Restoration of Foredunes and Transgressive Dunefields: Case Studies from New Zealand

Chapter · January 2013

DOI: 10.1007/978-3-642-33445-0_5

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Chapter 5
Restoration of Foredunes and Transgressive Dunefields: Case Studies from New Zealand

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5.1 Introduction

Most New Zealand dune systems have been modified in the past 100 years by grazing; by the planting or introduction (deliberate or accidental) of exotic species; by reshaping and covering with exotic materials (e.g., clays); by wholesale change or degradation associated with the development of dunes for recreational activities (e.g., golf courses; playgrounds; reserves [areas set aside for specific purposes such as recreation, research, conservation, etc.]); and change, removal and/or degradation associated with urban, rural and beach housing and tourist developments. 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 % (Hilton 2006) at least in part because of significant planting of exotic species. The New Zealand Biodiversity Strategy recognizes dunes and wetlands as the country's two most threatened environments.

Following the widespread destruction of natural vegetation cover on dunes by cattle and sheep grazing in the 1800–1940s, most active, mobile dune systems in the North Island of New Zealand were planted with introduced species. Marram grass (*Ammophila arenaria* (L.) Link) was planted widely from the late 1880s to protect infrastructure and to stabilize transgressive dunes, particularly those in the vicinity of road and rail links, and as a precursor to exotic plantation forestry

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M. L. Martínez et al. (eds.), *Restoration of Coastal Dunes*, Springer Series on Environmental Management, DOI: 10.1007/978-3-642-33445-0_5,

(McKelvey 1999). However, marram became naturalized and subsequently spread to dune systems of high conservation value. Marram can establish from marine-dispersed rhizome and is capable of colonizing remote dune systems tens to hundreds of kilometers from source (Konlechner and Hilton 2009). Consequently, most dunes of national conservation value now contain marram grass (Hilton et al. 2000), along with tree lupin (*Lupinus arboreus*) and a wide range of other weed species.

Ammophila species, particularly *Ammophila arenaria*, along with many other species (e.g., *Acacia, Pinus*) were introduced into coastal environments in many countries to stabilize dunes (e.g., New Zealand, USA, Australia, South Africa; McKelvey 1999; Marchante et al. 2003; Milton 2004). The introduction of marram grass has led to the development of foredunes and dune types that were previously either poorly developed or non-existent, changes in the morphology of dunes, the development of mono-specific stands and exclusion of native plant species, various ecological effects including the decline of faunal habitats and fauna, and spread to and invasion of other coastal sites (e.g., Carlton 1989; Aptekar and Rejmánek 2000; Hertling and Lubke 2000; Vega et al. 2000; Kirkpatrick 2001; Hilton et al. 2006; Konlechner and Hilton 2009; Pickart 2012). Thus, there is significant interest in how to remove marram grass, restrict invasions, and restore physical and ecological functioning to a state similar to that prevailing prior to planting and invasion.

Foredunes, as the foremost dune at the rear of the beach, have always been a desirable place from which to sit and watch the sea, and from which to conduct marine activities. From very early on in the history of building towns at the coast, foredunes were commonly utilized as sites for constructing various kinds of infrastructure, particularly houses, roads, and industrial structures. When the Victorians began to popularize visits to the beach in the 1800s, foredunes were converted to promenades, and altered/modified/destroyed for urban development. Thus, we now find that foredunes around the world have been altered, modified, or destroyed for industrial and urban development, parks and easier beach access and views (e.g., Ferreira and Dias 1992; Veloso-Gomes and Taveira-Pinto 1995; Rakodi and Treloar 1997; Nordstrom and Arens 1998; Batanouny 1999; Nordstrom 2004, 2008; Gomez-Pina et al. 2002; Seeliger 2003; Eppinga et al. 2006; El Banna and Frihy 2009). Now with the reduction or elimination of building on foredunes and greater foredune protection in some countries we are faced with the question: is it possible to restore, rebuild, or create a foredune following various levels of human-induced change and/or destruction?

In the following, we describe the restoration of two foredunes and a transgressive dunefield in New Zealand (Fig. 5.1), as examples of first, how the morphology and ecology of natural dunes were changed owing to human interventions (purposely or accidentally); and second, how the morpho-ecological states of the dunes have been purposely modified or restored to something approaching a natural state, and the processes and costs associated with that activity.

Restoration here has two dimensions. In the first and second cases examined, authorities aimed to re-establish the pre-disturbed dune form and indigenous vegetation cover. This work was undertaken in a metropolitan context. In the third

Fig. 5.1 Map of New Zealand indicating the dune restoration sites mentioned in the text

case, the goal of restoration was to restore the dynamic potential of a transgressive dune system that had been stabilized by the introduction of marram grass. Some planting of native species has occurred, but this was not the main activity or goal. The third case involves an isolated dune system in a national park setting with no history of direct human use.

5.2 Case Study 1: Foredune Restoration, Oakura Beach

Oakura Beach (New Plymouth, Taranaki Region, North Island, New Zealand) is a moderate to high wind and wave energy coastal system that has a very limited, if not zero to negative, sediment supply. It comprises a wide, rocky, predominantly sub-tidal reef that is thinly overlain by sand in the surf zone. The intertidal beach is relatively narrow at high tide and also has a low sediment volume. The entire Holocene (10,000 years to present) dune system comprises one low, narrow foredune, which indicates either that the sediment supply to this beach has always been extremely small, or that significant erosion has taken place in the past.

5.2.1 The Foredune

The foredune was a narrow (18-m wide), low (3.5 m above mean sea level) flat-topped terrace that had been significantly modified in the past. It extended 150 m alongshore. As with many foredunes on New Zealand coasts with moderate to high recreational activity, the dune crest had been flattened, some unknown amount of building fill had been emplaced in the dune, clay had been laid over the surface, and the soil had been planted with exotic kikuyu grass (*Pennisetum clandestinum*). The area behind the "dune" was open grass and trees and utilized as a recreation/picnic area. The seaward face of the dune commonly displayed an erosion scarp along its length (Fig. 5.2). The only naturally functioning portion of the dune was this stoss, or seaward face, which on occasions, between storms, would fill with aeolian sand. Following discussions with the local New Plymouth District Council, a plan was developed with the objectives of reshaping the foredune to a more natural shape, improving the natural functioning of the foredune (i.e., enabling beach–dune interaction; see e.g. Hesp 1989), and carrying out dune re-vegetation utilizing *Spinifex sericeus*, the primary indigenous foredune species in northern New Zealand.

5.2.2 Foredune Reshaping

The reshaped dune seaward slope (or stoss face) should ideally lie within the slope range of 1:5 (around 11°) to 1:3 (around 18°). These slopes approximate natural (unmodified or non-scarped) foredune stoss slopes in the region. However, at Oakura there were five significant factors that limited the dune reshaping exercise:

1. There was very limited space in which to reshape a foredune (approximately 10 m maximum from the dune scarp crest), since it was the Council's wish to retain the maximum lee dune recreation area.
2. The seaward toe of the reshaped foredune should not extend further seaward than the toe of the dune scarp and should preferentially be landward of that

Fig. 5.2 View of the Oakura Beach site prior to restoration

point. If it were seaward of the scarp toe, it would be very likely eroded in the next storm or spring high tide.
3. The foredune was quite low and should ideally be reshaped to a greater height to allow for, and mitigate against, storm erosion and potential storm overwash.
4. The foredune surface comprised clay and other materials, some of which would not be desirable for use in the reshaping and this lessened the volume of material available for dune reshaping.
5. Views from the reserve toward the beach should be maintained where possible.

