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Research Article

The loss of New Zealand's active dunes and the spread of marram grass (*Ammophila arenaria*)

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Abstract: This article examines the decline of New Zealand's active dunes in relation to the introduction of marram grass (*Ammophila arenaria*). The area of active dunes in New Zealand declined from 129 000 ha in the early 1900s to about 39 000 ha in 2000; a reduction of 70%. The extent of active dunes has declined since the 1950s in all regions, particularly in Northland, Auckland and the Manawatu. The loss of active dunes on the west coast of the North Island resulted primarily from the introduction of marram grass, followed by the establishment of *Pinus radiata* plantations and extensive pastoral farming. Between 1985 and 2005 marram grass extended its range to the detriment of the indigenous foredune flora. Conservation and resource management agencies should urgently identify dune systems for conservation management and marram grass eradication.

Key words: afforestation, dune conservation, dune inventory, marram grass.

Coastal dunes of Late-Holocene age are a distinctive element of the New Zealand coast. Active dunes, the focus of the present paper, are characterized by ongoing eolian sedimentation and a sparse or patchy vegetation cover. They are readily distinguished from older and stable dunes, associated with earlier phases of dune development (Shepherd 1987; Hesp 2001). These older dunes were, in the main, forested before European settlement and show advanced podzol development (Cowie 1963). The contemporary active dunes of New Zealand contain a diversity of dune environments and plant communities (Johnson 1992), many of which are local equivalents of the European dune ecosystem complexes identified by Olson and van der Maarel (1989). In other respects, the active dunes of New Zealand are very different from European dunes. New Zealand has only one widespread strandline species (the recently introduced *Cakile edentula*) and only three indigenous, primary sand-colonizing, foredune species – *Desmoschoenus spiralis* (a sedge), *Spinifex sericeus* (a grass) and *Austrofestuca littoralis* (a grass). Compared with European dunes, the active dunes of New Zealand, including the contemporary foredunes, are sparsely vegetated. In particular, New Zealand dunes lack the diversity of grass species of the genera *Ammophila*, *Leymus*, and *Elymus*, which are widespread on the foredunes of Europe (Doody 1991, 2001).

The active dunes of New Zealand represent the most recent phase of dune mobility and dunefield formation. The genesis of these dunefields has been examined, but not resolved. Debate has centred on the relative importance of human versus climatic disturbance (McGlone

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1983; McFadgen 1989). Human use of New Zealand dunes is very recent compared with the long history of occupation in Europe. The Polynesian settlers of New Zealand may well have disturbed, de-vegetated and destabilized particular dune systems. It is clear, however, that active dunes have been heavily modified since the arrival of Europeans in New Zealand, primarily as a result of the recent, widespread and very rapid stabilization of active dune systems with marram grass (*Ammophila arenaria*).

The majority of active dunes in New Zealand now bear little resemblance to the accounts of Leonard Cockayne, one of New Zealand's founding botanists. Since Cockayne's early descriptions of the flora and vegetation communities of dunes (Cockayne 1909, 1911), marram grass has been planted throughout New Zealand to stabilize active dunes, establish foredunes for property protection and prepare dunes for afforestation with North American conifers, particularly *Pinus radiata*. These activities, often in conjunction with sand mining, stock grazing, infrastructure development, urbanization and the introduction of a wide range of exotic plant, shrub and tree species (e.g. *Acacia sophorae* and *Ehrharta villosa* var. *maxima*), have contributed to the loss of the extent and natural character of active dune systems. Coastal sand dunes may be New Zealand's most threatened natural habitat, measured both in terms of the diminished extent and modification of vegetation of remaining areas.

New Zealand is a signatory to Agenda 21 and the Biodiversity Convention. Signatories commit to preparing inventories of critical coastal habitats, conserving and restoring critical habitats and identifying critical areas. In relation to coastal dunes, progress has been mixed and information on the conservation status of active dunes is incomplete. The present study aims to (1) identify and map active dunes with the intention of producing a comprehensive national inventory; (2) reveal trends in the reduction of active dune systems in each region; and (3) document the recent spread of marram grass since the first national census of dune flora in the early to mid-1980s. The strengths and weaknesses of existing dune inventories are discussed and further knowledge requirements identified.

Previous inventories

Several government agencies have prepared inventories of 'coastal dunes' (Table 1). The purpose and methodology of these surveys has not been consistent. The first survey was undertaken by Leonard Cockayne in the early 1900s. Cockayne (1911) estimated the total area of 'dune' in 1911 to be 128 740 ha, of which 118 900 ha were located in the North Island and 9 840 ha in the South Island and Stewart Island. These estimates excluded established shrub and forest on stabilized dunes, but included wetlands within active dune systems. The same approach has been adopted in the present study.

The New Zealand Land Resource Inventory (NZLRI) mapped the area of active dunes at a scale of 1 : 1 000 000 (Newsome 1987). For that purpose, sand dune communities were defined as 'communities dominated by herbaceous plants and low shrubs occurring on recent, unstable dune sands' (Newsome 1987, p. 130). Stable backdune habitat, typically dominated by woody shrub and tree species, was excluded. Because of the map scale employed, many smaller active dune systems, particularly along the east coast of New Zealand, were omitted. The maps of active dune systems were derived from data collected during the 1960s and 1970s for the NZLRI (NWASCO 1975–1979). The total area of active dune corresponding to Newsome's definition was estimated at 52 000 ha. A further 40 000 ha of backdune, dominated by exotic lupins (*Lupinus arboreus*) and shrubs, were identified. In addition, approximately 200 000 ha of 'former dunes' were described as being covered in pasture grasses, pine trees, gorse (*Ulex europeaus*) and other exotic species (Newsome 1987). Of the 305 000 ha of coastal sand dunes identified in the NZLRI (NWASCO 1975–1979), less than 10% were considered close to their 'original condition' (Hunter & Blaschke 1986). The phrase 'original condition' is presumed here to mean their condition around 1900, prior to the widespread stabilization of active dunes with marram grass.

