Rehabilitation of coastal foredunes in New Zealand using indigenous sand-binding species

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CONTENTS

Abstract

Techniques for revegetation of foredunes in New Zealand were investigated using three indigenous sand-binding species: pingao, spinifex and sand tussock. Emphasis was placed on the development of guidelines from research trials designed to investigate the rehabilitation of dunes by planting nursery-raised seedlings. The aim was to promote successful techniques that will be of use to coastal managers and community-based interest groups such as Beach Care and Coast Care.

Seed characteristics and methods for collection/preparation of seed are described. Pingao and sand tussock seedlings can be raised in large numbers in a nursery. Difficulties in raising spinifex seedlings at reasonable cost arise from low plant vigour and high mortality. Although transplanting of stolons and direct field seeding of spinifex are used successfully for management-scale restoration of sand dunes in New South Wales, trials in New Zealand have shown low survival rates from transplanted stolons and poor germination and growth after direct seeding.

Nursery-raised seedlings of all three species established successfully in trials in several North Island coastal areas and along the beaches near Christchurch. The most favourable planting site for sand-binders was the seaward face of the mobile foredune just above high water level, providing that only moderate sand accumulation is expected. Plant growth was significantly increased by the application of a slow-release fertiliser (Magamp) at time of planting in trials on the less exposed beaches of the eastern North Island. More active sand movement on the west coast of the North Island and along the Christchurch beaches was thought to increase nutrient supply to planted seedlings, but may cause high mortality at exposed sites by burying plants.

Because nursery-raised seedlings and planting-out are both expensive, consideration should be given to the alternative strategy of enhancing existing populations of sand-binding species. In either case the plants will require protection from human and animal activity. In the coastal environment, setbacks due to excessive sand accretion or erosion associated with storm events must be expected and should be rectified as soon as possible.

The development of a frontal dune with a continuous cover of vigorous sand-binding vegetation is seen as an achievable objective in coastal areas with a high amenity value. The most desirable end-result for the foredune habitat would be a self-sustaining ecosystem based on indigenous species.

1. Introduction

1.1 BACKGROUND

Sand dunes along most parts of the coast of New Zealand have been highly modified since the time of earliest human settlement. Degradation of the vegetation cover was initially attributed to widespread burning and grazing (Cockayne 1911) and more recently to residential and industrial development, recreational activities, spread of weeds, localised sand mining, and browsing and trampling by introduced animals. Inventories of the vegetation of sand dune and beach systems of the North Island (Partridge 1992) and of the South Island and Stewart Island (Johnson 1992) document some of the continuing widescale degradation of indigenous vegetation communities on sand dunes.

In recent years, numerous programmes aimed at restoration of natural communities on the sand dunes have been designed to meet a range of objectives including cultural, aesthetic and recreational values as well as conservation and biodiversity considerations. The 1991 Resource Management Act has placed an obligation on land managers to protect and preserve the natural character of the coastal environment, including areas of significant native vegetation, and to recognise traditional, cultural and historical values, particularly those of Maori.

Forest Research, Rotorua, has investigated methods of propagation and management-scale establishment of indigenous sand-binding species on foredunes. This programme was partially funded for several years by the Department of Conservation and the Foundation for Research, Science and Technology, with assistance from the Lottery Board and direct and in-kind contributions from several territorial authorities and Maori Trusts. A feature of the programme was the high level of collaboration with local community-based Beach Care and Coast Care groups which have contributed to the design and implementation of dune management programmes (Dahm 1994). Our aim was to interact with managing agencies (including the Department of Conservation) and with local communities in the consideration of management issues and, with their support, to establish trials as well as monitoring programmes which will result in practical methods for successful rehabilitation and management of dunes (Bergin et al. 1997).

Research has concentrated on the development of practical techniques for establishing three species: spinifex (*Spinifex sericeus* R.Br.), pingao (*Desmoschoenus spiralis* (A. Rich.) Hook. f.) and sand tussock (*Austrofestuca littoralis* (Labill.) E. Aleks.). Pingao and spinifex were identified by the botanist Leonard Cockayne early this century as major sand-binding species in the native flora that were widespread and performed an important role in stabilising foredunes (Cockayne 1911). He also indicated that sand tussock was widespread throughout the country.

1.2 OBJECTIVES OF RESEARCH

The main objective was assessment of the potential for local introduction of pingao, spinifex and sand tussock for the rehabilitation of degraded foredunes on New Zealand beaches. Supporting objectives were:

- To determine practical methods for the large-scale propagation of each species
- To analyse information in databases derived from establishment trials in the North and South Islands and to interpret the effect of applied treatments and major edaphic factors
- To produce practical guidelines for coastal managers wishing to revegetate degraded foredunes with these species

1.3 STANDARDISED METHODS

Details about the location and design of individual establishment trials and management-scale plantings are given below in Sections 2 (pingao), 3 (spinifex), and 4 (sand tussock). Methods which were similar for most trials are described here.

1.3.1 Seed collection and preparation

Seed was collected during summer months from a wide range of sites throughout the country over several years. Pingao and sand tussock seed and/or seedheads were stored dry in unsealed plastic bags or in paper bags in a refrigerator. Spinifex seedheads were stored under cover in hessian sacks at room temperature. Viability of seed was tested in the field, at later stages of seed preparation and at seed sowing using a dissection test on small samples of all three species.

1.3.2 Germination trials

Individual collections of seed were tested at the Forest Research Nursery, Rotorua. At specific intervals after collection, known quantities of seed were sown in trays containing equal amounts of peat and sand, in an unheated glasshouse. Date and rate of emergence during the first six weeks were determined from weekly assessments.

1.3.3 Raising plants

Seed from each collection was sown in trays in unheated glasshouses during late summer and winter. Seedlings were pricked out into containers 6–8 weeks after sowing. In order to find the best method for raising robust seedlings within two years of collection, several different sizes and types of containers were used. Pingao and spinifex were grown in potting mixtures containing different proportions of sand, peat, and pumice. Potting mixes of 3:1 peat:pumice (or sand) which allowed free drainage were found to give good results. A slow-release fertiliser (e.g. fine Magamp) at the rate of 2–2.5 kg/cubic metre was added to the potting mix. Care was taken to avoid over-watering or placing seedlings in areas where high humidity was likely to occur. A liquid general-purpose fertiliser was applied on an irregular basis to maintain vigour where necessary.

For all three species the aim was to raise seedlings of plantable size, in containers, within 2 years of collecting the seed. Before seedlings were to be planted on dunes, they were hardened-off over an approximately 3 month period. This involved exposing seedlings to increasingly harsh conditions by progressively removing shade protection or placing seedlings outside to become accustomed to increasingly colder conditions as the late autumn or winter planting season approached.

1.3.4 Establishment trials

The main pingao planting trials are located at Nuhiti Beach on the east coast of the North Island, Port Waikato on the west coast of the North Island, Whiritoa Beach on the Coromandel Peninsula (see Colour Plate 1) and South Brighton Beach near Christchurch, South Island. There are smaller trials at Waikawau Bay on the Coromandel Peninsula and Brighton Spit near Christchurch. Spinifex and sand tussock trials are located at Whiritoa Beach and Christchurch (Fig. 1).

Trial design

Seedlings were planted in circular clusters 1–3 m in diameter, each containing 5–30 individuals. Plants were approximately 50 cm apart but otherwise were arranged at random around a central wooden identification peg. Each group was discrete and restricted to a single microsite. All seedlings in a group received or represented one experimental treatment combination.

A fully replicated randomised complete block design was used for all trials. To allow for site variation and possible high mortality, seedling numbers were maximised. Each trial area was divided into several blocks (4–9) with each block located on a relatively uniform site.

Experimental treatments

The effects of a wide range of site types and treatments were tested. Nursery-raised seedlings of 1–3 species were planted at each site. For spinifex, the effects of direct seeding and planting of cuttings were also tested. The following factors were investigated:

- Container type—For most trials, seedlings were raised either in polythene planter bags (PB ¾) or in Hillson rootrainers. The effect of a range of plant size and container types was tested in a pingao trial at Nuhiti Beach.
- Site type—Trials were located in sparsely vegetated or bare foredune sites. The Nuhiti Beach trial was used to assess performance of pingao on the exposed bare foredune and on the stable vegetated rear dune.
- Fertiliser application—The effect of fertiliser treatment at time of planting was tested in all trials. Approximately 30 g of the slow-release fertiliser Magamp (magnesium ammonium phosphate; medium granule—7% nitrogen) were incorporated into the sand in which each treated seedling was planted. The effect of fast-release fertilisers (urea—46% nitrogen; diammonium phosphate—18% nitrogen) was tested in pingao trials at Whiritoa Beach.

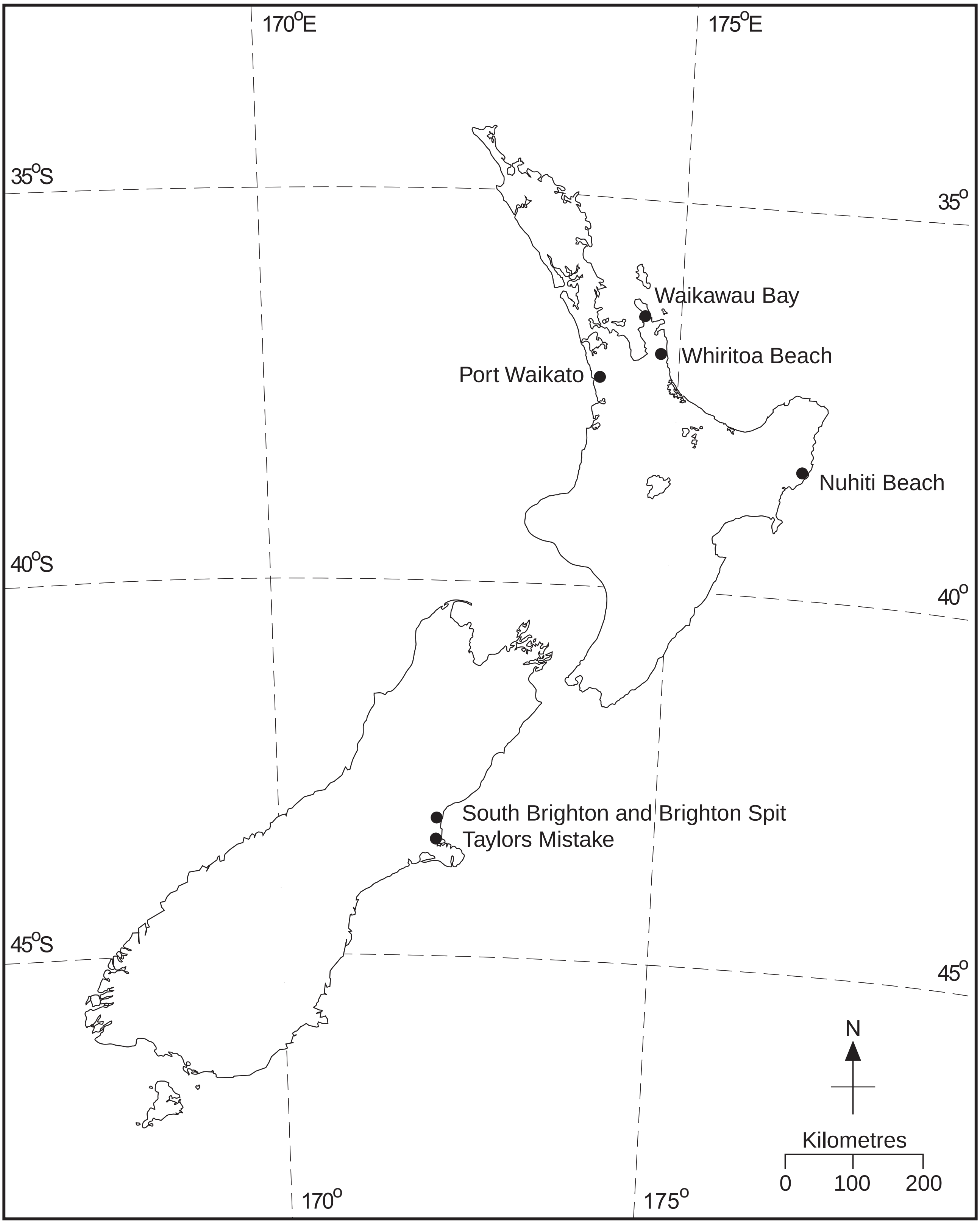


Figure 1. The locations of collaborative Forest Research planting trials investigating the performance of the indigenous sand-binding species: pingao, spinifex, and sand tussock, on coastal foredunes in New Zealand.

- Hydrogel application—Hydrogel is a water-storing material that may be tapped for water by plant roots during dry periods. The gel, in either dry or hydrated form, was incorporated into the sand at time of planting in trials at Nuhiti Beach and Waikawau Bay.

Assessment

At all sites and for all species, survival and leaf length or height growth of individual plants were measured. Subjective group-based assessments of ground cover, colour of plant foliage and general plant vigour or health were also made. At some sites, root collar or tussock diameter, plant length and breadth, the number of multiple shoots or the number of runners (above-ground stolons) per plant and the number of flowerheads per plant were recorded. The degree of sand accumulation or erosion at each group site was assessed from changes in sand level marked on the group identification peg.