Given these constraints, the very limited availability of sediment from other sources, and the potential for storm wave erosion, the reshaped dune profiles were constructed with a stoss (seaward) slope of around 18° (1:3) (Fig. 5.3). The dune height was maximized where possible to heighten the dunes a small amount while still conserving sediment. The dune lee slope was constructed with a slope of around 20° and, while it was desirable to produce a lower lee slope, dense planting and fencing ensured the stability of the slope.

5.2.3 Dune Volumes, Sand Placement, and Sand Removal from Oakura Beach

The approximate volume of sediment (per meter alongshore of the dune) required for reshaping is indicated in Fig. 5.3. The volumes required to construct the desired dune profile ranged from 1,200 to 2,700 m^3/m depending on the location alongshore. There was a greater amount of sediment available in the northern section of the area to be reshaped and a deficit in the southern area. That is, the amount of material required to produce a minimal dune shape in the southern section was less than that available from the excavated area. Since it was desirable to build the reshaped foredune as large as possible, and since there was more sediment in the northern area, some of this northern sediment was transported to the southern area to make up the deficit.

It was not clear prior to reshaping of the dune exactly how much fill of foreign materials might be in the dune, and thus, an additional 300 m^3 of sediment was potentially required for dune reshaping. This sediment was to be extracted from the beach adjacent to the Waimoku Stream (at the northern end of the beach) when stream re-alignment works took place. It was then to be transported along the beach at low tide and emplaced on the southern section.

5.2.4 Dune Planting

Prior to dune reshaping and planting the kikuyu grass was eliminated by spraying it three times with Roundup™ at 8-week intervals (Bergin et al. 2000). The dune was reshaped, restored to a relatively natural profile (Fig. 5.4), and mostly planted

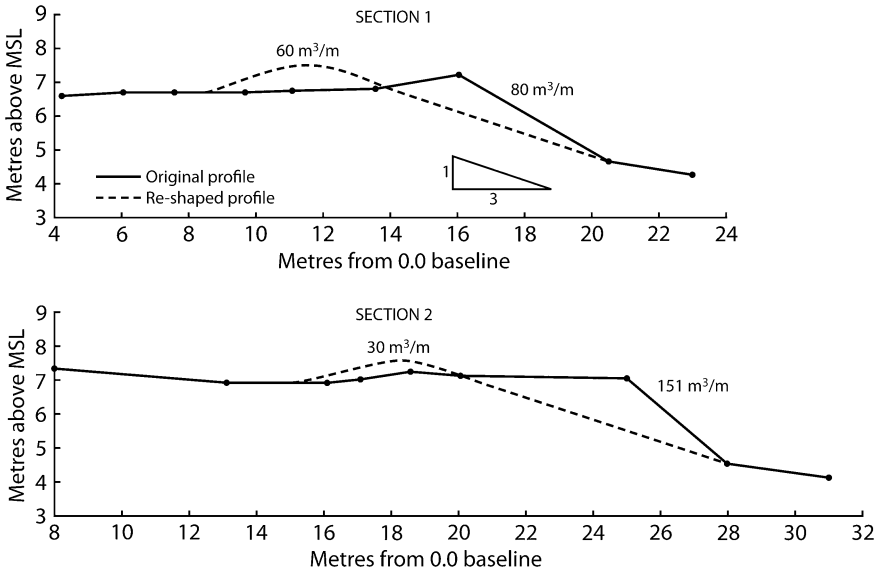

Fig. 5.3 Cross-sections of the original dune terrace, and the design foredune at two locations along the dune

Fig. 5.4 View of the heavy machinery reshaping the foredune. The former clay surface and fill have been removed, and sand from the northern end of the beach has been transported to the site to increase the dune volume

with *Spinifex sericeus* (primarily raised from seed) at a spacing of 50–70 cm. This close spacing was desirable because the operation of high-energy, west-coast, "roaring forties'" winds in this region means that there is a considerable chance of aeolian erosion occurring following planting. Some limited planting of *Carex pumila* plants was also undertaken as a trial to examine how well this native plant might survive in this environment (Bergin et al. 2000). The surface was fertilized with two slow-release NPK fertilizers at planting. A three-wire fence was erected along the front and back of the dune to restrict pedestrian access, and signs were erected to inform the public of the works. The plants grew rapidly and the dune displayed a high percentage of cover after 6 months (Fig. 5.5).

Fig. 5.5 View of the reshaped foredune in 2000, principally planted with etc., Spinifex sericeus, the native pioneer species for the region

5.2.5 Economics of the Work

The costs associated with this restoration project of a 150-m length of foredune included NZ$ 2,400 in consultancy fees, NZ$ 1,700 in heavy machinery hire, and planting and fencing at a cost of NZ$ 40 per linear meter (year 2000 prices).

5.3 Case Study 2: Foredune Restoration, East End Beach

East End Beach (New Plymouth, Taranaki Region, North Island, New Zealand) is a moderate- to high-energy coastal system that also has a very limited sediment supply. It comprises a wide, rocky, predominantly sub-tidal reef thinly overlain with sand in the surf zone and on the beach. Prior to restoration, the dune system comprised one erosional, relatively low, narrow foredune (Fig. 5.6). The foredune regularly displayed an erosion scarp along its length and had been significantly altered in the past by widening, leveling, and filling. It had been impacted by port works (to the south) and subsequent loss of sediment from the littoral drift system.

Following the short-term success of the Oakura restoration works, the New Plymouth District Council undertook to reshape and restore the foredune with the

Fig. 5.6 View of the East End foredune prior to restoration

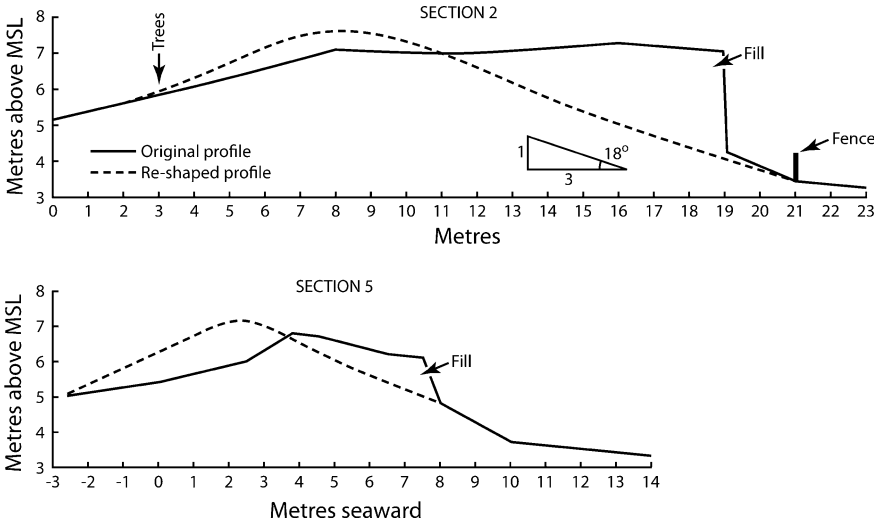

Fig. 5.7 Two cross-sections (Sect. 5.2 [southerly] and Sect. 5.5 [northerly]) of the foredune illustrating the pre- and post-restoration morphologies

objectives of restoring the dune to a more natural shape, and carrying out some dune re-vegetation utilizing native species, along a 150-m length of the dune.

