Changes in dune vegetation over 60 years in a sand-mined area of the NSW lower North Coast

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Abstract: Sand mining has been responsible for much of the degradation of the indigenous flora of sand dunes in New South Wales, to the extent that authentic foredune plant communities are now uncommon in much of NSW and southern Queensland. Dune heaths are very susceptible to invasion and infestation by the weed, bitou bush (*Chrysanthemoides monilifera* subsp. *rotunda*). This paper compares the floristic composition of dunes in 1941 (before sand mining) and 1997 & 1999 (after sand mining and invasion by bitou bush), at Bennetts Beach, Hawks Nest, on the lower north coast of NSW. The 1941 data provide a unique example of authentic foredune vegetation and is the first quantitative analysis of coastal dune vegetation in NSW. In 1941, 25 native species were recorded in the 0.5 ha site. Nine of these were considered to be characteristic of dune communities and eight of these nine were also recorded in a 1939 survey at Myall Lakes. Four other studies in the intervening 60 years contain species lists of dune vegetation in this general area (1986, 1995, 1997 and 1999). Of a total of 17 species considered to be strongly associated with dune habitats, five were reported in all of six surveys and 15 occurred in one or more of the more recent surveys (1986 and later); the two exceptions were *Austrofestuca littoralis* and *Senecio spathulatus*. Only one introduced weed was recorded in 1941 (*Cakile edentula*) and the only weeds recorded in 1939 were *Cakile edentula* and *Oxalis corniculata*, both cosmopolitan species. Thirteen additional weed species, the most abundant being *Chrysanthemoides monilifera*, were recorded in the more recent surveys. A set of 14 native species that are more typical of heath and eucalypt forest and woodland communities than of the dunes were absent in the 1939 and 1941 surveys but occurred in one or more of the post-mining surveys of 1995, 1997 and 1999. Detailed plant distribution and abundance were assessed in the same part of Bennetts Beach in 1941, 1997 and 1999. All show some patterns of zonation across the sand dune. However, clear phytosociological patterns of the dominant species that were obvious in 1941 were lacking in the 1997 and 1999 analyses. These contrasts suggest that post-mining revegetation has resulted in weed invasion, addition of native species from other communities, and a disruption of the distributions of typical dune species of species across the sand dunes that has been only partially recovered since sand mining and invasion of bitou bush.

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Introduction

In Bentham's *Flora Australiensis* (1866), descriptions of plants found on coastal sand dunes of New South Wales are attributed to collections made by the early explorers. More than a century later, the first publications on the sand dune vegetation of NSW came solely from work on the 'central coast' (Hamilton 1918; Osborn & Robertson 1939; Pidgeon 1940; Davis 1941), now referred to as the 'lower north coast'. There are now many reports on coastal dune vegetation in NSW (see the annotated bibliography by Clarke 1989a; also Carolin & Clarke 1991, Buckney & Morrison 1992, Clarke 1994). Clarke and Chapman (1989) argued that '...basic understanding of the distribution and abundance of coastal sand dune species and vegetation types was inadequate ... for support of informed management of dune vegetation.' The reports by Clarke (1989a,b), Clarke & Chapman (1989) and Chapman (1989) now provide a more comprehensive description of the current state of dune vegetation. Unfortunately, the indigenous dune floras of the central and north coasts of NSW have been altered considerably during the past 80 years or more, so that authentic foredune plant communities are no longer common (Chapman 1989).

Although users of the foredune environment, including off-road recreational vehicles, have caused disturbance to the indigenous flora, sand mining has been the most destructive. From as early as 1934, heavy mineral sands (e.g. rutile, zircon, ilmenite, monazite) have been mined along 1700 km of the eastern coastline of Australia, from Gladstone (Qld) to Port Kembla (NSW) (Allen et al. 1990). On the lower-north and north coasts of NSW, sand mining has occurred on beaches, foredunes and hind dunes. Mining companies are now required to rehabilitate these areas, including revegetation with native species (Fox & Fox 1978, 1984, Allen et al. 1990). The revegetated areas are particularly susceptible to invasion and infestation by bitou bush (*Chrysanthemoides monilifera* subsp. *rotunda* (DC) Norlindh). This plant was introduced from South Africa over 100 years ago (Chapman 1989, Parsons & Cuthbertson 1992) and, in the late 1940s, was identified as suitable for arresting sand drift after successfully colonising extensive mobile dunes north of Newcastle. Bitou bush spread rapidly north of Sydney to the sand islands of SE Queensland, and its successful competition with indigenous species led to the withdrawal in 1971 of the official support for its use in sand stabilization (Cooney et al. 1982).