Data analysis

Results are presented for assessments made up to two years after planting. Analysis of variance methods were used to test the significance of treatment and site factors on plant survival and growth. Differences between individual levels of treatment factors were tested using the Least Significant Difference (LSD) test.

2. Pingao trials

2.1 INTRODUCTION

Together with harakeke (*Phormium tenax* J. R. et G. Forst.), ti kouka (*Cordyline australis* (Forst. f.) Endl.) and kiekie (*Freycinetia banksii* A. Cunn.), pingao is one of the natural fibres extensively used for weaving by Maori. In pre-European times, pingao was widespread and abundant on foredunes in the North and South Islands (Cockayne 1919). Most populations are now reduced to small discontinuous patches, and this decline is continuing (Courtney 1984).

In recent times there has been a resurgence of interest in traditional weaving skills but in most districts the residual plant populations are too small to sustain the demand for pingao fibre. Trials used to develop techniques for rehabilitating degraded dunes will assist the development of a sustainable resource for weaving and will help to conserve and expand the present populations.

Planting of cuttings of pingao has been investigated for revegetation of dunes (Bicknell & Butcher 1986) but success has been variable and this method is considered to be less reliable than use of plants raised from seed.

2.2 NURSERY PROPAGATION

2.2.1 Seed collection and preparation

The ripe pingao seed is a 3–5 mm ovoid shiny black nut developed in 15–30 cm long flowerheads that are borne on stalks up to 90 cm tall. Pingao seed can be collected in large quantities from established stands during December–early January in both the North and South Islands (see Colour Plate 2). The ripening period varies from year to year and is probably influenced by local climate. In warmer areas, pingao sheds seed earlier than in cooler regions. Seedfall continues for 2–4 weeks and is prolonged in large colonies where vigorous plants develop numerous large flowerheads. Collection is best carried out when seed begins to fall and appears in sand hollows in the vicinity of flowering plants. At this stage the seeds are easily dislodged from dry seedheads by rubbing with the fingers. Immature seed is green and difficult to dislodge and should be avoided. Courtney (1984) has suggested that seed collected late in the season may be more difficult to germinate.

For large collections, seedheads should be cut from plants over a wide area and from relatively large colonies. This ensures that a small proportion of the total seed is collected and that it is derived from a range of different plants within one locality. Seed is easily separated from dry seedheads by rubbing. Winnowing to remove debris is difficult and unnecessary.

Soundness of seed can be assessed by cutting individuals in a small sample with a sharp blade. Viable seed is filled with white–cream coloured endosperm. Shrivelled seed with discoloured dry contents should be discarded. Large quantities of seed have been stored dry under refrigeration for several months in plastic bags or jars with no apparent major loss of viability.

2.2.2 Seed sowing and germination

Pingao was found to respond to the standard plant raising procedures used at the Forest Research Nursery in Rotorua, providing that watering was kept to a minimum. Seed with husks and debris was broadcast-sown on a seed-raising mix of 2:1 peat:pumice in seed boxes. No pre-treatment or storage was required. After covering with sieved potting mix to a depth of 3–5 mm, an inverted empty seed tray and a plastic cover were used to maintain high humidity with regular light watering. Covers were removed when germination commenced, and humidity levels were then minimised.

Germination trials indicated that seedlings emerged 11–20 days after sowing in late summer (Table 1) and in 26–31 days after winter sowing (Table 2). Collections from five different sites in 1988/89 had germination rates of 25 to 93%. In most years adequate numbers of seedlings were obtained from each collection. Before precautions were taken, rodents and birds destroyed several batches of sown seed.

2.2.3 Raising seedlings

Within one month of germination, seedlings were up to 7 cm tall and were easily transferred from seed boxes into containers filled with the standard

TABLE 1. VIABILITY OF PINGAO SEED COLLECTED IN 1988/89 FROM SEVERAL NORTH ISLAND SITES.

PROVENANCE	COLLECTION DATE	SOWING DATE	DAYS TO FIRST EMERGENCE	GERMINATION RATE (%)
Whatipu	14 Dec 88	mid Feb	17	93
Waikawau Bay	16 Dec 88	mid Feb	20	50
Whangamata	6 Feb 89	mid Feb	11	25
Whanganui	18 Dec 88	mid Feb	14	69
Hawkes Bay	20 Dec 88	mid Feb	14	36

TABLE 2. EMERGENCE AND SURVIVAL RATES OF PINGAO SEEDLINGS. VALUES ARE MEANS FOR 200 SEEDLINGS FROM EACH PROVENANCE (COLLECTION SITE) WHICH WERE POTTED-ON SIX MONTHS AFTER SOWING.

PROVENANCE	COLLECTION DATE	SOWING DATE	DAYS TO FIRST EMERGENCE	SURVIVAL AFTER ONE YEAR (%)
Ranaika	Mid Dec 93	19 May 94	31	94
Ocean Beach	Mid Dec 93	19 May 94	31	100
Santoft	7 Dec 93	19 May 94	28	96
Port Waikato	Late Dec 93/ early Jan 94	19 May 94	31	95
Whangamata	Late Dec 93	19 May 94	26	99
Whatipu	4 Dec 93	19 May 94	26	91
Otama Beach	Jan 94	19 May 94	28	100

Forest Research Nursery potting mix (3:1 peat:pumice plus slow-release fertiliser). Long roots were trimmed before individuals were pricked out, one per container, taking care to ensure that the main tap root was not deformed.

For practical purposes, the age and size of plants selected for transfer to the field is determined by resources and scale of restoration. Forest Research trials and other revegetation work has indicated that 18 month old seedlings performed well on suitable foredune sites and that large plants were not necessarily superior in this respect. The most successful plants were raised in PB¾ polythene bags or Hillson rootrainers. Within 18 months of sowing, seedlings were up to 50 cm tall with root collar diameters of at least 5 mm and root systems that held the potting mix firmly. Larger plants were obtained from seedlings potted-on into PB2 polythene bags or Tinus rootrainers and grown for a further year. Regular maintenance included fertiliser and fungicide applications when these were considered to be appropriate.

There was little seedling mortality in the nursery where drainage was adequate and watering and humidity were kept at a minimum. Seedlings pricked out into PB 2 polythene planter bags were up to 50 cm high within 15 months, mean survival for the seven provenances tested being 91% to 100% after 12 months (Table 2).

The cost of raising seedlings was found to be a significant proportion of the total cost of dune restoration programmes. In the North Island, 18 month old seedlings raised in Hillson rootrainers or similar sized containers cost $0.90 to $1.20 each (excluding GST). Older seedlings in larger containers cost $2.50. Freight costs are considerably lower for seedlings in smaller containers which are also easier to carry and to plant.

2.3 ESTABLISHMENT TRIALS

2.3.1 Nuhiti Beach

Trial site

The 1.5 km long beach at Nuhiti has a narrow dune system. A stable dune on the landward side is covered with short grasses, predominantly Indian doab (*Cynodon dactylon* (L.) Pers.) and harestail (*Lagarus ovatus* L.). The foredune has steep slopes with a sporadic cover of spinifex. Sand sedge (*Carex pumila* Thunb.) is common on the foredune.

Experimental factors

The trial was based on 110 groups (plots) each containing 30 pingao seedlings planted in August 1990. Treatments were factorial combinations of seedling type, foredune zone, and applications of Magamp fertiliser and hydrogel.

- Seedling types :
    - seedlings raised in Tinus rootrainers ex Whatipu seed
    - seedlings raised in Hillson rootrainers ex Whatipu seed
    - seedlings raised in large polythene planter bags (PB2) ex Whanganui seed
    - seedlings raised in smaller polythene planter bags (PB¾) ex Whanganui seed
    - seedlings raised in Hillson rootrainers ex Whanganui seed. These seedlings were placed in a very exposed, open position during the last few months of growth and no liquid fertiliser was applied.
- Foredune zones:
    - the seaward face (sparsely vegetated)
    - the area immediately inland from the foredune face (covered with exotic grasses).
- Treatment with Magamp fertiliser applied at time of planting. At the foredune site, selected groups of plants received a second dressing of Magamp 11 months after planting, when 30 g of fertiliser was placed in a 5–8 cm deep circular channel around each treated seedling and covered with sand.
- Broadleaf P4 hydrogel in hydrated form was applied to each treated seedling. Approximately 3 g of crystals mixed with 150 ml of water formed a large handful of gel that was placed in each planting hole.

Assessments

Maximum leaf length and root-collar diameter were recorded in April 1991 and April 1992. Roots of a few sample plants were excavated and examined in April

1991. At the 20-month assessment, survival rate, plant vigour index value (scale of 1 = weak to 5 = robust), foliage colour index value (1 = yellow to 3 = green), and the number of plants with multiple shoots were recorded.

Results

Roots of sample plants excavated after 8 months showed an increase in both volume and extension (often more than 40 cm). Hydrogel was still visible with rootlets penetrating the hydrated material.

The overall survival rate at the second assessment was significantly higher on the unstable dune (71%) than on the stable dune (64%) and was not affected by fertiliser or hydrogel treatments (Table 3). With a single exception, all seedling types showed survival rates exceeding 65%. Less than one-third of the small Whanganui provenance seedlings, which were severely hardened-off before planting, survived to April 1992. There was no evidence that rigorous hardening-off improved the performance of pingao plants in the field. Among

TABLE 3. PERFORMANCE OF PINGAO PLANTED AT NUHITI BEACH. VARIABLES OTHER THAN LEAF LENGTH AND ROOT COLLAR DIAMETER WERE ASSESSED 20 MONTHS AFTER PLANTING.

Treatment factors (seedling type, foredune zone, fertiliser at planting and hydrogel) were tested by normal analysis of variance; other factors (shelter, stability, vegetation) by unbalanced analysis of variance (adjusting for effects of the treatment factors). Within factor groups, values followed by the same letter are not significantly different (p = 0.05).

EXPERIMENTAL FACTORS	SAMPLE SIZE (No. of planted seedlings)	LEAF LENGTH (cm) AUGUST 1990 (at planting)	LEAF LENGTH (cm) APRIL 1995	ROOT COLLAR DIAM. (mm) AUGUST 1990 (at planting)	ROOT COLLAR DIAM. (mm) APRIL 1995	SURVIVAL (%)	PLANTS WITH MULTIPLE SHOOTS (%)	PLANT VIGOUR*	FOLIAGE COLOUR#
Seedling type									
Whatipu Large	180	112	55a	11.9	14.5a	76ab	61b	2.2b	1.8a
Whatipu Medium	720	72	42bc	10	12.6b	67b	45c	2.4b	1.6a
Whanganui Large	360	70	46b	12.8	16.4a	90a	86a	3.4a	1.6a
Whanganui Medium	1440	53	38c	8.4	12.8b	70b	72b	2.4b	1.4a
Whanganui Small	360	32	26d	7.2	7.2c	31c	5d	1.4b	1.3a
Foredune zone									
Seaward face	1620	63	43a	9.5	12.9a	71a	69a	2.6a	1.7a
Inland area	1620	63	37b	9.5	12.6a	64b	49b	2.0b	1.3a
Magamp fertiliser (at planting)									
Absent	1620	63	36a	9.5	11.6a	68a	50a	2.0a	1.4a
Present	1620	63	44b	9.5	13.8b	68a	69b	2.6b	1.6b
Hydrogel									
Absent	540	63	39a	9.5	12.5a	66a	56a	2.2a	1.4a
Present	1080	63	41a	9.5	12.8a	67a	61a	2.4a	1.4a

* Vigour score: 1—weak, 2—unthrifty, 3—average, 4—good, 5—robust.

\# Foliage colour score: 1—green, 2—intermediate, 3—yellow.

plants that had been hardened-off in the normal way, Whanganui seedlings raised in PB2 planter bags were larger and survived better than those raised in smaller planter bags. Rootrainer type influenced the size of Whatipu seedlings but did not have a significant effect on survival in the field.

At both assessments, leaf length of all seedling types in all treatment groups was found to have declined as a result of tip dieback. Root-collar diameter of most seedling types increased during the first 8 months, but due to sand accumulation root-collar diameter could not be used to measure long-term growth. The number of plants with multiple shoots after 20 months was considered to be a more appropriate index of growth and plant vigour.

Fertiliser applied at time of planting had a highly significant positive effect (see Colour Plate 3), 69% of plants in treated plots exhibiting multiple shoots compared with 50% in untreated plots (Table 3). This fertiliser response was equally strong on the stable rear dune site (with multiple shoot plants increasing from 29 to 46%) and the exposed foredune site (increasing from 41 to 61%). There was no measurable shoot response to the addition of fertiliser 11 months after planting on the unstable site. The overall effect of foredune zone was evident from the greater proportion of plants with multiple shoots on the foredune face (69%). On the stable dune, only 49% of plants developed multiple shoots. After 20 months, Whanganui plants raised in planter bags had greater numbers of multiple shoots than similar sized Whatipu plants raised in rootrainers. This effect was probably related to the larger quantity of potting mix available to plants raised in planter bags.

Plant health scores were significantly higher on the unstable foredune than at the stable site. Plants treated with fertiliser had higher health and foliage colour score values.

