COASTAL DUNE VEGETATION NETWORK

PERFORMANCE OF INDIGENOUS SAND-BINDERS PLANTED ON A RESHAPED FOREDUNE AT OAKURA BEACH, NEW PLYMOUTH

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A project jointly funded by the New Plymouth District Council, the New Zealand Foundation for Research, Science and Technology, and the Coastal Dune Vegetation Network, in collaboration with the local Oakura Beach community.

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ABSTRACT

A planting trial of indigenous sand-binders was undertaken on a reshaped section of foredune, Oakura Beach, south-west of New Plymouth in mid-2000. The aim was to determine whether mechanical recontouring of the existing sand dune and then replanting with indigenous sand-binders was sufficient to stabilise the dunes and protect the scenic reserve behind the foredune. The planting trial was a collaborative effort involving the New Plymouth District Council, Oakura Coast Care Group, Taranaki Regional Council and Ensis (formerly Forest Research). The trial was one of a series, partially funded by the Coastal Dune Vegetation Network, that were established at several exposed sites prone to significant erosion or large scale movement of sand.

The scarp at the Oakura Beach trial site was reshaped to a natural slope of approximately 15° and planted with spinifex (*Spinifex sericeus*) together with small numbers of pingao (*Desmoschoenus spiralis*) and sand carex (*Carex pumila*). Within 6 months of planting a dense sward of indigenous sand-binders had established and was beginning to trap wind-blown sand. Planting at 50 cm spacing gave quicker cover than planting at 70 cm spacing but 12 months after planting there was no difference in vegetation cover between the two initial plant spacings. Application of two different formulations of slow-release NPK fertiliser applied at planting gave similar results, and along with a light post-planting dressing of fast-release high-nitrogen fertiliser, contributed to the early growth and vigour of the sand-binders.

The Oakura Beach trial successfully maintained a dense cover of indigenous sand-binders over the first two years. Over the next three years, a significant loss of sand from the beach from low to high tide level contributed to severe erosion of the foredune and the formation of a steep tall scarp. This cycle of severe coastal erosion was also evident along other parts of Oakura Beach beyond where the reshaping and planting treatments had been applied. This indicated that recontouring of the dune and planting with indigenous sand-binders did not contribute to, or exacerbate erosion of the foredune.

Based on the results of the initial success of the Oakura Beach trial, the New Plymouth District Council has implemented an ongoing reshaping and planting programme along the northern suburbs of New Plymouth over the last four years. In contrast to Oakura Beach, the Each End and Fitzroy Beaches have had sufficient sand moving onshore for newly established sand-binders to begin the process of natural dune building. While at an early stage, this approach of returning beaches to a more natural shape and function by reshaping and planting with indigenous sand-binders, has obviated the need to continue the substantially more expensive option of armouring the beaches of New Plymouth with rocks, which severely compromises natural character, biodiversity and amenity values.

KEYWORDS: sand dunes, spinifex, pingao, reshaping, planting, erosion

INTRODUCTION

Erosion of the beach reserve by high seas during occasional storms was of increasing concern to the local community and the New Plymouth District Council (NPDC). The issues were highlighted at the second annual Coastal Dune Vegetation Network (CDVN) conference, held at New Plymouth in March 1999 (Steward and Ede 1999), leading to the view that the highly modified erosion scarp required reshaping and the establishment of a foredune zone of indigenous sand-binders. A collaborative trial was established at Oakura Beach, 15 km south of New Plymouth in mid-2000 by the local Coast Care group, NPDC, and Forest Research (now Ensis). The trial involved mechanically reshaping the foredune to a more natural angle and shape and revegetating it with indigenous sand-binding species, principally spinifex (*Spinifex sericeus*), but also some pingao (*Desmoschoenus spiralis*).

This report covers the establishment and early performance of the reshaping and planting trial at Oakura Beach including detailed monitoring over the 12 months after establishment and inspections of the site over the following five years. Observations on the subsequent implementation by the NPDC of reshaping and planting sand-binders on an operational scale on other beaches in the New Plymouth area, specifically East End and Fitzroy Beaches, are included. Recommendations for restoration of significantly modified foredunes along high energy coasts by mechanical reshaping, and establishment and management of indigenous sand-binders, are presented.

BACKGROUND

Foredunes and vegetation cover play an important role in beach dynamics, particularly in the natural cycles of dune erosion and recovery (Dahm *et al*. 2005). However, natural dune repair after storms is critically dependent on the presence of appropriate sand-trapping vegetation on the seaward face of the dune. In New Zealand, the key indigenous sand-binding species are spinifex and pingao (Bergin and Herbert 1998; Bergin 1999). While many exotic species such as marram grass (*Ammophila arenaria*), ice plant (*Carpobrotus edulis*) and kikuyu grass (*Pennisetum clandestinum*) have been used to stabilise dunes, these are not as effective as spinifex and pingao in repairing storm-damaged frontal dunes. In the absence of human disturbance, most natural foredunes in New Zealand are self-maintaining, but without a good cover of spinifex and pingao on the seaward dune face, natural dune repair between storms tends to be very limited (Dahm *et al*. 2005).

Human modification of coastal dunes over more than a century has been well documented and is common throughout New Zealand. It has often lead to major changes in dune morphology, vegetation and natural coastal processes (Dahm *et al*. 2005). In the late 1800s and early 1900s removal of the original dune vegetation leading to wind erosion was widespread on dunes in many regions of New Zealand including the west coast of the North Island. Since then human activities have continued to contribute to dune damage. These activities include stock grazing, uncontrolled vehicle use, high pressure from beach users, browsing by introduced feral mammals, displacement by exotic plant species, inappropriate development too close to the coast often leading to severe modification of dunes by levelling, capping with fill and grassing, and exploitation such as sand extraction. All of these have contributed to reduction or even elimination of key indigenous sand-binding species and loss of dune form and function.

The Oakura Beach is a typical example of a highly modified dune system with various layers of clay, soil and concrete rubble dumped, probably over many years, on the dune to provide a flattened reserve area. A steep erosion scarp up to 3 m high occurs at high water mark due to erosion of this modified dune by wave action. The vegetation, dominated by exotic species that are not good at sand-binding, together with the levelled cap of fill, contributed to formation of the steep scarp that is vulnerable to further erosion by storm waves.

PREVIOUS WORK

During the 1990s, coastal sand dune revegetation work in the North Island using indigenous species was focussed on east coast areas, particularly on the Coromandel and Bay of Plenty coasts (e.g. Environment Waikato 2001; Jenks and O'Neill 2004). Many of these east coast sites, while modified, usually have some of the indigenous sand-binders, principally spinifex and pingao, present on the foredune. Community-based restoration programmes, often involving planting and successful implementation of various initiatives, such as providing formal accessways in heavy-use areas and reducing rabbit populations, have lead to significant improvement in foredune form and function. Research over the last 10-15 years has provided support for these community and management agency programmes, (e.g. Bergin and Kimberley 1999).

While trials and operational programmes mainly on east coast North Island sites have provided some basic information on restoration of foredunes, there are problems directly applying the same principles to revegetation projects where physical factors such as wind and wave erosion, and storm events have a much greater impact on the coastal ecosystem, such as along most of the west coast of the North Island and the east coast of the South Island. In addition, some of these highly dynamic sites have severely modified and sometimes large dunes where reinstatement of natural dune function using indigenous sand-binding species is more difficult. Despite these challenges, there have been some previous small-scale successful revegetation programmes on west coast North Island sites such as the planting of spinifex at Port Waikato (Spence 1999) and at the Waiwhakaiho River mouth, north of New Plymouth (Slater *et al*. 1999).

Several trials, jointly funded by the New Zealand Foundation for Research, Science and Technology (FRST) Sand Dune Revegetation Programme and the CDVN, were established at sites where the primary driver of dune instability was the physical environment (Ede *et al.* 2000). In addition to the Oakura Beach trial established in 2000, trials were established at similarly exposed sites including Santoft Beach (Manawatu), Te Henga (Bethells Beach, Auckland), and New Brighton Beach (Christchurch) over the following two to three years. While each site comprised different dune systems and types of modification, trials at each site were designed to provide information that contained some common treatments so that results could be extrapolated to other, similarly exposed or difficult dune sites around the country and used to provide guidelines on dune restoration for local managers.

DESCRIPTION OF TRIAL AREA

The trial was located immediately south of the motor camp at Oakura Beach, 15 km south-west of New Plymouth, Taranaki (Fig. 1). This part of the coast is a moderate to high energy coastal system which has a limited sand supply (Hesp and Grant 2000). The beach comprises a wide, rocky, predominantly sub-tidal reef, thinly overlain by sand in the surf zone. The intertidal beach is relatively narrow at high tide and has a low sediment volume.