This paper reports detailed studies of species composition and zonation, nearly 60 years apart (1941 and 1997 & 1999), in foredune vegetation at Bennetts Beach, Hawks Nest, on the lower north coast of NSW. Along with surveys in nearby areas, conducted in 1939 (Osborn & Robertson 1939), 1986 (Myerscough & Carolin 1986) and 1995 (Kohler et al. 1995), they provide an opportunity to compare the current vegetation of mined, bitou-infested dunes with the 'authentic' dune plant community that existed in the 1940s. This paper has the following aims:

1. To place on record the first quantitative analysis (by Pidgeon 1942) of authentic foredune vegetation in NSW.

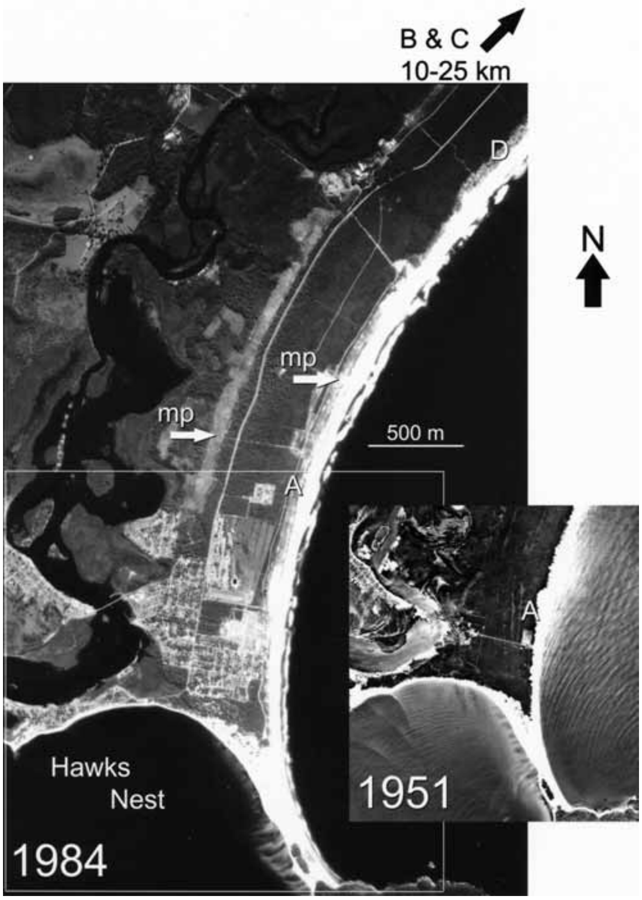

Fig. 1. 1984 aerial photograph showing the township of Hawks Nest, at the southern end of Bennett's Beach (Port Stephens 9332, 1984, B&W 1:40 000 NSW 3389, Run 3, Print 100). The inset shows the southern portion of the beach as it appeared in 1951, prior to sand mining (Port Stephens 9332, 1951, B &W 1:30 000 SYV1294, Run 4, Print 5093). The study areas referred to in the Methods are indicated on the 1984 photo. The sand mining paths are indicated as 'mp'. (Source of photos: © Land and Property Information, Panorama Ave., Bathurst, www.lpi.nsw.gov.au). The label 'A' in the 1951 inset indicates the location of the 1941 study and, in the 1984 photograph, indicates the location of the 1997 and 1999 studies. 'D' indicates the location of the herbicide study by Kohler et al. (1995). The broader surveys by Osborn & Robertson (1939) ('B'), Myerscough & Carolin (1986) ('C') were approximately 10–25 km north of the northern edge of this photograph, within Myall Lakes National Park.

2. To compare this community, as it existed before sand mining and invasion of bitou bush, with the floristic composition, abundance of species and current status of the mined and revegetated dunes in the same area in the late 1990s.

Study area

Bennetts Beach, on the northern shoreline of the entrance to Port Stephens, 250 km north of Sydney, extends north from the town of Hawks Nest (32°39'S; 152°11'E). In 1941, the area was undeveloped, as shown in the 1951 aerial photograph (Figure 1), with only a few houses, a general store, a road to the beach and a small caravan park. The sites referred to in this paper are shown in Figure 1 as: Site A, near Hawks Nest, where detailed transect surveys were conducted in 1941 and repeated nearby in 1997 and 1999; Sites B and C, the general location of surveys of the vegetation of the Myall Lakes area, first by Osborn and Robertson (1939), who provided a composite list of plant species found on the strand, fore-dune and fixed dune in the late 1930s, and more recently by Myerscough & Carolin (1986); Site D, the location of a survey by Kohler et al. (1995), conducted to assess the impact of herbicide spraying on native plant species.

Sand mining on Bennetts Beach, from Hawks Nest north along the coast, commenced in 1968, resumed in 1971–72, and again post-1986 (D. Stoupe, BHP Titanium Minerals Pty Ltd, Hawks Nest, pers. comm.). Mined areas appear clearly in the aerial photograph of 1984 (Figure 1) as broad bands of cleared vegetation, one of which extends along the beach, often from the high tide mark and all the foredune to the hind dune. At Bennetts Beach, the old stabilized dunes consist of alternating swales and ridges, and appear as multiple, parallel lines in the 1951 photograph in Figure 1.

Methods

Detailed vegetation sampling — 1941, 1997 and 1999

In 1941, vegetation was sampled in a 0.5 ha study site, extending for 114 m from a baseline above the beach face, across the foredune complex, windward and lee slope of the foredune ridge, to the swale. The location, now part of the golf course, is labeled 'A' on the 1951 photograph in Figure 1. Eleven parallel transect lines were established 15 ft (4.6 m) apart. Data were collected in contiguous rectangular quadrats (4.6 m × 0.9 m) along each transect line for a maximum length of 25 quadrats (114 m). Fence-lines and adjacent land ownership made the grid outline in 1941 slightly irregular (see shaded portion of Figure 2).