The application of hydrogel had no effect on survival or any of the plant growth indices.

2.3.2 Waikawau Bay

Trial site

The 3 km beach at Waikawau Bay is managed by the Department of Conservation as a recreation area and has an extensive fenced-off dune system. Small scattered patches of vigorous pingao plants occur naturally on the foredune where spinifex is the dominant species.

Experimental factors

Pingao seedlings raised in Hillson rootrainers from seed collected at beaches on the Coromandel Peninsula were planted in 58 groups of 25 in August 1990 at the northern end of the beach. Factors tested were:

- Seedling types
  - seedlings raised at Department of Conservation Nursery, Taupo
  - seedlings raised at Forest Research Nursery, Rotorua
  - seedlings raised at Tairawhiti Polytechnic Nursery, Gisborne.
- Foredune zones
  - an unstable foredune face with sparse vegetation cover
  - a stable vegetated area a few metres behind the foredune face.

- Magamp applied at time of planting
- Hydrogel applied at time of planting.

Assessments

Survival rate, maximum leaf length, plant vigour index value (scale of 1 = weak to 5 = robust) and foliage colour index value (1 = yellow to 3 = green) were recorded in December 1990 and April 1992.

Results

Nearly all the pingao planted at this site was browsed by rabbits. Consequently, there were no significant differences in survival rate or in leaf length 4 months after planting (Table 4). The only differences detected were in foliage colour and seedling vigour. Seedlings raised at the Forest Research Nursery had more yellow foliage than other seedling types. Seedlings at the unstable site had greener leaves and were more vigorous than those on the stable rear dune. Seedlings treated with Magamp were greener than untreated seedlings. Hydrogel had no effect on seedling performance.

TABLE 4. PERFORMANCE OF PINGAO PLANTED AT WAIKAWAU BAY AFTER 4 MONTHS GROWTH ON THE DUNES.

Leaf length in August 1990 is the mean for a random sample of seedlings measured at time of planting. Within factor groups, values followed by the same letter are not significantly different (p = 0.05).

EXPERIMENTAL FACTOR	SAMPLE SIZE (No. of planted seedlings)	LEAF LENGTH (cm) AUGUST 1990 (at planting)	LEAF LENGTH (cm) DECEMBER 1990	SURVIVAL (%)	PLANT VIGOUR*	FOLIAGE COLOUR#
Seedling type						
ex Taupo Nursery	200	65	22a	45a	3.2a	2.2a
ex Rotorua Nursery	200	37	23a	42a	2.0a	1.4b
ex Gisborne Nursery	1000	49	27a	69a	3.6a	2.3a
Foredune zone						
Unstable dune	700	50	26a	59a	4.0a	2.3a
Stable dune	700	50	26a	64a	2.4b	2.0b
Magamp fertiliser						
Absent	700	50	27a	64a	3.0a	1.6b
Present	700	50	24a	60a	3.6a	2.6a
Hydrogel						
Absent	700	50	26a	64a	3.4a	2.2a
Present	700	50	25a	60a	3.2a	2.1a

* Vigour score: 1—weak, 2—unthrifty, 3—average, 4—good, 5—robust.

\# Foliage colour score: 1—green, 2—intermediate, 3—yellow.

Only 19% of seedlings planted on the sheltered site survived for 20 months. Survivors were slow to recover from initial rabbit browsing. The effect of browsing during the second year was less severe than in the first year.

At the exposed site most plots were destroyed during the first year by a change in the course of a river channel. Plants in many of the remaining plots were subsequently inundated with sand. Up to 60 cm of additional sand was recorded on some plots and this caused severe mortality.

2.3.3 Whiritoa Beach South

Trial site

At its southern end, Whiritoa Beach on the Coromandel Peninsula consists of gently sloping sand with a very sparse cover of spinifex and sand convolvulus (*Calystegia soldanella* (L.) R. Br.) and knobby club rush (*Isolepis nodosa* (Rottb.) R. Br.). Sand sedge is present in lower-lying flat areas, usually near the high water mark.

Experimental factors

Pingao seedlings raised from local seed in Hillson rootrainers were planted in 50 groups of 20 plants. Experimental factors investigated were:

- Planting season. Seedlings were planted in:
  - September 1994 (spring)
  - April 1995 (autumn)
- Selected plots were treated with fertiliser:
  - at time of planting (Magamp applied in the planting hole)
  - after 12 months when either urea (46% N) or diammonium phosphate (18% N) was broadcast over the plot at a rate delivering 400 kg of nitrogen per ha. This rate has been recommended for enhancement of natural sand dune vegetation in Australia (Barr & McDonald 1980; Barr et al. 1983).

Assessments

Survival rate, vigour index value (scale of 1 = weak to 5 = robust), plant height, plant spread, root-collar diameter, the average number of shoots per plant, the number of plants with multiple shoots, pingao cover within the plot area and change in sand level were recorded in September 1996.

Results

There was a significant difference between the survival rate of spring-planted (78%) and autumn-planted (41%) seedlings (Table 5). Although spring-planted seedlings were vulnerable to late spring or early summer dry spells, they evidently had sufficient time to become well established before the onset of the following winter. In contrast, the autumn-planted seedlings failed to establish sufficiently well before the onset of winter storms and the accompanying mass sand movement. From the range of performance indices, it was concluded that growth rate and vigour scores of survivors were similar for autumn- and spring-planted seedlings.

Results demonstrated a significant increase in all growth indices when Magamp was applied at time of planting (Table 5). Survival was not affected, but among

TABLE 5. PERFORMANCE OF PINGAO SEEDLINGS PLANTED IN SPRING 1994 AND AUTUMN 1995, WHIRITOA BEACH SOUTH, COROMANDEL PENINSULA. TRIALS WERE ASSESSED 18 MONTHS AFTER THE AUTUMN PLANTINGS AND 2 YEARS AFTER THE SPRING PLANTINGS.

Magamp fertiliser was applied to individual plants; di-ammonium phosphate and urea were broadcast over the plots. Within factor groups, values followed by the same letter are not significantly different (p = 0.05).

	SAMPLE SIZE (No. of planted seedlings)	SURVIVAL (%)	PLANT VIGOUR*	HEIGHT (cm)	PLANT SPREAD† (cm)	ROOT COLLAR DIAMETER (cm)	AVERAGE NO. OF SHOOTS PER PLANT	PLANTS WITH MULTIPLE SHOOTS (%)	PINGAO COVER WITHIN PLOT AREA (%)	SAND ACCUMULATION DEPTH (cm)
Planting season										
Autumn	120	41b	3.3a	52a	51a	2.6a	2.7a	50a	29a	10.5a
Spring	200	78a	3.3a	46a	46a	2.6a	2.3a	52a	40a	9.0a
Fertiliser										
Control	120	53a	2.7b	40b	37b	1.3b	1.4b	25b	18b	4.7b
Magamp at planting	120	69a	4.0a	58a	58a	3.7a	3.5a	75a	53a	13.0a
DAP after one year	40	60	3.7	50	54	4.3	3.2	67	43	14.5
Urea after one year	40	88	2.6	42	36	1.3	1.5	42	28	9.0

* Vigour score: 1—weak, 2—unthrifty, 3—average, 4—good, 5—robust.

† Plant spread calculated as square root of (length x breadth).

Note: insufficient sample size to test effects of DAP and Urea.

survivors, treated pingao plants were on average 18 cm taller, had almost 3 times greater root collar diameters, were more vigorous and had more than twice as many shoots per plant. Plot cover was three times greater where Magamp had been applied (53%) than in untreated plots (18%). Greater sand accumulation on treated plots (13 cm) than on untreated plots (4.7 cm) probably reflected the increased sand-trapping effect associated with increased plant development.

Although the sample size was too small to allow statistical testing of the effects of diammonium phosphate (DAP) or urea treatment, DAP appeared to have increased plant growth. The degree of response seemed similar to that recorded for Magamp application at time of planting. In contrast, broadcast application of urea to established plants appeared to improve plot cover and the number of multiple shoots per plant, but had no effect on height growth, vigour, or root collar diameter.

2.3.4 South Brighton Beach

Trial site

The trial was laid out on the seaward face of the foredune which had a slope of about 1:4 and an approximate height of 9 m a.s.l. The slope was devoid of vegetation but the dune crest was dominated by marram grass (*Ammophila arenaria* (L.) Link). The dune face was exposed to the full force of the prevailing easterly winds.

Experimental factors

Pingao seedlings raised from local seed in RX90 plastic containers were planted in 10 groups of 20 plants in April 1995. Fertiliser treatment was the only factor investigated in this trial, the effect of Magamp being compared with that of the slow-release fertiliser Elite applied at the same rate at time of planting.

Assessments

Survival rate, vigour index value (scale of 1 = weak to 5 = robust), plant height, plant spread, root collar diameter, the average number of shoots per plant, the number of plants with multiple shoots, pingao cover within the plot area and change in sand level were recorded in April 1996.

Results

One year after planting, no significant differences in survival or growth associated with fertiliser treatment were apparent (Table 6). Mean plant height growth was 68 cm, and pingao cover 62%. Plants had a high vigour score (mean 4.9) and a large number of shoots per plant (12–19.7). Depth of accumulated sand ranged between 13 and 24 cm.

TABLE 6. PERFORMANCE AFTER ONE YEAR OF PINGAO PLANTED AT SOUTH BRIGHTON BEACH, CHRISTCHURCH. Values followed by the same letter are not significantly different (p = 0.05).

FERTILISER	SAMPLE SIZE (No. of planted seedlings)	SURVIVAL (%)	PLANT VIGOUR*	HEIGHT (cm)	PLANT SPREAD† (cm)	ROOT COLLAR DIAMETER (cm)	AVERAGE NO. OF SHOOTS PER PLANT	PLANTS WITH MULTIPLE SHOOTS (%)	PINGAO COVER WITH-IN PLOT AREA (%)	SAND ACCUMULATION DEPTH (cm)
Control	100	48a	4.9a	67.5a	116a	43.9a	19.7a	100a	42a	13.4a
Elite	100	63a	4.9a	68.5a	111a	33.4a	15.4a	96a	65a	23.8a
Magamp	100	82a	5.0a	69.1a	108a	26.5a	12.0a	99a	80a	20.6a

* Plant spread calculated as square root of (length x breadth).

† Vigour score : 1—weak, 2—unthrifty, 3—average, 4—good, 5—robust.

2.3.5 Brighton Spit

Trial site

The maximum height of rear dunes at this site was only about 6 m a.s.l. The trial was located near the toe of the foredune just above high water mark. Slopes were 1:10 or less, devoid of vegetation and exposed to prevailing onshore winds.

Experimental factors

Pingao seedlings raised from local seed in RX90 plastic containers were planted in 10 groups of 20 plants in April 1995. Fertiliser treatment was the only factor investigated in this trial, the effect of Magamp being compared with that of the slow-release fertiliser Elite applied at the same rate at time of planting.

Assessments

As for the trial at South Brighton, survival rate, vigour index value (scale of 1 = weak to 5 = robust), plant height, plant spread, root collar diameter, the average number of shoots per plant, the number of plants with multiple shoots, pingao cover within the plot area and change in sand level were recorded in April 1996.

Results

Severe browsing by rabbits was observed within days of planting. A poisoning operation was carried out and some plant recovery was observed 3 months later. Continued rabbit browsing and accumulation of sand to depths of up to 1m were responsible for the poor survival of planted pingao. Only three of the original 300 plants were present one year after planting.

2.3.6 Port Waikato

Trial sites

The west coast of New Zealand is exposed to the full force of the winds which prevail in latitudes 35–47°S, and there is considerable sand movement onto and from the foredunes. Dune blow-outs are common, especially where vegetation and sand have been disturbed. High recreational use associated with a carpark and Surf Club at the south end of the beach has narrowed the foredune which had little or no vegetation cover. Several large blow-outs immediately north of the Surf Club were probably the result of high recreational use and casual development of accessways from nearby roads. Fences have been erected in the blow-outs to trap the wind-blown sand.

Pingao was planted in collaboration with Environment Waikato, Franklin District Council, Department of Conservation and the Port Waikato Dune Care community group in May 1994.

Experimental factors

A total of 28 plots (20 seedlings/plot) was established. Seedlings raised from Port Waikato seed were approximately 40 cm high and were planted so that the sand level was at least 5 cm above the root collar. Three factors were investigated:

- Seedling type
  - – seedlings raised in Hillson rootrainers at Terra Firma Nursery, Taupo.
  - – seedlings raised in PB ¾ polythene bags at Forest Research Nursery, Rotorua
- Site types
  - – the steep foredune immediately adjacent to the carpark
  - – the blow-outs north of the Surf Club building where sand was highly mobile.
- Magamp fertiliser applied at time of planting.

Assessments

Survival and vigour of plants were noted in June 1994, May 1995 and May 1996.

Results

Six weeks after the trial was established, sand levels at the foredune site remained relatively stable and all pingao seedlings had survived. In contrast, at the blow-out sites, significant changes to sand levels had occurred. Roots of up to 40% of plants were partially or completely exposed, despite seedlings being planted in holes up to 15 cm deep. Sand level in most plots had decreased by 5–35 cm. Sand trapping fences, 70 cm high, had caused accumulation of sand within 1.5 m on the leeward side, and plots within this zone were inundated. Sand in plots more than 3 m from Sarlon mesh fences on the leeward side was excavated by the wind. Under these conditions, the most suitable planting sites were considered to be about 1.5–2 m on the leeward side of fences where a moderate degree of sand accumulation is likely to occur.