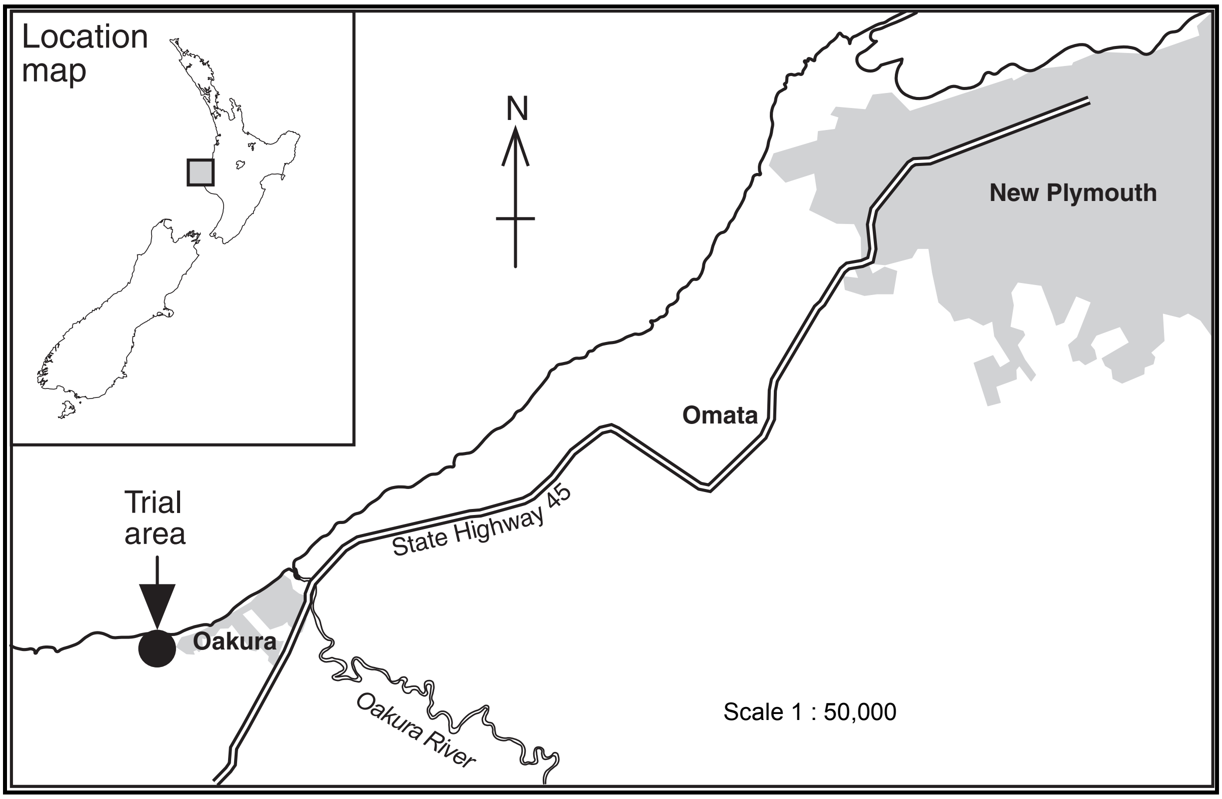

Figure 1: Location of the reshaping and planting foredune trial, Oakura Beach, New Plymouth.

The trial area was sited within a highly modified foredune reserve which is part of a recreation area popular with local residents and visitors. The foredune had been flattened, used as a dumping site for fill at various times, and had been overlain with soil to create a largely grassed site up to 40 m wide. At high water mark, an erosion scarp had formed along the entire length of the beach varying in height from approximately 2 m high at the northern end to 1 m high at the southern end. The landward margin of the reserve is an old sea cliff up to 50 m high covered in dense, mostly indigenous, shrub and tree vegetation.

When the trial was established in mid-2000, the reserve was dominated by mown exotic kikuyu grass with scattered trees and shrubs as individuals or in small groves (Fig. 2). Kikuyu grass occurred over the scarp face amongst occasional patches of ice plant. Layers of clay and topsoil from previous capping operations were visible along the length of the foredune scarp. Loose sand had accumulated on top of capped layers from dry sand blow from the beach at low tides. This implied that at times mobile sand was available for the establishment of a more naturally functioning dune on which indigenous sand-binders could help to trap sand along the foredune and build up a more effective barrier to erosion during future storm events.

Several pohutukawa (*Metrosideros excelsa*) trees from 2-8 m high and several large harakeke (*Phormium tenax*) were present within the 10 m wide seaward zone of the reserve to be reshaped and were vulnerable to erosion. As the reserve was narrow, there was public concern that the recontouring process along the frontal dune area would remove a significant part of the recreational area.

Figure 2: The trial site at Oakura Beach before reshaping and planting with indigenous sand-binders. The narrow dune which had been highly modified by dumping of fill and levelling was dominated by exotic kikuyu and patches of ice plant. With the loss of natural dune form and function, a steep erosion scarp had formed along the length of the beach and with each storm the coast was retreating landward. Sand overtopping previous layers of fill suggest that there were times when there was some sand movement inland and scope for a natural dune function to be restored.

OBJECTIVES

The overall objective was to determine whether a highly modified foredune dominated by exotic plant species and with a steep erosion scarp could be restored by mechanical reshaping to a more natural foredune profile and planting with indigenous sand-binding species. Specific objectives of the trial were:

- To mechanically reshape the degraded foredune by removing fill, topsoil and existing exotic vegetation and create a more natural dune profile for the planting of indigenous sand-binding plants;
- To compare performance of planted nursery-raised indigenous sand-binders – spinifex raised from cuttings, spinifex raised from seed and pingao seedlings;
- To compare two formulations of slow release NPK fertilisers applied at planting – Agpro™ tablets and Plantacote Pluss™ granules;
- To compare two plant spacings for the indigenous sand-binders – initially planned at 40 cm and 60 cm spacing, but changed to 50 cm and 70 cm spacing;
- To monitor performance of planted vegetation cover and sand movement over the reshaped dune site.

METHODS

RESHAPING THE FOREDUNE

Surveying and planning

Reshaping of the degraded dune at Oakura Beach aimed to achieve a slope for the seaward face in the range of 11-18° to approximate natural (unmodified or non-scarped) foredune stoss (seaward face) slopes in the region (Fig. 3). However, Hesp and Grant (2000) listed several significant factors which limited dune reshaping at Oakura Beach. These were:

- Only limited space was available in which to reshape a foredune (approximately 10 m wide) as the local community were keen to retain a reasonable width of grassed reserve on the backdune;
- The seaward toe of the reshaped foredune could not be extended further seaward than the toe of the present scarp. Any seaward extension would be highly vulnerable to erosion during the next storm or spring high tide;
- The existing foredune was relatively low (5-7 m in height). Ideally reshaping to a greater height would be preferable to allow for and mitigate against storm erosion and potential storm overwash;
- The existing foredune contained fill material, some of which would not be desirable for use in reshaping, but its removal would reduce the volume of material for dune reshaping;
- Local residents and beach users wanted to retain views of the beach from the reserve where possible.

A strip 180 m long and 10 m wide was demarcated for the location of the trial in consultation with the local Coast Care Group. Before reshaping, five topographical profiles, surveyed by Bland and Howarth Surveyors, were used to create reshaped dune profiles, to determine, from the approximate existing volumes of sediment, the quantity required for a reshaped dune and the deficit or surplus of sediment available (Hesp and Grant 2000). The profiles aimed for a stoss slope of approximately 18° (1:3) and lee slope of around 20°. The approximate volumes of sediment (per metre along the shore of the dune) to be excavated and deposited were calculated and used for deciding where material was to be relocated during the reshaping.

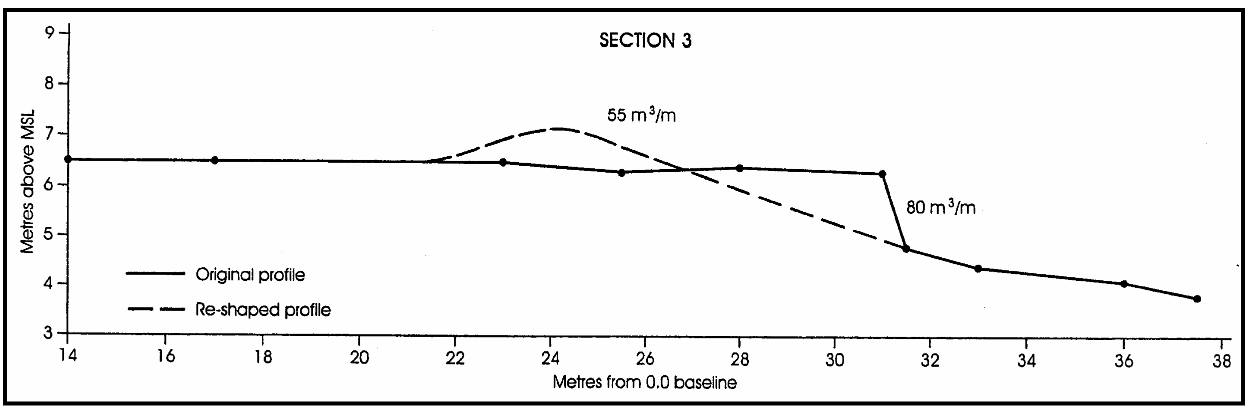

Figure 3: The aim with reshaping the dune at Oakura Beach was to change the original steep foredune profile to an approximately 18° slope extending 10 m wide on which a dense cover of native sand-binding species could be established (from Hesp and Grant 2000).

As there was an excess of sediment available at the eastern section of the area and a deficit in the western area, they recommended that some sediment from the eastern end be transported to the western end. Sourcing additional sand to make up any shortfall was to be considered if these estimated volumes available were not sufficient to produce a desirable dune profile.

Site Preparation
The exotic grass cover which was mainly kikuyu was sprayed three times over almost a four month period with glyphosate herbicide by a private spraying contractor using a pressurised gun sprayer. The spraying treatment was effective in killing the kikuyu grass and patches of ice plant (Fig.4).

Several large harakeke and small to medium-size pohutukawa trees were successfully removed from the edge of the erosion scarp to positions 20-25 m further inland of the shoreline immediately before dune reshaping commenced (Fig. 5). They were removed using a tracked excavator by digging around the root system with a narrow bucket and grasping the trees with the aid of a hydraulic arm and a chain for larger trees and moving a short distance to a hole dug in the backdune. The largest pohutukawa (pictured) was over 7 m high and when excavated was estimated at over 3 tonnes in weight. Once the trees were transplanted, local residents assisted in watering each plant. The removal of up to 10 pohutukawa and harakeke took less than half a day with the excavator.