5.3.1 Foredune Reshaping

The selected foredune section was situated just north of the main walkway onto East End Beach adjacent to the East End Surf Life Saving Club. Two typical topographic profiles are shown in Fig. 5.7, including the typical reshaped dune profiles. As in the case of Oakura, at East End there were four factors that limited the dune reshaping work:

1. Limited space in which to reshape a foredune (a maximum of 15–16 m (at the southern end) from the dune scarp crest to the edge of trees, which were native species and worth saving if possible).
2. The dune could not extend further seaward than the scarp toe.
3. The foredune was low.
4. The foredune contained a certain amount of fill material of unknown type.

Given these constraints, the very limited availability of sediment from other sources, and the potential for storm wave erosion, the reshaped dune profiles were constructed with a stoss slope of around 18° (1:3) to 22°. The dune height was maximized where possible to heighten the northern section of dunes a small amount, while still conserving sediment.

Fig. 5.8 The foredune at East End following restoration

The approximate volumes of sediment required to create the preferred dune profiles or morphologies were 200–400 m^3/m. The amount of material required to produce a minimum dune shape in the middle and northern sections was less than that available from the adjacent excavated areas. Since it was desirable to build the reshaped foredune at least as high as the present dune (see Fig. 5.7), some of the sediment comprising the southern section was transported to the middle and northern areas to make up the deficit in the landward parts of those sections.

Given that there was considerable uncertainty regarding the amount of fill material in the present dune, it was desirable to have available an additional 100 m^3 of sediment for dune reshaping. This sediment could be extracted from the beach near the training wall at Waiwhakaiho near the northern end of the beach. It could then be transported along the beach at low tide and placed on the 150-m section if required.

5.3.2 Dune Planting

Following the apparently "successful" trial at Oakura Beach (successful being defined here as the dune emplacement having worked according to the given specifications, it began to function normally, and the plantings survived (see Gallego-Fernández et al. 2010, paragraph 4, p. 1824); *Spinifex sericeus* was planted at 50-cm spacing across the foredune (success being measured in the short term—about 2 years—in this case). Some Pīngao (*Ficinia spiralis*), the other major pioneer species in New Zealand, was also cross-planted within the *Spinifex* (Fig. 5.8). Flax (*Phormium tenax*) and native tree species were planted along the leeward edge wherever the exotic and native existing trees had to be removed in order to obtain the desired profiles. A three-wire fence and signs were erected at planting.

5.3.3 Economics of the Work

The costs per meter of beach were approximately the same as at Oakura.

5.4 Case Study 3: Foredune Destruction, Transgressive Dunefield Restoration, Stewart Island

The impact of marram grass (*Ammophila arenaria*) on the morphology of beaches and foredunes on temperate coasts has been recognized for some time (e.g., Cooper 1958; Huiskes 1979; Carter et al. 1990; Hilton et al. 2005; Hilton 2006). Much less is known about the development of foredunes and coastal barriers following marram eradication. The potential to restore marram-dominated dunes, by eradicating the marram, is gaining recognition in New Zealand and elsewhere. There is, however, concern that marram eradication will initiate sand drift, to the detriment of down-wind infrastructure and ecosystems. An opportunity to monitor the geomorphology of a prograded bay-head barrier at Doughboy Bay, following a sustained marram eradication operation over a 12-year period (1998–2010) arose when the Department of Conservation (DoC) commenced a marram-control program in Rakiura National Park (Stewart Island, southernmost New Zealand) in 1999. Specifically, the DoC and the second author examined:

1. The response of marram to herbicide application
2. The rate of decay of marram following herbicide application
3. The nature of sedimentation following marram necrosis and decay

A parallel study of marram eradication in Mason Bay, a much larger and more complex dune system 2 km to the north of Doughboy Bay, commenced in 2000.

5.4.1 Study Area

The beach systems of Stewart Island are moderate to high wave and wind energy environments. Beach morphologies are of the intermediate type with a broad intertidal terrace comprising either sand or mixed sand and gravel. The back-beach morphology has probably narrowed and steepened following the introduction of marram grass and the development of continuous, uniform (Type I) foredunes (i.e., continuous, morphologically simple, high vegetative cover—after Hesp 2002). Hart et al. (2012) measured the wind regime at Mason Bay from June 2002 to February 2004 using a permanent Vector 3-cup anemometer at a height of 2 m located on the foredune crest. The predominant direction of sediment transport is onshore; the wind regime is dominated by strong, episodic, west to southwest (onshore) winds throughout the year. Annual average wind speed is 6.4 ms^{-1} with <1 % calm conditions. The dune systems of Doughboy Bay occur at the head of a pronounced embayment. Headlands shelter the southern and northern margins of the sandy shoreline, but the central dune system and adjoining barriers are highly exposed to onshore winds (Fig. 5.9).

Stewart Island, and Fiordland, the southern South Island beach and dune systems, retained relatively high natural values well into the twentieth century.

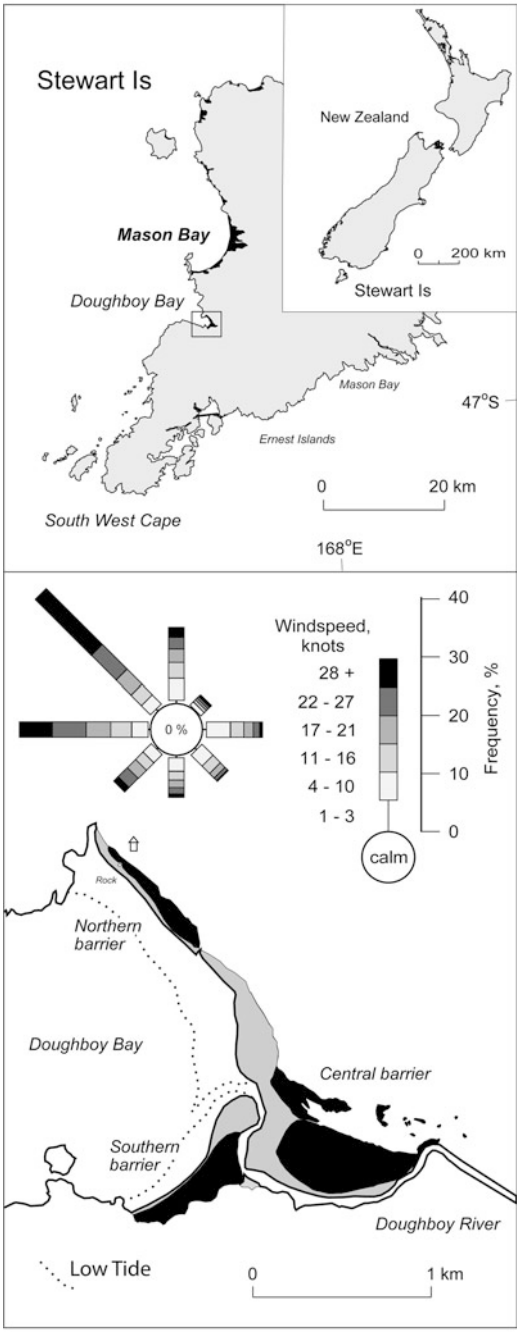

Fig. 5.9 Location of the southern barrier, Doughboy Bay, Stewart Island (Rakiura National Park). The prevailing and dominant winds are from the northwest. The wind rose is derived from data gathered at Southwest Cape, 20 km south of the study site, from 1992 to 2003

Marram has been planted at Mason Bay since the 1930s, initially at Kilbride at the southern end of the bay. Marram was probably also established from marine-dispersed rhizome. When the Department of Conservation was formed in 1987 all of the main Stewart Island dune systems contained marram grass, although many of these systems contained large areas that were free of marram. Fiordland and Rakiura National Parks now contain almost a third of New Zealand dune systems of national conservation significance (Johnson 1992; Hilton 2006). The Department of Conservation is committed to eradicating marram from both areas. Marram sites in Fiordland are sprayed annually, over just 1 or 2 days, using a helicopter to access sites where marram has been recorded. In contrast, the marram eradication operations on the west coast of Stewart Island involve the deployment of 4–5 personnel over a 6-month period, from November to May. This operation is probably the largest marram eradication program attempted.