A national programme to survey the diversity of New Zealand's indigenous flora, landforms and landscapes was initiated in 1983. The Protected Natural Areas Programme (PNAP) aimed to record the location and characteristics

Table 1 Comparison of past dune inventories with the present study (LRI – Land Resource Inventory; PNAP – Protected Natural Areas Programme; LENZ – Land Environments of New Zealand)

			Area (ha)			
Authority/Study	Source (date)	Mapping Scale	North Island	South Island & Stewart Island	National total	Comments:
Cockayne (1911)	C/F	unknown	118 900	9840	128 740	Cockayne included active dunes, but excluded shrubland and forest on stabilized dunes
Land Resource Inventory	V (1960/70s)	1 : 1 000 000			52 000	Excludes 40 000 ha of 'backdune' dominated by exotic shrubs and 200 000 ha of former dunes under pasture and plantation forest (Newsome 1987).
Protected Natural Areas Programme	1983–	1 : 50 000				Involves sub-regional surveys of 'ecological districts' with the objective of identifying RAPs (recommended areas for protection). Incomplete national cover; most districts containing dunes have not yet been surveyed.
Sand Dune & Beach Vegetation Inventory	F (1984–1988)	no maps				Assessment of conservation value of most dune systems in New Zealand; no mapping or area estimates of coastal dunes. This study identified 53 national priority sites for conservation (Johnson 1992; Partridge 1992).
Land Cover Database	S (1996–1997)	1 : 50 000	30 100	11 900	42 000	Maps active dunes, but excludes older vegetated dunes.
Land Environments of New Zealand	V (1998)	1 : 50 000				National classification of 'environments' based on variation in climatic, landform and soil variables.
This study	C/A (1950s)	1 : 25 000–1 : 63 660	110 884	18 518	129 402	Maps active dunes. Excludes older, forested dunes; also maps active dunes in 1950s, 1960s and 1980s by region.
	C/A (1990s)	1 : 50 000	28 763	10 041	38 804	

Source of information: V – soil and other environmental data; C – cadastral and land cover maps; F – field survey; A – vertical aerial photography; S – satellite data.
Existing classifications are generally based on physical geography and use manual classification techniques to draw visible ecological boundaries onto maps. Newer classifications such as LENZ are numerically based using computer programs to sort climate, landform and soils data to group areas containing ecosystems of similar type. Both approaches provide a wealth of information for conservation and resource management.
The numerically based approach means there are no geographic constraints and the classification can be used at varying scales, i.e. environments (containing similar ecosystems) can vary markedly in size and can be identified even where they are distributed across the landscape in a number of pieces.

of indigenous plant communities in the knowledge that many remaining communities of high conservation value were poorly represented in the existing system of national parks and reserves. Recommended Areas for Protection (RAPs) were assessed and identified on the basis of representativeness, diversity, special features, naturalness, viability, size and shape, and buffering from external stresses. The boundaries of individual RAPs were delineated on topographic maps at a scale of 1 : 50 000.

The PNAP has provided valuable information on the botanical characteristics and conservation status of some dune systems, including those in the Manawatu region (Ravine 1992). Several RAPs contain active or stabilized dunes. Most are fragments of much larger, modified dunefields. Relatively few ecological districts have been surveyed since the PNAP began in 1983. There are 179 ecological districts: 104 in the South Island and offshore islands, and 75 in the North Island. Of these, 123 contain stretches of coast. To date, only 33 PNAP reports have been published and only 25 of the 123 coastal ecological districts have been surveyed (18 in the North Island, 7 in the South Island). Ecological districts known to contain dune systems of national significance have yet to be surveyed. Two clusters of dunes of national significance occur in the far north of the North Island and far south of the South Island (identified by Johnson 1992 and Partridge 1992). The PNAP has not provided the rapid synoptic survey of New Zealand's vegetation cover envisaged in the early 1980s.

The Sand Dune and Beach Vegetation Inventory (henceforth 'the Inventory') conducted by the Botany Division of the former Department of Scientific and Industrial Research (Johnson 1992; Partridge 1992), provided the first national survey and systematic conservation assessment of coastal dunes in New Zealand (both active and forested). The aim of that survey was to identify dune systems with high natural values for conservation purposes (with an emphasis on botanical values). Fieldwork was carried out between 1984 and 1988 by regional botanists of the Department of Scientific and Industrial Research. Individual dune systems were scored 0 to 20, based on the diversity of plant communities and landforms, the number or proportion of native sand dune species, the degree of human or animal modification of the site, and the degree of invasion by weed species. Some large dune systems were not visited (e.g. Kokota Spit in Northland) and some dune systems, subsequently identified as having high conservation values (e.g. Tokomairiro River in Otago), were overlooked (Rapson 1996).

The Inventory identified 23 sites in the North Island, 21 in the South Island, and 9 on Stewart Island as 'national priority dune systems for conservation'. All had scores of 15 or more. Some regions have no sites of national significance (e.g. Otago). The majority of recognized sites are in the far north and far south of New Zealand.

As yet, there is no comprehensive database of the extent and conservation values of New Zealand's active dune systems. The Sand Dune and Beach Vegetation Inventory, despite its methodological limitations, has provided the only consistent, nation-wide, assessment of the conservation status of dune systems. It did not, however, map the boundaries or extent of individual dune systems, active or forested. The PNAP surveys provide more detailed site information, show dune systems of high conservation value and recommend sites for protection, but to date very few dune systems have been surveyed. The current character, and change in character, of a handful of dune systems have been described (Walls 1998), but trends in the state of New Zealand's dune systems have not been documented. Therefore, the current study identifies trends in the decline in area of active dunes at regional and national scales.

The nature of 'active dunes'

This study is concerned with 'active dunes'. The contemporary ecology of these dunes is primarily determined by eolian sedimentation. Plant diversity is low and mainly restricted to species adapted to, or tolerant of, erosion, burial, extreme solar radiation, desiccation and salt spray. *Desmoschoenus spiralis* (pingao), *Austrofestuca littoralis* (sand tussock), *Spinifex sericeus*, *Ammophila arenaria* (marram grass) and *Euphorbia glauca* (shore spurge) are commonly associated with active dunes. They tend to form relatively dense stands across foredunes, but cover may be sparse or patchy within larger dune systems associated with

transgressive dunes. A collection of other species, including the sand daphne (*Pimelea* spp.), sand coprosma (*Coprosma acerosa*), and *Isolepis nodosus*, are commonly associated with active dunes.

Active dunes are usually associated with the most recent phase of dunefield development around the New Zealand coast – equivalent to the Hoatan (McFadgen 1989) or the Waitarere phase (Cowie 1963; Muckersie & Shepherd 1995). They are readily distinguished from earlier phases of dune development through soil development, in that they show virtually no modification of the grey, quartzo-feldspathic sand parent material. This most recent phase is usually found adjacent to the coast although active dunes may occur well inland as remnants, or where the parent material of earlier phases has been disturbed. Distinctive dune morphologies, including foredunes, parabolic dunes or transverse dunes may be discernible, but not necessarily so. The seaward extent of an active dunefield coincides with the toe of the vegetated foredune, or seaward limit of incipient foredunes.

