28 years of vegetation change (1978–2006) in a calcareous coastal dune system

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***Abstract*:** Changes in vegetation structure and composition over a 28 year period (1978–2006) following removal of human-induced disturbances, were examined in a calcareous coastal dune system in Point Nepean National Park (38^0 19'S, 144^0 41'E) in south-eastern Victoria, Australia. In the early 1980s human habitation of Point Nepean was abandoned and disturbance regimes such as burning, slashing and land clearing were altered or removed, providing an opportunity to study the recovery of disturbed coastal vegetation. Broad-scale and community-level vegetation changes were assessed by comparing quadrat and GIS mapping data from 1978 with data collected in 2006. Results indicate a change in broad vegetation patterns; shrubland vegetation has replaced hind dune grasslands and disturbed areas and there has been a decrease in exposed coastal areas (such as blowouts, dunes and cliffs), and an increase in woody native species and highly invasive woody weeds. The changes highlight the importance of incorporating vegetation states in planning management actions in dynamic coastal vegetation.

Key words: invasion, coastal woodlands, disturbance, woody weeds, Nepean Peninsula

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Introduction

Woody plant invasion is a widespread phenomenon in Australia (e.g. Bennett 1994, Costello *et al.* 2000, Lunt *et al.* 2010) and overseas (van der Maarel *et al*. 1985, McMahon *et al*. 1996, Zbigniew and Stefania 2007). Invasion can be triggered by changes in land management, in particular reductions in the frequency or intensity of disturbance (Bennett 1994, Costello *et al.* 2000). In many Australian temperate coastal ecosystems, exclusion of post-European disturbances (e.g. livestock grazing, clearing) in the second half of the 20th century has been an intentional management action to facilitate vegetation recovery. Classical theories of vegetation succession underlie this management approach. While re-establishment of woody plant species in previously cleared coastal dune ecosystems has been documented (Burrell 1981, Molnar *et al*. 1989, Bennett 1994, Costello *et al.* 2000), there is little data to support the assumption that directional succession toward the pre-European vegetation communities is occurring. Change or alteration of disturbance regimes in coastal systems often increases the proportional representation of woody species (Burrell 1981, Weiss and Noble 1984, Molnar *et al*. 1989, Bennett 1994, Costello *et al.* 2000), however, these increases are often within communities in which they were previously absent or rare (Moxham *et al*. 2009*a*). General observations of increasing woody plant cover may also ignore on-going declines in previously abundant woody plant species (e.g. *Banksia integrifolia*).

Classical studies of coastal dune systems highlight the role of salt, wind, topography, climate, rate of erosion and deposition of sand, and soil composition in determining zonal patterns of vegetation (Patton 1934, Lewis 1982). The influence of these factors varies with distance from the seaward side (Patton 1934). Within vegetation zones, as successional phases in the dune system occur, organic matter accumulates and soil acidification takes place, increasing the amount of available phosphorus, the presence of sodium in the soil and the soil pH decreases (Patton 1934, Karle *et al.* 2004), facilitating establishment of the taller long-lived woody vegetation in this more protected soil rich environment. Based on these assumptions Burrell (1981) simplifies southern Australian coastal transitions into five dominant phases and zones: (1) strand plants, (2) dune grasses and sand binding species on the foredunes, (3) hind dune communities of (3A) closed-scrub graduating into (3B) low closed-forest up to 10 m high, and (4) low-open forest to low woodland (with or without *Eucalyptus* species).

European disturbance of coastal ecosystems of south-eastern Australia in the 19th and 20th centuries resulted in the removal of the taller woody plant species (e.g. species of *Allocasuarina, Acacia, Eucalyptus* and *Banksia*) particularly in hind dunes supporting phases (3) to (4); leading to invasion by *Leptospermum laevigatum* and *Acacia sophorae* (Coast Wattle) scrub in some instances (Burrell 1981, Weiss and Noble 1984, Molnar *et al*. 1989, Bennett 1994, Costello *et al.* 2000, Moxham *et al.* 2009*a,* Lunt *et al.* 2010). Disturbance regimes, such as fire, that regulate ecological dynamics were altered; grazing by native herbivores was replaced by more intense domestic livestock grazing regimes (Moxham *et al.* 2009*a*). A key question is whether removal of recent human disturbance in these hind dune ecosystems results in the vegetation reverting to the patterns expected under the classical model of dune vegetation transition or does it tend towards novel vegetation types?

This study examines changes in vegetation structure and composition in a calcareous coastal dune system on Point Nepean, Victoria, over a 28 year period (1978–2006). The area has had a varied history of management, since European settlement in 1835 including military occupation and has been managed as a National Park since 1988, when direct human disturbance was removed (McGregor & Johnstone 1987, Moxham *et al.* 2009*a*). The vegetation was surveyed in January 1978 and re-surveyed in 2006, and the two datasets examined for patterns of vegetation change.

Methods

Site description

Point Nepean National Park (38^0 19'S, 144^0 41'E) (575 ha in area) is on the southern tip of the Nepean Peninsula, approximately 60 km south of Melbourne in southern Victoria, Australia. It is bordered by the high tide mark to the north, south and west and landlocked on the east. The park has a maritime climate of hot summers (daily average 12 – 25^0C) and mild wet winters (daily average 6.5 – 13^0C) with a mean annual rainfall of 736 mm (Mornington station 086079, Australian Bureau of Meteorology 2006). The geology of the region dates from the Pleistocene epoch, with the southern peninsula composed of calcareous sands and dune limestone (Bird 1975; McGregor & Johnstone 1987; Oates & Taranto 2001). The inland study area is dominated by the Tertiary dune system, which is characterised by circular topographic features including moderate to steep slopes to an elevation of 54 m (a.s.l.) interspersed with flats and depressions to 10 m (a.s.l.) (McGregor & Johnstone 1987).

Historical vegetation structure and disturbance history of the Nepean Peninsula

At the time of European settlement much of the hinterland of the Nepean Peninsula was covered by open, grassy woodlands dominated by *Allocasuarina verticillata* (Drooping She-oak)., *Melaleuca lanceolata* subsp. *lanceolata, Banksia integrifolia* subsp. *integrifolia* and *Acacia* species, along with a range of other species (Moxham *et al.* 2009*a*). Depending on topography and environmental influences some areas supported shrublands, forests, grasslands and wetlands. There were bare areas of sand, eroding cliffs, stunted vegetation dominated by low shrubs and tussock grasslands along the coastline. On the beaches *Spinifex sericeus* (Hairy Spinifex) grasslands occurred in a narrow band and sometimes shrublands of *Atriplex cinerea* (Coast Saltbush).