This procedure was repeated in 1997 and 1999, in two locations, 250 m apart (labelled 'A' on the 1984 photograph in Figure 1), just north of the caravan park and golf course at Hawks Nest. These locations were selected to be near to the 1941 study without being obviously affected by foot or vehicle traffic or other disturbances. In was impossible to use the exact location of the 1941 survey because development had destroyed the site. In each of the 1990s surveys, the parallel transects extended from the strand to the swale margin of the main dune, which was 28 contiguous 4.6 m quadrats (130 m) in 1997 and 37 quadrats (170 m) in 1999. These two study plots clearly span the strip that was mined for sand, clearly seen in the 1984 aerial photograph (Figure 1).

In 1941, the percent cover of grasses, forbs, recumbent and tufted herbs was estimated by eye and numbers of erect herbs, small and tall shrubs and trees were counted in each 4.6 m × 0.9 m quadrat. In 1997 and 1999, percent cover was estimated by eye for all species. The 1941 density data for the erect herb, shrub and tree species were converted to % cover by multiplying by 5%, as these were relatively small plants in 1941 and a pilot study in 1997 indicated that the 5% conversion was a reasonable approximation for these species. These cover estimates were used to plot the spatial distributions of all species across the fore dune – hind dune gradient. For each species, cover was averaged across each corresponding quadrat position over the 11 transects, and this measure was then expressed as a moving average of each respective quadrat position and the adjacent quadrat (Figure 2). These data were used to prepare graphs illustrating the change in % cover across the dune, for the more common plant species, in each of the three surveys.

Fine-scale distributions of three dominant shrub species (*Leptospermum laevigatum*, *Monotoca elliptica* and *Banksia integrifolia*) and two dominant herb species (*Hibbertia scandens* and *Scaevola calendulacea*) were described using

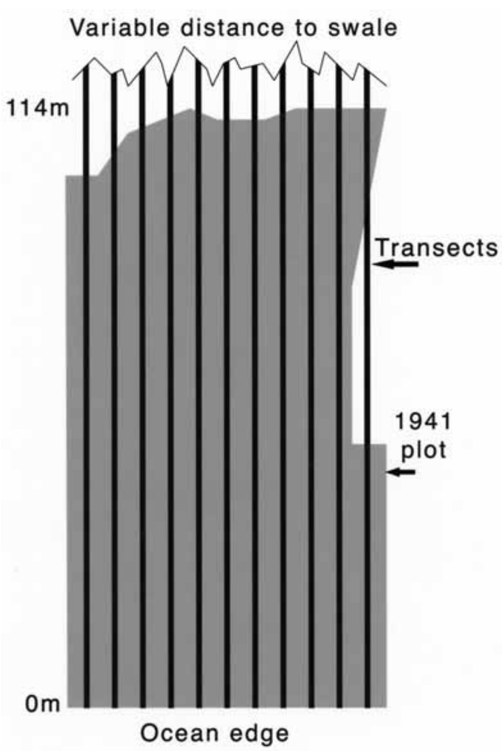

Fig. 2. Outline of the vegetation survey layout at site A (see Fig. 1) in 1941, repeated in 1997 and 1991. Vegetation data from contiguous 4.6 x 0.9 m quadrats in parallel transects, 4.6 m apart, were used to quantify zonation across the dune (see Fig. 3) and to assess phytosociological patterns using isonome mapping (see Fig. 4).

isonome maps (Pidgeon & Ashby 1942; Brewer 1995). For the three shrubs, the relative density of the species was calculated, as a percentage, for each quadrat (e.g. 15 individual plants of *Leptospermum laevigatum*, out of a total of 20 plants in a quadrat, yields a relative abundance score of 75%). For the herb species, this score was based on the cover estimates for the two herb species. The percentage scores for individual species were then plotted on separate maps of the grid, and lines drawn to connect areas of equal relative density values, in the same was as contour maps are drawn (Brewer 1995). These lines, or 'isonomes' (from *iso* = equal and *noma* = distribution) are essentially contours of equal relative density.

General surveys in 1939, 1986 and 1995

Osborn and Robertson (1939) described the vegetation of the Myall Lakes based on three surveys (spanning 1934 and 1935). Their species lists of the coastal vegetation appear to be composites from the three visits to the area, collected mostly in what is now Myall Lakes National Park. Three dune zones identified by Osborn and Robertson, 'strand', 'foredune' and 'fixed dune', support the vegetation that was examined in detail in our studies.

Myerscough and Carolin (1986) defined the plant communities occurring on sands and headlands in the coastal portion of Myall Lakes National Park, and prepared a vegetation map of the area. Their study area broadly overlaps the area surveyed by Osborn and Robertson (1939), to the north of our detailed Hawks Nest vegetation surveys. The plant communities defined by Myerscough and Carolin (1986) that represent the vegetation of our studies are 'foredune complex' and 'beach-dune thicket'. Although some of the area surveyed by Myerscough & Carolin had been mined for sand, their vegetation descriptions were based on what they refer to as the 'putative undisturbed state'. Their species lists for the two relevant communities appear to have been based on a transect just north of Bombah Broadwater, about 25 km north of our study sites.

Kohler et al. (1995) reported an experimental study designed to assess the impact on native plant and animal species of aerial herbicide spraying to control bitou bush (*Chrysanthemoides monilifera*). This site extends for 2 km, from about 3 km north of Hawks Nest virtually to the southern boundary of the Myall Lakes National Park. The sand dune vegetation was divided in to contiguous strips, 44 m wide, representing a range of herbicide treatments and untreated controls. Vegetation was surveyed in 10 of these treatment strips, using 5 m wide transects that extended approximately 100 m, from the western edge of the hind dune to the ocean edge of the foredune.