Methodology

Mapping active dunes

Classification of active dunes was, in general, straightforward. Active dunes were identified on the basis of (1) vegetation cover (usually sparse); (2) vegetation type (with a predominance of primary sand colonizing species); (3) proximity to the foreshore; and (4) morphological evidence of transgressive dune formation and migration. Two cases, Karikari Beach in the Northland Region, and Mason Bay on Stewart Island (Southland), illustrate how these criteria were applied. The active dunefield east of Puheke, a conspicuous volcanic cone, comprises a foredune (dominated by *Desmoschoenus*), backed by a sparsely vegetated dunefield that contains multiple transverse dunes (Fig. 1). The seaward edge of the dune system is defined by the toe of the vegetated foredune. The landward boundary is defined by a wetland. Older dunes, probably of last interglacial age, form the hinterland. The second case, the central dunefield in Mason Bay, extends almost 3.5 km inland and is about 1.2 km wide (Fig. 2). The western boundary is also defined by the edge of the foredune vegetation. Mobile sands are transgressing over a mature podocarp forest (growing on older dunes) along the southern boundary. The northern boundary is Duck Creek and an area of broadleaf (*Griselinia littoralis*) forest, which separates the central and northern dunefields in Mason Bay. The northern and southern dunefields are transgressing over an older dunefield of long-walled parabolic dunes, which is undated, but probably of Late-Holocene age. The central dunefield contains a sequence of landforms – a massive foredune complex (associated with marram grass), long-walled parabolic dunes, stonefields and an extensive sand sheet with a sparse vegetation cover. Wetlands, dominated by

Figure 1 Active dunes on the Karikari Peninsula, Northland. The photograph is taken from Puheke (see Fig. 3) looking east towards Cape Karikari. The active dunes comprise a range of dune forms, including foredunes, deflation surfaces and transverse dunes. It extends between the toe of the vegetated foredune and the Waimango wetland and stabilized dunes of Late-Holocene or last interglacial age. Soil development is poor or non-existent and vegetation cover is sparse.

Figure 2 Active dunes at Mason Bay (central dunefield), located on the west coast of Stewart Island. The photograph is taken looking towards Big Sandhill from above the foredune. The dunefield comprises a mosaic of dune forms and environments, including a marram-dominated foredune complex, long-walled parabolic dunes, deflation surfaces (stonefields), sand sheets, interdune wetlands and rock outcrops.

Leptocarpus similis, have recently developed in the deflation zones of parabolic dunes. Given the size of the wetlands relative to the area of the central dunes (272 ha) – the largest is 0.5 ha – they were included in the estimate of 'active dunes'. These two cases were typical of most dune systems. The extent of active dunes was usually clearly delineated, because of the contrast between the relatively sparse vegetation of the active dunes and the established shrub, or forest cover, of the stable dunes.

Four sets of maps have been generated for each region at a scale of 1 : 63 360 (1950s, 1970s, 1980s) or 1 : 50 000 (1990s). The maps were mainly compiled from aerial photographs. A range of other sources were also utilized, including topographic maps, soil maps, the Coastal Resource Inventory (CRI), the Sand Dune and Beach Vegetation Inventory (Johnson 1992; Partridge 1992), PNAP survey reports, local government planning maps, published reports, scientific papers, unpublished theses, soil and geological maps, and regional as well as specialist local inventories. Most early topographic maps represent active dunes very precisely, particularly the 1 : 25 000 series (Fig. 3). In most cases the maps of active dunes were derived from multiple runs of aerial photography spanning a number of years; hence the maps represent a decade (1950s, 1970s, 1980s and 1990s).

The most recent maps produced in the present study (1990s) were derived from aerial photographs taken for regional councils. Most regional councils have obtained low-level vertical, colour, aerial photography from about 1993. The Manawatu-Wanganui Regional Council, for example, obtained aerial photographs of their coast between May 1995 and May 1997. In addition, the Department of Conservation holds more recent aerial photographs in some regions. Comprehensive aerial photography was not available for five regions/unitary authorities (Auckland, Wellington, Nelson, Marlborough, West Coast), and estimates of the area of active dune in these regions/districts were partly derived from published and unpublished sources, including maps in planning reports and academic theses. The aerial photographic interpretations were confirmed, in many cases, during fieldwork in dune systems in Southland, Otago, Canterbury, Auckland and Northland in the period 1995–2005.