Prior to European settlement the Boonwurrung (Bunurong) people occupied and continually utilised the Nepean Peninsula (Spillane 1971, O'Neill 1988), influencing disturbance regimes such as fire and probable native herbivore grazing. Settlement of the area by Europeans in 1835 marked a dramatic and rapid change to new disturbance regimes, including vegetation clearance, which has shaped the vegetation associations evident today (see Moxham *et al.* 2009*a*).

The first squatting licences at Point Nepean were established in 1835 (Power *et al.* 1985) and preliminary land clearing was undertaken for pastoral runs. By the 1840s, timber harvesting and lime-burning were also taking place (Harrington 2000). *Allocasuarina verticillata* was the most useful timber species for early settlers as eucalypt species were apparently absent (Calder 1975, Moxham *et al.* 2009a). Lime-burners targeted *Allocasuarina verticillata* and possibly *Acacia uncifolia* for fuel for the kilns. The process of extracting lime from the dunes required the removal of all vegetation, disturbing the soil surface (Calder 1975). Wattles and *Leptospermum laevigatum* regenerated following these disturbances and mature wattles were stripped of their bark, which was sent to the tanneries (Calder 1972, Searle 1991). Timber was also harvested to fuel Melbourne's bakeries during the 1850s and was so scarce by 1853 that the government halted the removal of timber unless required for lime-burning (O'Neill 1988). In 1852 a quarantine station was established at Point Nepean and from 1882 to 1986 the area was used for defence force activities and training, increasing human activities and bringing novel disturbances such as bombing, the establishment of infrastructure, and mowing and slashing. Lime-burning ceased by the 1920s in the area (Hollinshed 1982). In 1988 Point Nepean became a National Park with restricted public access due to unexploded ordnance, the legacy of defence activities. Management of the vegetation also changed at this time; most of the infrastructure (tracks, buildings and cleared areas) were abandoned and some of the slashing/mowing and burning regimes ceased. Thus all vegetation on the Nepean Peninsula may be considered secondary or tertiary regeneration/regrowth following human-induced disturbances (Calder 1975). In the last 20 years there has been tenfold increase in human visitation from approximately 5,000 to 50,000 per annum in the public access area of the park (Parks Victoria 2004).

1978 sampling

In January 1978, 41 (25 m x 25 m) quadrats in selected vegetation types were sampled. In each quadrat, canopy height and projective foliage cover were recorded according to Specht (1970). Species cover/abundance was estimated using the Bridgewater scale (1971). Various environmental characteristics were recorded including landform, soil type, aspect, and any evidence of disturbance and erosion. Plots were staked in one corner and locations marked on the final vegetation map. Based on the quadrat data, field reconnaissance, aerial photography and topographic maps (1:4,800) Parr-Smith and Smith (1978) developed a map of vegetation structural formations and vegetation complexes. The complexes were three broad groups each sharing generic vegetation and environmental characteristics: (1) 'Coastal vegetation' of the foredunes, cliffs and beaches; (2) 'Scrub' vegetation of the hind dunes, and (3) areas 'Disturbed' by human activities. They also categorised the vegetation using the vegetation structural classifications of Specht and Specht (1999).

2006 sampling

In spring 2006, 62 (10 m x 10 m) quadrats were sampled. The 41 1978 plots were relocated as accurately as possible in each vegetation type though some were not able to be relocated and were substituted by quadrats placed in the general vicinity. An extra 21 quadrats were also sampled. A stratified-random point generator in GIS (Arcview Version 3.2) was used to direct quadrat positioning, with a minimum of three replicates per vegetation type. The smaller quadrat size enabled this dataset to be combined with a larger statewide data set. Some vegetation types were sampled with up to five quadrats to capture the structural variation of vegetation in the landscape. In each quadrat the following characteristics were recorded: GPS location, aspect, altitude, landscape position, evidence of disturbances, height (m) of dominant canopy species, percent live foliage cover of canopy trees, mid-storey trees, shrubs, perennial grasses, perennial forbs and weeds. The percent cover of litter, bare ground and moss was also recorded along with the length of logs > 100 mm diameter and branches < 100 mm diameter, and the presence or absence of bryophytes. All vascular plant species were identified and their percent cover recorded using a modified Braun-Blanquet scale as per Ough (2001). Plant taxonomy followed Walsh and Stajsic (2007) and structural types were determined according to Specht and Specht (1999).

The smaller quadrats sampled in 2006 compared to 1978 is likely to influence estimates of abundance and frequency of species encountered. Rare or infrequent species are less likely to be encountered in the smaller quadrats due to a smaller total survey area (2.56 ha in 1978, 0.61 ha in 2006). In considering differences in individual species frequencies between the two studies, these differences in sampling area should be taken into consideration.

Vegetation mapping

Current (2006) vegetation was mapped using GIS layers obtained from the Victorian Department of Sustainability and Environment Corporate Geospatial Data Library. These included aerial photography (Melbourne 2005 image), topography and extant Ecological Vegetation Classes (EVC, Oates & Taranto 2001). The Ecological Vegetation Class (EVC) is a classification system higher than the floristic community level (Parkes *et al.* 2003) and was the main vegetation unit used in the collection of data in 2006. The EVC is defined by both floristic and structural attributes, as well as ecological processes that may be characteristic of its environment (Woodgate *et al*. 1996). For comparison with the 1978 data set, the structural types in each EVC were classified according to the system of Specht and Specht (1999) and assigned to a structural formation or a vegetation complex.

The Parr-Smith and Smith (1978) vegetation map was digitised and geo-rectified. The 1978 map and extant EVC maps were then combined to produce a rough layer of vegetation types to stratify the landscape for the field survey. EVC boundaries were refined during this study using aerial photography and the new quadrat data collected in each vegetation type. This was then digitised to produce a final layer of vegetation types.

The overall changes in the area (ha) covered by the different vegetation groups are represented graphically. Differences in species and lifeform frequency between 1978 and 2006 were compared by the non-parametric Wilcoxon signed-rank pairs test, as normality could not be improved (Kent & Coker 1992).

Results

Vegetation description – 2006

Detailed descriptions of the vegetation, associated structural attributes, landscape position and characteristic species (following Oates & Taranto 2001, Moxham *et. al.* 2009*a*) described in the 2006 survey are provided below (also see Table 1).