On the foredune high survival rates and vigorous growth were recorded two years after planting. Vegetated areas showed evidence of sand trapping and dune-building. Marker pegs had been removed and detailed assessments were not possible. Observations suggested that there were few differences between any recognisable plant groups in terms of survival or growth rates. Fertiliser treatment had no obvious effect on growth. It is possible that sand accumulation and sea spume provided an adequate nutrient supply to planted seedlings. Restriction of beach access to designated walkways and fencing of planted areas has assisted successful revegetation of this site.

Two years after planting, survival rates on the blow-out sites were estimated to be less than 50% although changes in sand level made accurate assessment difficult. Survivors tended to be grouped together and were often found in the vicinity of sand fences. The combination of mesh fencing (across the blow-out area at right angles to the prevailing wind) and planting on the leeward side of the fences appeared to be effective in initiating the process of infilling and dune building. Further fencing and planting by the local Beach Care group at intervals of 5–10 m inland from the toe of the foredune has resulted in complete vegetation cover of many blow-outs. After four years, sand levels are similar to those of adjacent foredune sites. Provision of accessways and exclusion of beach users, combined with fertiliser treatment to encourage plant growth has been an integral part of the revegetation strategy for these blow-out sites.

3. Spinifex trials

3.1 INTRODUCTION

Spinifex is native to Australia and to New Zealand where it is widespread on sand dunes (Craig 1984). In Australia, it has been used for many years as one of the major species in large scale sand dune rehabilitation programmes (Beach Protection Authority of Queensland 1981; NSW Public Works Department and Soil Conservation Service 1987). Establishment techniques used in Australia are now being evaluated at several New Zealand dune sites.

Spinifex is dioecious, i.e. male and female flowers are borne on separate plants. Male and female plants form colonies of equal size (Conner 1984; Maze & Whalley 1990). The male plant (Fig. 2D) produces pale brown, branched but compact inflorescences about 5 cm long on short branches (Harty & MacDonald 1972). The female plant is characterised by large, softly spiny, spherical inflorescences about 20–30 cm in diameter (Fig. 2B). The female inflorescence is commonly a single terminal head but second or third heads may develop on one stem. The head contains many spine-like branches 10–15 cm long. Each spine has a single spikelet just above its base. The head becomes detached from the plant and the spines are an aid to wind dispersal of seed along the shoreline (see Colour Plate 4).

Both male and female inflorescences can become infected by a floral smut, *Ustilago spinificis* Ludw.I. High infection rates have been found in both Australia and New Zealand. The appearance of the diseased female inflorescence is strikingly different from normal as infected spikelets are borne 1.5–4 cm above the base of each spine (Fig. 2E). Kirby (1988) found that almost all infected inflorescences were sterile and estimated that the reproductive cost of the smut can be up to 20%.

3.2 NURSERY PROPAGATION

A number of nurseries have attempted to raise spinifex plants on an operational scale. The main methods used have included:

- Setting of cuttings taken from stolons of mature plants (Christchurch City Council nursery, Linwood).
- Propagation from seed using standard nursery practices. Unsorted seed collections are sown in seed boxes and, following germination, are pricked out into containers (Forest Research Nursery and several others).
- Direct sowing of seed into final containers (Forest Research Nursery, Rotorua).

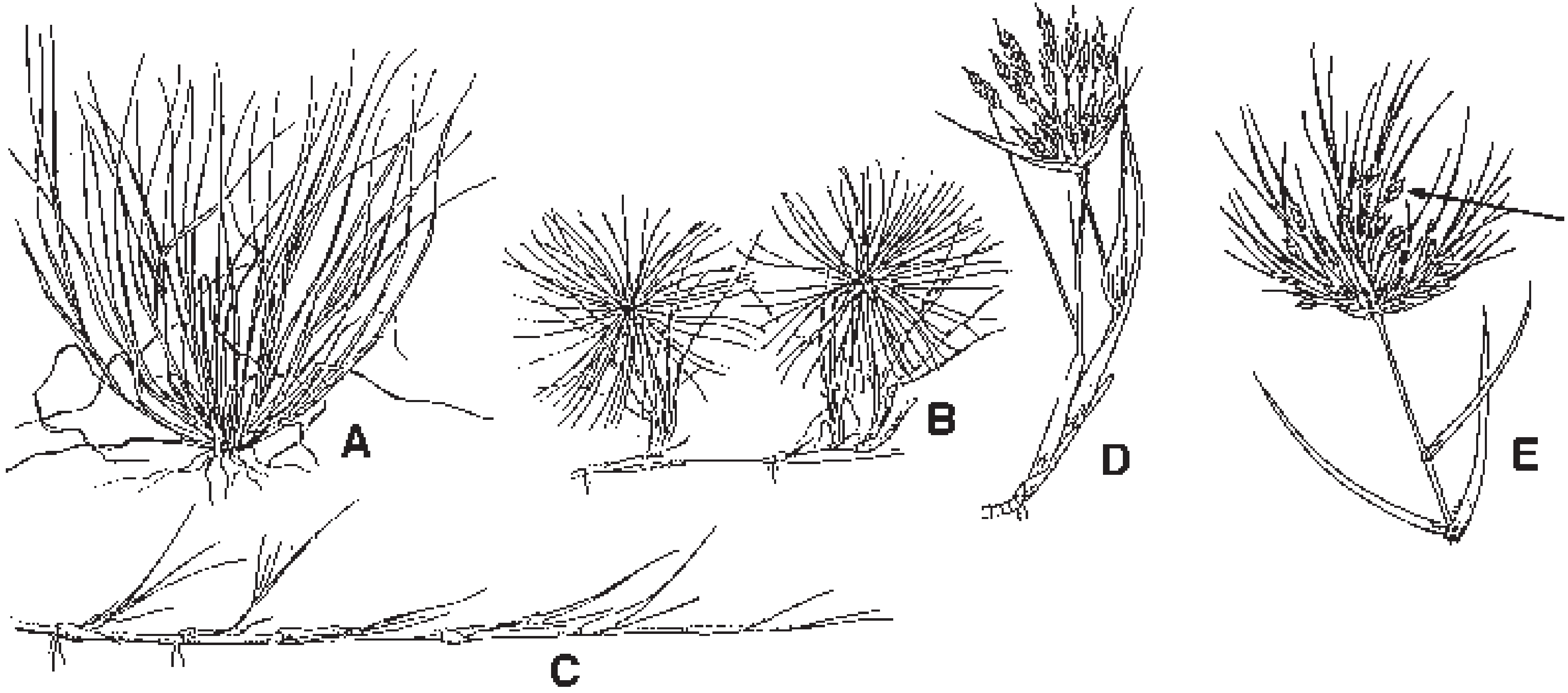


Figure 2. Growth characteristics of spinifex (*Spinifex sericeus*). A—typical established plant showing tillering; B—stolon or runner with vertical branches bearing female flowerheads or spikes; C—stolon showing roots at nodes; D—male flowerhead; E—diseased female flowerhead infected by floral smut (*Ustilago spinificis*). A major distinguishing factor between diseased and normal flowerheads is that spikelets (arrowed on illustration E) are borne 1.5–4 cm above the base of each spine. For revegetation purposes, collection of these seedheads should be avoided. (Illustrations A, B, and C reproduced from McDonald 1983; D and E by Dale Williams, Department of Conservation.)

3.2.1 Propagation from cuttings

A pilot trial at Forest Research Nursery which attempted to produce plants from sections of rooted and non-rooted stolons, was unsuccessful. A heated glasshouse was used, but the effects of misting or bottom heat were not tested.

The Christchurch City Council Nursery has reported some success with more refined propagation facilities. Cuttings were 10–15 cm section of stolons, each containing at least one node. They were taken from mature plants and placed into propagation cells with the node surrounded by potting mix. Under bottom heat and misting conditions, large numbers of cuttings rooted at the nodes. Each rooted cutting was transferred to a final container equivalent in size to a PB¾ (RX90 plastic pot). An estimated 80% of the original cuttings were ready for planting out within 18 months of setting. At this stage, individual plants had 3–6 leaves and were about 35 cm high. The intensive care required, together with some expected mortality, has contributed to the estimated cost of at least $2.50 per plant.

3.2.2 Seed collection and preparation

Collections of spinifex seed were made at Port Waikato and at beaches on the Coromandel Peninsula in February 1994, 1995, and 1996 when seedheads were beginning to be detached from parent plants. Seedheads were picked by hand from vigorous female plants and placed in large hessian sacks. Several sacks per hour were obtained from most sites. Smutted seedheads were not collected.

The 1995 collections were made at Whiritoa Beach and Matarangi Beach. At Whiritoa, irregular distribution of male and female plants was noted and collections A–H represented small discrete colonies of female plants (Table 7). The proximity of each sampled colony to neighbouring male or female colonies was recorded. At Matarangi, separate collections represented:

1—untreated foredune plants

2—foredune plants treated with fast-release high-nitrogen fertiliser one year earlier (Bergin & Herbert 1994)

3—detached seedheads collected from the strandline.

In New South Wales, large collections of spinifex seed are successfully stored in cool dark sheds with rodent control (Soil Conservation Service of NSW 1990). Hanging sacks of seedheads from the rafters of a cool shed was found to be a practical means of keeping seed away from rodents.

Individual spikelets containing seed were obtained by pulling the seedhead apart. Large pieces of chaff were removed. The seed at the base of each spine was still covered by scales. Seed viability was assumed if the swollen base of a spine was firm to the touch. Dissection of a random sample was used to confirm batch viability where white endosperm was exposed.

Seedheads comprised 41–160 spikelets. The number of spikelets per seedhead varied with site and with year of collection (Table 7). The proportion of spikelets containing sound seed varied between collections, ranging between 0.2 and 42.9%. Only five of the 16 collections showed viability exceeding 25%. The proportion of sound seed at Whiritoa was not related to the proximity of male plants.

TABLE 7. CHARACTERISTICS OF SPINIFEX SEED COLLECTIONS, 1994–1996.

PROVENANCE/ SEEDLOT		COLLECTION DATE	SAMPLE SIZE (No. of seed-heads sampled at random)	MEAN NO. OF SPIKELETS/ SEEDHEAD*	PROPORTION OF SPIKELETS CONTAINING VIABLE SEED (%)	APPROX. TIME REQUIRED TO OBTAIN 100 VIABLE SEEDS (mins)
Matarangi		17 Feb 94	50	160	22.3	15
Whangamata		26 Feb 94	50	147	2.9	55
Whiritoa		23 Feb 94	50	137	14.1	20
Port Waikato		Feb 94	50	110	8.0	35
Whiritoa	A	8 Feb 95	20	41	42.9	20
	B	8 Feb 95	20	52	8.8	40
	C	8 Feb 95	20	55	1.1	ND
	D	8 Feb 95	20	55	0.2	ND
	E	8 Feb 95	20	81	3.0	145
	F	8 Feb 95	20	45	16.4	20
	G	8 Feb 95	20	54	25.1	25
	H	8 Feb 95	20	46	18.6	25
Matarangi	1	9 Feb 95	20	66	25.9	20
	2	9 Feb 95	20	86	9.1	35
	3	9 Feb 95	20	48	28.9	15
Papamoa		7 Feb 96	50	89	42.3	30

ND = Not determined (impractical to continue).

Extraction and sorting of spikelets containing sound seed was time-consuming. When at least 25% of the seed was sound, it took 15–25 minutes to identify 100 viable seeds (Table 7). Where seed soundness was low it was impracticable to extract sound seed.

3.2.3 Seed sowing and germination

In a detailed laboratory study of spinifex seed, Harty & McDonald (1972) showed that germination was significantly inhibited by light. Only 14% germination was recorded in light compared with 56% in the dark. This suggested that spinifex seed must be buried in the sand before appreciable germination will occur. Nursery culture of spinifex seedlings has proved difficult in both New Zealand and Australia. At the Forest Research Nursery, large losses occurred at most stages of propagation.

Methods

Three techniques for germinating spinifex seed were evaluated using different seed collections (Table 8):

- Burying of whole seedheads to mimic the natural foredune process. Up to six seedheads were flattened on to the surface of a standard peat/pumice potting mix in a seed tray and covered with sieved potting mix to a depth of 1–2 cm.

- Scattering of spikelets containing sound seed (together with seedhead chaff and debris) on the surface of a standard peat/pumice potting mix in a seed tray and covering with sieved potting mix to a depth of 0.5 cm.
- Sowing of individual spikelets containing sound seed directly into plant containers. The rationale was that seedling mortality associated with transfer from seed trays to plant containers would be avoided if germination in individual containers was successful. Direct sowing into the final container is only feasible if individual spikelets with sound seed can be obtained in sufficient quantities. Each spikelet was placed vertically into the potting mix so that the seed was 2–3 cm below the surface and the spine pointed upwards. One or two seeds were sown per container.