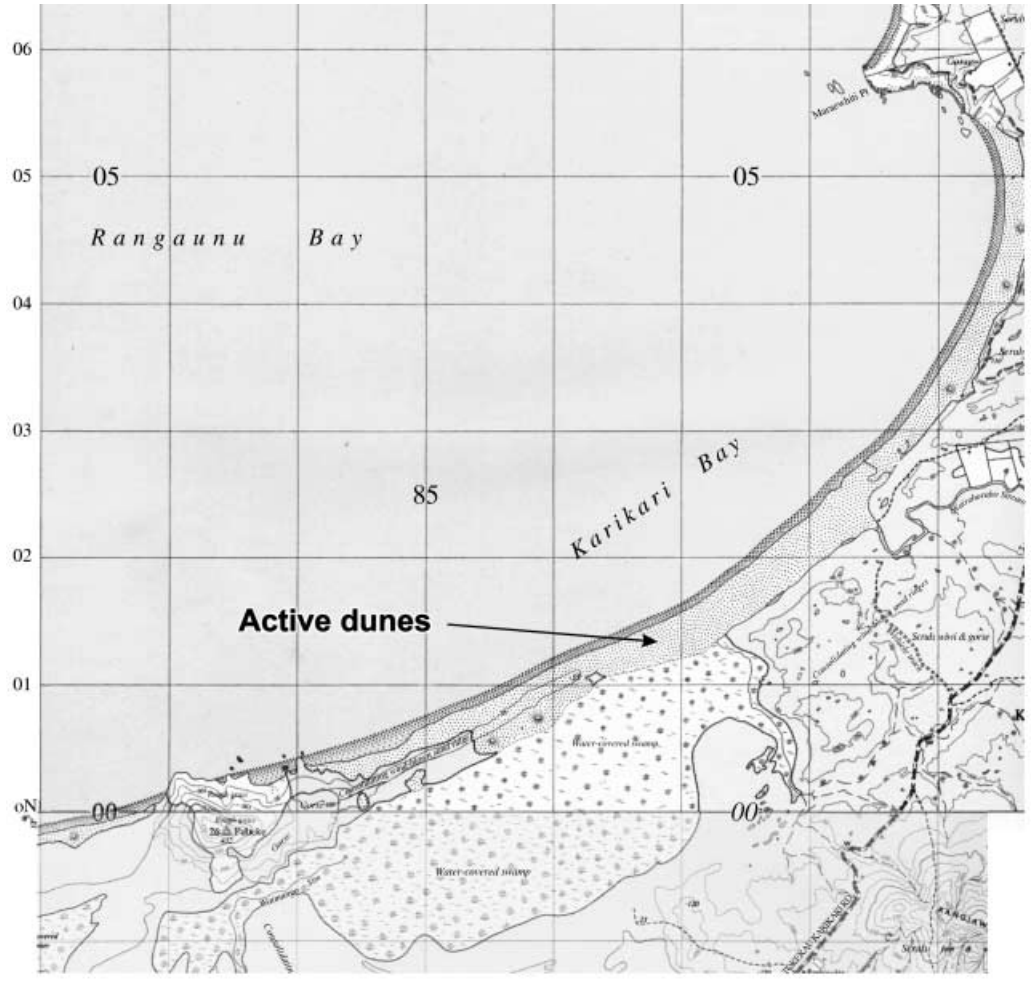

Figure 3 Active dunes have been clearly and accurately represented in most topographic map series. This section of NZMS2 shows the active dunes along a section of Karkikari Bay (shown in Fig. 1).

The boundaries of active dune systems were identified using the above criteria, then digitized at the map or photo scale and stored in a Geographic Information System (ARC-INFO). Map data were converted from transverse Mercator projection to New Zealand Map Grid, and regional and subregional maps (3–4 per region) generated. ARC-INFO was used to calculate the area of each active dunefield, sum the areas of active dunefields in each region and produce maps of active dunes in the 1950s, 1970s, 1980s and 1990s for each local government district/region. These districts and regions are shown in Figure 4, with the location of the three subregional maps referred to in the results.

Draft maps were sent to technical staff in all regional and district councils and Department of Conservation conservancies for review and verification. The initial mapping, based on the above sources, identified all but a few active dune systems, and they were subsequently added. Delineation of the boundaries of active dune systems was difficult in a few cases, particularly where the aerial photographic coverage is poor and the active dune/hinterland vegetation boundary indistinct. Dune system resolution varies from a few metres to tens of metres, depending on the scale and quality of the aerial photographs used. The regional maps have been derived from aerial photographs and

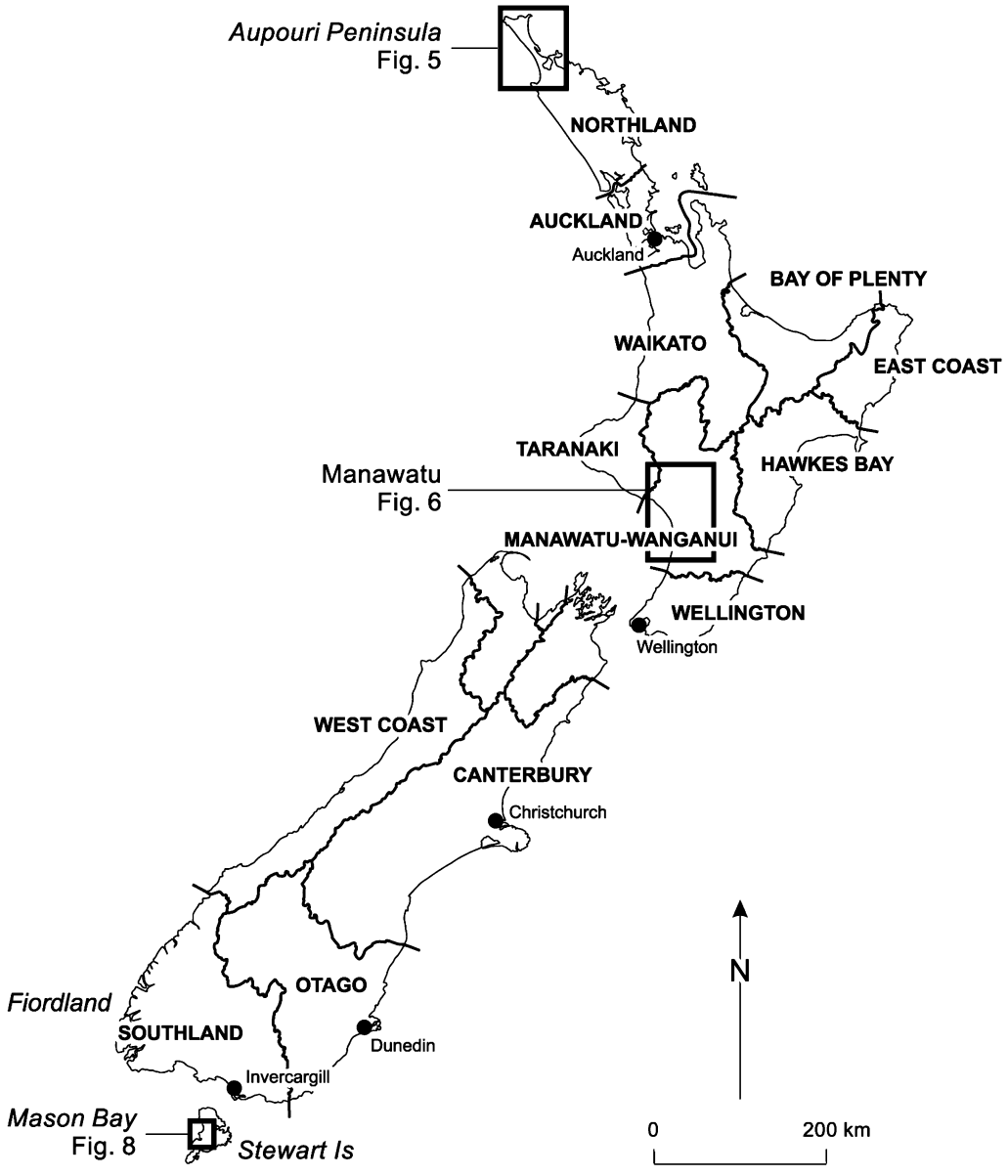

Figure 4 The boundaries of regional councils and unitary authorities and location of case study dune systems.

maps at a range of scales, but usually between 1 : 10 000 and 1 : 63 000.