Coastal Alkaline Scrub (EVC 858) dominates the hind dune system (scrub complex). Variable in structure ranging from a woodland or shrubland to closed scrub. Dominant canopy species include *Leptospermum laevigatum* (Coast Tea-tree), *Melaleuca lanceolata* subsp. *lanceolata* (Moonah), *Leucopogon parviflorus* (Coast Beard-heath) and *Allocasuarina verticillata* (Drooping She-oak) (Oates & Taranto 2001). Coastal Moonah Woodland (listed as threatened under the *Victorian Flora and Fauna Guarantee Act* 1988) is one of several floristic communities belonging to this EVC (DSE 2002, Moxham *et. al.* 2009*b*); the study area contains the largest continuous stand of this community in the region.

On the hind dune swales and flats occurs an un-resolved unit (referred to as **Calcareous Swale Grassland** (EVC 309)). The grassy ground layer is dominated by *Poa labillardieri* (Common Tussock-grass) and the canopy, when present, is composed of *Banksia integrifolia* subsp. *integrifolia* (Coast Banksia).

In exposed situations on upper slopes and crests of secondary dunes along the southern coastline, **Coastal Dune Scrub** (EVC 160) forms a low closed shrubland. It is dominated by *Acacia longifolia* var. *sophorae* (Coast Wattle), *Leptospermum laevigatum* (Coast Tea-tree) and sometimes, by stunted *Melaleuca lanceolata* subsp. *lanceolata* (Moonah).

In the coastal complex, on the exposed primary dunes and headlands **Coastal Headland Scrub** (EVC 161) and **Spray-zone Coastal Shrubland** (EVC 876) form wind-pruned shrublands. Dominant species include *Correa alba* (Coast Correa) and *Leucophyta brownii* (Cushion Bush). **Coastal Tussock Grassland** (EVC 163) also occurs on the exposed cliffs with the grass *Austrostipa stipoides* (Prickly Spear-grass) prominent. **Coastal Dune Grassland** (EVC 879) is found on the siliceous sandy beaches of the more protected Bay side. It is dominated by *Spinifex sericeus* (Hairy Spinifex). **Berm Grassy Shrubland** (EVC 311) occurs on sand deposits formed by low wave action on the sheltered bay beaches. It is composed of low succulent shrubs such as *Atriplex cinerea* (Coast Saltbush), over a ground layer of grasses and herbs.

Table 1. Alignment of the vegetation classifications at Point Nepean used by Parr-Smith and Smith (1978), the Vegetation Complexes and Vegetation structural formations (as per Parr-Smith and Smith 1978), with Ecological Vegetation Classes, landscape positions and dominant characteristic species (Parr-Smith & Smith 1978, Oates & Taranto 2001)

Vegetation complex	Vegetation structural formation	Ecological vegetation class (EVC)	Landscape position	Dominant characteristic species
Coastal complex (3)	Grassland (2b)	Coastal tussock grassland (163)	Exposed coastal cliffs	*Austrostipa stipoides*
	Coastal scrub (3a)	Coastal dune scrub (160)	Exposed crests & slopes of secondary dunes	*Leucopogon parviflorus, Acacia longifolia* var. *sophorae, Leptospermum laevigatum, Melaleuca lanceolata* subsp. *lanceolata*
	Heath (3b)	Coastal headland scrub (161)	Exposed parts of the coast	*Leptospermum laevigatum, Leucopogon parviflorus, Pimelea serpyllifolia* subsp. *serpyllifolia, Correa alba*, *Leucophyta brownii*
	Coastal cliffs (3c)	Spray-zone coastal shrubland (876)	Exposed parts of the coast	As Above
	Fore dune (3d)	Berm grassy shrubland (311)	Fore dune	*Atriplex cinerea*
	Fore dune (3d)	Coastal dune grassland (879)	Fore dune:	*Spinifex sericeus*, *Ammophila arenaria, Cakile maritima*
	Beach/ cliff/ blowout (3d–g)	Beach/cliff (999)	Beach, Cliff, Blowout	N/A
Disturbed complex (2)	Scrub grassland (2a)	Disturbed and exotic vegetation (998)	All	Dominated by exotic species (namely *Stenotaphrum secundatum* and *Polygala myrtifolia var. myrtifolia*) and/or *Leptospermum laevigatum, Melaleuca lanceolata* subsp. *lanceolata, Poa labillardierei, Lepidosperma gladiatum*
	Denuded (2c)	Disturbed areas/ infrastructure (997)	All	N/A
Scrub complex (1)	Scrub complex (1)	Coastal alkaline scrub (858)	Sheltered secondary dunes & hind dunes	*Leptospermum laevigatum, Melaleuca lanceolata* subsp. *lanceolata, Leucopogon parviflorus, Acacia uncifolia, Allocasuarina verticillata, Bursaria spinosa* subsp. *macrophylla, Hibbertia sericea, Adriana quadripartita, Poa labillardierei, Pimelea serpyllifolia* subsp. *serpyllifolia, Rhagodia candolleana* subsp. *candolleana, Alyxia buxifolia, Tetragonia implexicoma, Dichondra repens, Swainsona lessertiifolia*
	Grassland (2b)	Calcareous swale grassland (309)	Swales & flats of hind dunes	*Poa labillardieri*