Comparisons of species in surveys

Species recorded in each of the surveys were classified as either native or introduced to Australia. The native species were further categorised as being (i) strongly associated with sand dune habitats, (ii) naturally occurring in sand dunes but also occurring commonly in a range of other habitats, and (iii) characteristic of habitats other than sand dunes. Decisions were based on information contained in Myerscough & Carolin (1986), Clarke (1989a,b), Clarke & Chapman (1989), Chapman (1989), Carolin & Clarke (1991), Benson & McDougall (1993), and Harden (1993).

Results and discussion

Vegetation composition

Twenty-five species were recorded in the 1941 survey (Table 1). Of these, 9 were considered to be closely associated with sand dunes, 15 were other native species that are also commonly found in other habitats, and one is a cosmopolitan weed species (*Cakile edentula*). The survey by Osborn and Robertson (1939) at Myall Lakes adds six species to this list of 25: *Apium prostratum*, *Calystegia soldanella*, *Correa alba*, *Dodonaea triquetra*, *Euphorbia sparmanii*, and *Senecio spathulatus*. This is perhaps understandable, because the Osborn & Robertson list is a composite of several visits, the total area searched was certainly greater than the 11 transects surveyed in 1941 (Robertson pers. comm.), and the site was 15–20 km further north.Comparing the 1941 list with the 1997 and 1999 studies, conducted in the same way in the same area (close to Hawks Nest), reveals seven species that were absent in the later two surveys (*Actites megalocarpus*, *Austrofestuca littoralis*, *Breynia oblongifolia*, *Conospermum taxifolium*, *Leucopogon parviflorus*, *Pomax umbellata* and *Stephania japonica*). Only one of these (*A. littoralis*) was also absent in the other recent surveys (1986 & 1995). There were, however, many new species (21) recorded at Hawks Nest in 1997/99. Nine of these additional species are introduced weeds and 10 are native species more typical of heath, woodland and forest communities (Table 2; see also Clarke 1989b), and are listed by Myerscough & Carolin (1986) as being present in communities other than ‘foredune complex’ or beach-dune thicket’ (see Table 1).

It is striking that the 1941 study detected only one exotic weed species, *Cakile edentula*, which has a cosmopolitan distribution (Carolin & Clarke 1991). Osborn and Robertson found *Cakile edentula* and also *Oxalis corniculata*, which also has a cosmopolitan distribution (although even this may have been a native *Oxalis* taxon such as *Oxalis rubens*; D. Benson pers. comm.). The later studies all reported many weed species, including invasive species such as *Chrysanthemoides monilifera* and *Ipomoea cairica*.

Vegetation profile across the dune

The distributions and densities, over the 0.5 ha study area at Bennetts Beach, of the 29 species recorded in the sample quadrats in 1941 are shown in Figure 3 (a) in relation to the dune profile (from Brewer 1941). A set of species was clearly confined to the foredune, just above the strand, with *Spinifex sericeus* and *Carpobrotus glaucescens* dominating; although in this region there was a high percent cover of bare sand. *Hibbertia scandens* and *Scaevola calendulacea* dominated the lower slope of the foredune ridge, associated with a number of other species, including the most seaward appearance of shrub species. From the upper windward slope and dune crest to the swale, *Monotoca elliptica* and *Leptospermum laevigatum* were obvious dominants. These two shrub species had the greatest ecological amplitudes, experiencing exposure to salt-laden winds on the seaward face of the foredune ridge and also shelter and higher humidity on the lee slope and swale, where they formed closed-canopy thickets with sparse ground flora and some species of climbers. The transects finished at 114 m; beyond this there was a sharp ecotone (at *c*. 120 m) to open woodland of *Banksia serrata*. This species covered the undulating barrier ridges to about 160 m. A low heath separated the *B. serrata* woodland from *Eucalyptus pilularis* open forest, which extended to 230 m.

Table 1. Plant species recorded from four sites in the lower north coast, NSW.

Site **A** (Bennetts Beach): Pidgeon (1941) and this study (1997 & 1999); Site **B**: Osborn & Robertson (1939); Site **C**: Myerscough & Carolin (1986); Site **D**: Kohler et al. (1995) [see Fig. 1 for location of sites].

represents species recorded by Myerscough & Carolin from plant communities other than ‘beach-dune thicket’ or ‘foredune complex’.

d: denotes species that are strongly associated with coastal dunes, although some occur in other nearby habitats such as coastal headlands and heaths.
N: denotes native species that occur naturally on dunes but are not restricted to that habitat.
O: denotes species that are native to other Australian plant communities but do not naturally occur in these coastal dunes.
W: denotes weed species introduced to Australia.