Figure 4: Spraying of the kikuyu-dominated erosion scarp and seaward part of the reserve with glyphosate herbicide proved effective in reducing regrowth from plant fragments. One small patch of marram grass should have been sprayed with Gallant™ to prevent subsequent invasion of a small area of the trial after indigenous sand-binders were planted.

Figure 5: Pohutukawa **(above)** ***and harakeke*** **(below)** ***that had been planted on the coastal reserve, but were growing on the edge of the scarp due to landward coastal erosion, were successfully transplanted to inland positions before dune reshaping.***

Reshaping Procedure
The 180 m section of dune was reshaped under the supervision of Lachlan Grant (Gourdie Consulting) during the week of 10-14 July 2000 using a 13 tonne Komatsu tracked excavator. Exploratory excavation at a couple of sites indicated that while there were layers of subsoil, there were no major deposits of solid material. Where practical, compacted subsoil layers were removed and placed along the most landward edge of the reshaped dune before being covered in loose sand. At least one layer of subsoil approximately 20 cm deep that had been spread over the original dune some years ago was up to a metre below the surface. It was decided that it would have been too time consuming to remove this from the dune profile so it was mixed in with the sand as dune reshaping progressed.

The first step in reshaping the dune involved removing the top layer of dead vegetation and topsoil along a 5 m wide strip immediately landward of the dune scarp and placing it toward the back of the approximately 10 m wide zone where the crest of the dune was to be formed. Some of the compacted fill layers were also removed from the seaward edge of the foredune and placed along the landward margin of the reshaping area. Sand was then moved from just above high water mark and placed about 7-12 m from the high water mark to form a bund (Fig. 6).

Based on sand volume calculations by Hesp & Grant (2000), surplus sand was shifted, using a heavy tractor and trailer, from the eastern to the western end of the reshaped part of the dune where there was insufficient sand to form a new dune (Fig. 7).

The reshaped foredune was formed to give a 15° slope forming an even grade from the high water mark up to the crest of the dune approximately 9 m landward. Finally, the dune was levelled smooth for planting by using an excavator to drag a heavy metal levelling bar over the surface (Fig. 8). Reshaping the 180 m long dune, of which the trial would occupy approximately 140 m, took approximately 3 days to complete.

Protection
A fence was constructed around the entire reshaped dune to discourage people from trampling over it. Along the landward margin of the dune at the base of the bund the fence was substantial, being several wires, windbreak cloth and battens. The other fences consisted of posts at wide intervals and two wires. Signs were erected with details on the dune reshaping and planting trial.

Maintenance
Continuing weed control included using a knapsack sprayer with a coarse nozzle to spray kikuyu grass along the landward margin during calm conditions, to prevent re-invasion of the site from the grassed reserve.

One application of urea fertiliser at the rate of 50 kg N/ha was applied in October 2000.

Regular inspections were carried out by the local Coast Care Group and NPDC staff to identify fence and signage maintenance requirements.

Figure 6: Sand was taken from near high water mark and moved landward. Where practical, consolidated layers of clay or other compacted fill were placed towards the back of the dune.

Figure 7: Sand was shifted from the eastern end of the trial site where there was a surplus to the western end to make up for a deficit of material required to form a reshaped dune.

Figure 8: The final stage of mechanical reshaping involved smoothing off the dune to a 15° slope for the planting of sand-binders. Care was taken to ensure the toe of the newly reshaped foredune did not extend beyond the position of high water mark before reshaping.

Monitoring sand movement

Changes in sand levels were monitored in relation to vegetation cover using transects across the dune profile and plot pegs set at known heights throughout the trial area.

The trial extended over four of the original five profiles, and location of each of the four permanent transects is shown in Figure 9. These were surveyed before (April 2000) and after (August 2000) reshaping. Subsequent surveys were carried out in February and June 2003 and again in October 2004. Profile diagrams extending from below mean sea level to inland of the reshaped dune were produced for each survey transect.

One-metre-long treated wooden pegs were driven into the sand to fixed heights throughout the trial plots to monitor localised sand movement. All plot boundary pegs (50 x 50 mm) as well as the eight numbered row pegs (50 x 25 mm) per plot along the baseline on the crest of the dune, were inserted to 30 cm above ground. Two further pegs (50 x 50 mm) were placed in each plot, one in the centre (40 cm above ground) and the other at high tide mark (30 cm above ground). All peg locations are marked on Figure 9. Peg heights were measured to determine changes in sand movement 6 and 12 months after planting.

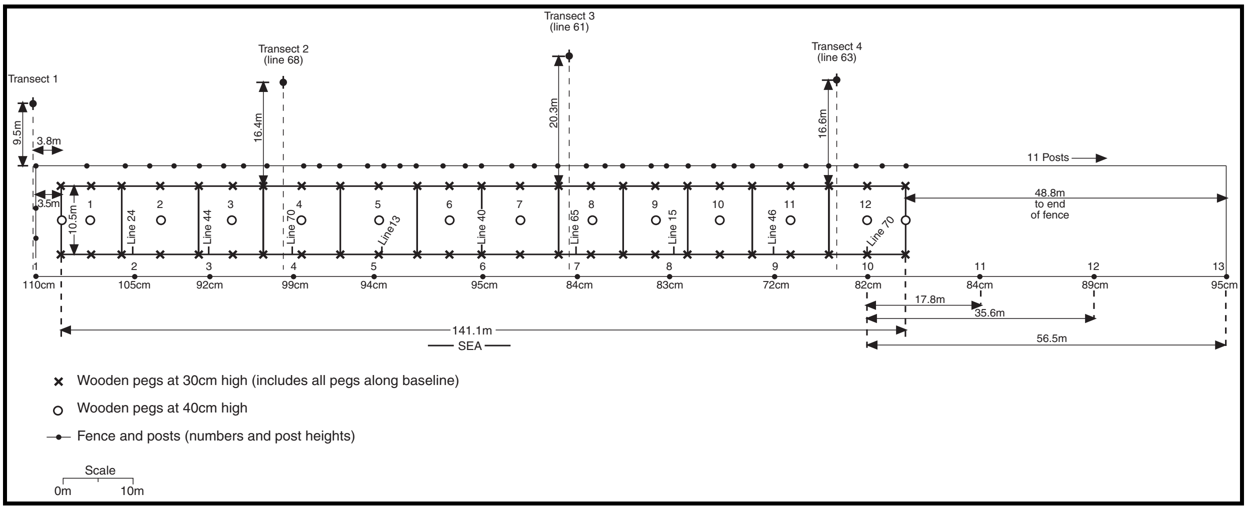

Figure 9: Location of transects and pegs for monitoring changes in sand level on a reshaped foredune, Oakura Beach, New Plymouth.

PLANTING TRIAL

Planting trial design

Three major factors were tested in the trial:

1. Types of plant material:
   - Spinifex plants raised from seed
   - Spinifex plants raised from cuttings
   - Pingao plants raised from seed
2. Types of slow-release NPK fertilisers applied at planting:
   - Agpro™ tablets (2 tablets per plant)
   - Plantacote Pluss™ (30 g per plant).
3. Plant spacings:
   - 50 cm
   - 70 cm.

Plant material

The sources of stock, method of raising, container type and condition of plants at planting were as follows:

- ***Spinifex raised from seed*** – Seed was sourced from several local beaches, at Waiwhakaiho, Timaru Road, Oakura and Tapaue coastal areas, collected in February 1999 and raised at Naturally Native NZ Plants Ltd Nursery, Whakatane; plants were raised from sorted seed pricked individually into containers according to guidelines given in Bergin (2000); the 12-month-old seedlings were raised in Tinus™ rootrainers; plants were in good condition and most had adequate binding of potting mix during planting.
- ***Spinifex raised from cuttings*** – Runners were sourced from a local beach at Waiwhakaiho in December 1999; each plant was raised from a short section of runner at the Parkscape Nursery; the 9-month-old plants were raised in Tinus™ rootrainers; plants were tall but some losses occurred due to poor rooting and only partial binding of potting mix during planting.
- ***Pingao*** – Seed was sourced from Bell Block Beach north of New Plymouth and grown at Parkscape Nursery; seedlings were 12 months old at planting, raised in PB ¾ polythene planter bags; plants were small but vigorous with root systems only partially holding potting mix together; some disturbance to the root ball during planting was unavoidable.

- ***Sand carex*** – A small number of these were raised in PB ¾ polythene planter bags; plants were in good condition at planting and ranged in height from 12-25 cm.

Plants were established using techniques described by Bergin and Herbert (1998) for pingao and Bergin (2000) for spinifex. All planting was carried out so that the top of the container potting mix on the plant roots was at least 5 cm below sand level to improve chances of survival if sand levels lowered during the establishment phase.

Fertiliser

Details for the two slow-release fertiliser formulations incorporated into the planting pit are given in Table 1. Nitrogen, which is considered the element most likely to be limiting on sand dunes, was present in similar levels, at 12-14%, in the two fertiliser types. To ensure the correct amount of fertiliser is applied to each plant, tablets would be expected to have advantages over measuring out a small container of granules, where there is scope to vary the dose. However there was variation in size of Agpro™ tablets supplied for the trial, with many tablets easily breaking up, leaving considerable quantities of fine material in containers, so that extra effort was required to ensure that the appropriate rate was applied to each plant.

Table 1: Label information on formulation and application rate of the slow release fertilisers used at planting for pingao and spinifex, Oakura Beach, New Plymouth.

Fertiliser	Distributor/ Marketer	Nitrogen (N) (%)	Phosphorus (P) (%)	Potassium (K) (%)	Amount applied to each seedling at planting
Agpro™ (tablets)	Agpro NZ Ltd, Auckland	12	8	6	2 x 10 gram tablets
Plantacote Pluss™ (granulated pellets)	Aglukon Spezialdunger GmbH & Co.	14	3.9	12.4	28 g

Each plant received either two tablets of Agpro™ or 30 g of Plantacote Pluss™ granules. The two Agpro™ tablets were placed along the side and near the base of the root ball. Application of the Plantacote Plus™ involved spreading granules of fertiliser evenly around the sides of the root ball near the base of the planting hole. A near full film canister was used to measure 28 g of fertiliser to each plant.

