species found in most of these quadrats, while *G. dentata* was not recorded in any transects and only one *Sebaea ovata* plant was located (away from the transect). Other alien species included *Trifolium repens, Leontodon taraxacoides* and *Trifolium dubium* with a 72% total average alien cover.

Quadrats 25–30

The dry vegetation at the end of the transect was dominated by *Leontodon taraxacoides* and the clovers (in decreasing order of abundance) *Trifolium repens, T. campestre, T. dubium, T. arvense* and *T. glomeratum*, with a total average alien cover of 57%.

Appendix 5

WHITIAU TRANSECT MONITORING DATA

In November 2002, seven different vegetation types were recorded along the 40-m transect (see section 6.2.2), essentially running from *Schoenus nitens* herbland vegetation to *Apodasmia similis*-dominated rushland. The *A. similis* rushland was divided into three zones: dense pure *A. similis* and areas where *Lotus pedunculatus* or *Coprosma acerosa* were also important components of the vegetation. In addition to *S. nitens* herbland vegetation to *A. similis*-dominated rushland, the beginning of the transect (Quadrats 1–6), which was fertilised by DOC earlier in 2002, had an alien grass- and rush-dominated vegetation, but indigenous turf plants were still present. Also, two scrapes made to evaluate whether such cleared areas could restore small endangered indigenous turf species (see section 7.5) were located in Quadrats 23 and 39–40.

The vegetation types were visually assessed without detailed surveys in November 2002; so that direct comparison could be made of this and Hawkens Lagoon data with Pouto data. A second assessment using 1-m^2 quadrats was carried out in February 2003.

February 2003

Quadrats 1–6

The fertilised area was dominated by *Paspalum dilatatum* (30% average cover), with much lower covers of *Juncus articulatus* and *Schedonorus phoenix* (average total alien species cover of 40%). *Schoenus nitens* and *Apodasmia similis* were the most abundant indigenous species in these quadrats, together occupying an average area of 15%.

Quadrats 7–17

The *Schoenus nitens* herbfield contained an average alien species cover of 25%. Alien species (in decreasing order of abundance) were *Leontodon taraxacoides*, *Paspalum dilatatum*, *Agrostis stolonifera*, *Schedonorus phoenix* and *Lotus pedunculatus*.

Quadrats 18–22

The *Apodasmia similis*/*Lotus pedunculatus* vegetation identified in 2002 had an average total alien cover of 22%. *Lotus pedunculatus* was the dominant alien species, with lesser amounts of *Leontodon taraxacoides, Schedonorus phoenix, Agrostis stolonifera, Holcus lanatus* and *Trifolium fragiferum.*

Quadrat 23

The first scrape had a total cover of 20%, with *Juncus articulatus* the only alien species with cover > 1% recorded and 6% total alien cover.

The two *A. similis*-dominated vegetation types both had averages of around 20% alien cover.

Quadrats 24–28

The dominant alien species were *Schedonorus phoenix*, *Anthoxanthum odoratum*, *Lotus pedunculatus*, *Trifolium fragiferum*, *Holcus lanatus* and *Leontodon taraxacoides*.

Quadrats 29–48

The total cover of alien species averaged < 20%, with low covers of (in decreasing order of abundance) *Schedonorus phoenix*, *Leontodon taraxacoides*, *Holcus lanatus*, *Paspalum dilatatum*, *Lupinus arboreus*, *Sporobolus africanus*, *Lotus pedunculatus*, *Conyza bonariensis*, *Anthoxanthum odoratum* and *Medicago lupulina*.

Quadrats 49–50

The second scrape supported sparse vegetation (12% total cover) with *Juncus articulatus* the only alien species (5% cover).

November 2003

Quadrats 1–6

The same alien species in similar proportions and covers to previous surveys were observed. *Schoenus nitens* and *Apodasmis similis* had both increased in abundance in these quadrats, occupying an average cover of 25% and 20% respectively.