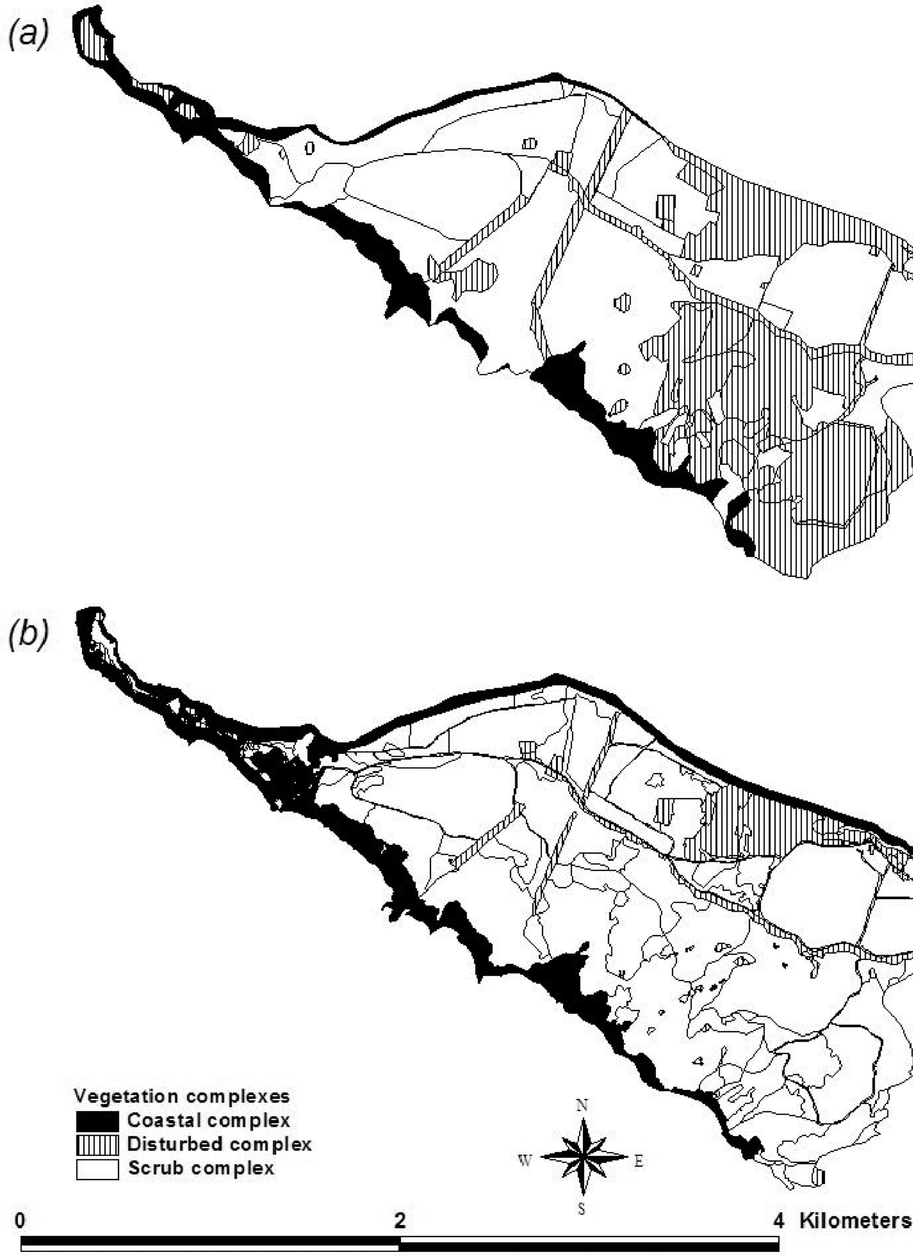

Fig. 1. The study area at Point Nepean, displaying broad vegetation groups (Vegetation Complexes) in (*a*) 1978 and (*b*) 2006.

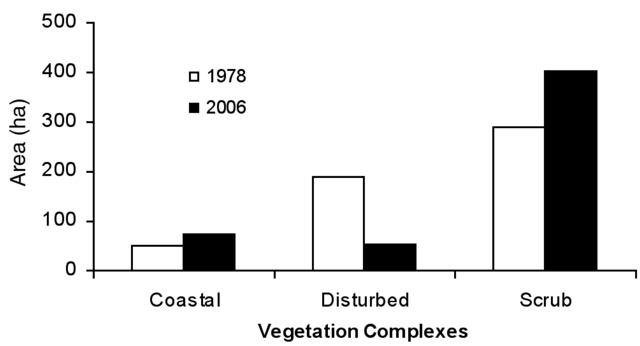

Fig. 2. Total area (ha) of broad vegetation complexes (coastal, disturbed and scrub) at Point Nepean in 1978 and 2006.

Table 2. Results of the Wilcoxon matched-pairs test (two sided). Significant results (*P* 0.001) are mark with an *

Lifeform	*P*-value	Sample size
Total	0.001*	173
Native	0.001*	107
Exotic	0.001*	66
Small trees	0.018*	10
Shrubs	0.068	27
Herbs	0.001*	90
Grasses	0.001*	46

Table 3. Percent frequency of species recorded in vegetation in Point Nepean National Park in 1978 (41 quadrats) and 2006 (62 quadrats). Species are listed in lifeform groups. Frequency is estimated using presence data where frequency is defined as the number of occurrences divided by the total number of quadrats sampled for that year). * Denotes exotic species.