Trial layout

The planting trial, located within the fenced area on the reshaped dune just above high water mark, was 141.1 m long and 10.5 m wide. It comprised three replicates, each of four plots. Different treatment combinations of plant spacing and fertiliser were applied randomly to the plots within each replicate (Table 2; Fig. 10).

The bulk of the trial was planted with spinifex raised from seed. The smaller numbers of spinifex raised from runner cuttings and the pingao seedlings were allocated systematically to each plot in rows from high water mark to backdune. The aim was to establish all plant types across the dune profile to compare performance from seaward to landward parts of the foredune. Within each replicate there were two plots with plants at 70 cm spacing and two plots with plants at 50 cm spacing (Fig. 10).

Table 2: Plant spacing and fertiliser treatments for the replicated indigenous sand-binder planting trial, Oakura Beach, Taranaki.

Plot number	Replicate number	Plant spacing (cm)	Fertiliser type
1	1	50	Agpro™ tablets
2	1	70	Plantacote Pluss™
3	1	50	Plantacote Pluss™
4	1	70	Agpro™ tablets
5	2	70	Plantacote Pluss™
6	2	50	Agpro™ tablets
7	2	70	Agpro™ tablets
8	2	50	Plantacote Pluss™
9	3	50	Plantacote Pluss™
10	3	50	Agpro™ tablets
11	3	70	Plantacote Pluss™
12	3	70	Agpro™ tablets

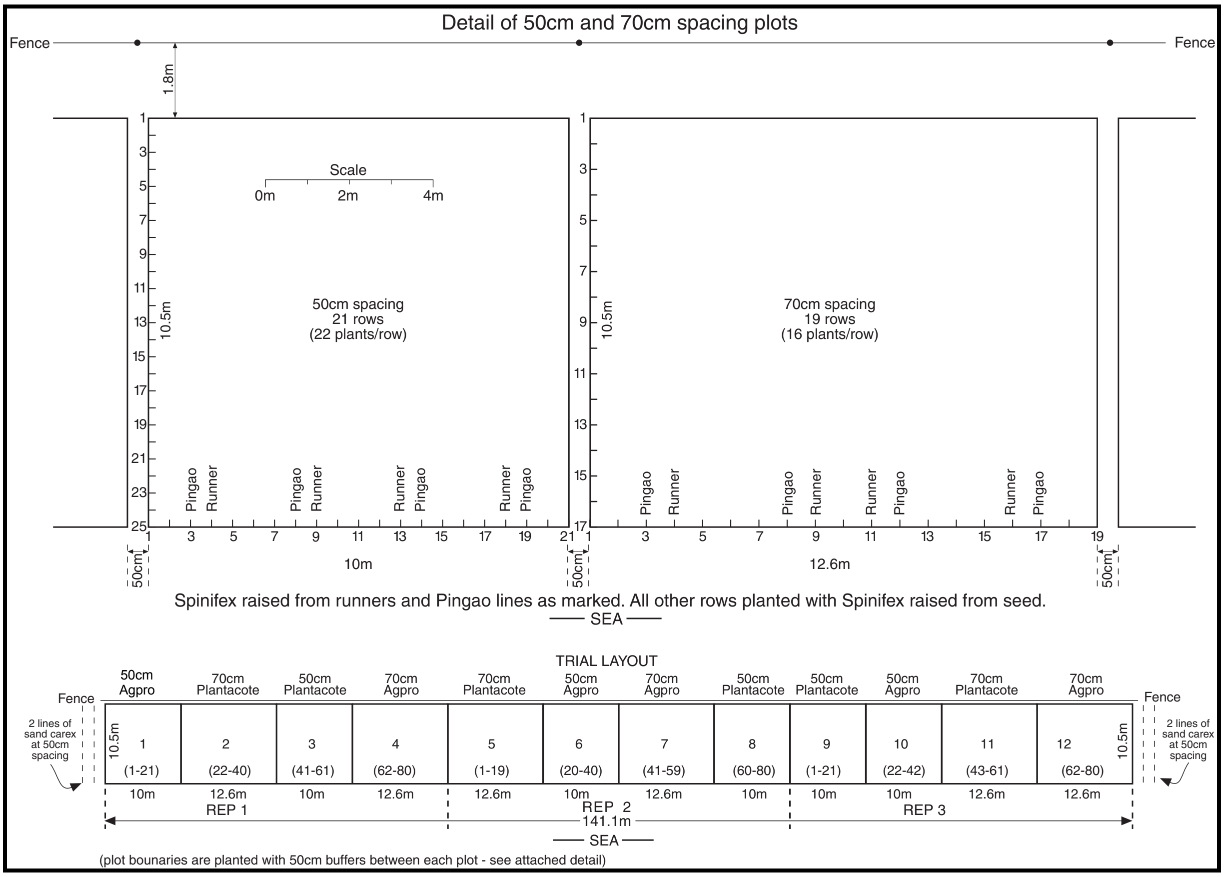

Figure 10: Layout of trial and detail of plots established on a reshaped foredune, Oakura Beach, New Plymouth.

To reduce influence of treatments in adjacent plots, outermost rows of each plot were planted with spinifex raised from seed, as buffers. Two lines of sand carex (*Carex pumila*) were placed at each end of the main trial, with 50 cm spacing between lines and with Plantacote Pluss™ fertiliser applied at planting.

The planting operation

The trial was planted over two days in mid-July 2000 immediately after reshaping was completed, with up to two teams of four persons each (Fig. 11).

Posts in the fence located on the landward side of the reshaped dune were used as permanent markers for each plot, using red-numbered aluminium number tags. A baseline along the crest of the new dune demarcated the landward margin of the trial with 50 x 50 mm treated wooden pegs marking corners of each plot. Wooden pegs 50 x 25 mm, numbered with small aluminium tags, marked the four rows of pingao and four rows of spinifex raised from cuttings in each plot. Unmarked rows were spinifex raised from seed.

Plants were placed using a rigid grid pattern to ensure that the 50 cm and 70 cm spacings were adhered to. Planters followed a taut marked string that was placed from high water mark to the crest of the dune, and was systematically moved along the dune as each line was planted. Detail of the plot layout and pattern of planting of the three types of plant material in each plot is given in Figure 10, with numbers indicating those lines which were marked with pegs. The rigid planting pattern and the occasional 'marker line' of planted pingao assisted reconstruction of plots for future assessments.

Figure 11: Immediately after reshaping was completed the nursery-raised indigenous sand-binders were planted by the local Oakura Coast Care group, the Oakura School community, and staff of NPDC, Taranaki Regional Council and Forest Research (now Ensis).

Monitoring of vegetation cover
The variables assessed included:

- survival
- plant height
- plant spread
- plant vigour and health - a subjective assessment into one of five categories:
  1 - weak – few or no leaves, just alive
  2 - unthrifty – loss of leaves, poor foliage colour and plant vigour
  3 - average – moderate health and vigour
  4 - good – minor browsing or leaf discolouration, otherwise good growth
  5 - robust – healthy plant with good foliage colour and growth

As plant cover increased, other assessments of growth included:

- number and length of runners on spinifex
- occurrence of flowering
- percentage ground cover of vegetation by species

The subjective assessment of plant vigour and health was based on a comparison of plant condition within each plant type. Plant growth assessment was entered onto customised field record forms and measurements later entered into the computer for analysis.

At each inspection, general comments regarding the condition of the trial site and that of the vegetation were recorded. These included such factors as incidence of browsing, disturbance by beach users, wave erosion, weed growth and maintenance requirements such as repairs to fences and, if appropriate, replacement of plants.

An initial assessment was made immediately after planting for height, plant spread and plant vigour. The trial was assessed for survival 3 months (October 2000) and six months (January 2001) after planting. At 6 months plant height and spread was also assessed, by sampling in each plot six rows covering the range of types of plant material, to indicate growth performance.

In addition, photographs were taken to monitor growth of plants and to record progress of vegetation cover.

RESULTS

RESHAPING THE FOREDUNE

Reshaping procedure
Relocation of sand along the beach was satisfactory and additional sand was not required. Following the list of constraints reached from initial investigations (Hesp and Grant 2000), the very limited availability of sediment from other sources, and the potential for storm wave erosion, the reshaped dune was constructed with a stoss slope of about 15°. The planned height of the reconstructed dune along the landward edge at 1-1.5 m above the level of the reserve compromised some of the beach views particularly as a dense sward of spinifex developed. Final height was approximately 80 cm above the reserve level. The lee slope of the bund was steep at approximately 25° and while it would have been desirable to produce a lower angle lee slope, dense planting and fencing ensured a good degree of stability.

All pohutukawa and harakeke that were transplanted from the reshaped seaward zone to more landward sites nearby survived and grew well.

Protection

The substantial post, wire and shadecloth fence along the rear of the dune has effectively prevented beach users from walking through the trial area. The shade cloth has slowed spread of kikuyu from the grassed backdune site. There was only minor build up of sand along the rear fenceline probably due to the dense sward of spinifex seaward trapping most sand. The minimal post and wire fencing along the toe of the dune was also effective in keeping beach users off the trial area.

Maintenance

The shadecloth fence on the landward edge of the replanted dune acted to some degree as a barrier to exotic grasses spreading into the spinifex zone. The spraying treatment was effective in killing the kikuyu grass and patches of ice plant throughout the 10 m wide zone along the top of the foredune and the scattered vegetation on the scarp (Fig. 4). A small patch of marram grass near the centre of the 180 m zone was not killed by the spray programme, and lead to subsequent localised regeneration from plant fragments in part of the trial after planting. Small establishing marram grass plants and other weed species required hand-pulling over the first year before spinifex became dominant. Gallant™ would have been suitable for eradication of the marram grass.