The herbicide employed is a systemic, grass-specific chemical—native grasses are probably more vulnerable to the herbicide than marram grass. At many locations this has proved a minor issue, since marram commonly forms uniform stands and the key native grasses have already been displaced. At some sites aerial operations have been avoided to ensure that non-target species have not been affected. Precision mapping with the aid of GPS has facilitated this process. Nongrass species were monitored in a series of permanent quadrats in the Doughboy Bay dunes for 6 years, from (and just before) the first application of herbicide in 1999 till 2006. No decline in vigor was noted. A decline in species diversity did occur, however, as a result of renewed sedimentation following marram necrosis.

Marram is capable of rapid invasion of both progradational and transgressive dune systems in southern New Zealand. Marram was planted at Kilbride in Mason Bay in the 1930s and then spread north, by marine-dispersed rhizome. It became established in the foredune north of Martins Creek in the early 1950s, and then spread to the hinterland of the dune system by wind-blown seed. Some sections of the dunes were also planted by farmers in the 1960s (possibly earlier). Marram grass was also well established in Doughboy Bay by the late 1950s. By 1998 marram had occupied most available habitat in Doughboy Bay (30 ha) and was established across 676 ha (68 %) of active dunes in Mason Bay. The rate of spread was rapid—Hilton et al. (2005) estimated that areas of dense marram (>50 % cover) increased from 1.4 ha in 1958 to 74.9 ha in 1998. Without intervention, marram grass would likely have invaded most of the dune system by between 2023 and 2043 (Jul 1998).

Marram control on the southern barrier of Doughboy Bay, Stewart Island (Rakiura) was initiated by the Department of Conservation in an attempt to restore natural processes and patterns of sedimentation and dune flora and fauna. Information from the southern barrier, one of three in the bay, is presented. This barrier contains a sequence of four foredune ridges that have developed in conjunction with marram. Marram had become the dominant foredune species in Doughboy Bay by 1958 (Hilton et al. 2005; Hilton and Konlechner 2010). Prior to the establishment of marram grass the southern barrier probably comprised a simple

Fig. 5.10 An aerial oblique view of the southern barrier. The "scarp" separates the prograded foredune barrier associated with marram, which formed after the first aerial photograph was obtained in 1958 from the pre-marram dune system. The latter contains remnant blowouts and parabolic dunes

foredune complex, with some blowout and parabolic dune development at the northern (relatively exposed) end of the barrier. At this time the flora of the barrier would have comprised both dune-specific and cosmopolitan scrub and forest margin plants. Some species, including the endemic *Euphorbia glauca* (shore spurge) and the indigenous sand tussock, (*Poa billardierei* (Spreng.) Soreng et al. 2009; formerly *Austrofestuca littoralis)*, had probably been eliminated by introduced mammal browse and granivory before marram invasion. Pīngao (*Ficinia spiralis* (A. Rich.) Muasya and de Lange 2010; formerly *Desmoschoenus spiralis*) would have grown across much of the barrier, and moribund colonies persist where marram grass has not invaded. Only one pīngao plant was observed within the marram foredune ridge sequence in 1999. Ironically, the diversity of the marram-dominated ridges was very high—a consequence of the stability and senescence of marram on the inner ridges as the barrier prograded.

The geomorphology of the barrier was also transformed. Transgressive dunes, blowouts and, parabolic characterized the surface of the pre-marram barrier; however, these dunes are now stable and vegetated, since they are located in the lee of the sequence of marram-forced foredunes. In 1999 the seaward half of the barrier comprised a series of linear foredunes (Figs. 5.10, 5.11). Remnant blowouts and saucer-shaped parabolic dunes, now stable, occupy the landward half of the barrier. During the period from 1958 to 1998 the southern barrier prograded 60–200 seaward and 400 m to the north. This northward growth of the barrier was forced by marram colonization of the pre-marram barrier margins. Pīngao may have been established there from time to time, but both aeolian and marine sedimentation would have prevented prolonged colonization and foredune establishment.

The Doughboy case is typical of the impact of marram grass on the dune systems of southern New Zealand. The DoC intervened in the Doughboy Bay case

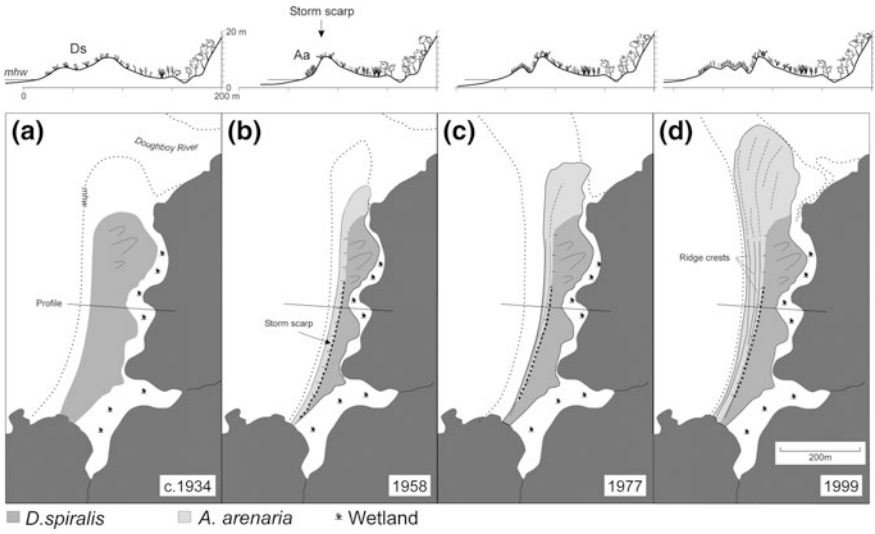

Fig. 5.11 Barrier and dune system development, 1934 to 1999 (Hilton et al. 2009)

because of initial concern that marram was adversely affecting three of the surviving six populations of *Gunnera hamiltonii* in the Bay, an endangered coastal herb. The impact was twofold. Marram was overgrowing and shading the herb, which has a low growth form. Second, marram was growing in the most exposed central section of the Bay, on the distal tip of the southern barrier. This development was forcing the mouth of the Doughboy River to the north, with the result that the northern bank of the river was eroding, with the imminent loss of the only wild female colony of *Gunnera hamiltonii*. Were it not for the conservation status of this species (nationally critical), the Marram Eradication Program (MEP) on Stewart Island might not have commenced. In 1999 there was no national overview of dune conservation in New Zealand or national program of dune restoration. Such a program has still to emerge, although the Department of Conservation is engaged in a process of national ecosystem and site prioritization.