Status	**Species**	**A**			**B**	**C**	**D**
		1941	1997	1999	1939	1986	1995
N	*Acacia longifolia*					+	
N	*Acacia suaveolens*			+		#	+
d	*Acacia sophorae*	+	+	+	+	+	+
N	*Acacia ulicifolia*					#	+
N	*Actinotus helianthi*					#	+
d	*Actites megalocarpus*	+			+	+	
N	*Aotus ericoides*		+			#	+
N	*Apium prostratum*				+		
W	*Arctotheca populifolium*			+			
N	*Astroloma pinifolium*		+	+		#	+
d	*Austrofestuca littoralis*	+			+		
N	*Banksia integrifolia*	+	+	+	+	+	+
N	*Banksia serrata*	+	+	+	+	+	+
N	*Billardiera scandens*					+	+
N	*Bossiaea ensata*	+	+				+
N	*Bossiaea heterophylla*						+
N	*Breynia oblongifolia*	+			+	+	+
W	*Briza maxima*						+
W	*Cakile edentula*	+	+	+	+	+	
N	*Callistemon citrinus*					#	+
N	*Calystegia soldanella*				+		
d	*Carex pumila*			+			
d	*Carpobrotus glaucescens*	+	+	+	+	+	+
N	*Cassytha pubescens*		+				+
W	*Chloris gayana*					+	
W	*Chrysanthemoides monilifera*		+	+		?	+
N	*Comesperma ericinum*						+
O	*Commelina cyanea*		+		+	+	
N	*Conospermum taxifolium*	+					+
W	*Conyza albida*		+	+			
W	*Conyza bilboana*		+	+		+	
d	*Correa alba*				+	+	+

Status	Species	A 1941	A 1997	A 1999	B 1939	C 1986	D 1995
N	*Correa reflexa*					+	
N	*Cymbopogon refractus*					+	
N	*Cynodon dactylon*		+	+		#	
N	*Dianella caerulea*	+	+	+	+	#	+
N	*Dichelachne crinata*					+	
N	*Dillwynia glaberrima*		+			#	+
N	*Dodonaea triquetra*				+	+	
d	*Euphorbia sparrmanii*				+	+	
W	*Gladiolus gueinzii*		+			+	+
N	*Gonocarpus micranthus*					+	
N	*Gonocarpus teucrioides*					+	+
N	*Hardenbergia violacea*	+		+		#	+
N	*Hibbertia fasciculata*					#	+
N	*Hibbertia linearis*		+			#	+
N	*Hibbertia obtusifolia*		+			#	+
N	*Hibbertia scandens*	+	+	+	+	+	+
d	*Hydrocotyle laxiflora*					+	
W	*Hydrocotyle bonariensis*		+	+		+	+
W	*Hypochoeris radicata*					+	
N	*Imperata cylindrica*			+		+	+
W	*Ipomea cairica*					+	
d	*Isolepis nodosa*	+	+	+	+	+	+
N	*Juncus usitatus*					+	
N	*Kennedia rubicunda*	+	+	+	+	+	+
N	*Lasiopetalum ferrugineum*					+	
d	*Leptospermum laevigatum*	+	+	+	+	+	+
N	*Leptospermum liversidgei*					#	+
N	*Leucopogon ericoides*					#	+
N	*Leucopogon lanceolatus* var. *gracilis*		+	+	+	#	+
d	*Leucopogon parviflorus*	+				#	+
N	*Leucopogon virgatus*					#	+
N	*Lomandra longifolia*	+	+	+	+	+	+
N	*Monotoca elliptica*	+	+	+	+	#	+
N	*Monotoca scoparia*					#	+
N	*Myoporum insulare*						+
N	*Opercularia varia*					+	
O	*Oxalis corniculata*				+	+	
d	*Oxalis rubens*			+			
N	*Pandorea pandorana*	+	+		+	+	+
N	*Pelargonium australe*		+		+	+	
W	*Pelargonium capitatum*		+				
N	*Persoonia lanceolata*		+	+		#	+
N	*Phebalium squameum*						+
N	*Pimelea linifolia*					+	
N	*Platysace lanceolata*		+			#	+
N	*Plectranthus parviflorus*					+	
N	*Pomax umbellata*				+	+	
O	*Portulaca oleracea*			+		+	
N	*Pteridium esculentum*	+	+	+		+	+
d	*Rhagodia candolleana*					+	
N	*Ricinocarpus pinifolius*						+
N	*Sarcopetalum harveyanum*					+	
d	*Scaevola calendulacea*	+		+	+	+	+
N	*Schoenus ericetorum*						+
N	*Senecio lautus* ssp. *maritimus*	+	+	+	+	+	+
d	*Senecio spathulatus*				+		
N	*Smilax glyciphylla*		+	+		#	
N	*Solanum cinereum*					+	
d	*Spinifex sericeus*	+	+	+	+	+	+
N	*Stackhousia spathulata*				+	+	+
N	*Stephania japonica* var. *discolor*		+				+
N	*Styphelia viridus* ssp. *viridus*						+
N	*Viola hederacea*					+	
W	*Vulpia bromoides*					+	
N	*Tetratheca thymifolia*					+	
N	*Wahlenbergia gracilis*					+	
d	*Wikstroemia indica*					+	
N	*Zoysia macrantha*					+	
	Total no. species	25	36	32	31	57	55

Table 2. Comparison of total numbers and categories of species recorded in 1941 compared with 1997 and '99 at Hawks Nest.