SAND MOVEMENT AND DUNE PROFILES

There were no major changes in the dune profile over the first 6 months after reshaping. Some localised sand movement was evident within some plots, particularly where plants were at the wider spacing of 70 cm. Twelve months after planting sand accumulation along the toe of the dune was up to 15 cm in depth.

At the 18 month assessment, about four months after a late winter storm, a scarp 50-75 cm high was evident along the base of the trial. Sand levels along the seaward fence had dropped by an average of 50 cm and were relatively consistent along the length of the trial area. In contrast, sand levels along the mid slopes increased by up to 10 cm since planting with no significant difference along the landward edge of the dune. There was no significant difference in sand levels between planting treatments.

Profile data taken 3-4 years after reshaping has shown a consistent drop in the level of the beach at Oakura. Profiles and photographs taken at two survey sections are shown and described in Figures 12 and 13 for Section 1, and Figures 14 and 15 for Section 4. All profiles showed a significant drop in beach levels and landward retreat of the foredune.

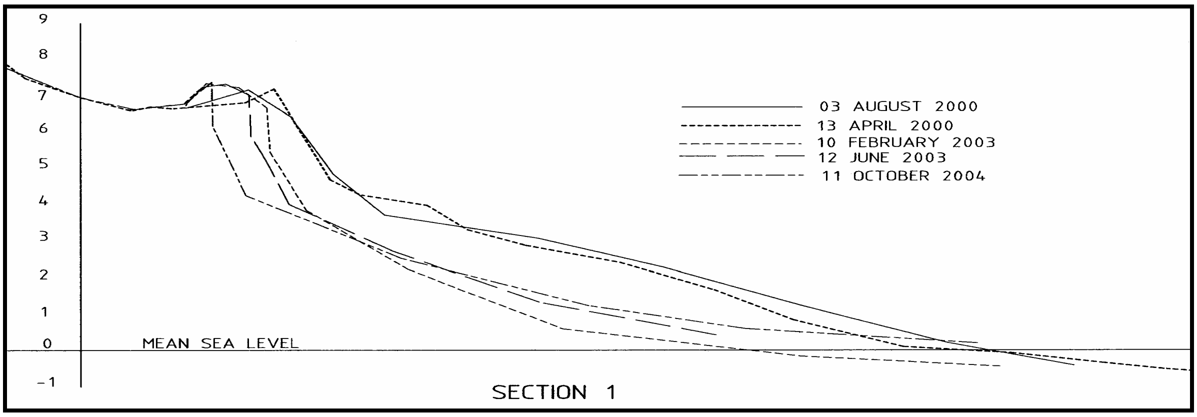

Figure 12: Survey Section 1 located near the western end of the reshaping and planting trial area, Oakura Beach. The dotted line of the profile taken in April 2000 before reshaping shows the steep erosion scarp of the highly modified dune. The continuous line (August 2000) taken immediately after reshaping shows the change to a lower angle foredune slope and rounded bund formed landward. Surveys taken 2-3 years later show significant landward retreat of the foredune forming a steep scarp (see photograph below) and major losses of up to 2 m in depth of sand from the beach above mean sea level.

Figure 13: Foredune scarp at least 3 m high at Survey Section 1 showing a dense vigorous sward of spinifex trailing over the scarp. Despite the severe erosion and lowering of the beach level at this western end of the trial, the dense cover of indigenous sand-binders has taken hold at the toe of the scarp and is beginning to accumulate some sand.

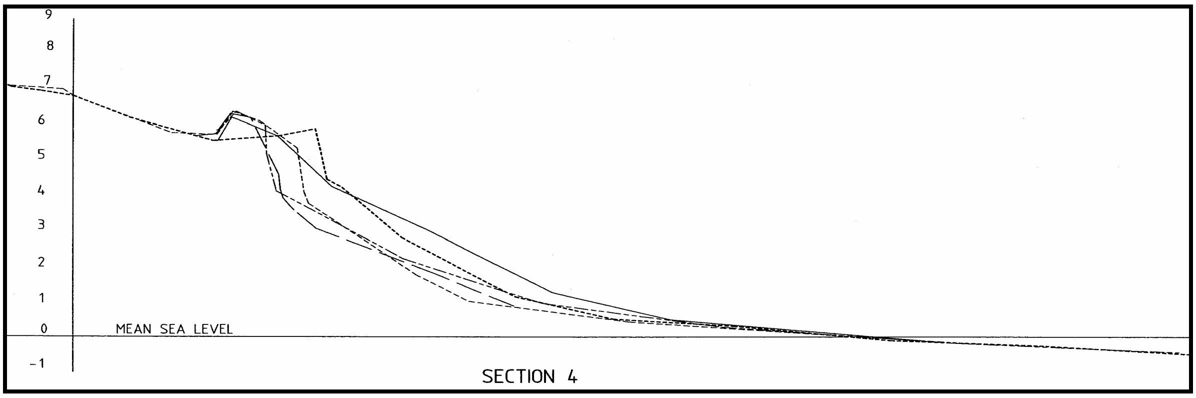

Figure 14: Survey section 4 located near the eastern end of the reshaping and planting trial area, Oakura Beach. The natural reshaped profile (solid line surveyed August 2000) clearly shows the change from the steep foredune scarp before the trial was established (dotted line) and rounded bund formed landward. Surveys taken 2-3 years later show there has been far less sand lost from the beach here than at the western end and although there has been landward retreat of the foredune, this is not as great as at the western end of the trial area.

Figure 15: Foredune scarp up to 2 m high at Survey Section 4 near the eastern end of the trial areas where less sand has been lost from the beach. Although the cut back to the foredune is significant, it has not been as severe as at the western end.

Five years after the dune was reshaped at Oakura, the beach has dropped by up to 3 m and at least 8 m of the foredune has been lost (Fig. 16). The dune has been cut back to the extent that layers of consolidated fill not removed from the dune were uncovered and are now contributing to the formation of a steep erosion scarp (Fig. 17).

Figure 16: The level of the beach has dropped by up to 3m along Oakura Beach where the reshaping trial was established. Consequently, the reshaped foredune has undergone severe erosion. The white stake **(photograph above)** ***marks the toe of the dune after reshaping 5 years earlier indicating at least 8 m of the dune has disappeared. Despite significant erosion, vigorous spinifex trailing over the erosion scarp is beginning to establish along the high water mark and trap wind blow sand as part of the natural dune repair process*** **(below).** ***While reshaping and planting of indigenous sand-binders has not halted landward advance of the coastline, erosion along the trial areas has not been any worse than along adjacent areas of the Oakura Beach that were not reshaped.***

Figure 17: Layers of fill that were not removed during the mechanical reshaping along parts of the landward margin of the dune have now become exposed and graphically show why all compacted material must be removed to ensure appropriate dune function. These compacted layers of clay and soil are preventing the collapse of the dune, forming a relatively solid steep erosion scarp. If only loose sand was present, the erosion scarp would quickly form a gentle slope as sand dried out, allowing the spinifex runners to more effectively begin the natural dune repair process.

Significant coastal erosion landward is not confined to the area of the reshaped dune trial. Foredunes that were not reshaped and left covered in kikuyu, harakeke and other vegetation westward along the beach toward the Oakura town centre have severely eroded. Previous coastal protection defences are collapsing, large blocks of compacted fill are falling away due to undermining by high seas and a steep scarp remains at high tide level (Fig. 18).