	1978	2006
Small trees		
Acacia longifolia subsp. *sophorae*	0	3
Acacia mearnsii	0	5
Acacia uncifolia	12	47
Allocasuarina verticillata	0	2
Banksia integrifolia subsp. *integrifolia*	0	13
Bursaria spinosa subsp. *spinosa*	0	2
Leptospermum laevigatum	54	77
Leucopogon parviflorus	54	65
Melaleuca lanceolata subsp. *lanceolata*	41	35
Pittosporum undulatam	0	8
Shrubs		
Adriana quadripartita	5	2
Alyxia buxifolia	10	44
Atriplex cinerea	15	6
Cakile maritima subsp. *maritima*	5	5
Correa alba	10	11
Correa reflexa	0	3
Dodonaea viscosa subsp. *spatulata*	0	3
Hibbertia sericea s.l.	5	26
Leucophyta brownii	17	10
Muehlenbeckia adpressa	7	3
Olearia axillaris	12	29
Olearia glutinosa	7	3
Olearia sp. 2	0	2
Pimelea serpyllifolia subsp. *serpyllifolia*	68	52
Pomaderris paniculosa subsp. *paralia*	15	15
Pultenaea canaliculata	0	2
Pultenaea tenuifolia	0	13
Rhagodia candolleana subsp. *candolleana*	54	60
Tetragonia implexicoma	54	42
Tetragonia tetragonioides	0	2
**Chrysanthemoides monilifera*	0	19
**Conyza* sp.	0	15
**Coprosma repens*	0	2
**Lycium ferocissimum*	0	2
**Myoporum insulare*	2	6
**Polygala myrtifolia* var. *myrtifolia*	22	63
**Rhamnus alaternus*	0	37
Woody parasites		
Amyema miquelii	0	5
Amyema pendula	0	5
Amyema preissii	0	10
Herbs		
Dianella brevicaulis	0	35
Dianella revoluta s.l.	7	3
Acaena novae-zelandiae	0	5
Actites megalocarpa	0	11
Ajuga australis	0	10
Apalochlamys spectabilis	7	0
Apium prostratum subsp. *prostratum*	7	11
Caladenia latifolia	0	5
Carpobrotus rosii	27	15
Cassytha pubescens s.s.	7	2
Clematis microphylla	46	60
Comesperma volubile	10	6
Convolvulus erubescens ssp. *agg.*	0	24
Corybas sp.	0	5
Crassula peduncularis	0	3
Crassula sieberiana	0	15
Cynoglossum australe	0	19
Cyrtostylis sp.	0	2
Daucus glochidiatus	7	45
Dichondra repens	51	63
Dipogon lignosus	0	2
Disphyma crassifolium subsp. *clavellatum*	0	2
Euchiton sp.	0	2
Galium sp.	10	16
Helichrysum leucopsideum	7	3
Hydrocotyle laxiflora	7	40
Kennedia prostrata	5	10
Lagenophora stipitata	27	19
Luzula sp.	0	2
Microtis sp.	0	2
Oxalis sp.	5	21
Ozothamnus turbinatus	0	3
Parietaria debilis	0	5
Pelargonium australe	2	2
Pterostylis cucullata	0	2
Sarcocornia sp	0	2
Scaevola albida	0	8
Senecio odoratus var. *odoratus*	27	56
Senecio sp.	5	2
Senecio spathulatus	0	8
Stackhousia monogyna	0	2
Swainsona lessertiifolia	39	58
Thinopyrum junceiforme	12	16
Threlkeldia diffusa	15	24
Thuidiopsis furfurosa	0	16
Viola hederacea	0	6
Viola sp.	0	2
Wurmbea latifolia	0	11
Zygophyllum billardierei	5	10
**Anagallis arvensis*	24	21
**Anchusa arvensis*	0	3
**Asparagus asparagoides*	12	48
**Asparagus scandens*	0	3
**Cakile* sp	0	5
**Carduus tenuiflorus*	0	2
**Centaurium* sp.	0	29
**Cerastium glomeratum*	17	6
**Cerastium* sp.	0	34
**Cirsium vulgare*	0	3
**Dolichos lignosus*	5	0
**Euphorbia peplus*	0	5
**Fumaria muralis* subsp. *muralis*	0	2
**Hypochoeris glabra*	0	23
**Hypochoeris radicata*	12	6
**Hypoxis glabella*	0	2
**Leontodon taraxacoides*	0	3
**Lotus* sp.	0	2
**Malva dendromorpha*	0	2
**Malva* sp.	0	2
**Medicago* sp.	0	2
**Melilotus indicus*	0	3
**Minuartia mediterranea*	0	24
**Orobanche minor*	0	5
**Parapholis incurva*	0	2
**Petrorhagia dubia*	0	5
* *Petrorhagia* sp.	0	2
**Plantago lanceolata*	0	3
**Polycarpon tetraphyllum*	0	2
**Romulea* sp.	0	2
**Senecio elegans*	20	11
**Sherardia arvensis*	0	2
**Silene nocturna*	0	13
**Silene vulgaris*	0	2
**Sonchus oleraceus*	7	10
**Stellaria angustifolia*	0	2
**Trifolium dubium*	0	3
**Vinca major*	0	2
Grasses and sedges		
Austrodanthonia caespitosa	0	2
Austrodanthonia sp.	0	61
Austrostipa flavescens	24	58
Austrostipa stipoides	10	5
Carex breviculmis	17	21
Cynodon dactylon	5	0
Dichelachne crinita	7	5
Diplotaxis tenuifolia	0	5
Distichlis distichophylla	0	3
Elymus scaber	15	19
Ficinia nodosa	20	29
Lachnagrostis billardierei s.l.	24	21
Lepidosperma gladiatum	32	58
Lomandra longifolia	0	6
Poa ensiformis	0	5
Poa labillardierei	56	61
Poa labillardierei var. *labillardierei*	0	3
Poa morrisii	0	2
Poa poiformis	27	5
Poa poiformis var. *ramifer*	0	15
Poa rodwayi	0	5
Poa sp.	0	2
Schoenus nitens	20	3
Spinifex sericeus	10	6
Themeda triandra	0	6
**Aira* sp.	34	52
**Ammophila arenaria*	10	5
*Avena sp.	0	11
**Briza minor*	0	10
**Bromus diandrus*	7	10
**Bromus hordeaceus* subsp. *hordeaceus*	0	2
**Bromus* sp	0	10
**Catapodium rigidum*	29	53
**Ehrharta longiflora*	0	8
**Ehrharta erecta* var. *erecta*	0	18
**Holcus lanatus*	0	2
**Lagurus ovatus*	41	39
**Pennisetum clandestinum*	0	3
**Phalaris* sp.	0	3
**Psilurus incurvus*	0	5
**Rostraria crista*	0	27
**Sporobolus africanus*	0	11
**Stenotaphrum secundatum*	10	13
**Vulpia ciliata*	7	0
**Vulpia myuros*	17	56

Vegetation description – 1978

Parr-Smith and Smith (1978) describe the hinterland vegetation of Point Nepean as predominately dune 'Scrub' dominated by *Leptospermum laevigatum* and *Melaleuca lanceolata* subsp. *lanceolata* (Table 1). The dune 'Scrub' is interlaced with areas of *Poa labillardierei* grasslands and exotic grasslands, as a result of vegetation clearance. Different vegetation sub-units occur in the dune 'Scrub' as fine scale mosaics, with subtle changes in species dominance and structural characteristics ranging from shrublands through to woodlands and low open forests. In the 'Coastal' complex wind-pruned heath communities composed of *Leucophyta brownie* and *Correa alba* occur on exposed coastal areas; interlaced with coastal cliff communities of *Austrostipa stipoides* grasslands. With wind-pruned heaths of *Leptospermum laevigatum, Leucopogon parviflorus* and *Pimelea serpyllifolia* occur on the dunes. On the protected bay-side dunes a coastal scrub dominated by *Leucopogon parviflorus* occurs. In some places on the protected foredunes *Spinifex sericeus* grasslands *and Atriplex cinerea* shrublands occur.