5.4.2 Methods of Eradication

Marram grass has primarily been controlled using herbicides in New Zealand. Mechanical methods of control—excavation, burial, solarization, salt treatment—have been trialed by local authorities and conservation groups. However, unlike some jurisdictions (e.g., California and Oregon; Pickart 1997; Wiedemann and Pickart 2004), there is general acceptance that herbicides are the most effective treatment option. Some early treatments in Fiordland National Park employed Roundup^{TM}, but this caused general necrosis of nearby native species and

excessive dune disturbance. Gallant™ (Gallant-NF™, Gallant-Ultra™), a selective (grass-specific), systemic herbicide has been used by the Department of Conservation since the mid 1980s. Gallant can be sprayed on pīngao (or "pīkao" in southern New Zealand), a sedge, at usual concentrations and application rates, without stress or necrosis. *Spinifex sericeus*, a grass, does not grow in southern New Zealand. However, Gallant cannot be used in the presence of native grasses, including the native sand tussock, *Poa billardierei*. Gallant has two disadvantages. It is relatively expensive at around NZ$ 180/liter (in 2010). Second, the effects when used on marram grass are relatively slow to appear—in southern New Zealand (47° S Lat.) 12 months should be left between application and assessment. That is, the effectiveness of a marram eradication operation cannot be assessed until the following growth season. Complete necrosis of above-ground biomass is usually observed within 6 months of herbicide application, but regrowth can be anticipated in early spring. Other "knockdown" herbicides have been trialed, but they have been found to be less effective and more expensive over time. Gallant remains the best option.

Prior to the formation of the Department of Conservation in 1987, the New Zealand Forest Service targeted the northwest beaches of Stewart Island, which then contained small infestations of marram, of the order of 10^1–10^2 m^2. These populations had developed from rhizome that may have originated on the west coast of Stewart Island, Southland or South Westland. Knapsacks were used to apply Gallant from time to time, depending on other priorities, the availability of transport, and the weather. The beaches of northwest Stewart Island are accessed by boat or small aircraft that are capable of landing at low tide. These operations were of the utmost importance, since they prevented the establishment of large infestations at a time when there was no policy or funding for the systematic control of marram grass on Stewart Island.

The Department of Conservation commenced aerial (helicopter) operations in Doughboy Bay in February 1999. By this time marram had produced a dense cover over the northern and southern barriers and was rapidly invading the central dunes. The area of dense marram, associated with the four foredune ridges described above, an area of approximately 7 ha, was sprayed with the herbicide Gallant NF™ using a Robinson-22 helicopter in February (mid-summer) 1999. Helicopters have since been used to spray large areas of marram grass, particularly marram growing in the foredune environment, primarily using Jet-Ranger aircraft (Fig. 5.12). The 1999 helicopter operations on the southern barrier at Doughboy Bay were repeated in 2000 and 2001. The initial results were spectacular—complete necrosis of leaf material was observed 4 months after the first helicopter operation. However, numerous shoots had established from surviving rhizome by late spring. The helicopter was used to spray this regrowth in February 2000. Further regrowth was sprayed during the summer of 2000/2001 using a 500 liter pump unit mounted on an ARGO amphibious vehicle (Fig. 5.13). Subsequent regrowth, primarily from in situ seeds, has been sprayed using the ARGO or with knapsacks, or hand-pulled during systematic search and destroy operations in the

Fig. 5.12 A Jet-Ranger helicopter equipped with a spray boom, engaged in marram control operations, Mason Bay, December 2010

period 2004–2010. This process is ongoing owing to the persistence of the marram seed bank (Konlechner and Hilton 2010).

There is no evidence that elements of the herbicide remain in the sand following prolonged use, consistent with the manufacturer's advice, which is that Gallant breaks down rapidly after application. This issue has not been evaluated; however, we have noticed vigorous recruitment of native plant seedlings in areas where marram has received aerial spraying for 3 years. It is likely that any residual chemical would be rapidly washed through the sand because of the high rainfall and high permeability of the sandy soils.

Observations of marram decay were made over 4 years (1999–2004) in a series of 14 permanent 2 × 1-m quadrats spaced across the southern barrier (see Woodley and Hilton 2003; Hilton et al. 2009). Five stages of decay were apparent. Permanent transects were established across the barrier to determine gross changes in barrier morphology (Fig. 5.14). Profiles were surveyed annually, from 1998 (prior to the operation) to 2007 using a dumpy level or a total station. The topography and vegetation cover of one area (approximately 40 × 140 m) was surveyed annually using a total station from 2002 to 2007. Digital terrain models were derived using a total station and topography and vegetation cover within the area was mapped and the data presented using SURFER^{TM}. The shelter afforded by different stages of Marram decay was also observed using an anemometer array and is reported elsewhere (Woodley and Hilton 2003).

5.4.3 Barrier and Dune Development Following Marram Eradication

The morphology of the southern barrier changed slowly following the aerial application of herbicide in February 1999. Substantial sedimentation did not commence until the winter of 2006 and then only north of Transect 4 (henceforth "T4"). This slow response of the barrier to de-vegetation was due to the slow rate of decay of in situ marram rhizome. In addition, it took 3 years of herbicide

Fig. 5.13 Department of Conservation rangers spraying marram grass using an ARGO all-terrain vehicle equipped with a 500 liter spray tank and two 50 m hoses

treatment to reduce marram to a density of 1 % cover or less. The leaves browned and died following the initial application of herbicide, during the winter of 1999. However, regrowth occurred from surviving rhizome during November and December 1999, particularly along the stoss face of the foredune. The rate of sand loss from the stoss face of the foredune has increased since 2004, with concomitant sand drift and deposition downwind (e.g., T2, Figs. 5.14, 5.15). By December 2006 the series of ridges was no longer visible north of T3. The surface of the barrier north of T3 now comprises an active sand-sheet. Since 2006 the distal end of the barrier, north of T3, has experienced relatively rapid sedimentation, with significant loss of sand to the Doughboy River. At the southern, relatively sheltered, end of the barrier the foredune ridges are still preserved, although the

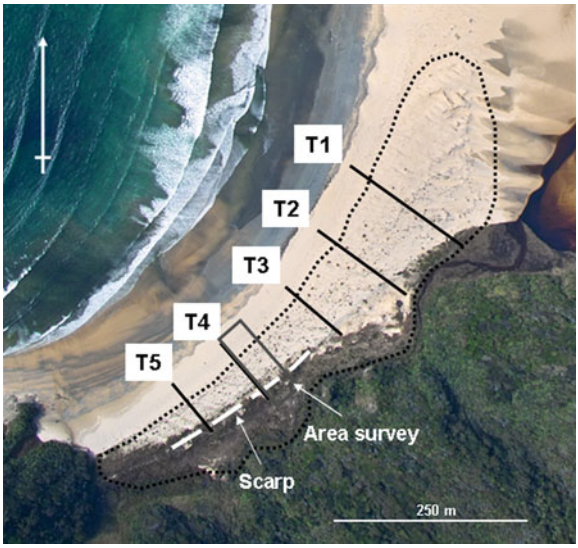

Fig. 5.14 Location of profile lines and features referred to in the text, southern barrier, Doughboy Bay