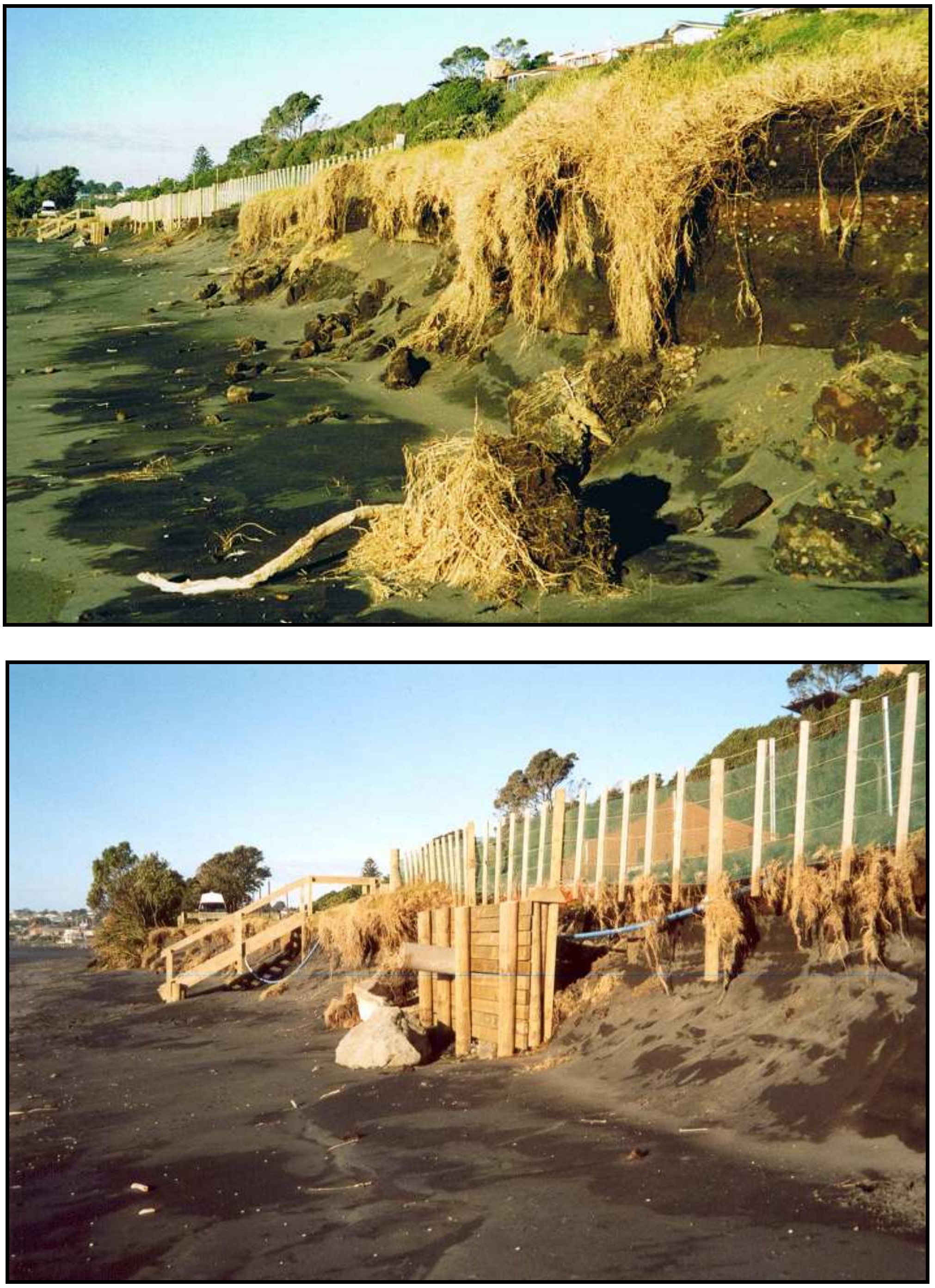

Figure 18: These foredunes at Oakura Beach adjacent to the reshaped and planted trial area have continued to erode significantly as the beach level has dropped. Areas of fill in excess of a metre deep within the dune profile and vegetated in kikuyu grass are forming a steep erosion scarp and with continuing wave erosion falls as blocks on to the beach as the foredune is undercut **(above).** ***Measures to control undercutting*** **(below)** ***require constant maintenance and will only be temporary as they are constantly undermined.***

PERFORMANCE OF PLANTED SAND-BINDERS

Initial assessment
A random selection of 60 plants of each type of plant material was assessed immediately after planting for height, plant spread and plant vigour. The assessment indicated that pingao, although vigorous, were shorter than the spinifex (Table 3). Spinifex raised from cuttings, while they were the tallest, had the poorest vigour of all three plant types.

Table 3: Assessment of the three different plant types immediately after planting on a reshaped dune, Oakura Beach, New Plymouth. Assessments are based on measurements from 60 plants selected at random from each plant type.

Plant material	Height (cm)	Spread* (cm)	Vigour[†]
Pingao	19.7	19.6	3.5
Spinifex from cuttings	27.4	13.6	2.8
Spinifex from seed	26.2	15	3.6

* Plant spread calculated as square root of (length x breadth).
[†] Vigour score: 1 – weak, 2 – unthrifty, 3 – average, 4 – good, 5 – robust.

Survival
Overall survival 3 months after planting was 80% and after 6 months was 70% (Table 4). At six months, survival across all treatments was 79% for spinifex raised from seed, 66% for spinifex raised from cuttings and only 48% for pingao seedlings (Fig. 19). The small size of the pingao seedlings planted is likely to be a factor in the relatively high mortality of this species. Conversely, the high quality of spinifex plants raised from seed is likely to have contributed to good survival with this type of plant material.

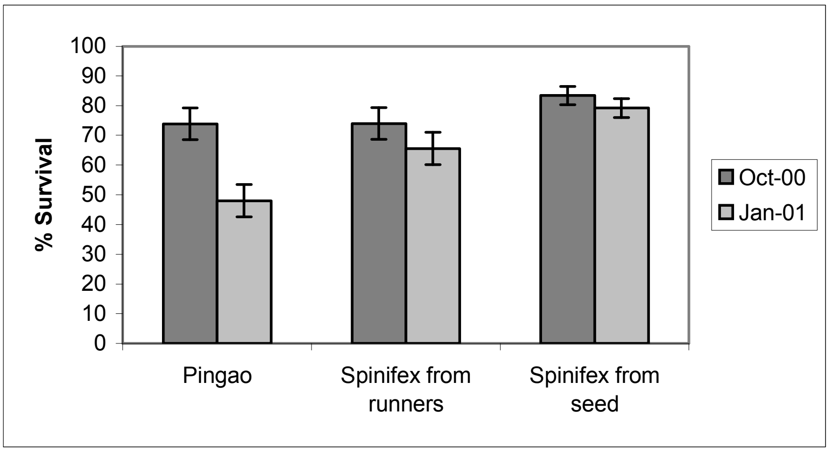

Figure 19: Survival of sand-binders 3 months (Oct 2000) and 6 months (January 2001) after planting on a reshaped foredune, Oakura Beach, New Plymouth.

Growth

Within types of plant material, there was significantly better height growth where plants had been established at the narrow spacing of 50 cm compared to those planted at 70 cm spacing (Fig. 20). Height growth of spinifex and pingao raised from seed is comparable, but significantly better than spinifex raised from runners. Spinifex raised from seed had the highest vigour score, and pingao the lowest (Table 4).

Table 4: Survival and growth of sand-binders 3 months and 6 months after planting on a reshaped foredune, Oakura Beach, New Plymouth. Within treatments, values followed by the same letter are not significantly different (p = 0.01).

Treatment	Survival October 2000 (%)	Survival January 2001 (%)	Height (cm)	Spread (cm) +	Mean no. of pingao shoots/ plant	Mean no. of spinifex runners/ plant	Mean spinifex runner length (cm)	Vigour (1-5)*	Mean no. of spinifex flowers/ plant
Spacing									
50 cm	81.4 a	72.9 a	42.4 a	46.8 a	3.2 a	1.74 a	68.4 a	4.2 a	5 a
70 cm	77.7 a	67.6 a	35.0 b	45.2 a	3.0 a	1.67 a	66.7 a	3.8 b	6 a
Fertiliser									
Agpro™	77.9 a	68.0 a	38.8 a	46.4 a	3.0 a	1.83 a	67.3 a	4.0 a	5 a
Plantacote plus™	81.4 a	72.8 a	38.6 a	45.6 a	3.2 a	1.58 a	67.8 a	4.0 a	6 a
Plant material									
Pingao from seed	73.9 a	48.1 a	41.3 a	39.9 a	3.1 a			3.4 a	
Spinifex from runner	74.0 a	65.6 ab	33.8 b	44.3 a		1.37 a	70.4 a	4.0 b	11 a
Spinifex from seed	83.5 a	79.4 b	41.0 a	53.8 b		2.04 b	64.7 b	4.5 c	0 b
All	**79.7**	**70.4**	**38.7**	**46.0**	**3.1**	**1.71**	**67.5**	**4.0**	**6**

+ Plant spread calculated as square root of (length x breadth)
* Vigour score: 1 - weak, 2 - unthrifty, 3 - average, 4 - good, 5 - robust

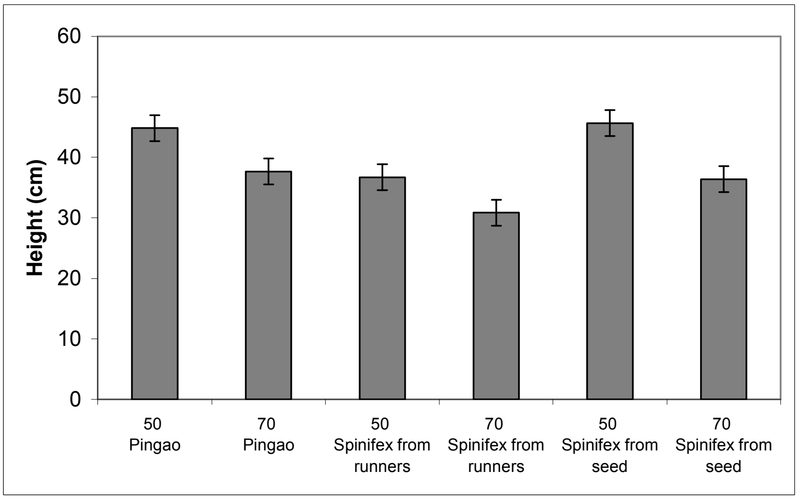

Figure 20: Height of sand-binders 6 months after planting at two different spacings of 50 cm apart and 70 cm apart, on a reshaped foredune, Oakura Beach, New Plymouth.

***Figure 21: The sand-binding plants were placed at 2 spacings – 50 cm apart* (above) *and 70 apart* (below)*. Even this small difference in spacing showed the greater vulnerability of spinifex and pingao planted at wider spacing compared to closer spacing. Note the larger areas of bare sand vulnerable to wind erosion at the wider spacing* (below) *compared to greater density planting treatment* (above).**

There was a significant difference in height growth and plant vigour between the two spacing treatments but not for other parameters assessed (Table 4). Some mutual benefit between seedlings planted at the closer spacing may have been beneficial in height growth and vigour. Some gaps had opened up in the blocks planted at larger spacing suggesting lower density planting may be more vulnerable to wind erosion (Fig. 21). Only half the number of plants is required to be planted in a given area at the wider spacing of 70 cm (approximately 20,000 plants per ha) compared to planting at 50 cm spacing (40,000 seedlings per ha).

At 6 months spinifex raised from runners had fewer, longer runners than spinifex raised from seed (Fig. 22, Table 4). Spinifex raised from runners appeared to form runners earlier than those from seed, and produced more flowers within the first year of planting, with most of the flowers male. There were no differences in growth observed between plants under the two fertiliser treatments (Table 4).