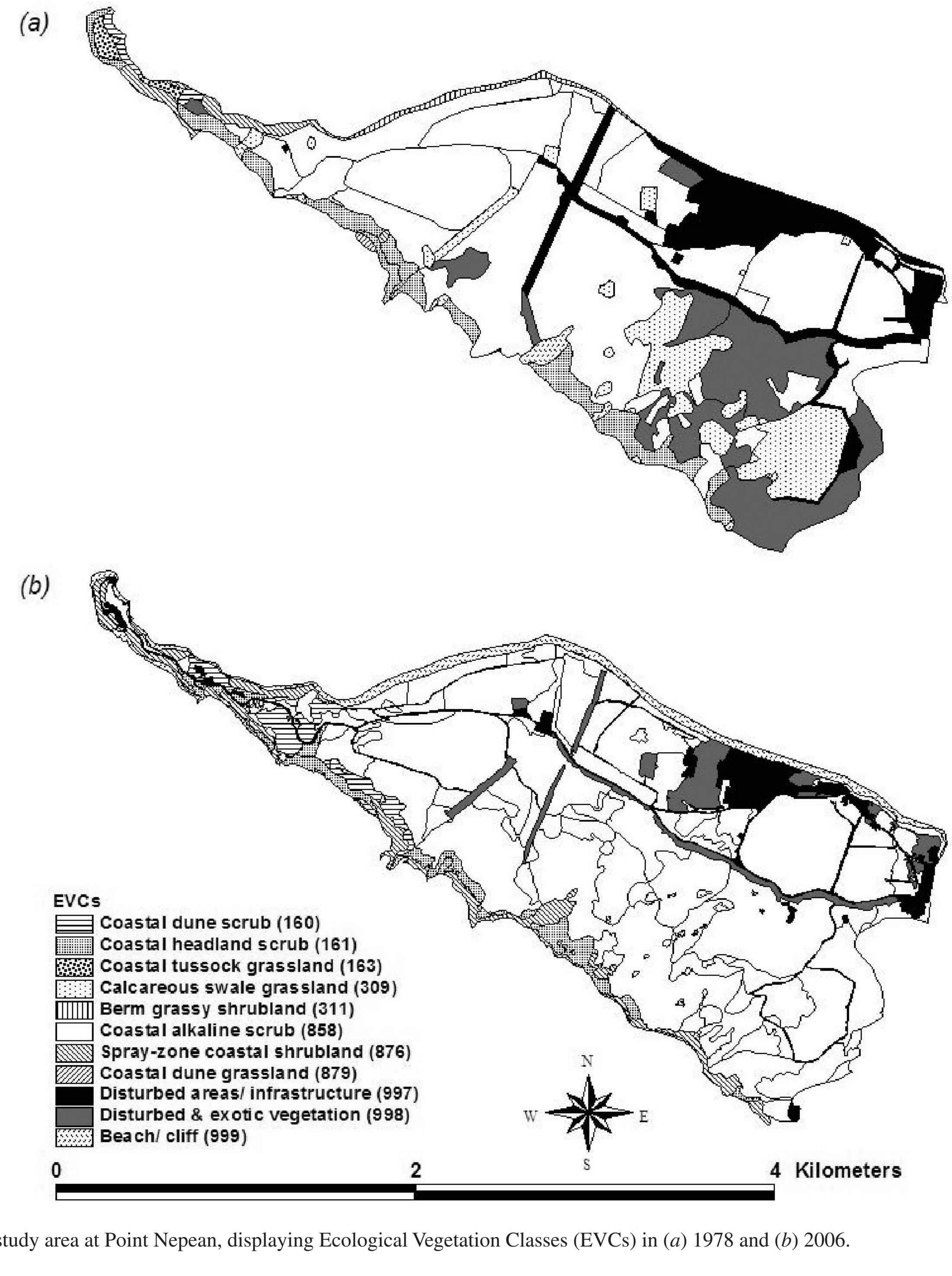

Fig. 3. The study area at Point Nepean, displaying Ecological Vegetation Classes (EVCs) in (*a*) 1978 and (*b*) 2006.

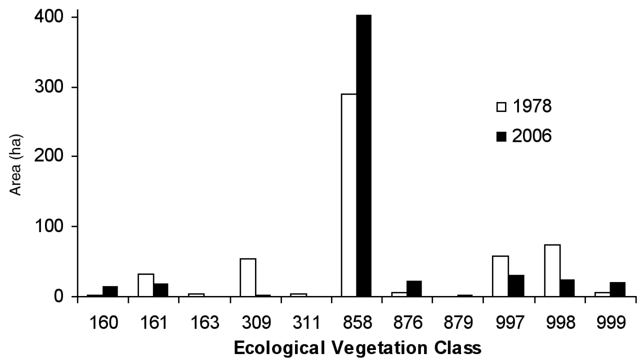

Fig. 4. Total area (ha) of Ecological Vegetation Classes in 1978 and 2006 at Point Nepean. Coastal Dune Scrub (160), Coastal Headland Scrub (161), Coastal Tussock Grassland (163), Calcareous Swale Grassland (309), Berm Grassy Shrubland (311), Coastal Alkaline Scrub (858), Spray-zone Coastal Shrubland (876), Coastal Dune Grassland (879), Disturbed Areas including infrastructure (997), Disturbed and Exotic Vegetation (998) and Beach/cliff/blowout (999).

Changes in vegetation structure between 1978 and 2006.

The majority of vegetation change at Point Nepean since 1978 has occurred in the hind dune system. Between 1978 and 2006 the area of disturbed vegetation and ruined infrastructure decreased by 135 ha (25%) as a result of increases in the area of scrub complex (55% increase, 113 ha) and a slight increase in the coastal complex (4% increase, 22 ha) (Table 1, Figs. 1 and 2).

The Ecological Vegetation Class Coastal Alkaline Scrub (EVC 858) covered the majority of the park in both 1978 and 2006 and increased by 21% (112 ha) between 1978 and 2006 (Figs. 3 and 4). The observed increase was due to invasion by woody species such as *Leptospermum laevigatum,* into grassland areas within the hind dune system. Spray-zone Coastal Shrubland (EVC 876) and Coastal Dune Scrub (EVC 160) also increased between 1978 and 2006 but Grassy vegetation (Coastal Tussock Grassland EVC 163 and Calcareous Swale Grassland EVC 309) was almost absent in 2006 largely due to replacement by Coastal Alkaline Scrub. These changes are reflected in the vegetation structural formations, devised by Parr-Smith and Smith (1978), with an increase in shrubland associations (Fig. 5) and a decrease in grasslands and the shrubland/grassland interface by 2006.