Natives not associated with dunes	Natives associated strongly with dunes
Present in 1941, absent in 1997/1999	
Breynia oblongifolia[a]	*Actites megalocarpus*[a]
Conospermum taxifolium[a]	*Austrofestuca littoralis*
Pomax umbellata[a]	*Leucopogon parviflorus*[a]
Stephania japonica[a]	
Absent in 1941, present in 1997 &/or 1999	
Acacia suaveolens[ab]	*Carex pumila*
Aotus ericoides[ab]	*Oxalis rubens*
Astroloma pinifolium[ab]	
Cassytha pubescens[a]	
Commelina cyanea[a]	
Cynodon dactylon[b]	
Dillwynia glaberrima[ab]	
Hibbertia linearis[ab]	
Hibbertia obtusifolia[ab]	
Imperata cylindrica[ab]	
Leucopogon lanceolatus[ab]	
Persoonia lanceolata[ab]	
Platysace lanceolata[ab]	
Portulaca oleracea[a]	
Smilax glyciphylla[b]	

Introduced weeds

Present in 1941, absent in 1997/1999	Absent in 1941, present in in 1997 and/or 1999
—	*Arctotheca populifolia*
	Chrysanthemoides monilifera
	Conyza albida
	Conyza bilboana
	Gladiolus gueinzii[a]
	Hydrocotyle bonariensis[a]
	Pelargonium capitatum

Total	Introduced weeds	Natives not assoc. with dunes	Natives associated strongly with dunes
1941 (25)	1	15	9
1997 (36)	5	26	5
1999 (32)	5	19	8

[a] also present in the dunes in one of the later surveys at Myall Lakes (1986 and/or 1995)

[b] recorded in Myerscough and Carolin in another community, not in Foredune Complex or Beach-dune Thicket.

Broadly similar patterns of distribution and density across the dunes were evident in the 1997 and 1999 studies at Hawks Nest: *Spinifex hirsutus* was obviously a foredune species; *Carpobrotus glaucescens* mostly occurred on the windward part of the foredune; *Monotoca elliptica* favoured the dune crest to the swale; and *Leptospermum laevigatum* clearly dominated the leeward part of the foredune and the swale. These patterns were detectable even though the post-mining topography differed somewhat. The eastern face of the dune was shallower and the dune crest flatter and broader (Figure 3 (b)). Thus, the 50 m point in the 1941 study represents the location of the hind-dune slope whereas this topographic feature occurs at 160 m in the 1999 study.

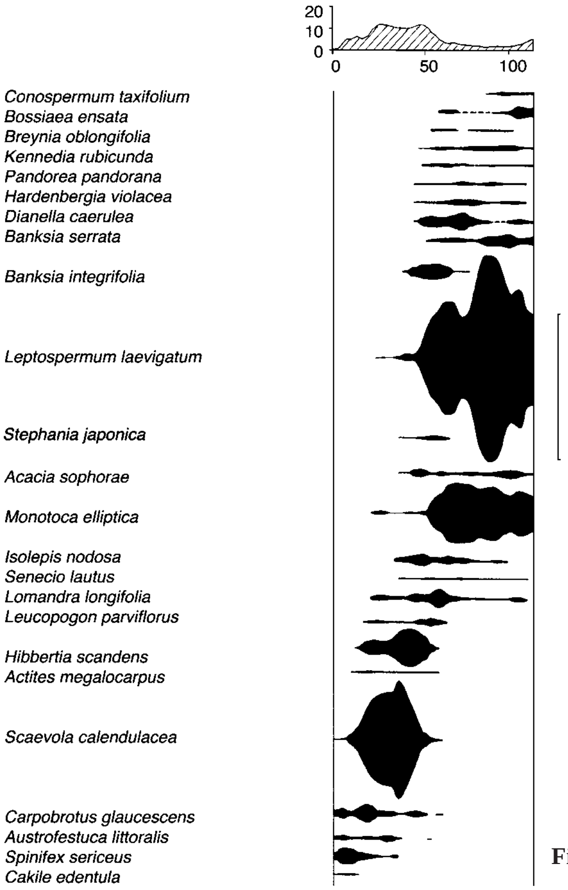

Fig. 3a.

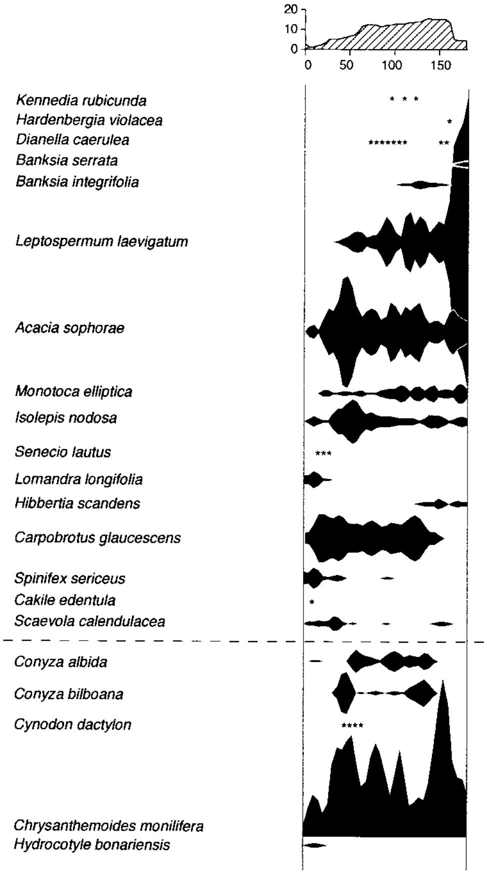

Fig. 3c.