Results

The Matarangi data indicated that time taken for spinifex seed to germinate may be related to the season of sowing. Seed sown in early winter took nearly 3 months to germinate whereas seed sown in spring took only 2 months (Table 8). Comparisons made with four 1995 collections indicated that the germination period was reduced by careful orientation of individual spikelets during sowing (Table 8). Burial of whole seedheads and broadcast sowing of spikelets gave similar results. Whole spinifex seed was still found after 19 months storage under dry conditions at room temperature but germination rates were not determined.

TABLE 8. TIME TAKEN FOR GERMINATION OF SPINIFEX SEED COLLECTED IN 1994 AND 1995, USING THREE SOWING METHODS.

PROVENANCE	SEED COLLECTION DATE	DATE OF SOWING	SEED STORAGE PERIOD (months)	NO. OF DAYS TO EMERGENCE		
				WHOLE SEEDHEADS BURIED IN SEEDBOX	SPIKELETS BROAD-CAST IN SEEDBOX	INDIVIDUAL SPIKELETS SOWN UP-RIGHT IN CONTAINERS
Matarangi	17 Dec 94	18 May 94	3	–	83	–
		30 Nov 94	9.5	–	–	31
Whangamata	26 Feb 94	18 May 94	3	89	89	–
		30 Nov 94	9.5	–	–	31
Whiritoa	23 Feb 94	18 May 94	3	75	76	–
		30 Nov 94	9.5	–	–	31
		25 Sep 95	19	–	–	54
Port Waikato	1 Feb 94	18 May 94	3	99	87	–
		25 Sep 95	19	–	–	54
Whiritoa G	8 Feb 95	27 Jun 95	4.5	–	140	86
Matarangi 1	9 Feb 95	27 Jun 95	4.5	–	144	78
Matarangi 2	9 Feb 95	27 Jun 95	4.5	–	142	80
		25 Sep 95	7.5	–	–	58
Matarangi 3	9 Feb 95	27 Jun 95	4.5	–	137	89
		25 Sep 95	7.5	–	–	60

3.2.4 Raising seedlings

Standard nursery practice

Seedlings potted-on after broadcast-sowing or burial of whole spikes showed variable survival rates. Of 300 seedlings potted into PB¾ planter bags in 1994, only 26% were alive 12 months after potting. Of 190 seedlings potted in 1995, 89% were alive one year later. Commercial nurseries in the Bay of Plenty have reported high mortality of seedlings after transfer to pots.

Seedlings sown in planting containers

After sowing of paired individual spikelets, moderate to high survival rates (55–75% after 7 months) were observed in all but one of the six seedlots tested (Table 9). Among the 1995 collections at least one seedling/container survived for 19 months in 45–83% of containers. Four of the six provenances tested produced at least one live seedling in 80% of containers after 19 months. Up to 10% mortality was observed during the period between the 7 month and 19 month assessments. In spite of the sorting of viable seed, only 30–71% survival was noted after 19 months. Survival was similar for seed sown in pairs in PB¾ planter bags and in Hillsons rootrainers.

TABLE 9. SEEDLING SURVIVAL FROM SPINIFEX SPIKELETS SOWN UPRIGHT IN PAIRS IN PB ¾ PLANTER BAGS.

YEAR	PROVENANCE	NO. OF CONTAINERS IN SAMPLE	SURVIVAL AFTER 7 MONTHS		SURVIVAL AFTER 19 MONTHS	
			PROPORTION OF CONTAINERS WITH ONE OR MORE LIVE SEEDLINGS (%)	PROPORTION OF SOWN SEED (%)	PROPORTION OF CONTAINERS WITH ONE OR MORE LIVE SEEDLINGS (%)	PROPORTION OF SOWN SEED (%)
1994	Matarangi	160	84	63	ND	ND
	Whiritoa	160	86	64	ND	ND
1995	Whiritoa	160	79	55	79	55
	Matarangi 1	160	62	39	45	30
	Matarangi 2	120	88	75	83	71
	Matarangi 3	160	87	64	80	60

ND = Not determined.

3.3 ESTABLISHMENT TRIALS

The planning of Forest Research planting trials has been influenced by results of Australian sand revegetation studies. In Australia, difficulties in propagating spinifex seedlings on an operational scale prompted trials investigating direct seeding and in situ transplanting of vegetative material. These techniques have been evaluated at three sites in New Zealand and small numbers of nursery-raised seedlings have been included in the trials for comparison.

3.3.1 Whiritoa Beach (near Surf Club)

Trial site

A trial planted in September 1993 on the south side of the Whiritoa Beach Surf Club was used to investigate the relative effectiveness of sexual and vegetative methods for establishing spinifex. The planting site was located on the seaward face of the foredune, above the high water mark, using gaps in the existing light spinifex cover.

Experimental factors

Comparisons were made between establishment rates when vegetative plant material, planted nursery-raised seedlings, and directly-sown seed were used.

- Vegetative material:
  - Terminal stolon sections approximately 1.2 m in length were buried individually in 10–15 cm deep trenches so that 7.5 cm of each tip was left exposed (method of NSW Public Works Department and Soil Conservation Service 1987). The stolons were obtained from plants growing on the foredune face.
  - Divided sections (divisions) of established plants were planted in 15 cm deep holes. Each division consisted of tillers, roots and sections of underground stolons including several nodes (method of NSW Public Works Department and Soil Conservation Service 1987). Plant material was obtained from stable dune areas where no above-ground stolons were present.
- Nursery-raised seedlings, 18 months old and 30–40 cm high were planted to a depth of 5 cm above the root collar.
- Direct seed sowing. Two methods were used:
  - Separated but unsorted spikelets were placed in short trenches 10–15 cm deep and covered with sand.
  - About 3 seedheads were placed in 15 cm deep spade holes (method of NSW Public Works Department and Soil Conservation Service 1987).
- Fertiliser application. All material was tested with and without fertiliser which was incorporated with sand in the planting hole (40 g/hole). Two fertiliser types were compared:
  - Slow-release NPK Magamp
  - Fast-release N fertiliser Nitram (ammonium nitrate—34% N). This product is used in Queensland for broadcast application to sand dune vegetation (Barr & MacDonald 1980).

Assessments

Plant survival was assessed in October 1993 and in February 1994. Seed germination rate was monitored at approximately 6 week intervals for 6 months after establishment.

Results

Highest survival rates (>85% after 5 months) were recorded for nursery-raised seedlings (Table 10). Use of Nitram killed all planted seedlings within 5 months, possibly because the fast-release high nitrogen formulation is more suited to broadcast application. Magamp did not influence survival rates, but treated seedlings were considered to be larger and had greener foliage.

After 5 months, stolons showed slightly higher survival rates (40%) than divisions (31%), but growth was not vigorous. Greater effort is required in obtaining division material. Use of stolons would be more practical and less harmful to the environment. Survival of plants developing from stolon cuttings in dune restoration projects in Queensland is estimated to be about 50% (Bergin & Herbert 1997). The lower values in this trial were probably related to difficulty experienced in finding suitably vigorous vegetative material in early September. Stolons are more likely to be young, green and actively growing in the autumn. Autumn transplanting of cuttings is preferred in Queensland.

Germination rates of seedlings after direct sowing were poor. Seedlings were first observed almost 4 months after sowing with a small number ranging in height from 3 to 20 cm. The poor viability of seed used in the trial probably contributed to the low germination rate.

TABLE 10. ESTABLISHMENT OF SPINIFEX FROM STOLONS, DIVISIONS, AND PLANTED SEEDLINGS AT WHIRITOA BEACH, COROMANDEL PENINSULA.

PLANT MATERIAL	NO. OF INDIVIDUALS PER SAMPLE	SURVIVAL AFTER 6 WEEKS (%)	SURVIVAL AFTER 5 MONTHS (%)
Stolons	20	70	40
Divisions	80	36	31
Seedlings	80	94	85

3.3.2 Whiritoa Beach South

Trial site

The spinifex trial was established on the foredune near to the pingao trial at the south end of Whiritoa Beach, Coromandel Peninsula.

Experimental factors

Plant establishment from stolon material was compared with that from direct seeding and from nursery-raised seedlings. Factors tested were:

- Use of stolons taken from nearby mature plants. Terminal stolon sections approximately 60 cm long were planted individually into 10 cm deep channels so that 5–10 cm of each tip was left exposed. Five stolons were planted within a circular plot 3 m in diameter.
- Direct sowing. Up to 3 seedheads were placed in 10–15 cm deep spade holes (method of NSW Public Works Department and Soil Conservation Service 1987). Twenty planting holes were evenly distributed within a circular plot 3 m diameter. Seedheads collected at Whiritoa in 1994 and 1995 were used. The 1994 seedlot contained 14% sound seed and the Whiritoa G seedlot contained 25% sound seed (Table 7).
- Use of nursery-raised seedlings. Eight groups of seedlings (8 seedlings/ group) were planted.

- Magamp was applied to the nursery seedlings by incorporating 30–40 g of fertiliser into each planting hole.
- Planting season. Stolons, seedheads and seedlings were planted in spring 1994 and in autumn 1995.

Assessments

Survival, plant growth characteristics and sand accumulation were assessed in April 1996. Germination rates were monitored at approximately 6-week intervals for the first six months.

Results

Overall survival from a total of 100 transplanted stolons was less than 5%. Transplanting of stolons was time-consuming in terms of both collection and planting. Although much of the work was willingly carried out by volunteers in locally based Beach Care groups, the effort was not justified.

After one year, plants were observed in fewer than 10% of the seedhead burial sites (Table 11). Only one plant was present at most sites and vigour was generally poor. Germination was observed within 2 months of spring sowing but autumn-sown seed did not germinate until the following spring. There was a tendency for spring-sown plants to be more numerous and larger than autumn-sown plants, but this could not be tested statistically.

TABLE 11. PERFORMANCE OF SPINIFEX PLANTS DEVELOPING FROM BURIED SEEDHEADS, WHIRITOA BEACH SOUTH, COROMANDEL PENINSULA. THIS ASSESSMENT WAS MADE ONE YEAR AFTER BURIAL. Values followed by the same letter are not significantly different ($p = 0.05$).

PLANTING SEASON	SURVIVAL (%)	PLANT VIGOUR*	HEIGHT (cm)	PLANT SPREAD† (CM)	ROOT COLLAR DIAM. (cm)
Autumn	4.6 a	3.1 a	13.0 a	4.0 a	0.37 a
Spring	9.6 a	3.1 a	23.7 a	5.0 a	0.39 a

* Vigour score: 1—weak, 2—unthrifty, 3—average, 4—good, 5—robust.

† Plant spread calculated as square root of (length x breadth).

At least 80% of nursery-raised seedlings survived for 2 years (Table 12). Neither planting season nor application of Magamp affected survival or height growth. Mean plant height after two years was 41.2 cm. Magamp fertiliser application at time of planting had a significant effect on other indicators of plant growth and increased plant spread, root collar diameter, length of runners and overall plant vigour (Table 12). Greater accumulation of sand was associated with growth improvement due to fertiliser treatment (see Colour Plate 5).

3.3.3 South Brighton Beach

Direct sowing trial

This was established in April 1995 near to the pingao trial on the foredune face at South Brighton Beach, Christchurch. Up to three seedheads collected from

TABLE 12. PERFORMANCE OF NURSERY-RAISED SPINIFEX SEEDLINGS, WHIRITOA BEACH SOUTH, COROMANDEL PENINSULA.
Assessments were made in autumn 1996. Within factor groups, values followed by the same letter are not significantly different (p=0.05).

	SAMPLE SIZE (No. of planted seedlings)	SURVIVAL (%)	PLANT VIGOUR*	HEIGHT (cm)	PLANT SPREAD† (cm)	ROOT COLLAR DIAMETER (cm)	MEAN NO. OF STOLONS PER PLANT	MEAN LENGTH OF STOLONS PER PLANT (cm)	SPINIFEX COVER WITHIN PLOT AREA (%)	SAND ACCUMULATION DEPTH (cm)
Planting season										
Autumn 1994	48	83 a	4.1 a	40.8 a	44 a	13.8 a	1.9 a	167 a	38 a	24 a
Spring 1995	60	84 a	4.0 a	41.8 a	42 a	11.5 a	1.0 a	74 a	43 a	27 a
Magamp fertiliser										
Absent	54	87 a	3.5 b	40.6 a	32 b	6.6 b	0.3 a	14 b	14 b	15 b
Present	54	80 a	4.7 a	42.1 a	54 a	20.2 a	2.9 a	257 a	71 a	32 a

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

the nearest spinifex population (north of Kaikoura) were placed in individual 10–15 cm deep spade holes. Ten plots each comprising 10 burial sites were established. Results after 6 months indicated that fewer than 5% of the sites contained one or more plants. These were only 1–5 cm high and after a further 2 months had disappeared. Considerable sand movement on the relatively steep site, caused by strong easterly winds in late spring, was thought to account for the failure.

Planting trial

In spring 1996, one hundred 18-month-old spinifex plants raised from cuttings at the Christchurch City Council Linwood Nursery were planted by the Council's Coast Care Unit within a fenced area in front of the South Brighton Surf Club. Approximately 30 g of Magamp/seedling were applied at planting. After 2 months, a very high survival rate and strong growth of most plants were noted. Some seedlings were inundated by sand near wind-break fences erected parallel to the seaward edge of the foredune.