The distribution of marram grass

Marram grass is recognized as invasive and a threat to the ecology of active dunes in New Zealand (Hilton *et al.* 2005). Maps of the extent of marram grass and indigenous species around the New Zealand coast in 1985 and 2005 are presented. The maps represent the distribution of the dominant foredune species (*Desmoschoenus*, *Spinifex* and *Ammophila*). The purpose is to determine the degree to which marram grass has spread in the period 1985–2005 and displaced the above indigenous species. Marram grass has been planted in many dune systems in backdune environments (landward of the foredune) in association with

forestry operations, including many dune systems in Auckland and Northland so it would be misleading to incorporate backdune data. The 1985 maps are based on site descriptions provided in the Sand Dune and Beach Vegetation Inventory of New Zealand (Johnson 1992; Partridge 1992). The 2005 maps are based on data derived from information provided by key informants in district and regional councils and the Department of Conservation. Specialist staff in these organizations were contacted in 2004/2005, and asked to report the extent and dominance of marram grass in their region/conservancy. This data was augmented by recent published and unpublished accounts of specific dune systems and visits to most Northland, Auckland, Southland, Otago and Stewart Island dune systems in the period 2000–2005.

The resulting maps indicate the distribution of the primary foredune species and trends in the spread of marram grass. Three categories of marram grass infestation were recognized: (1) marram grass is the only or dominant species; (2) marram grass and indigenous species occur in more or less equal proportions; and (3) foredunes are dominated by indigenous species. In practice, the 'dominance' of marram grass in the 1980s can only be inferred from the site descriptions of Partridge (1992) and Johnson (1992) as their inventory contains few quantitative estimates of species cover.

Results

National and regional trends in the area of active dunes

The total area of active dunes in New Zealand in the early 1900s comprised 128 740 ha (Cockayne 1911). This is close to the estimate derived from the 1940s/1950s topographic maps used in the present study (129 402 ha). Active dunes are present in all regions; however, the largest systems occur along the west coasts of the three main islands. In 1958 active dunes, comprising transgressive dunes in the main, occurred along the west coast of the Aupouri Peninsula (32 100 ha) (Fig. 5) and the Manawatu coast (12 627 ha) south of the Wanganui River (Fig. 6). The active dunes of the Aupouri Peninsula, which comprise transverse and parabolic dune forms, extend approximately 80 km alongshore and approximately 5 km inland. In both cases older, stable, dunes form the hinterland.

The area of active dunes in New Zealand declined from 129 402 ha in the 1950s to 38 949 ha in the 1990s – a reduction of about 70% over the last 40 years. All regions experienced a decline over this period, although the proportion varied (Table 2). The extent of active dunes declined 7% in the Wellington region, but the Manawatu Region lost over 80% (Table 3). Regions with the largest area of active dune in the 1950s experienced the greatest decline.

Loss of active dunes occurred throughout the post-World War II period, although at

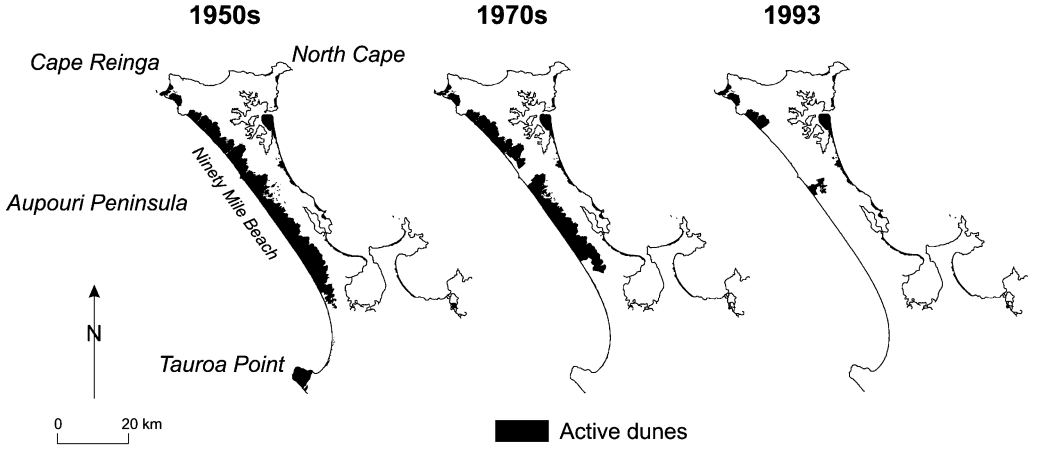

Figure 5 The area of active dunes on the Aupouri Peninsula has declined as a result of afforestation. Significant remnants of active dunes survive in a range of reserves and on Māori land near North Cape.