Quadrats 7–17

The *Schoenus nitens* herbfield contained an average alien species cover of 25% (as in February 2003) and the same species with the exception *Agrostis stolonifera,* which was not recorded in this vegetation in November 2003.

Quadrats 18–22

The *Apodasmia similis/Lotus pedunculatus* vegetation had not changed from February 2003, but had a slightly reduced average alien cover (15%).

Quadrat 23

The first scrape had been colonised by the indigenous *Gunnera dentata* which had a cover of 20%. *Juncus articulatus*, *Lotus pedunculatus* and *Leontodon taraxacoides* were the only alien species with cover > 1% recorded, and total alien cover was 4%.

Quadrats 24–35

The dominant alien species were *Lupinus arboreus*, *Schedonorus phoenix*, *Lotus pedunculatus*, *Holcus lanatus* and *Vicia sativa*, and total alien cover was 30%.

Quadrats 36–48

The total cover of alien species averaged 12%, with low covers of (in decreasing order of abundance) *Medicago lupulina*, *Schedonorus phoenix*, *Holcus lanatus* and *Lupinus arboreus*.

Quadrats 49–50

The second scrape had a sparse vegetation (12% total cover), with *Juncus articulatus* (5%) and *Paspalum dilatatum* (3%) the only alien species with covers > 1%.

December 2005

Quadrats 1–6

The vegetation contained an average 40% cover of alien species, predominantly the perennial grasses (in decreasing order of cover) *Schedonorus phoenix*, *Paspalum dilatatum* and *Agrostis stolonifera*, but also *Leontodon taraxacoides*, *Lotus pedunculatus* and *Trofolium fragiferum.* The chronically threatened *Mazus novaezelandiae* var. *impolitus* was common in these quadrats.

Quadrats 7–17

Apodasmia similis had increased in average cover to 30% and exceeded the cover of *Schoenus nitens.* Thus, the vegetation was classified as rushland. Alien species had increased in abundance in these quadrats, occupying an average cover of 36% respectively, with similar species and relative abundances to those recorded on previous monitoring occasions.

Quadrats 18–22

Leptospermum scoparium had colonised the area, and had an average height of 1.2 m and cover of 20% amongst 60% covers of *Apodasmia similis.* Alien species had increased in abundance (total average cover of 45%), with the most abundant species being *Lotus pedunculatus*, *Holcus lanatus*, *Anthoxanthum odoratum*, *Schedonorus phoenix*, *Medicago lupulina* and *Leontodon taraxacoides.*

Quadrat 23

The first scrape continued to be colonised by indigenous species, with *Schoenus nitens* the dominant species by cover. The acutely threatened *Sebaea ovata* was found in this quadrat, the only plant of this species located at Whitiau on this monitoring occasion. The only alien species with cover > 1% recorded was *Leontodon taraxacoides*. Total alien species cover was 4%.

Quadrats 24–35

The dominant alien species were *Lotus pedunculatus*, *Schedonorus phoenix*, *Lupinus arboreus*, *Leontodon taraxacoides*, *Holcus lanatus*, *Anthoxanthum odoratum*, *Melilotus indica* and *Vicia sativa*. Total alien cover was 40%.

Quadrats 36–48

The vegetation was similar to that in Quadrats 18–22, with *Leptospermum scoparium* becoming common. Total cover of alien species averaged 30%, with low covers (> 1%) of (in decreasing order of abundance) *Leontodon taraxacoides*, *Holcus lanatus*, *Anthoxanthum odoratum*, *Schedonorus phoenix*, *Melilotus indica*, *Medicago lupulina* and *Lupinus arboreus*.

Quadrats 49–50

The second scrape had vegetation dominated by the alien *Juncus articulatus* (35% average cover), with no other alien species having covers > 1%. The chronically threatened *Selliera rotundifolia* was present in these quadrats, with several other turf species and seedling *Leptospermum scoparium* and *Apodasmia similis*.