3.3.4 Taylors Mistake

Trial site

Historical records indicate that the southern limit of spinifex was near to Christchurch (McCombs 1992) but no local population existed in 1996. In that year, the Christchurch City Council Coast Care Unit planted about 1000 spinifex seedlings on part of the relatively sheltered beach of Taylors Mistake

(Banks Peninsula). All seedlings had been raised at the Christchurch City Council's Linwood Nursery.

Experimental factors

Twenty groups of 10 seedlings planted in autumn 1996 were used to test two factors:

- Application of Magamp at planting.
- Use of rabbit-proof enclosures. Seedlings for the trial were planted in autumn and assessed for a range of parameters in autumn 1997.

Assessments

Survival, plant vigour and growth were assessed in December 1996 and in April 1997.

Results

A high survival rate was noted in late 1996. No browsing damage to spinifex outside the enclosures was observed despite the presence of rabbit sign in the vicinity of the trial. The 25–35 cm high seedlings were vigorous and it was clear that growth had occurred since planting. No differences attributable to planting season or to fertiliser treatment were apparent at this stage.

One year after planting, survival rates exceeded 85%. Height growth, plant spread and mean length of stolons had all been increased by fertiliser treatment (Table 13).

TABLE 13. PERFORMANCE OF SPINIFEX SEEDLINGS PLANTED IN AUTUMN 1996 AT TAYLORS MISTAKE, CHRISTCHURCH. PLANTS WERE ASSESSED AFTER 12 MONTHS.
Values followed by the same letter are not significantly different (p = 0.05).

TREATMENT	SAMPLE SIZE (No. of planted seedlings)	SURVIVAL (%)	PLANT VIGOUR*	HEIGHT (cm)	PLANT SPREAD† (cm)	MEAN NO. OF STOLONS PER PLANT	MEAN LENGTH OF STOLONS PER PLANT (cm)
Control	100	88a	4.1a	40.0a	62.4a	0.69a	58.3a
Magamp	100	94a	4.7a	43.8b	72.9b	1.04a	78.9b

* Vigour score: 1—weak, 2—unthrifty, 3—average, 4—good, 5—robust.

† Plant spread calculated as square root of (length x breadth).

3.3.5 Port Waikato

Trial sites

The trial was located at two sites on Port Waikato Beach, adjacent to the pingao trials near the carpark and in the blow-outs to the north of the Surf Club. It was established in May 1994.

Experimental factors

Two planting methods, two site types and the effect of fertiliser application were tested:

- Direct seed sowing. Using the 1994 Port Waikato seed collection (8% viable seed), a handful of spinifex spikelets was buried in each of twenty holes (15 cm deep) per plot (6 plots on the carpark site and 8 plots on the blow-out sites).
- Use of cuttings taken from nearby mature plants. Plenty of green, flexible spinifex stolons were available at Port Waikato Beach for immediate use. Seven plots each containing five 60–80 cm stolon tips buried in trenches 10–15 cm deep were established at each site. A 10 cm terminal section of each stolon was left exposed.
- Site types
  - – the steep foredune immediately adjacent to the carpark
  - – the blow-outs north of the Surf Club building where sand was highly mobile
- Magamp fertiliser (medium granule) incorporated into sand at time of sowing/planting.

Assessments

Plants were examined in early July 1994 and May 1995.

Results

On the foredune, no seedlings were observed 6 weeks after sowing and no perceptible growth of the stolon material was noted. In autumn 1995 (one year after planting) two of the 35 stolons planted had developed into vigorously growing plants.

At the blow-out sites most of the buried stolons and spikelets were partially or entirely uncovered 6 weeks after planting. Within a year, all plots had disappeared as a result of sand movement. Hundreds of spinifex stolons planted in the same area by the local Beach Care group produced only a few well-established plants.

4. Sand tussock trials

4.1 INTRODUCTION

Sand tussock is a grass that grows in discrete, compact tufts up to 70 cm tall. It is native to Australia and New Zealand and occurs on foredunes where there is some sand movement. Cockayne (1911) reported that sand tussock was found in all parts of the coast of New Zealand and described it as a sand collector that can survive slow sand accumulation. During this century its range and abundance have been greatly reduced. Currently it is mainly found on sand plains, although it sometimes occurs on mobile foredunes (see Colour Plate 6).

4.2 NURSERY PROPAGATION

4.2.1 Seed collection and preparation

A population of about 15 sand tussock plants at Whiritoa Beach was observed over a two year period. Each tussock produced numerous flowering spikes in late spring and seedheads developed during summer. Ripe seed was collected from seedheads in early January 1994 and early February 1995. Natural seed shedding occurred in mid to late summer. Seed was easily separated from the spike and was successfully stored dry at room temperature or in the refrigerator until sowing.

4.2.2 Seed germination and raising of seedlings

Seed was sown in winter, 4 months after seed collection. It was broadcast onto a seedbed and received a light covering of sieved potting mix. Germination took 20–25 days under unheated glasshouse conditions.

Seedlings were pricked-out into PB¾ containers or Hillson rootrainers 2–3 months after sowing, when they were approximately 5–7 cm high. At the Forest Research Nursery, a mean height of 30 cm and tussock base diameter of 2–5 cm was achieved within 18 months of sowing. Survival rate was high. Similar sized RX90 pots have been used successfully by the Christchurch City Council Nursery at Linwood. Propagation costs for 15–18 month old sand tussock seedlings were similar to those for pingao seedlings ($1 per seedling).

4.3 ESTABLISHMENT TRIALS

4.3.1 Whiritoa Beach

Trial sites

Three sand tussock trials were established at Whiritoa Beach in autumn 1995. The first was located at the southern end of the beach adjacent to the spinifex and pingao planting trials (see description in Section 2). One sand tussock plant was found at this site before trial establishment. The second trial was located at the northern end of the beach on dunes adjacent to the small estuary. The planted area, just above the high water mark, was sparsely colonised by spinifex. One large naturally established sand tussock plant was also found in vicinity of this trial. The third trial was located on the foredune north of the Surf Club on the main beach, where a light vegetation cover dominated by spinifex and sand convolvulus was present. The site is very exposed and the seaward edge was affected by swash at high tide during easterly storms.

Experimental factors

The Whiritoa South trial consisted of 40 plots each planted with 10 seedlings. The Whiritoa North and Whiritoa Surf Club trials each consisted of five plots containing 10 seedlings. Factors tested were:

* Magamp fertiliser applied at time of planting
* The effect of planting season (Whiritoa South trial only). A second duplicate planting was carried out in spring 1995.

Assessments

Trials at all three sites were assessed for survival and growth approximately 18 months after autumn planting and 12 months after spring planting.

TABLE 14. PERFORMANCE OF NURSERY-RAISED SAND TUSSOCK SEEDLINGS PLANTED AT WHIRITOA BEACH, COROMANDEL PENINSULA.
Assessments were made in autumn 1996. Within factor groups, values followed by the same letter are not significantly different (p = 0.05).

	SAMPLE SIZE (No. of seedlings planted)	SURVIVAL (%)	PLANT VIGOUR*	HEIGHT (cm)	PLANT SPREAD† (cm)	TUSSOCK DIAMETER (cm)	SAND TUSSOCK COVER WITHIN PLOT AREA (%)
Whiritoa Beach south							
PLANTING SEASON							
Autumn 1995	100	86 a	3.9 a	49.3 a	43 a	7.3 a	33 a
Spring 1996	100	75 a	3.7 a	48.8 a	32 a	3.7 b	21 b
Magamp fertiliser							
Absent	100	90 a	2.8 b	37.2 b	21 b	3.1 b	14 b
Present	100	70 b	4.9 a	62.1 a	50 a	7.9 a	41 a
Whiritoa Beach north							
(AUTUMN PLANTING)							
Magamp fertiliser							
Absent	50	55	1.9	36.8	18	54.7	7
Present	50	49	2.8	43.0	23	48.9	12

* Vigour score: 1—weak, 2—unthrifty, 3—average, 4—good, 5—robust.

† Plant spread calculated as square root of (length × breadth).

Results

On the exposed site (Whiritoa Surf Club), only two of the 50 planted seedlings survived for one year. Sand movement (up 30 cm accumulation) was thought to have contributed to the high mortality. The lower survival rate of 50% recorded at the northern site was associated with high water levels caused by storms and high tides and the accumulation of litter along the strand line. At the relatively sheltered Whiritoa South site, at least 75% of seedlings survived for one year after planting (Table 14).

Application of Magamp fertiliser significantly increased plant survival, vigour and all measured growth parameters at the southern site (Table 14, and see Colour Plate 7). Treated plants were 25 cm taller, and provided more cover. At the northern site, use of fertiliser also appeared to have had a positive effect, but statistical analysis of data was not possible. At the southern site, tussock diameter and plant cover were greater in the autumn-planted plots (Table 14).

4.3.2 South Brighton Beach

One hundred seedlings were planted on a steep, relatively exposed foredune site in April 1995. Magamp was applied at time of planting and plant survival and growth were assessed in April 1996. Survival rate after one year was low (47%). Fertiliser improved plant vigour and height (Table 15), but data for other growth parameters were too variable to provide clear evidence of a response to fertiliser treatment.

4.3.3 Brighton Spit

At Brighton Spit, 100 seedlings were planted on the foredune but only one survived. Most seedlings were severely browsed by rabbits within a few days of planting.

TABLE 15. PERFORMANCE OF NURSERY-RAISED SAND TUSSOCK SEEDLINGS PLANTED AT SOUTH BRIGHTON BEACH, CHRISTCHURCH, 12 MONTHS AFTER PLANTING.
Values followed by the same letter are not significantly different (p = 0.05).

TREATMENT	SAMPLE SIZE (No. of planted seedlings)	SURVIVAL (%)	PLANT VIGOUR*	HEIGHT (cm)	PLANT SPREAD† (cm)	MEAN NUMBER OF FLOWERHEADS PER PLANT	SAND TUSSOCK COVER WITHIN PLOT AREA (%)	SAND ACCUMULATION DEPTH (cm)
Magamp	50	56 a	4.5 a	45.5 a	67 a	0.63 a	53.0 a	9.4 a
Control	50	35 a	2.8 b	23.4 b	39 a	0.13 a	11.3 a	–2.5 a

* Vigour score: 1—weak, 2—unthrifty, 3—average, 4—good, 5—robust.

† Plant spread calculated as square root of (length x breadth).

5. Discussion

5.1 SEED COLLECTION AND PROPAGATION

Of the three indigenous sand-binding species investigated here, pingao has been most widely raised in nurseries and many thousands of pingao have been planted on dunes. No major problems have been encountered in collecting seed and raising seedlings throughout the country.

Difficulties in obtaining sufficient quantities of viable spinifex seed require further research if nursery-raised seedlings are to be used in large-scale revegetation of degraded dunes. Although no correlation between seed viability and proximity to male plants could be demonstrated in a small survey at Whiritoa Beach, this, and a number of other factors relating to phenology and seed formation, needs to be investigated. These include closer examination of the effects of proportions of male and female plants, the prevailing wind direction, and climatic conditions during the pollination period.

The techniques of sowing sorted viable spinifex seed, sowing directly into the final container, and increased chances of success through sowing spikelets in pairs, offer some practical solutions to problems encountered in the raising of seedlings. Separation of spikelets containing sound seed is unlikely to be cost-effective if viability is lower than 20%. Where seed collections have a higher proportion of sound seed, the time taken to sort viable seed can be offset by elimination of the need for seed trays. Losses associated with seedling transfers can be avoided by direct sowing into final containers. Mortality during later stages of seedling growth in the nursery requires further investigation. Currently, high mortality at this stage means that spinifex seedlings cost at least twice as much as pingao and sand tussock seedlings. Plants can be grown from stolon sections but this technique requires bottom heat and misting which adds to the cost. Improvement of survival rates of seedlings grown from seed should be accorded high priority in future research programmes.

Sand tussock is easily raised from seed in the nursery but because the species is represented by only a few plants in scattered locations, seed sources are restricted. For large-scale propagation and planting programmes it is recommended that an area of plants should be grown from seed (preferably obtained from a local natural population), to provide a secure long-term seed source.

5.2 ESTABLISHMENT OF SAND-BINDERS ON FOREDUNES

Forest Research trials and management-scale planting programmes have demonstrated that three indigenous sand-binding species, pingao, spinifex and sand tussock, can be established on foredune sites throughout New Zealand (see Colour Plate 8). Propagation and planting techniques developed here will assist in extending the distribution of pingao and in modifying the current “threatened” status of sand tussock. Trials with all three species have indicated that good-quality seedlings treated with slow-release fertiliser at time of planting can successfully colonise moderately mobile sand on foredunes.

Seedling size and time of planting will vary according to the objectives of the planting programme; the resources available; and climatic conditions. Although the effects of seedling size were only tested on pingao, responses of spinifex and sand tussock are likely to be similar. Trials and operational programmes indicated that 15 month old pingao seedlings raised in Hillsons rootrainers or similar sized containers to a height of 50 cm will perform well when planted on dunes. The poor performance of small, rigorously hardened-off seedlings at Nuhiti Beach suggested that a threshold value for size may be associated with tolerance to dune conditions. Although the performance of pingao raised in larger containers is likely to be better, this advantage may be offset by the higher cost of containers, increased space requirements, and difficulty of transport to beach sites.