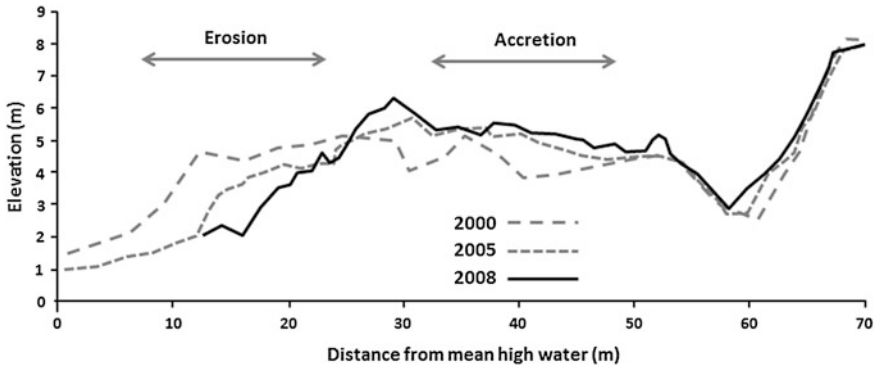

Fig. 5.15 A comparison of the first (2000), 2005 and most recent (2008) profiles surveyed across T4. Erosion is occurring seaward of 25 m. Landward of 25 m the barrier is accreting (Konlechner and Hilton 2010)

foredune has experienced some minor erosion. The zone of active sedimentation reached the relict storm scarp south of T3 (Fig. 5.16) in 2010. This sandsheet should overtop the relict scarp before 2015. In general, the dune ridges of the northern section of the barrier are eroding relatively rapidly, fueling downwind sedimentation and the development of a slip face. This feature is advancing landward (i.e., to the east).

Depositional and erosional features, aligned more or less parallel to the prevailing westerly winds, now etch the surface of the barrier. The foredune ridges are now no longer evident. Shadow dunes have formed behind surviving specimens of flax (*Phormium tenax*), and clusters of pīngao (Fig. 5.17). Pīngao was systematically planted across the barrier in 2002, 2003, and 2004, in clusters of 5–7 plants, 20–30 m apart. The subsequent plant growth and associated shadow dune development has been rapid. These dunes are now 2–3 high and 10–20 m in length. The plantings located between T2 and T3 were initially successful; however, many are now eroding as the surrounding surface of the barrier is lowered and the sides of the shadow dunes are undercut. This section of the barrier only formed in conjunction with marram grass establishment—aeolian processes now exceed the capacity of pīngao to sustain these shadow dunes.

5.4.4 Problems Associated with Marram Eradication

We anticipated that marram would be eradicated over a period of 3–5 years at the outset of the MEP in Doughboy Bay. In fact, spray operations are ongoing, although the scale of the operations will be significantly reduced by 2013. Completion of the Doughboy Bay operation has been delayed by two processes—germination of in situ seed and two marram rhizome stranding events (Hilton and Konlechner 2011). The latter is relatively trivial, but worthy of mention. A patch

Fig. 5.16 A sequence of photographs from between T3 and T4, showing the initial marram cover and progressive de-vegetation and sandsheet and nebkha development (1999–2011)

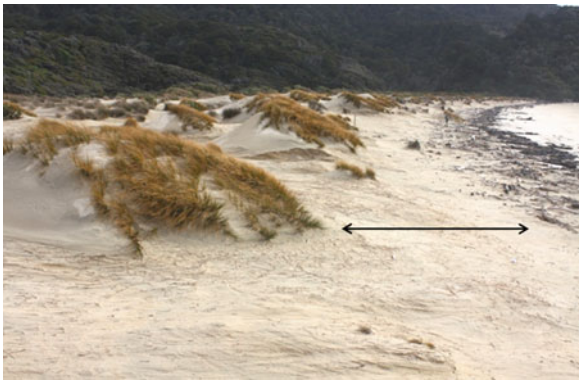

Fig. 5.17 The stoss face of the foredune after marram eradication. The arrow indicates where most marram seedlings have emerged, on an annual basis, since 2005. The shadow dunes have formed under pīngao, planted by the Department of Conservation in 2003

of marram adjacent to the Doughboy River had been left unsprayed, because of the proximity of a colony of *G. hamiltonii* to blowout, while alternative management options for the site were being considered. Two storm events, in 2005 and 2008, resulted in large quantities of marram rhizome being washed into Doughboy Bay. This rhizome was deposited above the spring high tide level on the beach fronting the three barriers. Vigorous marram growth and incipient foredune development resulted within 12 months on both occasions. This growth was subsequently sprayed, but not before some flowering occurred.

The presence of a marram seed bank has been more problematic (Konlechner and Hilton 2010). The biological literature provided little guidance as to the longevity of marram seeds, which are trapped in foredunes as they prograde and accrete. The monitoring program referred to above has involved precise annual mapping of seedlings across a DTM using a Leica total station. Seedlings started to emerge in 2004 after the decay of the marram grass leaf material and erosion of the former stoss face of the foredune (shown in Fig. 5.17). Seedlings have been emerging ever since; which indicates that marram seed banks are viable for at least 10 years. Wind-dispersed seed has been a problem in the much larger dune systems of Mason Bay, which reach 3.2 km inland of the foredune. The foredune and adjacent dunes, comprising a zone of about 800 m, is dominated by marram grass. Seed is blown from this zone into the sparsely vegetated dune hinterland in large quantities, resulting in a pattern of numerous, but widely dispersed seedlings. The implications of both in situ germination and seed dispersal by wind for the MEP have been significant. The mechanical methods used to apply spray—helicopters and the ARGO—are not suitable for the location and treatment of widely scattered plants. A system of grid search was trialed in November 2006, which employed lines of searchers, equipped with hand-held GPS units. The breadcrumb trails on the GPS screen were used to maintain direction and spacing and ensure total coverage of the search area. Every marram plant encountered was way-pointed and subsequently sprayed or hand-pulled. In November 2006, the four-person

volunteer team searched 70 ha over 4 days. A total of 5,817 plants were surveyed, 4,712 of which were pulled. Effective execution of this simple method is critical to the success of the MEP on Stewart Island. Marram grass will be eradicated from Doughboy Bay over the next 3–4 years, but only if operations are conducted annually, systematically, and with precise spatial control. Eliminating the first 99 % of marram from the Doughboy site has proved relatively straightforward, compared with the task of finding and destroying seedlings. If missed, these seedlings will produce flowering plants within 24 months. The Department of Conservation operations team employed the grid search method for the first time in January 2010 and the method was honed and improved over the 2010/2011 season. Establishing smaller management units, installing the boundaries of these units on the GPS units carried by the operations team, and checking coverage on a daily basis have ensured the necessary coverage.

5.4.5 Economic Costs

The cost of the MEP on Stewart Island, primarily involving ten dune systems, eight of which are dune systems of national conservation significance, is approximately NZ$ 240,000 pa in 2010. Most of this cost, approximately NZ$ 180,000, was spent at Mason Bay. This sum comprises labor (NZ$ 86,000); helicopter spraying (NZ$ 11,000); herbicide purchase (NZ$ 12,000); transport of people and supplies by fixed wing aircraft and helicopters (NZ$ 25,000); and maintenance supplies and sustenance (approximately NZ$ 24,000). The University of Otago has an annual contract (NZ$ 13,000) to assess the effectiveness and environmental impact of the MEP at Doughboy and Mason Bay and to contribute to the development of the MEP strategy.