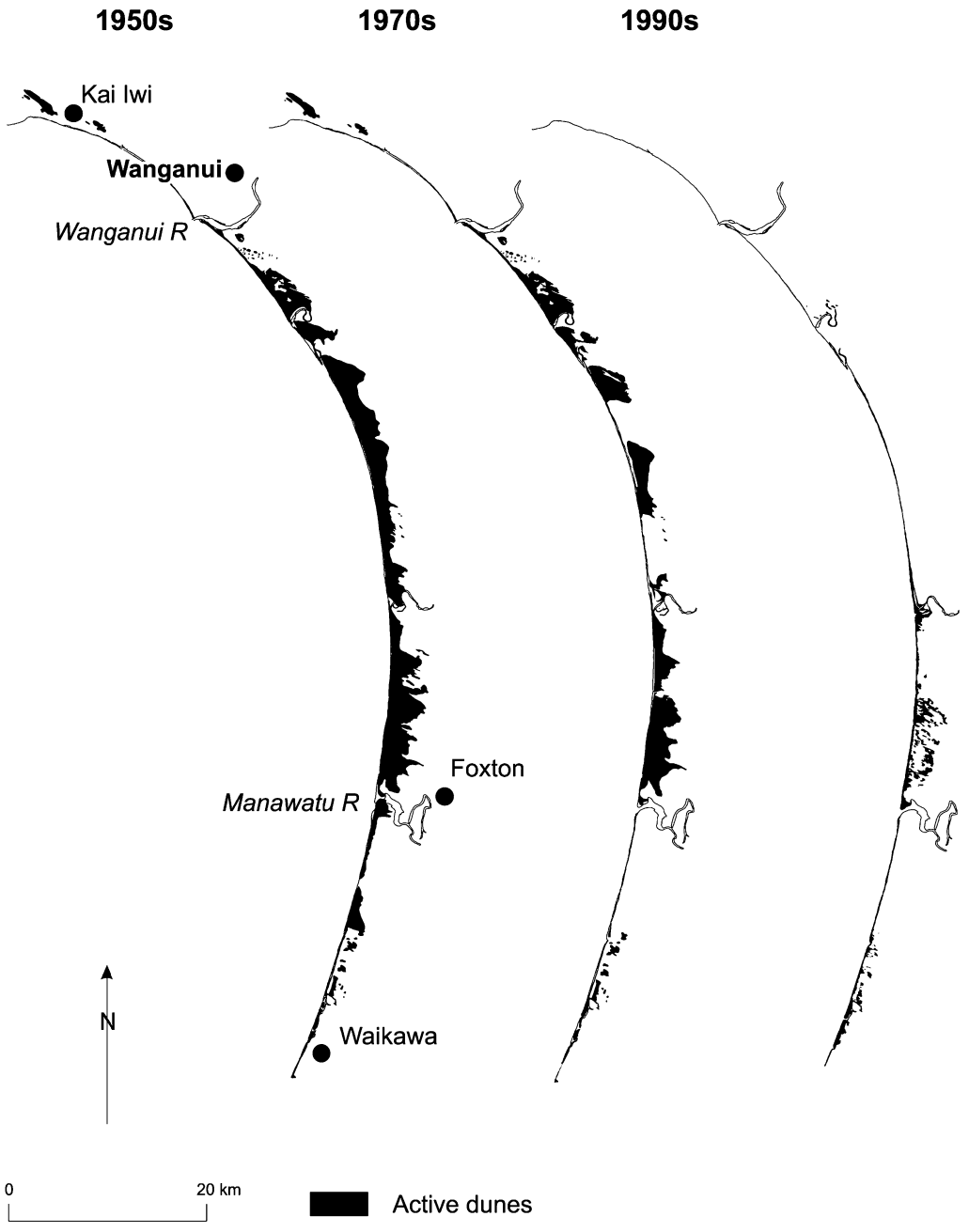

Figure 6 The area of active dunes has also declined in the Manawatu region, as a result of afforestation and agriculture.

different rates in different regions. Canterbury region experienced a 60% decline between the 1950s and 1970s, largely as a result of stabilization and afforestation of the Pegasus Bay dunes. In contrast, the area of active dune in Otago changed little until the 1970s, when many dune systems north and south of Dunedin were stabilized with marram grass and farmed or converted to plantation forestry. The area of active dune then declined rapidly. Nationally, the rate

Table 2 Trends in area of active dunes by region

Region	1950s (ha)	1970s (ha)	1980s (ha)	1990s (ha)	Percentage decline (%)
Auckland	15 223.84	8 555.70	4 812.50	NA	68.39
Bay/Plenty	1 692.39	1 363.65	982.26	928.14	45.16
Canterbury	5 207.68	2 075.10	1 928.15	1 846.10	64.55
East Coast	726.49	677.19	693.41	673.03	7.36
Hawkes Bay	2 790.38	2 614.47	1 720.39	1 441.70	48.33
Marlborough	379.46	379.46	247.37	NA	34.80
Nelson	NA	512.39	NA	NA	NA
Northland	64 199.43	38 348.38	24 728.13	15 180.92	76.35
Manawatu	16 627.08	8 600.51	2 636.41	2 359.93	81.31
Otago	1 775.01	1 754.35	1 075.52	1 039.27	41.44
Southland	4 854.55	4 295.54	3 894.75	3 343.02	31.33
Taranaki	1 471.46	1 447.39	419.80	433.45	70.54
Tasman	3 007.05	2 577.75	750.44	654.81	78.22
Waikato	7 168.14	4 600.75	2 155.92	2 022.07	71.79
Wellington	984.89	982.64	914.086	NA	7.2
West Coast	2 781.88	2 435.99	2 399.40	NA	13.75
Total	129 402	81 221	50 012	38 949	69.90

Table 3 Proportion of active dunes in each region (1950) (ranked by area) and percentage lost (1950s–1990s)

Region	Percentage of national total (1950s) (%)	Percentage lost 1950s–1990s (%)
Northland	49.6	76.3
Manawatu	12.8	81.3
Auckland	11.8	68.4
Bay of Plenty	1.3	45.2
Waikato	5.5	71.8
Canterbury	4.0	64.5
Southland	3.8	31.3
Tasman	2.3	78.2
Hawkes Bay	2.2	48.3
West Coast	2.1	13.7
Otago	1.4	41.4
Taranaki	1.1	70.5
Wellington	0.8	7.2
East Coast	0.6	7.4
Nelson	0.4	NA
Marlborough	0.3	34.8

of loss of active dune has slowed since the 1990s, probably because most of the remaining active dunefields are in the conservation estate.

The retention of relatively large areas of active dunes in some regions is notable, given the national trend. Southland, incorporating Fiordland and Stewart Island, lost just 31% of active dunes and the West Coast only 14%. The area of active dunes on Stewart Island (1 258 ha) has not changed significantly since the first available maps and aerial photographs, although marram grass has invaded large areas of the Doughboy Bay and Mason Bay dunes. Stewart Island and Fiordland comprise just 3.8% and 2.1% of the New Zealand post-War area of active dunes, respectively. However, they contain a disproportionately large number of sites identified by Johnson (1992) and Partridge (1992) as dune systems of national conservation significance – 23 of the 53 national priority sites occur in Southland, 10 of these in Fiordland, and 9 on Stewart Island. A further 12 such sites are in Northland, although that region lost approximately 76% of its active dunes. This pattern is the result of two circumstances. First, marram grass has been in the remote Fiordland and Stewart Island dune systems for only a few decades; populations of marram grass on these coasts result from long-distance dispersal, rather than deliberate and concerted introductions. Second, marram grass does not, in general, displace *Desmoschoenus* or *Spinifex* from the foredune in the north of the North Island.

Causes of the decline in area of active dunes

The decline in area of New Zealand's active dunes is largely the consequence of forestry and agriculture. Urbanization, infrastructure development, sand mining, waste disposal and military activities, have been of secondary importance, particularly near major urban centres. Marram grass has been used to stabilize active dunes before their conversion for these purposes. Marram grass was first recorded growing in New Zealand in 1873 at Miramar, near Wellington (Buchanan 1873). By 1900 large quantities were being imported from Australia, primarily to stabilize active dunes near major cities. The distribution of marram grass increased significantly when the (former) Lands Department began planting marram following the publication of Cockayne's 1911 report. Cockayne advocated the stabilization of sand dunes, with the intention of reducing sand dune migration and establishing production forestry. The (former) New Zealand Forest Service subsequently developed technology to stabilize and fertilize active dunes and establish *Pinus radiata* plantations. Large areas of formerly active dunes in Northland, Auckland, Manawatu and Waikato were afforested during the 1960s, 1970s and 1980s (McKelvey 1999) following the general planting of marram grass (Fig. 7). The decline in area of active dunes on the Aupouri Peninsula, for example, following World War II (from 32 100 ha to 8 735 ha), was a consequence of afforestation.