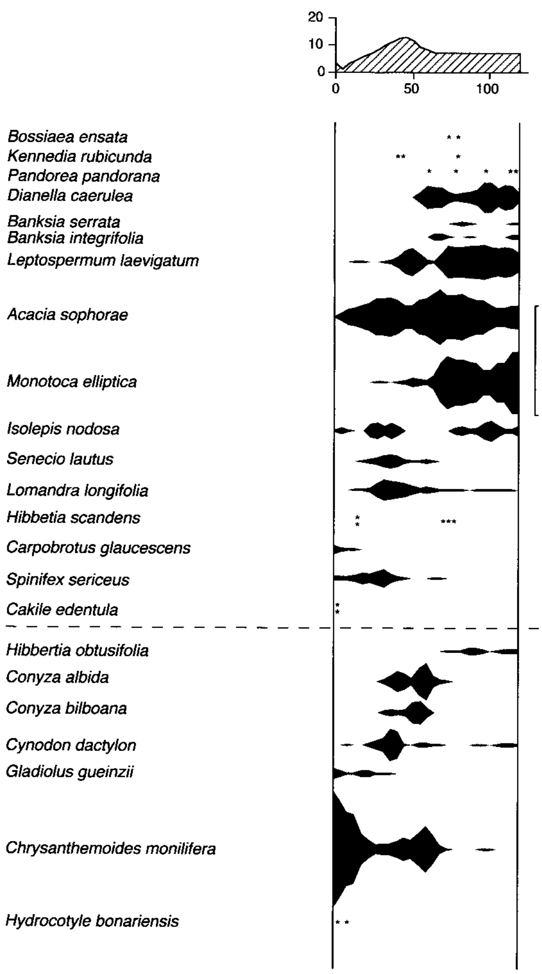

Fig. 3b.

Fig. 3 (a,b,c). Diagrams of variation in abundances of the more common plant species across the sand dunes at Site A (a) from Pidgeon (1942), and from this study (b) in 1997 and (c) in 1999. Each polygon represents a separate species and the width of the bar represents the mean of the % cover values for that species over the 11 transects, at the particular distance from the seaward edge of the plot. The scale bar on the right of each figure represents 50% cover. The polygons below the dashed lines in (b) and (c) are the species that were not present in the initial survey in 1941. Spots (small asterisks) represent rare occurrence of species at a % cover too low to be represented by polygons.

Even taking into account the topographic differences, there are some contrasts in distributions of particular species between the studies. First, *Chrysanthemoides monilifera* occurred only in the 1997 and 1999 transects, where it was most abundant on the foredune slope and crest. Perhaps the presence of *C. monilifera* accounts for the rarity of *Scaevola calendulacea* in 1997 and 1999 compared to 1941. The abundance of *Acacia sophorae* was much greater in the later two studies than in 1941. Several species extended further seaward in the later surveys than in 1941, including *Leptospermum*, *Acacia*, and *Isolepis nodosa.*

While it is tempting to interpret differences between the 1941 and the later surveys as representing change over time, it is important to recognise that there are differences between the two nearby sites that were studied in 1997 and 1999, indicating that spatial differences may be substantial. The topography of these two later sites also differed quite markedly.