Floristic changes

Despite a much smaller total sampling area, 168 plant species were recorded in the 2006 quadrats compared to 135 in 1978. A total of 273 species (157 native, 116 exotic) were recorded throughout the survey area in 2006 i.e. in quadrats and observed (63% of species recorded in the 2006 quadrats were native compared with 54% in 1978). Exotic species recorded in the quadrats slightly increased from 62 in 1978 to 65 in 2006.

The frequency of several native woody species increased between 1978 and 2006, including *Leptospermum laevigatum*, *Acacia uncifolia* and *Alyxia buxifolia* (Sea Box) (Tables 2 and 3, Fig. 6). Exotic species that have increased include grasses and herbaceous species such as *Aira sp., Asparagus asparagoides* (Bridal Creeper), *Catapodium rigidum* (Fern Grass), and the highly invasive woody weeds *Polygala myrtifolia* var. *myrtifolia* (Myrtle-leaf Milkwort), *Chrysanthemoides monilifera* (Boneseed) and *Rhamnus alaternus* (Italian Boxthorn). This generic increase in woody invasive species occurred predominately in the hind dune system.

Changes in the hind dunes species

A number of characteristic native species of the hind dune scrub complex (see Table 1) changed in frequency. There were increases in the groundlayer species *Swainsona lessertiifolia* (Coast Swainson-pea), *Dichondra repens*

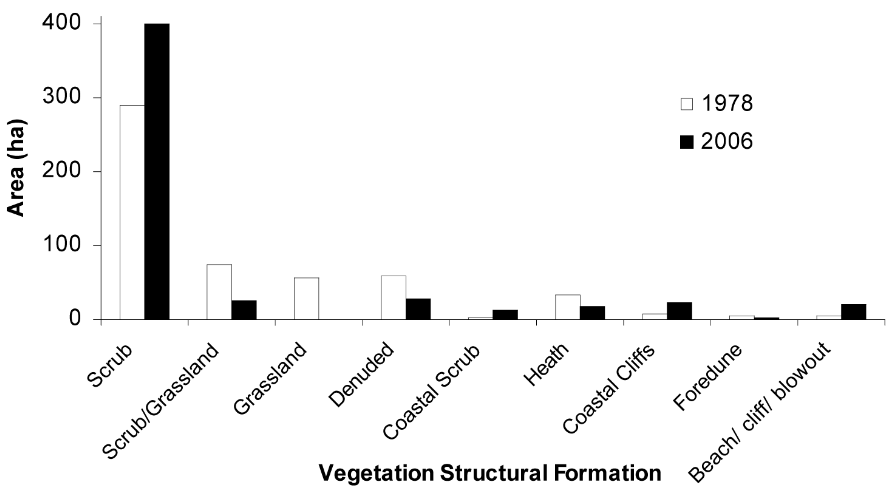

Fig. 5. Total area (ha) of vegetation structural formations (Parr-Smith & Smith 1978) in 1978 and 2006 at Point Nepean.

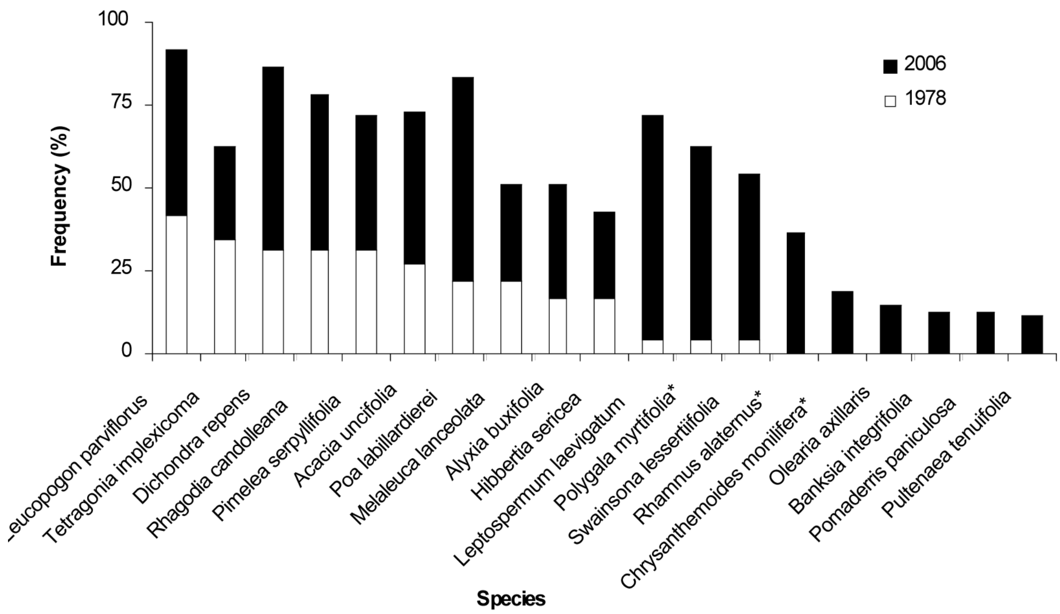

Fig.6. Percent frequency (stacked) of characteristic native species and dominant woody species recorded in vegetation quadrats, in the hind dune shrubland associations (i.e. Coastal Alkaline Scrub/Scrub complex) in 1978 and 2006 at Point Nepean. Characteristic species as per Parr-Smith & Smith (1978) and Oates & Taranto (2001).

(Kidney Weed), *Rhagodia candolleana* subsp. *candolleana* (Sea-berry Saltbush) and interestingly *Poa labillardieri* and the native woody species *Leptospermum laevigatum* and *Acacia uncifolia* (Fig. 6). In 1978 the dominant woody species of the hind dune system were *Melaleuca lanceolata* subsp. *lanceolata*, *Leucopogon parviflorus*, *Pimelea serpyllifolia* subsp. *serpyllifolia* (Thyme Rice-flower) and *Acacia uncifolia* (Fig. 6). While *Melaleuca lanceolata* subsp. *lanceolata, Acacia uncifolia*, *Leucopogon parviflorus* and *Pimelea serpyllifolia* subsp. *serpyllifolia* were still prevalent in 2006, particularly in least disturbed areas where they formed low woodlands, *Leptospermum laevigatum* and the exotic *Polygala myrtifolia* var. *myrtifolia* also occurred at a high frequency. The exotic woody species *Rhamnus alaternus* and *Chrysanthemoides monilifera* were also more widespread in the hind dune system in 2006 (Fig. 6).