Marram grass is able to disperse and invade active dunes very rapidly, as illustrated by the case of Mason Bay, on the west coast of Stewart Island. Farmers at the southern end of Mason Bay introduced the grass in the 1930s (Hilton *et al.* 2005). In 1958 a few small areas of marram grass were present north of Martin's Creek (8.8 ha), approximately 9 km north of the liberation site. By 2000, the area of active dunes containing marram grass had increased to 270 ha, which then equalled approximately 47% of the active dunes north of Martin's Creek (Fig. 8). The rate of invasion during this period was exponential (Jul 1998).

Many of the dune systems mapped as 'active dune systems' in the present study are likely to have low conservation values where marram grass has been present for more than 25 years. Such is the case at Mason Bay. Duncan (2001) found that marram grass has displaced indigenous species from the foredune environment and caused the development of a new foredune. The Department of Conservation has embarked on a programme of marram grass eradication

Figure 7 Men planting marram grass on Aupouri Peninsula, Northland, 1910. (A. Northwood, by permission, Alexander Turnbull Library)

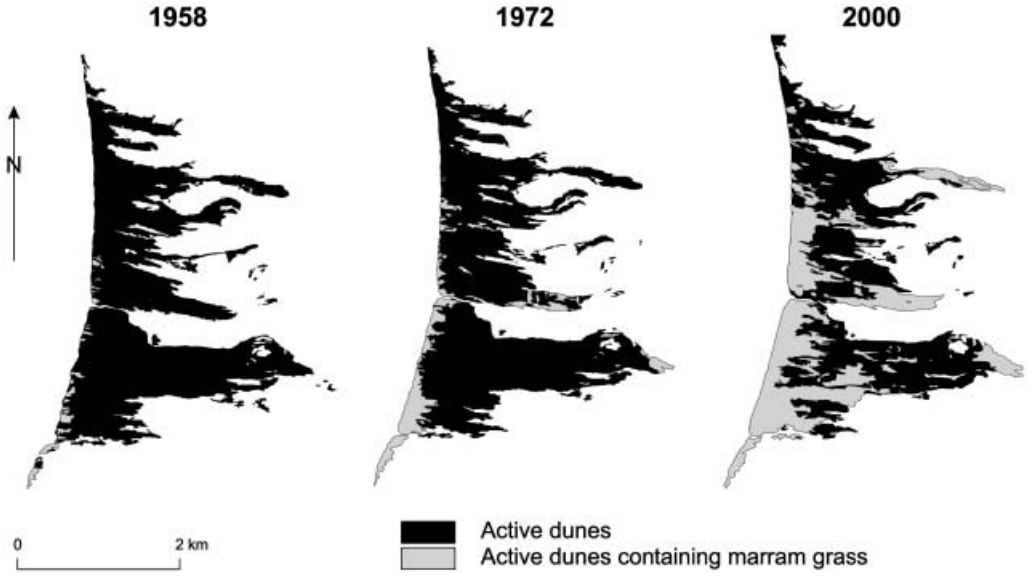

Figure 8 The area of active dunes and active dunes containing marram grass in the central and northern dunes, Mason Bay. The maps indicate the history of rapid marram grass invasion between 1958 and 2000.

at Mason Bay, which is located in Rakiura National Park.

Marram grass is now widespread in New Zealand and is the main threat to the remaining active dune systems. The Sand Dune and Beach Vegetation Inventory surveyed 332 South Island and Stewart Island beaches and 289 North Island beaches during the 1980s (Johnson 1992; Partridge 1992). At the time marram grass was the dominant or only foredune species around much of the coast of the South Island between Cape Foulwind in the northwest and Puysegur Point in the southwest (Fig. 9). Marram grass was also found in Fiordland and on Stewart Island, as well as south Westland. Many of the infestations were small and indigenous foredune species were still common. By the 1980s marram grass had been widely planted in the North Island, particularly in the large active dune systems of Northland, Auckland and the Manawatu. Indigenous species still dominated the foredunes north of Hawkes Bay on the east coast. However, by this time marram grass was the dominant species on most of the west coast of the North Island.

The cover of marram grass increased significantly in the period 1985–2005. In the South Island, only two areas, Fiordland and Stewart Island, still contained dune systems substantially free of marram grass. Kaitorete Spit, south of Christchurch, contains marram grass; however, the active dunes are still relatively intact. Marram grass is now the dominant species around most of the North Island, with the exception of the northeast coast between North Cape and East Cape and scattered sections of coast north of Hawkes Bay, Wellington and Auckland. Indigenous species have not been displaced between North Cape and East Cape on the northeast coast of the North Island, except where marram grass is being actively managed in association with forestry operations (e.g. Pakiri), or in areas of coastal subdivision and development. It seems likely that, within 20 years, marram grass will dominate the foredunes of nearly all New Zealand dune systems, except where it is being actively controlled. The potential for marram grass to invade dune systems on the northeast coast of the North Island, between East Cape and North Cape, as well as the west coast of the Northland Region, has yet to be determined.

Discussion

The area estimates of active dunes provided in the present study accord with the early estimates of Cockayne (1911), that is, the national area