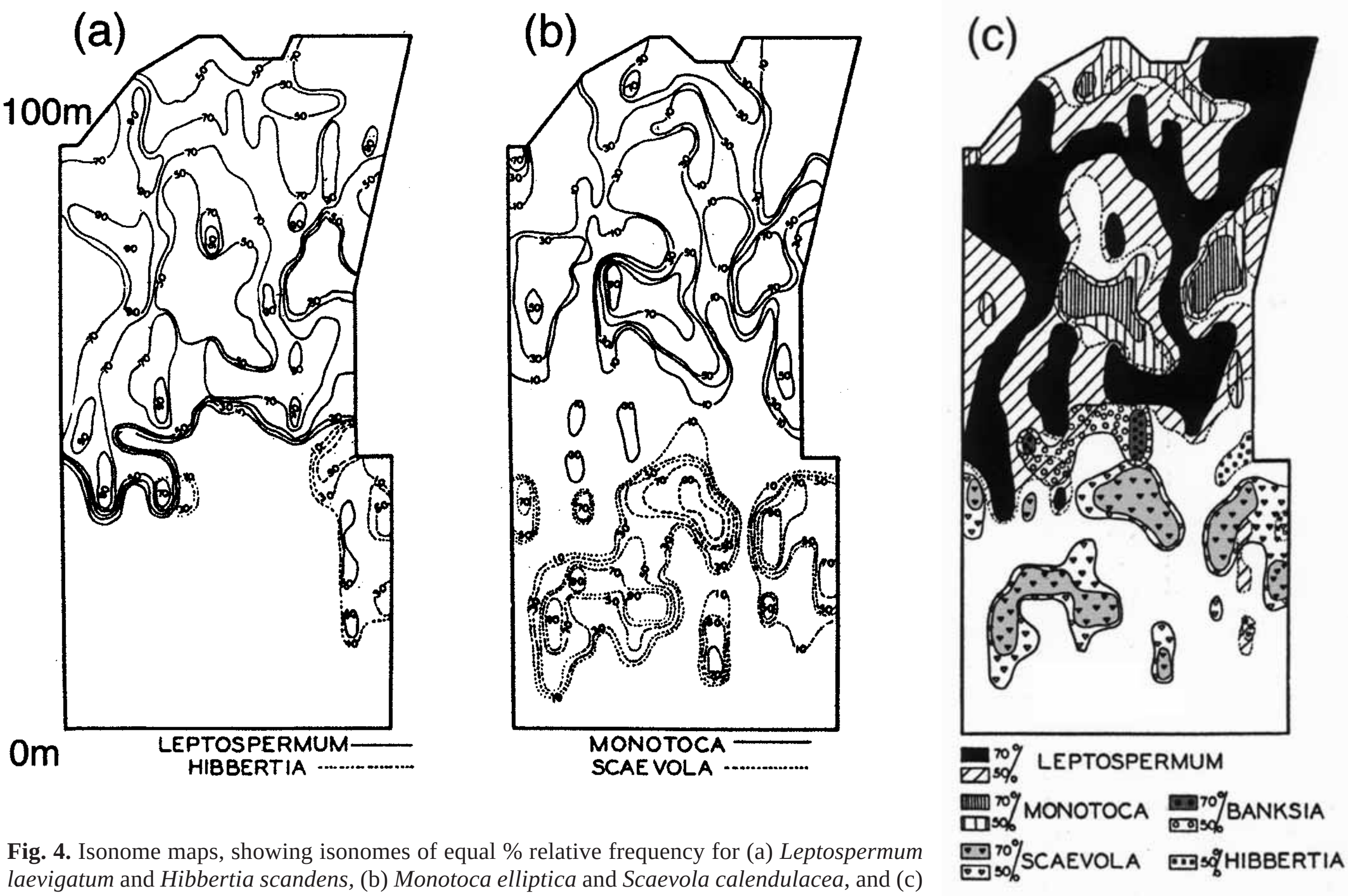

Fig. 4. Isonome maps, showing isonomes of equal % relative frequency for (a) *Leptospermum laevigatum* and *Hibbertia scandens,* (b) *Monotoca elliptica* and *Scaevola calendulacea*, and (c) all four species plotted together, along with *Banksia integrifolia,* for the 50% and 70% isonomes (reproduced from Pidgeon 1942).

Phytosociology

Isonome maps (showing isonomes from 10% to 90% relative density, with 20% intervals) for *Leptospermum laevigatum* and *Hibbertia scandens* are shown in Figure 4 (a) and for *Monotoca elliptica* and *Scaevola calendulacea* in Figure 4 (b). The two dominant shrubs, *Leptospermum laevigatum* and *Monotoca elliptica* had complex isonomes, with obvious centres of high relative density, covering most of the grid from about 45 m. In contrast, the dominant herbs (*Hibbertia scandens* and *Scaevola calendulacea*) were more sparsely distributed. Centres of high relative density of these four species are shown together, along with *Banksia integrifolia*, in Figure 4 (c). Five isonome maps have been superimposed, using only two categories of relative density (50–70% and > 70%). This composite pattern of distribution reveals a clear pattern in which there are obvious centres of high relative density surrounded by lower relative densities. One interesting feature of the composite map is the integrity of the centres of high relative density (> 70%) of *Monotoca elliptica* and *Leptospermum laevigatum*. These patterns are not evident by visual inspection of the vegetation at the site.

Attempts to construct isonome maps from the data collected in the 1997 and 1999 studies failed because there were no centres of high relative density. Rather, each of the more abundant species appeared to be distributed randomly within its zone.

Conclusions

This comparison of sand dune vegetation in the 1930s and 1940s with similar sites in the 1990s has revealed marked differences. There are many more cosmopolitan weed species present now than 60 years ago. The authentic dune vegetation at Hawks Nest displayed a clear zonation pattern, with particular species favouring different regions of the dune profile. Furthermore, dominant species showed a clear phytosociological pattern in 1941, revealed in isonome maps. Now, after sand mining and spread of invasive weeds, the zonation is not as clear, with several species extending more broadly across the dune, and no phytosociological patterns detectable for any of the dominant species.

We propose that a combination of processes has altered the vegetation of the Hawks Nest site. First, sand mining eliminated the original vegetation and reformed the dune topography. Second, revegetation after sand mining resulted in many species being planted across the dunes, with seeds sourced from a range of plant communities (thus explaining the presence of species such as *Acacia suaveolens,* see Table 1; Morrison & Rupp 1995). Buckney & Morrison (1992) also found that the restored plant community in sand-mined forest at Myall Lakes differed markedly from adjacent, unmined forest, and that the communities in the mined area were actually diverging from the original, unmined community over a 15 year period. It is interesting that in these forest sites, two species usually associated with the coastal dunes, *Carpobrotus glaucenscens* and *Leptospermum laevigatum*, occurred in mined areas but not in four, adjacent, unmined areas. This supports the conclusion that a wide range of native species were used in post-mining habitat restoration.

In the coastal sand dune community we studied, it seems that insufficient time has passed for the species that were established after mining to reassort themselves into a community resembling the authentic composition and structure detected in the early studies. Indeed, the physical reforming of the dunes and appearance of invasive and highly competitive weeds such as *Chrysanthemoides* may prevent the process of species reassortment. We suggest that future revegetation programs in sand dunes should take account of the zonation patterns present in the original sand-dune vegetation, planting only appropriate species (that are associated with dune communities) and confining them to the correct zones. For some species (e.g. *Leptospermum* and *Monotoca*), the isonome data suggest that planting in dense clusters would better approximate their distributions in the authentic dune communities.

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