The effect of planting season was only tested at one site and in one year for each species. It is likely that seasonal performance of planted sand-binders will vary from year to year depending on climatic conditions. Autumn-planted seedlings may be subjected to winter storms that could reduce survival. Spring-planted seedlings are likely to succumb to early summer drought if root systems have not developed and extended into lower sand levels. In operational plantings, large numbers of sand-binders have established successfully when planted from autumn through to early spring.

Where the slow-release NPK fertiliser Magamp was applied at time of planting, values for growth indices were often higher, plants often became darker green in colour and higher vigour scores were often recorded. Chronic nitrogen deficiency is known to be a characteristic of unstable coastal sand in New Zealand (Hunter et al. 1991), and it is almost certain that the nitrogen component of the fertiliser was responsible for this effect.

Mobile dunes with low to moderate rates of sand accumulation are the preferred habitat for sand-binding plants. Group planting of all three species was effective in promoting sand-trapping within 6 months. Planting programmes with these species should be focussed on the foredune, particularly on its seaward face. Well-established plants are more likely to resist larger accumulations of storm-driven sand, but inundation or sand excavation invariably have a negative effect on survival.

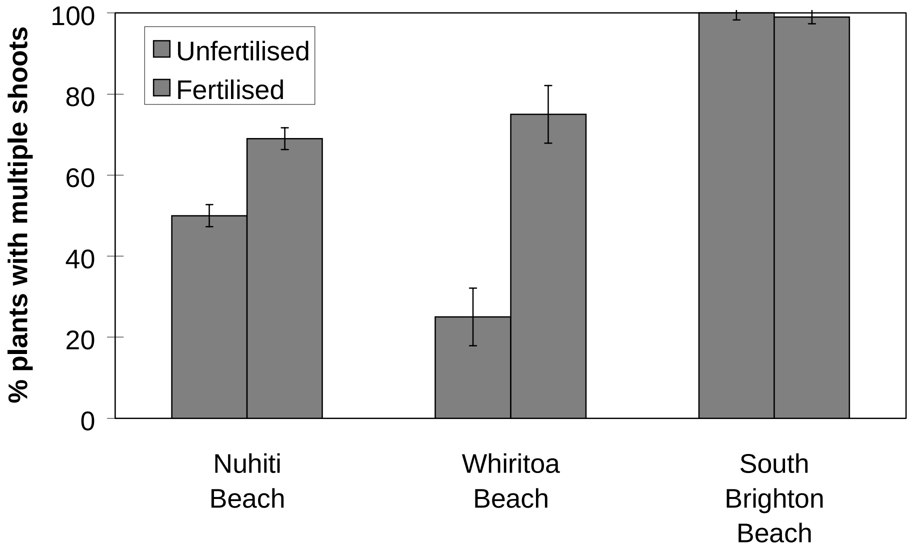
Hydrogel tested with pingao at two sites did not improve growth of planted seedlings. Effectiveness of this material may depend on levels of intensity and duration of drought which were not experienced in these trials. The cost of material and labour involved in the application of hydrogel is unlikely to be justified in large-scale revegetation programmes.

5.3 SITE EFFECTS

5.3.1 Pingao

Twelve months after planting, the growth performance of surviving pingao (measured as percentage of plants with multiple shoots) appeared to be poorer

Figure 3. Percentage of planted pingao exhibiting multiple shoots in three trials after 12 months. Bars show standard errors of means.



at two North Island sites than at South Brighton Beach (Fig. 3). There was a significant growth response to fertiliser treatment in the North Island trials. In contrast, growth of pingao at South Brighton Beach was not influenced by application of fertiliser. Magamp applied at time of planting did not significantly improve plant survival at North Island sites (Fig. 4).

The greater mobility of the finer sand combined with the strong on-shore easterly winds at the South Brighton Beach site evidently favoured pingao establishment and may have compensated for any nutrient deficiency. Sand accumulations up to 20 cm were observed within 12 months (Fig. 5). Fresh sand, possibly containing additional nutrients (Willis 1965) may have masked the effect of fertiliser. In contrast, the lower degree of sand accumulation at Whiritoa Beach, where sand grains are larger and winds more moderate, may have been responsible for the more pronounced response to fertiliser. Sand movement and the vigour of established pingao and spinifex on foredunes both appeared to be lower on the relatively sheltered northeastern coasts of the North Island than on more exposed beaches (North Island west coast; South Island eastern and southern coasts). At Nuhiti Beach, pingao seedlings planted

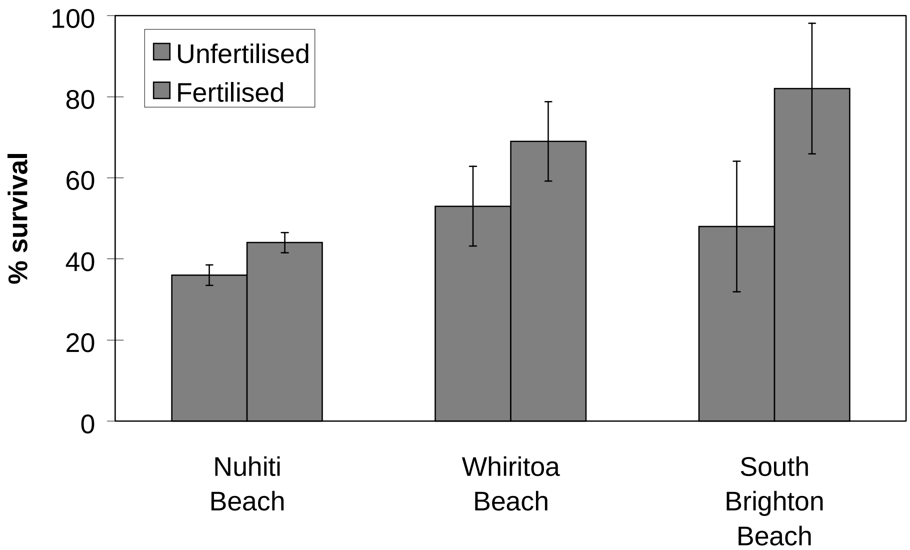
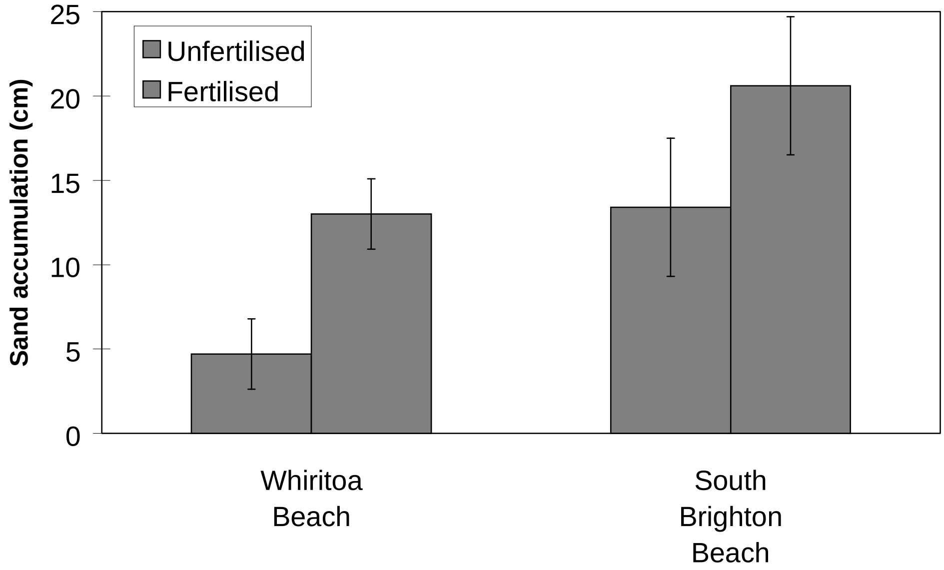


Figure 4. Survival of planted pingao in three trials after 12 months. Bars show standard errors of means.

Figure 5. Sand accumulation around planted pingao in two trials after 12 months. Bars show standard errors of means.



on exposed unstable foredunes with sparse vegetation cover consistently outperformed seedlings planted on stable, densely vegetated dunes. Improved vigour of pingao due to fertiliser treatment has resulted in increased sand accumulation in fertilised plots.

5.3.2 Spinifex

Although it is difficult to raise large numbers of seedlings, planting trials have shown that spinifex can be successfully established on bare foredunes.

Nursery-raised seedlings planted at two foredune sites (Whiritoa Beach and Taylors Mistake), showed similar survival and growth rates to those of planted pingao seedlings. Fertiliser treatment did not affect spinifex survival (Fig. 6) but improved growth rates (Fig. 7). Although sand movement could not be measured at Taylors Mistake, it was clear that considerable sand accretion had occurred and this may have masked the effect of fertiliser. Growth of spinifex was greater at Taylors Mistake than at Whiritoa Beach in spite of the Simpson

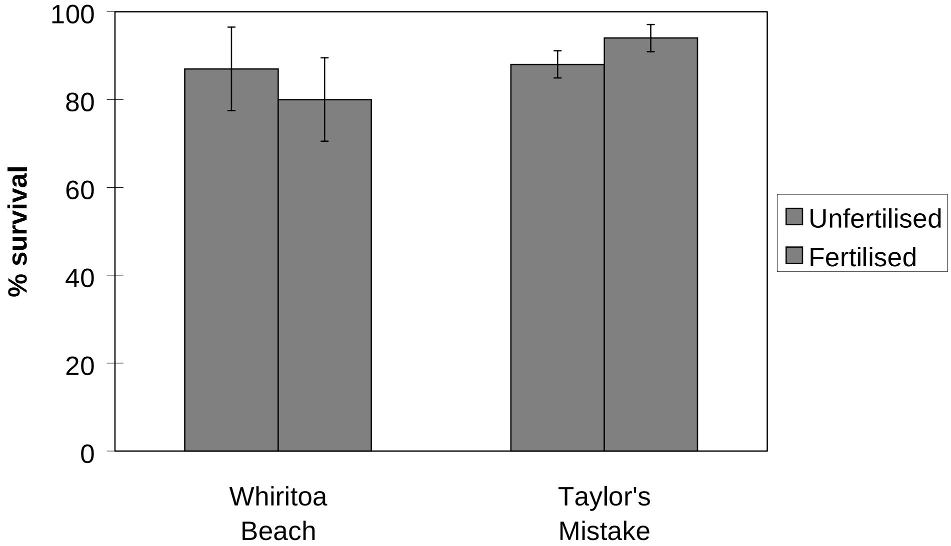
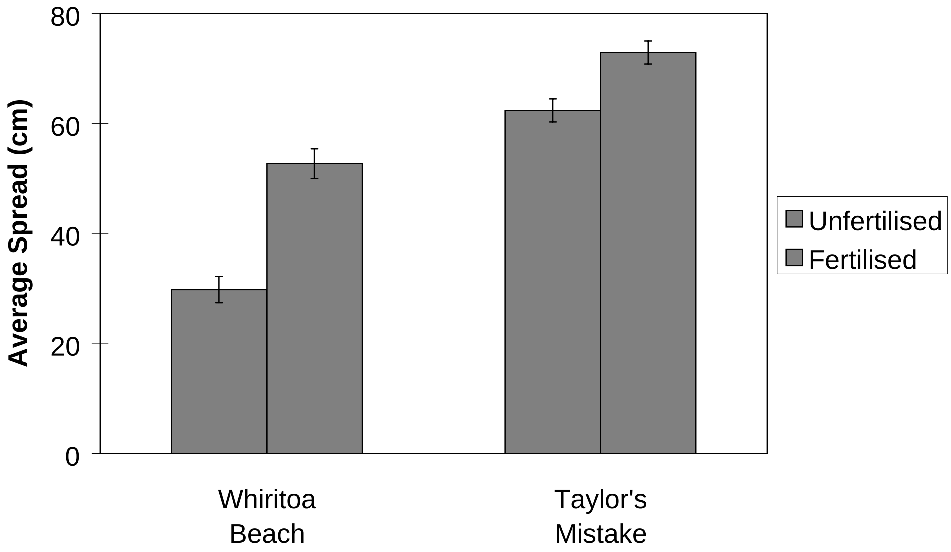


Figure 6. Survival of planted spinifex in two trials after 12 months. Bars show standard errors of means.

Figure 7. Average spread of planted spinifex in two trials after 12 months. Bars show standard errors of means.



(1974) observation that Christchurch represented the southern limit of the natural distribution of spinifex in pre-European times.

Poor establishment of spinifex stolon cuttings and poor germination of spinifex seed sown directly on the dunes was surprising in view of the fact that these techniques are used successfully in New South Wales and Queensland (Soil Conservation Service of NSW 1990; Beach Protection Authority of Queensland 1981). Direct seeding trials in New Zealand have been limited by the low proportion of sound seed per seedhead and the reasons for this infertility require further research.