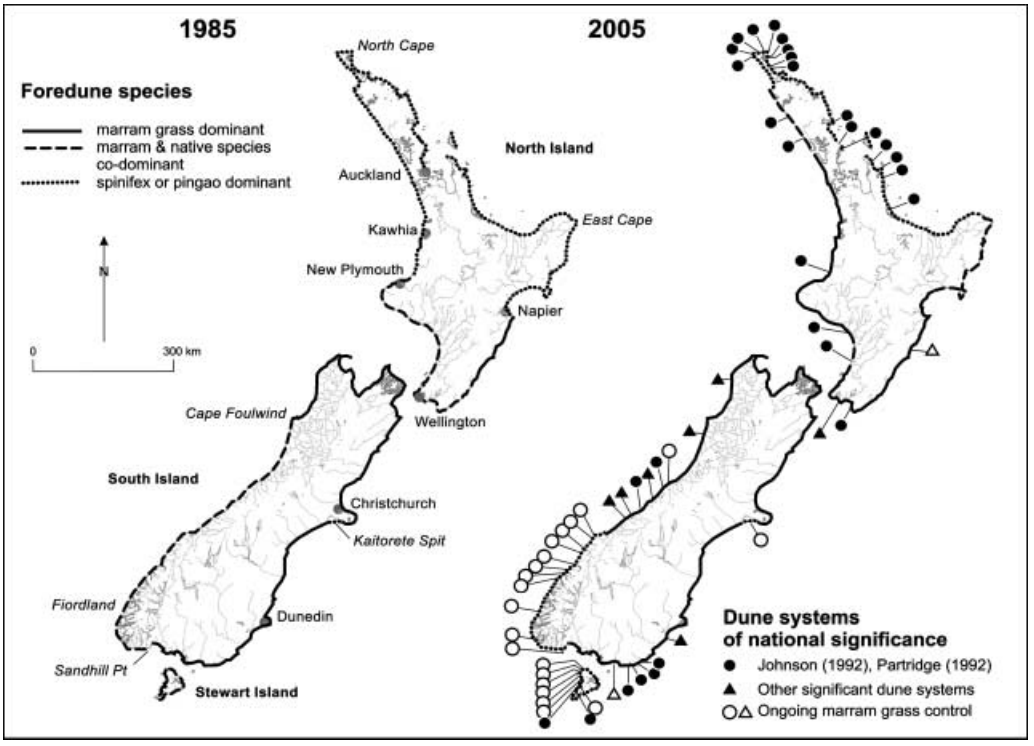

Figure 9 Location of 'national priority dune systems for conservation' (circles) recommended by Partridge (1992) and Johnson (1992) – with additional sites identified by the author (triangles) – and sites where marram grass control is ongoing (open circles). Marram grass has continued to spread and displace indigenous foredune species since the mid-1980s. Marram grass is present in backdune environments in northern New Zealand, but does not appear to displace indigenous foredune species. Marram grass has displaced *Desmoschoenus* in most dune systems in the Chatham Islands.

of active dunes in the 1950s was very close to the area around the beginning of the 1900s. Newsome's (1987) estimate of the area of active dune system at around 52 000 ha is consistent with estimates presented here for the late 1970s, when the New Zealand Land Resource Inventory was published (NWASCO 1975–1979).

It is unclear to what extent the estimates of Cockayne's (1911) and the results of the present study indicate the 'natural' (pre-human), pre-European (<200 years), or pre-Polynesian (<1000 years) area of active dunes. There have so far been too few studies of dunefield formation during the Late Holocene in New Zealand. Hesp (2001) suggests phases of transgressive dune development in the Manawatu, from 600 to 1000 years BP and 150 years BP to the present day, are associated with Polynesian and European settlement, respectively. By the 1940s much of the indigenous lowland vegetation cover of New Zealand had been cleared for pastoral farming and agriculture. Dune systems were routinely grazed by livestock and other introduced species, including rabbits. Dunes and adjacent beaches were being mined for building sand, and settlements were expanding over dune systems. Exotic plant and animal species had colonized most, if not all, active dune systems. Finally, intensive planting of active dunes was occurring along the west coast of the North Island for plantation forestry (Sale 1985).

These pressures had a severe impact on the state of certain dune systems, but at the national level their impact was minor compared to what happened in the period 1950–2000. The total area of active dunes had declined to 39 000 ha by the early to mid-1990s. Moreover, that figure

is likely to overestimate the current area of active dunes. The most recent aerial photography available for the Northland Region, which then contained the largest area of active dunes, was flown in September 1993. Conversion of active dunes in this and other regions has slowed, but continued, since that time.

The current study documents the decline in area of active dunes, not the change in the area and diversity of particular dune habitats, their ecological integrity, or the conservation status of dune communities or individual species. Many of the active dunes mapped in the current study are degraded following marram grass invasion and dune stabilization. These dunes are geomorphically inert, although they are morphologically intact. The impact of marram grass has been particularly severe on the east and south coasts of the South Island and the west coast of the North Island. The area of active dunes in the Otago Region, for example, has declined by approximately 41% since the 1950s, a moderate loss by national standards. However, only two Otago beaches, Tahakopa Bay and the Tokomairiro River Mouth, retain significant areas of the indigenous flora usually associated with active dunes. Marram grass comprises over 90% of the vegetation cover in both these dune systems.

Many remaining active dune systems – the Manawatu dune system, for example (Fig. 6), are mere remnants of previously much larger areas. Many of those fragments are of national significance, despite their reduced area, in that they contain threatened or regionally threatened species. There are now relatively few dune systems with the sequence of semi-vegetated, unstable dunes to stable, vegetated dunes described by Cockayne (1958). At many sites the backdunes have been converted to forestry or agriculture and the foredune is dominated by marram grass.

Conclusions

The information required to effectively manage and conserve New Zealand's remaining active dune systems is still far from comprehensive. The location and boundaries of all remaining dune systems of significant conservation value, both active and forested, have yet to be determined. In general, these will be sites with no or only low levels of marram grass infestation. Second, there is no ready basis for assessing the extent to which protected and actively managed dune systems are representative of regional or national diversity. As yet no attempt has been made to develop a typology of New Zealand dune systems, based on dune form and geomorphic process, despite the evidence for distinctive regional variations in the physical and, to a lesser degree, botanical character of active dune systems. Third, there have been comparatively few and very localized attempts to map and interpret dune environments and associated plant communities. New Zealand has a poor knowledge of the biodiversity of specific dune systems, including the threat posed to dune systems by invasive plants. Emphasis has been placed on marram grass in the current paper, in large part because it is the major threat to active dunes throughout most of New Zealand. The active dunes of Northland are vulnerable to other exotic species, including *Acacia longifolia*.

Existing dune inventories, namely the Sand Dune and Beach Vegetation Inventory of New Zealand and occasional Protected Natural Areas Program survey reports, have provided an overview of the decline in natural character of dune systems and identified active dune systems of exceptional conservation value. Further work is urgently required to (1) develop a biophysical classification of active dune habitats comparable with that developed for European dunes; (2) develop inventories of particular dune habitats (e.g. interdune wetlands) and threatened or localized dune species; and (3) map and monitor the distribution of key indigenous and exotic species. Given the rate at which the area and natural character of New Zealand's active dunes have declined over the last 40 years, the opportunity for conserving the remaining active dunes may not last beyond the next decade.

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