A technical advisory committee, the "Dune Restoration Advisory Group'" was formed in 2009 to achieve effective communication among managerial, technical, and operational staff within the Department of Conservation and between the Department and University staff. The DRAG meets twice a year. In addition, University and DoC staff participate in joint field evaluations at least twice a year. These forums have provided opportunities for important technical and strategic developments during 2010 and 2011.

The cost of annual operations at Doughboy Bay is currently just NZ$ 11,000. This sum should decline significantly over the next 2–3 years as the need for helicopter operations declines. By 2013–2015 the Department hopes to enter a surveillance phase involving the annual deployment of two rangers who will use knapsack spray equipment to spray emerging seedlings or plants growing from stranded rhizome. The annual cost of operations at Doughboy Bay should then fall to approximately NZ$ 2,000 pa.

Fig. 5.18 View of the Oakura foredune in 2008. The dune displays a prominent scarp, and has been invaded by a variety of weed species

5.5 Post-Restoration and the Future

In the case of the Oakura restoration, by 2008, the dune had been scarped by waves on numerous occasions (as expected given the very limited or negative sediment budget), but had also lost around 8 m in width. The dune had also been seriously invaded by weed species (Fig. 5.18). This may be, in part, a response to over-fertilizing, which happened at least once, but also to the fact that the spinifex senesced to some degree following dune stabilization. Like many pioneer species, spinifex requires sand deposition to drive growth. On a beach such as this, with very limited sand deposition onto the middle to upper stoss slope and crest, secondary native plants should have been introduced to mimic the natural successional tendencies in such areas. In the case of the East End restoration, the dune appears to be functioning naturally and while there is occasional wave scarping, the sediment budget on this beach is such that scarp filling and re-establishment of scarp and beach cover by native species occur.

The Stewart Island study indicates that marram-dominated dunes degrade slowly, even on high-energy windward coasts. Marram leaf, stolon, and rhizome material degrades in a predictable sequence and affords the substrate, at the early stages of decay, significant protection. Substantial loss of sand from the southern barrier in Doughboy Bay only started to occur in 2006, 7 years after the commencement of the operation. Further, this loss is only occurring from the section of the barrier in the most exposed part of the system. This section, the northern third of the landform, formed as a result of marram invasion.

The geomorphology of the study area has been fundamentally changed by the removal of marram, although the current landscape reflects landforms associated with post-marram sedimentation and landforms associated with the marram phase of progradation. The northern third of the barrier has experienced accelerating aeolian erosion since the commencement of the MEP. Re-colonization of this section of the barrier by indigenous pioneer species is now unlikely. We also anticipate ongoing erosion of the current de-vegetated foredune and a landward shift in the position of the beach. By 2030 the southern barrier should resemble the

pre-marram 1950s barrier morphology (see Hilton et al. 2005). Clearly, it has been advantageous to have an understanding of the impact of marram on barrier development in setting restoration goals and interpreting landform change following the initial herbicide operations. It has been possible to account for and justify the destabilization of the barrier, the first step in re-establishing a dune system with transgressive dune elements, albeit at the expense of downwind wetlands and other ecosystems.

5.6 Discussion and Conclusion

The motivation to "restore" dunes in the cases presented was twofold. In the North Island cases, local authorities sought to re-establish a stable foredune that was foremost, a more naturally functioning foredune with native species, that was aesthetically pleasing, and that provided some protection from storm-forced episodic erosion. The scope of the restoration was constrained by the small accommodation space and sediment supply. In contrast, the Rakiura National Park, Stewart Island, operations were motivated by a desire to re-establish the natural character of dune systems dominated by transgressive dune forms, low species diversity, and high dynamism. The accommodation space is not limiting and concerns about the downwind impact of marram eradication have been addressed. At Doughboy Bay a progradational sequence of foredunes had developed in association with marram grass where none had previously existed. There is now an understanding that the operations will liberate sand and some loss of downwind habitats, in part an artifact of marram invasion, will be lost. For example, a wetland dominated by jointed wire rush (*Leptocarpus similis*) developed as the barrier prograded to the north in Doughboy Bay. This wetland will soon be inundated by sand.

There is clearly a need to adopt a long-term perspective in all such restoration projects. The Department of Conservation might have hoped that the eradication of marram grass from Doughboy Bay would take well under a decade. In fact, complete eradication may not be achieved before 2015, 15 years after the program commenced. It could take longer, depending on the longevity of buried marram grass seed. The presence of a viable marram grass seed bank, two rhizome stranding events (2005 and 2008) and the inclement weather have all delayed the completion of the project. This is hardly surprising, given that the Doughboy operation was the first, large-scale operation of its type. In the case of Oakura, the dynamics of this sediment-starved beach are having a significant effect on the stability and longevity of the reconstructed foredune, and a lack of weed maintenance and planting of intermediate species by the Council authorities has resulted in a decline in the natural ecological value of the foredune.

These three studies demonstrate the need for conservation managers to adopt a long-term management perspective, the great importance and role of monitoring, and action following monitoring. The MEP on Stewart Island will be achieved

when all marram plants are destroyed and the marram seed bank is exhausted. Thereafter, the DoC will need to undertake ongoing surveillance, involving annual visits to the site and systematic searches for marram, including marine-dispersed rhizome from the mainland. In this regard, the MEP will be on-going, although the costs of these operations will be lower than at present.

Acknowledgments The research and work conducted at the Oakura and East End Beach sites in the Taranaki Region was conducted while the first author was acting as a consultant and director of Coastal and Environmental Services. Thanks to Lachlan Grant, who assisted Hesp with the consulting, and Grant Porteous, Director of Parks, and Ken Shischka of the New Plymouth District Council for their assistance and support. The research of Hilton and students on Stewart Island, Rakiura National Park is supported by the Department of Conservation. Particular thanks to Brent Beaven, Biodiversity Manager, and Al Check, Ranger-Biodiversity, Rakiura National Park; and the DoC Southland Conservancy "Dune Restoration Advisory Group" (DRAG) for invaluable support. Thanks to Marisa Martinez, Juan B. Gallego-Fernandez, and anonymous referees for their fine critiques.

References

Aptekar R, Rejmánek M (2000) The effect of sea-water submergence on rhizome bud viability of the introduced Ammophila arenaria and the native Leymus mollis in California. J Coast Conserv 6:107–111

Batanouny KH (1999) The mediterranean coastal dunes in Egypt: an endangered landscape. Estuarine Coastal Shelf Sci 49(Suppl 1):3–9

Bergin DO, Ede FJ, Kimberley MO, Davidson T, Jamieson P (2000) Establishment of indigenous sand binders on a reshaped foredune, Oakura Beach, New Plymouth. Unpublished report, Forest Research, Rotorua, New Zealand, p 19

Carlton JT (1989) Man's role in changing the face of the ocean: biological invasions and implications for conservation of near-shore environments. Conserv Biol 3:265–273

Carter R, Hesp P, Nordstrom K (1990) Erosional landforms in coastal dunes. In: Nordstrom K, Psuty N, Carter R (eds) Coastal dunes: form and process. John Wiley & Sons Ltd, Chichester, pp 217–250

Cooper WS (1958) Coastal sand dunes of Oregon and Washington (Memoir 72). Geological Society of America, Boulder, Colorado, p 85