Discussion

In the 28 years between 1978 and 2006 broad scale changes in the vegetation of Point Nepean have occurred. The coastal vegetation of the foredunes, cliffs and blowouts has increased slightly, perhaps indicating primary succession, and secondary succession of disturbed areas, but the major change has been the widespread shrubland invasion of the hind dune system. This change is predominately reflected in the invasion of taller woody species into native and exotic grasslands and disturbed areas. Invasive woody species include both native species characteristic of this zone and exotic woody species that have increased in areas that were previously, grasslands, disturbed vegetation or ruined/abandoned infrastructure.

The removal of disturbance regimes such as burning and grazing have been frequently reported to trigger the invasion of woody species (Kirkpatrick 1975, van der Maarel *et al*. 1985, Molnar *et al*. 1989, Offor 1990, Bennett 1994, McMahon *et al*. 1996, Lunt 1998, Costello *et al.* 2000, Zbigniew and Stefania 2007), and our study supports this. Native woody species (e.g. *Alyxia buxifolia*) increased on the more exposed hind dunes, and *Leptospermum laevigatum* increased in abundance to form shrublands on the protected hind dune system. Exotic woody invasive species such as *Polygala myrtifolia* var. *myrtifolia* have also increased in these systems, particularly in the hind dune and the area covered by grasslands (Parr-Smith & Smith 1978) has declined.

Bennett (1994) studied changes in coastal vegetation at Wilsons Promontory south-east of Point Nepean over a 50 year period and highlighted the expansion of *Leptospermum laevigatum* into both coastal secondary grasslands and *Banksia* woodlands. This expansion coincided with changes in human-induced disturbance regimes, the halting of burning, removal of cattle and an increase in grazing pressure by kangaroos and rabbits. This change in grazing regime led to an increase in woody species encroachment due to cessation of cattle browsing on shrubs and the creation of bare ground for seedling establishment (Bennett 1994). At Point Nepean grazing is low due to the exclusion of exotic herbivores (as much as reasonably practicable) and lack of native herbivores in the park. The major changes in disturbance regimes in recent years have been (1) the change in burning and slashing/mowing regimes in some locations, (2) the removal of human disturbances brought about by the halting of defence activities and (3) the increase in human traffic in some areas of the park. As neither domestic stock nor large native herbivores have used the area since the late 1800s (O'Neill 1988) it is likely that the change in burning, slashing/mowing regimes and other human activities that have occurred in different areas of the park underlie the recent expansion of woody species. Conversely, the process of invasion by woody species may have begun at a much earlier stage. There is anecdotal historical information suggesting invasion by *Leptospermum laevigatum* began much earlier and the beginning of it may well date back to the late 19th century (Moxham *et al*. 2009*a*).

In a previous study (Moxham *et al.* 2009*a*) we examined the historical accounts of vegetation of the Nepean Peninsula and highlighted the changing hind dune system from woodlands to *Leptospermum laevigatum* scrublands with the arrival of European land use and changes to disturbance regimes. It is thought that *Leptospermum laevigatum* communities were once restricted to a narrow band along the coast (Moxham *et al.* 2009*a*), indicating that this species may be a relatively recent component of the hind dune vegetation. *Leptospermum laevigatum* is a vigorous colonising species (Burrell 1981; Offor 1990; Bennett 1994), competitively excluding other species that inhabit similar niches, such as *Melaleuca lanceolata* subsp. *lanceolata* and *Leucopogon parviflorus*. *Melaleuca lanceolata* subsp. *lanceolata* and *Leucopogon parviflorus* have remained relatively stable in frequency at Point Nepean since 1978 and vegetation dominated by these species occurs in areas that have had the least disturbance (Moxham *et al.* 2009*a*). However, the composition and thus structure of these hind dune communities appears to have changed with the increase in frequency of *Leptospermum laevigatum* and *Polygala myrtifolia* var. *myrtifolia*. Given the probable historical distribution of *Leptospermum laevigatum* (see below, Moxham *et al.* 2009*a*) these results indicate that the current hind dune vegetation may be forming new communities in this landscape. Indeed at a statewide level Lunt *et al.* (2010) indicate that changes brought about by woody plant invasion in coastal systems may reflect a more enduring longer-term process.

The management of vegetation with a history of varied and intensive disturbances in an urban landscape context provides challenges. What should be the objective of management and what vegetation types or transitional phases are desired? The various vegetation structures of Point Nepean reflect past and present disturbance underlying physical processes. The hind dune landscapes vary in structure and include small areas of grasslands and low woodlands and more extensive areas of shrublands. Some of these vegetation communities are now rare in the landscape and have high conservation value (e.g. Coastal Moonah Woodland, calcareous swale grassland). Historically these hinterland areas may have been covered with woodlands and forests (Moxham *et al.* 2009*a*) but the changes since 1978 demonstrate an increasing cover of shrublands, a pattern that we expect to continue. Should we be actively managing to encourage development of the historical vegetation (e.g. open woodlands of *Allocasuarina verticillata, Melaleuca lanceolata* subsp. *lanceolata, Banksia. integrifolia* subsp. *integrifolia* and *Acacia* species), or manage the current composition to maintain the existing species and structure? A primary management aim might be to maintain the existing native species diversity in the National Park for the long-term. This could be undertaken by examining the interaction between the less common species and their habitat structure to prioritise management zones and strategies. Indeed the mosaic of coastal vegetation types representing a complete system is now becoming scarce due to increasingly urbanised landscapes and Point Nepean represents one of the last remaining examples of this complete coastal dune ecosystem (fore dune and hind dune system) in the region. However, as this area now occurs in a relatively densely-populated urban landscape, practical considerations such as potential fire hazards as well as human preference must influence the decision making process. The inherent dynamic nature of the shrublands dominated by *Leptospermum laevigatum* must also be considered as this will affect the resources required to direct or maintain vegetation structure and composition.

In summary, there has been widespread change in the coastal vegetation at Point Nepean, particularly in the hind dune landscape following the removal of human-induced disturbances. Areas of disturbed vegetation (including exotic and disturbed native vegetation), ruined/abandoned infrastructure, exposed coastal sites (such as blowouts, dunes and cliffs) and grasslands have decreased while scrub communities have increased. The increase in shrublands may have begun before the 1978 Parr-Smith and Smith survey. The coastal system is highly dynamic. Various vegetation states are evident and National Park management actions will depend on which state is desired and the location in the coastal landscape (e.g. swale, tertiary dune etc).

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