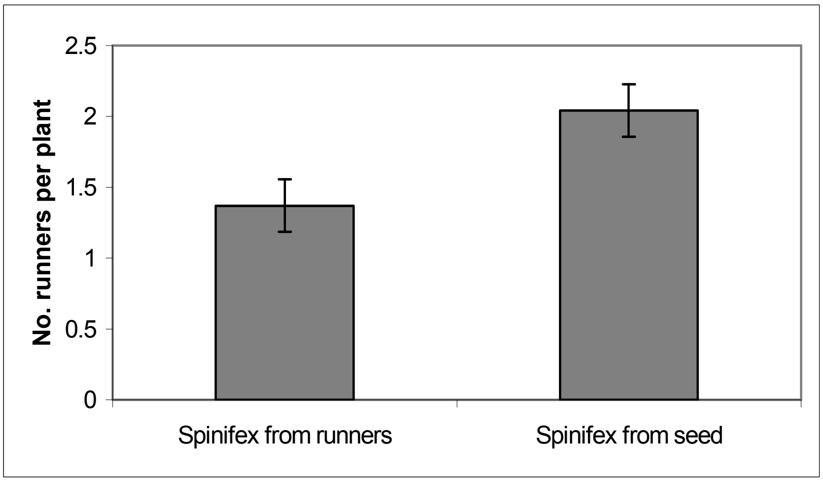

Figure 22: Number of runners per plant for spinifex raised either from seed or runners, 6 months after planting on a reshaped foredune, Oakura Beach, New Plymouth.

By twelve months after planting, cover was established on the trial site and up to 15 cm of sand had accumulated at the toe of the reshaped dune (Figure 23).

Eighteen months after planting

Percentage plant cover and a plant vigour score were estimated for each treatment block 18 months after establishment. Most blocks were covered in dense spinifex laced with long runners. Plant cover for blocks planted at 50 cm spacing was estimated at 98% compared to 87.5% for blocks planted at 70 cm spacing.

All plant types were vigorous but spinifex from seed was consistently taller, often up to 75 cm higher, compared to lower stature spinifex raised from cuttings. Many of the pingao were vigorous even amongst dense spinifex, although the number surviving was lower than for spinifex. Vigorous spinifex runners were trailing down a scarp at the toe of the dune.

Figure 23: Within 12 months of planting, the gentle natural slope of the reshaped and planted trial site (on right) is in contrast to the near vertical erosion face (in the background) covered in kikuyu grass.

DISCUSSION

One year after reshaping and planting the trial at Oakura Beach, a dense cover of indigenous sand-binders had become established. In the absence of severe storms over this initial period, up to 15 cm of sand had accumulated at the toe of the reshaped dune indicating that the natural process of dune building was beginning to take place. At 18 months, mid-slope pegs indicated that 10 cm of sand had accumulated along the central zone of the foredune. This indicated that sand, probably blown from the beach during the first year, was being trapped by the developing sward of indigenous sand-binders.

However, the occurrence of several storms from the second year onwards saw a significant loss of sand from the beach, reducing the level between high and low tide marks by up to 3 m. Wave erosion caused the landward retreat of the reshaped dune by up to 8 m. Similar erosion of the foredune adjacent to the reshaped dune indicates that a significant section of this beach is undergoing erosion and that it is not confined to the trial area. The trial has shown that reshaping and planting in itself would not necessarily halt erosion on part of the coast that is undergoing a natural erosion cycle. Investigation of long-term sand movement trends on the particular section of coast are advisable before planning a dune reshaping project.

Despite the storm erosion and apparent net loss of sand from the beach over the next 2-3 years, not only from along the trial area, reshaping and planting with sand-binders was considered a likely practical method for returning a highly modified dune scarp to a low angle foredune, mimicking natural processes of foredune 'cut and fill' erosion and accretion cycles (Dahm *et al*. 2005). If successful, mechanical reshaping and planting would be far less costly protection than engineering options such as seawalls or rocks which would destroy many beach values and despite the expense may fail if coastal erosion is inevitable because of a long-term trend of a landward advance of the coastline (Dahm *et al*. 2005).

The Oakura trial has shown that careful planning is essential before degraded dunes are reshaped and planted. As site preparation, any existing cover must be removed and exotic grasses sprayed out to reduce the infestation of newly reshaped dunes by vigorous species such as kikuyu. Any marram grass should be killed using Gallant® before reshaping, to minimise regrowth of any plant fragments that will be spread throughout the newly reshaped dune. The Oakura trial also showed that for a reshaped dune a width of 10 m is a minimum to allow for a foredune face of approximately 15° slope. High survival and fast early growth of indigenous sand-binders are enhanced where:

- good quality nursery-raised seedlings are used;
- exposed bare sites such as along the dune crest are planted at a dense spacing of 50 cm apart although wider spacing will be adequate for less exposed zones;
- slow-release fertiliser is applied at planting. It has been shown in trials elsewhere that an application of fast-release fertiliser broadcast 3-4 months after planting is effective practise.

After planting, it is essential that exotic weed cover is kept to a minimum within the sand-binding zone to ensure that a flexible sand barrier of spinifex and pingao is maintained for future repair of dunes after storms or damage from high seas. Protection of newly planted areas with fences and installation of informative signs are essential. Active and ongoing input and support of the local community is vital to the success of dune restoration projects, particularly for popular coastal areas.

Based on the results of the initial success of the Oakura Beach trial, the New Plymouth District Council has, over the last four years, implemented an ongoing reshaping and planting programme along the northern suburbs of New Plymouth. These beaches were in a similar state of degradation to Oakura Beach (Fig. 24). Dunes were dominated by kikuyu grass and extensive areas of woody, mainly exotic shrubs and small trees tolerant of the exposed coastal climate and prevailing westerly winds. Many of the techniques for mechanical reshaping and planting with indigenous sand-binders evaluated at the Oakura trial site were considered relevant to these degraded sites.

Within a year of the Oakura Beach trial, NPDC pilot-tested a 100 m section of coast at East End Beach where continuation of rock armouring was being considered. In consultation with local residents, the council reshaped and planted the dune, mainly with spinifex. Wooden accessways for residents and visitors were installed at regular intervals over reshaped dunes and fences were installed to reduce trampling of planted seedlings (Fig. 25).

Figure 24: The degraded foredune along East End Beach **(above)** ***dominated by kikuyu grass and exotic woody species. A steep scarp had formed and was subject to erosion by storms and high seas. Reshaping to a natural angle and planting with mainly spinifex*** **(below)** ***has restored natural dune form and function.***

Figure 25: Regularly-sited formal accessways **(above)** ***and fencing*** **(below)** ***will ensure planted dunes are protected from beach users and yet give ready access to the beach.***

Within a year of reshaping and planting, spinifex has dominated dunes from near high water mark to the landward edge of the dune. Pingao planted in small groups near the crest of the dunes amongst the spinifex has formed vigorous conspicuous colonies (Fig. 26).

Maintenance has included replacing spinifex planted along the toe of dune where they had been washed out by high seas soon after planting. Some replanting of spinifex, especially on the most exposed sections along the crest of the reformed dunes, has been required. Light dressings of fast-release high-nitrogen fertiliser in spring and autumn have boosted growth in the first year.

Figure 26: East End Beach, New Plymouth almost 2 years after reshaping and planting with indigenous sand-binders* (above) *and 3 years after planting* (below). *NPDC planted mainly spinifex with pingao planted in small groups along the upper slopes or crests of the dune to add diversity.

In contrast to Oakura Beach, the Each End and Fitzroy Beaches have had sufficient sand moving onshore for newly established sand-binders to begin the process of natural dune-building. While at an early stage, this approach of returning beaches to a more natural shape and function by reshaping and planting with indigenous sand-binders, has obviated the need to continue the substantially more expensive option of armouring the beaches of New Plymouth with rocks which severely compromise natural character, biodiversity and amenity values (Fig. 27).

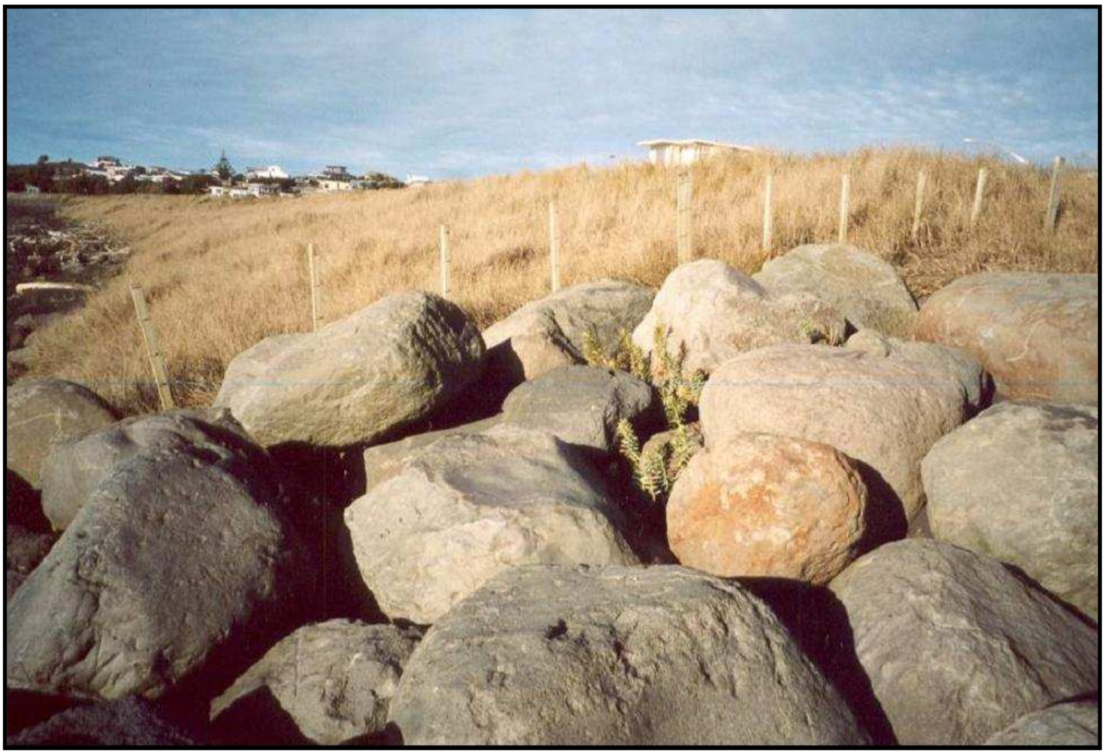

Figure 27: East End Beach, New Plymouth, where rock armouring used to reduce erosion has, in consultation with local communities, been replaced by a New Plymouth District Council programme to reshape degraded eroding dunes and plant indigenous sand-binders. Where there is sufficient space, the aim has been to restore natural dune function with a flexible sand dune barrier that will survive future storm events and high seas. Many of the natural character and amenity values are also restored compared to the more expensive options of using rock and seawalls.