El Banna ME and Frihy OE (2009) Human-induced changes in the geomorphology of the northeastern coast of the Nile delta, Egypt. Geomorphology 107(1–2):72–78

Eppinga MB, Rietkerk M, Dekker SC, De Ruiter PC (2006) Accumulation of local pathogens: a new hypothesis to explain exotic plant invasions. Oikos 114(1):168–176

Ferreira O, Dias JMA (1992) Dune erosion and shoreline retreat between Aveiro and Cape Mondego (Portugal). Prediction of future evolution. Proceedings of the international coastal conference, Kiel, pp 187–200

Gallego-Fernández JB, Sánchez IA, Ley C (2010) Restoration of isolated and small coastal sand dunes on the rocky coast of northern Spain. Ecol Eng 37(2011):1822–1832

Gomez-Pina G, Munoz-Perez JJ, Ramirez JL, Ley C (2002) Sand dune management problems and techniques, Spain. J Coast Res SI 36:325–332

Hart A, Hilton MJ, Wakes S, Dickinson K (2012) The impact of Ammophila foredune development on downwind aerodynamics and parabolic dune development. J Coastal Res 28(1):112–122

Hertling UM, Lubke RA (2000) Assessing the potential for biological invasion—the case of Ammophila arenaria in South Africa. S Afr J Sci 96:520–527

Hesp PA (1989) A review of biological and geomorphological processes involved in the initiation and development of incipient foredunes. In: Gimmingham CH, Ritchie W, Willetts BB, Willis AJ (eds) Coastal sand dunes, Proceedings of the royal society of Edinburgh, 96B:181–202

Hesp PA (2002) Foredunes and blowouts: initiation, geomorphology and dynamics. Geomorphology 48:245–268

Hilton M, Macauley U and Henderson R (2000) The New Zealand Active Duneland Inventory.Department of Conservation. Wellington, New Zealand, p 152

Hilton MJ (2006) The loss of New Zealand's active dunes and the spread of marram grass (Ammophila arenaria). NZ Geogr 62:105–121

Hilton MJ, Konlechner TM (2010) A review of the marram grass eradication program (1999–2009), Stewart Island, New Zealand. Proceedings, the New Zealand plant protection society inc. and the council of Australasian weed societies Inc.—17th Australasian weeds conference, 26–30 September 2010, Christchurch, New Zealand, pp 386–389

Hilton MJ, Konlechner T (2011) Incipient foredunes developed from marine-dispersed rhizome of Ammophila arenaria. J Coast Res SI 64:288–292

Hilton MJ, Duncan M, Jul A (2005) Processes of Ammophila arenaria (marram grass) invasion and indigenous species displacement. Stewart Island, New Zealand. J Coast Res 21(1): 175–185

Hilton MJ, Harvey N, Hart A, James K, Arbuckle C (2006) The impact of exotic dune-grasses on foredune development in Australia and New Zealand: a case study of Ammophila arenaria and Thinopyrum junceiforme. Aust Geogr 37:313–335

Hilton MJ, Woodley D, Sweeney C, Konlechner T (2009) The development of a prograded foredune barrier following Ammophila arenaria eradication, Doughboy Bay, Stewart Island. J Coast Res SI 56:317–321

Huiskes AHL (1979) Biological Flora of the British Isles. Ammophila arenaria (L.) Link (Psamma arenaria (L.) Roem. et Schult.; Calamagrostis arenaria (L.) Roth). J Ecol 67:363–382

Johnson PN (1992) 'The sand dune and beach vegetation inventory. II. South Island and Stewart Island'. DSIR land resources scientific report no. 16, Christchurch

Jul A (1998) Marram grass (Ammophila arenaria) invasion of Mason Bay, Stewart Island. Diploma of Wildlife thesis, University of Otago, Dunedin New Zealand, p 80

Kirkpatrick JB (2001) Ecotourism, local and indigenous people, and the conservation of the Tasmanian Wilderness World Heritage area. J Royal Soc N Z 31(4):819–829

Konlechner TM, Hilton MJ (2009) The potential for marine dispersal of Ammophila arenaria (marram grass) rhizome. J Coast Res SI 56:434–437

Konlechner TM, Hilton MJ (2010) An examination of the seed bank of Ammophila arenaria (marram grass). The New Zealand plant protection society inc. and the council of Australasian weed societies inc.—17th Australasian weeds conference, 26–30 Sept 2010, Christchurch, New Zealand, pp 390–393

McKelvey P (1999) Sand forests. Canterbury University Press, New Zealand, p 168

Marchante H, Marchante E, Freitas H (2003) Invasion of the Portuguese dune ecosystems by the invasive species Acacia longifolia Andrews Willd: effects at the community level. In: Child LE, Brock JH, Brundu G, Prach K, Pysek P, Wade PM, Williamson M (eds) Plant invasions: ecological threats and management solutions. Backhuys Publications, Leiden, Netherlands, pp 75–85

Milton SJ (2004) Grasses as invasive alien plants in South Africa. S Afr J Sci 100:69–75

Muasya AM, de Lange PJ (2010) Ficinia spiralis (Cyperaceae) a new genus and combination for Desmoschoenus spiralis. NZ J Bot 48:31–39

Nordstrom KF (2004) Beaches and dunes of developed coasts. Cambridge University Press, Cambridge, p 356

Nordstrom KF (2008) Beach and dune restoration. Cambridge University Press, Cambridge, p 187

Nordstrom KF, Arens SM (1998) The role of human actions in evolution and management of foredunes in The Netherlands and New Jersey, USA. J Coast Conserv 4:169–180

Pickart A (1997) Control of European beachgrass (Ammophila arenaria) on the west coast of North America. In: Kelly M, Wagner E, Warner P (eds) Proceedings of the California exotic pest plant council symposium, vol. 3, pp 82–90

Pickart AJ (2012) Dune restoration over two decades at the Lanphere and Ma-le'l Dunes in 543 Northern California. In: Martínez ML, Gallego-Fernández JB, Hesp PA (eds) Restoration of 544 coastal dunes. Springer, Berlin. Chap. 10

Rakodi C, Treloar D (1997) Urban development and coastal zone management: an international review. Third World Plan Rev 19(4):401–418

Seeliger U (2003) Response of Southern Brazilian coastal foredunes to natural and human-induced disturbance. J Coast Res SI 35:51–55

Soreng RJ, Gillespie LJ, Jacobs SWL (2009) Saxipoa and Sylvipoa—two new genera and a new classification for Australian Poa (Poaceae: Poinae). Aust Syst Bot 22:401–412

Vega LE, Bellagamba PJ, Fitzgerald LA (2000) Long-term effects of anthropogenic habitat disturbance on a lizard assemblage inhabiting coastal dunes in Argentina. Can J Zool 78:1653–1660

Veloso-Gomes F, Taveira-Pinto F (1995) Portuguese urban waterfronts expansion near coastal areas. In: Reis Machado J, Ahern J (eds) Environmental challenges in an expanding Urban world and the role of emerging information technologies conference, Lisbon, Portugal

Wiedemann AM, Pickart AJ (2004) Temperate zone coastal dunes. In: Martinez ML, Psuty NP (eds) Coastal dunes ecology and conservation. Springer, Heidelberg, pp 53–66

Woodley D, Hilton MJ (2003) A model of Ammophila arenaria necrosis, decay and sedimentation following herbicide application. Proceedings, coasts & ports conference, Auckland