Planting of spinifex seedlings is likely to result in a greater degree of mixing of male and female plants (Colin Ogle pers. comm.). Rates of natural seedling establishment in the past have probably been very low, and a large area of sand may be occupied by either a single male or a single female plant. Closer admixtures of male and female plants should result in the development larger

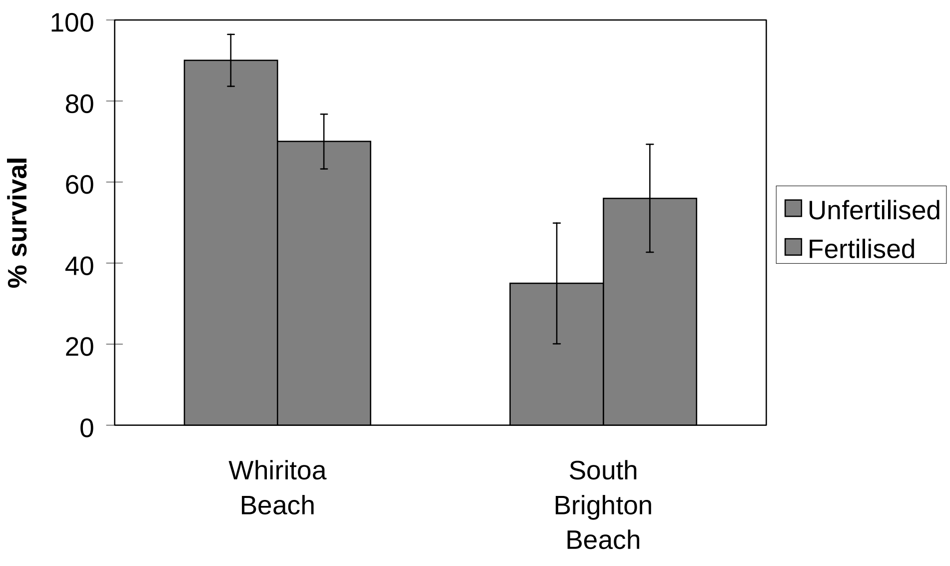


Figure 8. Survival of planted sand tussock in two trials after 12 months. Bars show standard errors of means.

quantities of viable seed. Monitoring to compare seed production in planted and natural colonies will be carried out to test this hypothesis.

5.3.3 Sand tussock

The planting of 50 cm high seedlings raised in PB¾ planter bags or Hillson rootrainers has resulted in 80% survival and good growth on foredunes within 2 years under conditions of moderate sand accumulation.

As with pingao and spinifex, fertiliser treatment did not influence survival (Fig. 8) but improved plant spread (Fig. 9). Plants on the more mobile sand of South Brighton foredunes were larger after 12 months than those planted on the less exposed site at Whiritoa Beach.

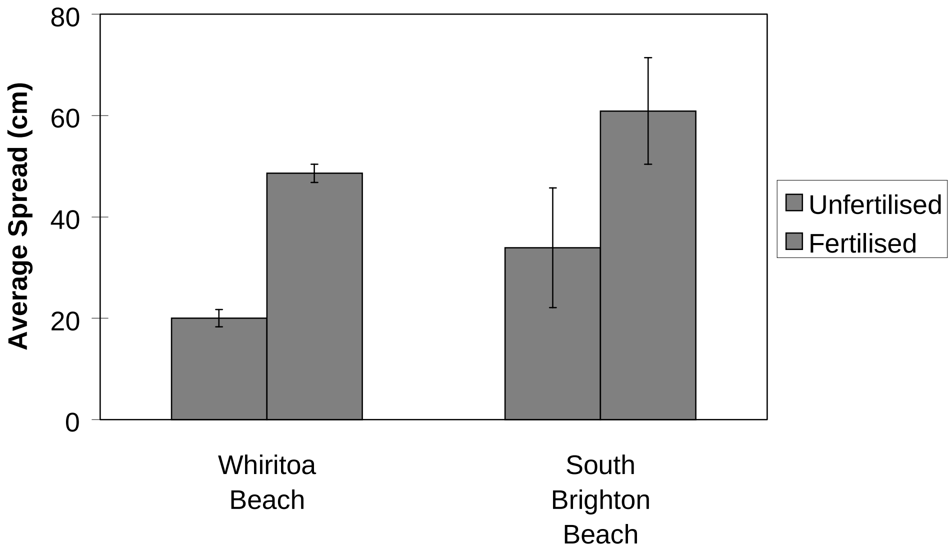


Figure 9. Average spread of planted sand tussock seedlings in two trials after 12 months. Bars show standard errors of means.

5.4 FOREDUNE REHABILITATION STRATEGIES

Currently, the most effective technique for establishing sand-binding species on dunes in New Zealand appears to be the planting of nursery-raised seedlings. Rehabilitation of any ecosystem by planting will always be expensive. Nursery-raised seedlings cost at least $1 each and planting-out is labour-intensive. An alternative strategy is the enhancement and protection of existing vegetation remnants, which should be considered before undertaking a planting programme. Depending on local circumstances, this may require additional management options such as provision of fencing and accessways in high public-use areas; the development of education programmes; the use of sign posts emphasising the importance of dune vegetation; the exclusion of grazing stock; control of wild animals such as rabbits; or use of fertiliser to improve the vigour of vegetation cover. Appropriate combinations of these options may be worthwhile. If planting is to be carried out, one or more of these options is also likely to be necessary.

A decision to reconstruct indigenous foredune communities, or to enrich remnant vegetation by planting, may be appropriate for cultural, historical, or practical reasons, or to improve local amenities or landscapes. It is important to acknowledge that the scale on which this can be achieved is likely to be limited in comparison with sand stabilisation programmes that have been undertaken behind the foredune using marram grass and other exotic plant species (Wendelken 1974; Gadgil & Ede 1998). Except on the foredune face, marram grass is likely to be more vigorous and less susceptible to disturbance than indigenous sand-binding species. Marram is less suited to revegetation of foredune faces than spinifex and pingao where the indigenous sand-binders are more tolerant of direct exposure to salt-laden winds. Marram grass is often dominant on dunes immediately landward of the foredune face (Esler 1978).

Use of indigenous species for sand dune rehabilitation should be initially confined to areas that have high ecological, cultural or community value. It will succeed best where there is a real desire by local community and managing agencies for enhancement of the natural character of the dunes. Planted areas nearly always require continued vigilance and maintenance. Partnership between local Beach Care or Coast Care groups and local authorities has already resulted in worthwhile restoration of degraded dunes in several popular coastal areas (Bergin et al. 1997) (see Colour Plate 9).

It has been demonstrated that pingao, spinifex and sand tussock grow best under conditions of moderate sand movement. Due to the continually changing nature of the coastal environment, it is not always easy to identify areas where greatest success can be expected. Foredunes are exposed to adverse weather and sea conditions which include unusually high tides, storms, strong winds from different directions, salt spray, extremes of temperature and drought and the destructive effects of introduced animals and human activity. Failures must be expected from time to time. Often the degree of damage due to storms or human impact varies considerably over short distances and from one year to the next. A rehabilitation strategy that spreads risk of failure over time and across a defined area will be most likely to succeed. Where planting is considered, the aims should be to produce large numbers of seedlings at low cost; to plant the most sheltered areas first; and to accept setbacks.

5.5 MAINTENANCE AND MONITORING

Successful restoration of degraded dunes on an operational scale will require continued vigilance. Regular inspection and follow-up maintenance of fences, signs, and accessways will be needed. The replanting of damaged areas and regular fertiliser application may be required to enhance growth of surviving plants.

The success of a restoration programme will be determined by the effects of interaction between management practice and local conditions. Two important indicators of success are plant vigour and the continuity of the vegetation cover. Both should be monitored regularly so that maintenance can be carried out and management practices modified as required. It is only necessary to measure small areas, providing that they represent the vegetation development over the whole planted site.

Measurement of the growth rate of grasses and sedges is difficult. At first, the most useful indices of success will be survival rate and lateral growth rate of individual plants. Leaf length is unreliable. The number of shoots per pingao plant or the number and length of spinifex stolons will provide a reasonable indication of growth rate. For sand tussock, diameter of the base of the plant is the most practical index. Later, when it is difficult to distinguish individual plants, vigour and plant cover per unit area can be assessed directly.

The most desirable end result is a frontal dune with a continuous cover of vigorous sand-binding vegetation undisturbed by human or animal activity. Uncontrollable disturbance caused by wind and/or wave damage will be minimised if the zone containing sand-binding and sand-trapping vegetation is wide enough to allow spontaneous recolonisation and consequent dune-building. The long-term objective of a dune rehabilitation programme should be progression towards the development of a naturally self-sustaining ecosystem, which is based on indigenous species wherever practicable.

5. Acknowledgments

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Colour Plates

Plate 1. Forest Research has established a series of planting trials along this bare foredune at Whiritoa Beach, Coromandel Peninsula, using three sand binding species: pingao, spinifex, and sand tussock. Nursery-raised seedlings were established in small groups for each species, and a range of treatments including effect of fertiliser at planting were applied. Spinifex establishment from seed sowing and transplanting of runners was also investigated.

Plate 2. Pingao (golden sand sedge) at Hicks Bay, East Coast. Pingao seedheads develop in late spring/early summer.

Plate 3. Seven-month-old pingao treated with 30 g Magamp fertiliser per seedling at time of planting. Fertiliser has improved growth rate, vigour and plant colour.

Plate 4. Spinifex (silvery sand grass) at Tairua Beach, Coromandel Peninsula. Seedheads begin to detach from female plants in January.

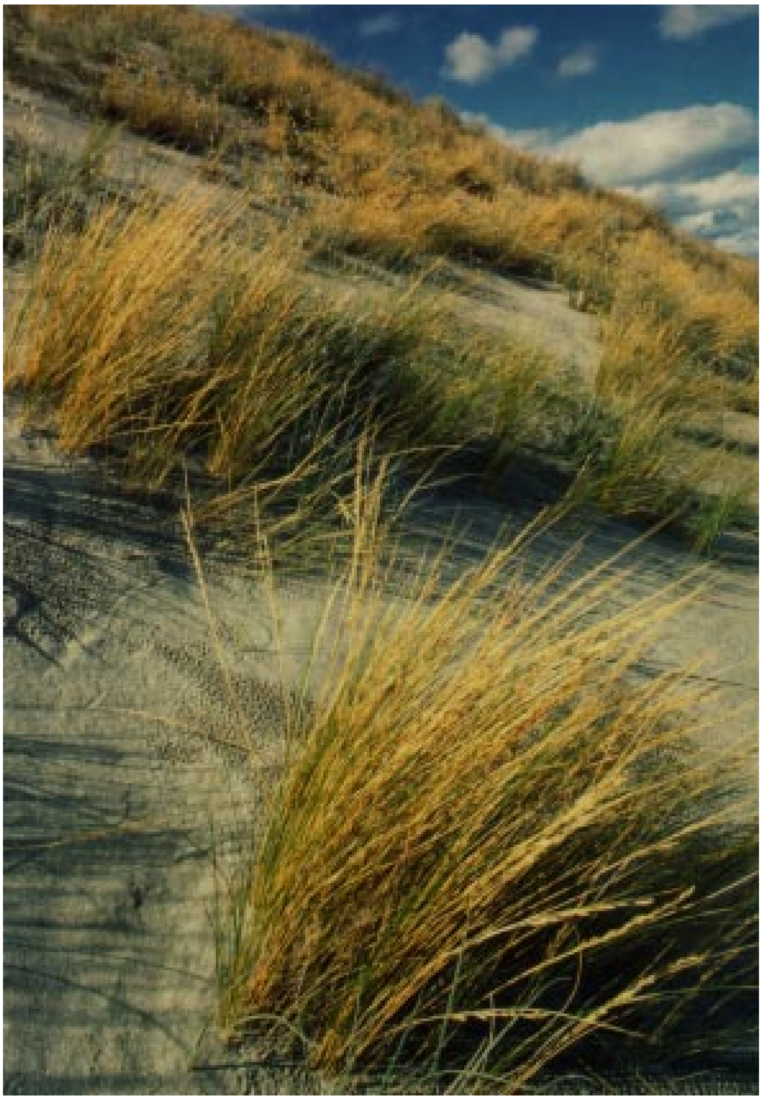

Plate 5. *(Above)* Seven-month-old spinifex treated with 30 g Magamp fertiliser per seedling at time of planting. Fertiliser has improved growth rate and stimulated stolon formation.

Plate 6. *(Left)* Sand tussock at Tolaga Bay, East Coast. Seedheads form during summer and seed can be collected in January.

Plate 7. *(Above)* Twelve-month-old sand tussock treated with Magamp fertiliser at time of planting (foreground) have grown considerably larger than non-fertilised plants (small plot located behind). Fertilised plants are already trapping sand and initiating the dune building process.

Plate 8. *(Right)* A two-year-old mixture of spinifex, pingao and sand tussock planted on a bare foredune site at Papamoa Beach, Bay of Plenty. Fencing, signs,

Plate 9. Nursery-raised seedlings of spinifex being planted in a bare area along the foredune by a Beach Care group, Tairua Beach, Coromandel Peninsula. Community-based Coast Care and Beach Care groups have been successful in many areas of New Zealand in the revegetation of foredunes.