RECOMMENDATIONS

Based on observations and experiences with the Oakura Beach dune reshaping trial and the management of the reshaped dune at East End Beach, the following notes are given to assist with planning and implementation of dune reshaping works:

Planning:

- Plan ahead a minimum of one year in advance of implementation of physical works.
- Investigate options other than reshaping such as restoration of existing vegetation to improve sand-trapping and building up a foredune.
- Choose a site that has a reasonable chance of success, i.e. avoid beaches where there is currently a period of active erosion and there is unlikely to be sand blown off the beach at low tide and available for trapping by sand-binders.

- Conduct a site analysis that includes local offshore and onshore systems, historical rates of erosion; install permanent dune profile survey sites and carry out a site survey to determine sand volumes to be moved or harvested.
- Consult and collaborate with the local community including Coast Care groups, other local interest groups, residents, iwi, Department of Conservation and the regional and local councils. Collate information, and use collective knowledge and resources for seeking expert advice, undertaking education programmes, determining resources required and locating their likely sources.
- Determine rear dune affects and limitations for reshaping degraded foredunes. These may include redirection of storm water or changes to the use or activity of the dune system, to allow sufficient width for a reshaped dune.
- Apply for consents for any sand harvest and placement and any options for follow up work such as sand replenishment of the foredune toe after storms.
- Determine availability of suitable local contractors and equipment and appropriate supervision and auditing.
- Determine availability of local propagation materials and a means of production of plants.
- Investigate effective pest animal and plant control requirements. Select options acceptable to the local community and appropriate to the site, and ensure implementation.
- Produce a project plan with timelines including how the site will be maintained in the future.
- Provide a budget for works including maintenance of plantings such as fertiliser and weed control.

Production of plant material

- While a survey of local dunes may indicate the appropriate selection of plant species and ratios, virtually all dune systems in New Zealand have been highly modified. For North Island sites, a ratio of 80% spinifex to 20% pingao is recommended. North Island sites usually have mostly spinifex with small patches of pingao and other minor species such as sand carex.
- Source plant propagation material and collect seed. Preferably collect from local or nearest natural populations. Seed collection of spinifex and pingao should be carried out at least a year in advance of planting in revegetation programmes. For both these species, contract nursery production of plants from seed is the most effective method. Consult the CDVN Bulletins on the major indigenous sand-binders for guidelines to planning seed collection (Bergin and Herbert 1998; Bergin 2000).
- Ensure nurseries produce high quality plants, preferably at least 50 cm, tall where root systems adequately fill containers to withstand handling so that roots and potting mix remain intact during planting, and that seedlings are hardened off prior to planting.

Preparation of the site

- Erect signage to inform and educate local users of reshaping and revegetation work in progress. Collaborate with the local Coast Care group to keep local contacts informed regularly.
- Carry out eradication of exotic grass vegetation on the site using several applications (minimum of two) of glysophate to control kikuyu and other weeds; spray marram grass with Gallant® at a rate of 15ml/litre. Time applications to achieve the best kill rates without leaving the site bare for an unnecessarily extended period.
- Confirm the natural position of the toe of the dune which must be landward of the mean high water mark, as all works must be behind this line. Do not attempt to move the toe of the dune forward of this line.

Reshaping

- Ensure that the machinery operators are involved early on and understand the objective; continuity of contractors will also significantly ease management of future operations.
- Time reshaping work during the lowest tides.
- Reshape using machinery to remove all clay, rubble and fill (everything that is not sand); some of the compacted material may be used to build the rear of the dune but needs to be well buried and sufficiently landward of any expected wave erosion. The Oakura trial has shown that any layers of clay/soil left in the dune inhibit establishment of sand-binders, and once eroded form scarps that do not rebuild at natural angles.
- Restore the seaward face of the dune profile to 15-20° using only clean sand; steeper backslopes of 20-30° are possible.
- Height of the new dune should be no less than the existing natural dunes dominated by native vegetation where they occur.
- Minimum width of the reshaped dune should be 10 m, preferably wider.
- Length of the new dune should be in sections of no less than 100m – preferably 200m to avoid end effects.
- Consolidate and level out the reshaped dune with levelling bars before planting.

Planting pattern and techniques

- For the Taranaki coast, spinifex is likely to be the best native sand-binder due to the rate of establishment, coverage and sustainable recovery.
- On reshaped dunes, pingao appears to perform best on the upper slope and crest of the foredune whereas young spinifex can be damaged by wind on the newly established, exposed sites.
- The Oakura trial showed that the quality and suitability of plant material directly influences the establishment and survival rate; overall spinifex plants raised from seed gave significantly greater and faster cover than spinifex from cuttings or pingao; spinifex plants from cuttings produced longer but fewer runners.
- Sand carex is useful to mix with spinifex, especially in areas adjacent to access ways, where this plant appears more resilient to foot traffic.

Planting and layout

- The Oakura trial showed that the optimum plant spacing for establishment was 50 cm although spacing of 70 cm on less exposed sites is likely to achieve similar results.
- Planting should be carried out using guidelines given in the CDVN Technical Bulletins (Bergin and Herbert 1998; Bergin 2000).
- Key points to remember are that plants should be watered immediately prior to planting, they should be planted at least 5 cm deeper than the original container level, and there should be slow-release nitrogen fertiliser in each planting hole.
- In Taranaki, only spinifex should be used on the lower foredune as it is the most effective to repair toe erosion events. Pingao can be planted in large groups on the upper slope, crest and backslope of the foredune.

Protect with fencing and signage

- Erect a rear dune fence, preferably a standard seven wire post and batten fence.
- Add cloth windbreak to the full length of the rear fence and secure with wooden slats on the battens to reduce further landward movement of the mobile sand.
- Erect a foredune fence with posts 8-10 m apart. Two wires are adequate. Posts should be 2.5 m long with approximately 1 m remaining above sand level.

- Install access points at each end of the dune using board and chain or similar systems that are laid over the sand and can move up or down with sand level changes.
- Install signage to mark accessways and to inform beach users of the restoration activities at the site. Include recognition of the local participants.
- Resurvey dune profiles immediately after shaping and planting is completed.

Programme maintenance

- Manage invasive species, especially marram grass that can be controlled by careful application of Gallant® amongst establishing plants. Regular hand-pulling may be effective on a localised scale until canopy closure with native sand-binders. If the dune is pure sand the range of herbaceous adventive species is likely be limited especially on the exposed seaward face of the dune.
- Monitor growth of planted indigenous sand-binders to provide information on which plant establishment patterns, density and methods are most successful and incorporate improvements into ongoing dune revegetation programmes.
- Where practical within the first few months of planting carry out maintenance of newly planted seedlings, such as uncovering plants buried with sand or re-planting those that may be undermined.
- Monitor nature and frequency of animal pest damage to vegetation to determine ongoing control requirements.
- Apply fertilizer to optimize growth of establishing plants in spring and autumn during the first year after planting. Use light broadcast dressings of high nitrogen urea, preferably during light rain or when it is expected.
- Repair any damage to fences, accessways and signage as this occurs. Timely repair of vandalism and storm damage emphasizes the commitment and maintains the protection of the investment.
- Monitor profiles to provide useful information such as cycles of sand build up and loss in relation to overall dune profile and type and vigour of vegetation cover.
- Consider sand replenishment of scarps after major storm damage if vegetation cover is seriously affected and not likely to recover quickly. Consents need to be in place to harvest sand to fill in the toe if the dune is seriously damaged.
- Replace plants to fill in gaps created by plant losses. Establishment of seedlings planted late in the season may be boosted with premixed "crystal rain".
- Encourage active and ongoing input and support from the local community – their involvement in all aspects will give the best long-term result for a dune restoration programme.

ACKNOWLEDGEMENTS

The trial is a collaborative effort between the local Oakura Beach community, New Plymouth District Council and the Coastal Dune Vegetation Network including Ensis (formerly Forest Research). Patrick Hesp (formerly Massey University) carried out beach profiles and sand budgets; Lachlan Grant (Gourdie Consulting) assisted with supervising reshaping of the foredune; Fiona Ede (formerly Forest Research) and Trish Davidson (formerly New Plymouth District Council) undertook consultation with the local community and were involved in the initial trial design. Planting was carried out by the Oakura Coast Care Group, the staff and students of Oakura School, Trish Davidson and other New Plymouth District Council staff, Mitchell Dyer (Taranaki Regional Council) and Greg Steward (Ensis). The trial has been maintained by the New Plymouth District Council and monitored jointly by New Plymouth

District Council and Forest Research (now Ensis). Mark Kimberley (Ensis) carried out statistical analysis.

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