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REHABILITATION OF COASTAL DUNES USING INDIGENOUS SAND BINDING SPECIES

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ABSTRACT

Techniques for revegetation of degraded foredunes using the three major indigenous sand binding species, pingao, spinifex and sand fescue have been investigated. Emphasis has been on developing guidelines from both trials and observations of management-based practices for the rehabilitation of dunes largely based on the planting of nursery-raised seedlings. The aim is to develop practical techniques that are of use to coastal managers and community-based interest groups such as Beach Care and Coast Care.

Seed characteristics and methods for collection and preparation of seed for raising seedlings are described. Pingao and sand fescue seedlings can readily be raised in large numbers in a nursery. However, there are difficulties in the nursery-raising of spinifex seedlings at reasonable cost due to lack of vigour and high mortality of seedlings.

Nursery raised seedlings of all three indigenous sand binding species can be successfully planted on foredunes. Establishment trials have been established in several North Island sites and along the beaches near Christchurch. The preferred site for planting sand binders is the active foredune just above high water level where moderate sand accumulation can be expected. Growth is significantly boosted with the addition of a slow-release fertiliser at planting especially on the less exposed beaches of the eastern North Island. Greater sand movement on the west coast of the North Island and along the Christchurch beaches probably provide greater nutrient supply to planted seedlings but high mortality on some sites can occur.

Transplanting of cuttings and direct seeding of spinifex have been investigated at two beaches using successful techniques developed in Australia where spinifex is also a local native species. In contrast to management-scale restoration of dunes in New South Wales, there was poor survival of cuttings and poor germination and growth from direct seeding of spinifex in the New Zealand based trials.

KEYWORDS: sand dunes, restoration, planting, *Desmoschoenus spiralis, Spinifex sericeus, Austrofestuca littoralis*

INTRODUCTION

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 widescale grazing and fire (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 the continuing widescale degradation of indigenous vegetation communities on foredunes.

In recent years, there have been numerous programmes to restore natural communities on the sand dunes to meet a range of objectives including cultural, aesthetic and recreational values as well as conservation and biodiversity considerations. In addition, the Resource Management Act (1991) places 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.

The Indigenous Forest Management section, New Zealand Forest Research Institute (FRI), Rotorua, has been investigating methods of propagation and management-scale establishment of indigenous sand binding species on foredunes. This programme has been 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 has been the high level of

PART I - PINGAO

SEED COLLECTION AND PREPARATION

Pingao seed, is a 3-5 mm ovoid shiny black nut borne on 15-30 cm long flowerheads that are on stalks up to 90 cm tall. Pingao seed can be collected from established stands in large quantities in December-early January in both the North Island (Table 1) and South Island. Ripening of seed can vary from year to year probably due to differences in local climate. Pingao in those parts of the country with higher temperatures sheds seed earlier than plants from cool regions. Seedfall continues for 2-4 weeks being prolonged in large colonies where vigorous plants have numerous large flowerheads. Collection is best carried out just as seed is beginning to be shed. This is evidenced by seed and debris accumulated in sand hollows in the vicinity of flowering plants. At this stage seed can be easily dislodged from dry seedheads by rubbing with the fingers. Immature seed is green and difficult to dislodge and collections should be delayed until nuts have turned shiny black. Courtney (1984) suggested that seed collected late in the season may be more difficult to germinate but this was not tested in the FRI trials.

For large collections, seedheads are cut from pingao when seed has begun to shed naturally. Selection of seedheads over a wide area and from relatively large colonies not only ensures that a small proportion of the total seed is collected, but also ensures that seed is collected from a range of different plants within one locality. Seed is easily separated from dry seedheads by scraping with fingers or a blunt object resulting in a large quantity of seed husks containing the seed. Winnowing to separate seed from debris is difficult to carry out without losing viable seed. Intensive cleaning of seed has not proved necessary for large scale nursery-raising techniques.

Soundness of seed can be quickly determined by cutting a small sample of seed during collection using a sharp blade to identify a full white-cream coloured endosperm content of viable seed. Shriveled seed can be readily identified and are invariably hollow or have discoloured dry contents. Large quantities of seed have been stored dry for several months in plastic bags in a refrigerator with no apparent major loss of viability.

SEED SOWING AND GERMINATION

Pingao responds to standard nursery raising procedures used for a large number of species at the FRI Nursery in Rotorua. Pingao seed is broadcast sown along with the large quantities of husk and debris onto a seed raising mix of 1:1 peat:pumice in seed boxes. No pre-treatment, including storage, is required. Seed is covered with sieved potting mix to a depth of 3-5 mm and covered with an inverted empty seed tray and a plastic cover to maintain high humidity. Regular watering is necessary. Covers are removed once germination begins.

Germination trials over several years indicate that seed sown in late summer germinates in 11-20 days (Table 1). If sown in the winter germination takes longer, from 26-31 days (Table 2). Collections from five different sites in 1988/89 gave 36% to 93% germination. In most years adequate numbers of seedlings are obtained from seed collections and where seed has been sown thickly, a lush grass-like sward develops. Germination can be dramatically affected by rodents and birds with several collections of sown seed in 1993 and 1994 at the FRI Nursery virtually wiped out.

RAISING SEEDLINGS

Within one month of germination, seedlings are up to 5 cm tall. Pingao are easily transferred from seed boxes into a range of container options using standard nursery procedures. Seedlings are carefully removed from the tray, separated and long roots trimmed before pricking into containers. It is important to ensure that the main tap root is not deformed. The preferred standard potting mix at the FRI Nursery is 1:1 peat:pumice or similar. Depending on how long plants are to raised in the nursery, seedlings can be initially pricked into small containers such as paper pots and then transferred to larger containers several months later. Alternatively, seedlings can be pricked directly into the final container.

The preferred age and size of plants depends on resources and scale of restoration. FRI trials indicate that 18 month old seedlings perform well on suitable foredune sites and that larger plants are not necessarily more successful for dune planting. Ideally plants should be raised in containers of similar size to PB 3/4 polythene bags or Hillson rootrainers. Within 18 months of sowing seed, seedlings should be up to 50 cm tall with root collar diameters of 5-10 mm and root systems that bind the potting mix ready for planting. Regular maintenance includes fertiliser and fungicide applications as appropriate.

Where larger plants are preferred, seedlings will need to be potted-on into large containers such as PB 2 polythene bags or Tinus rootrainers and grown for a further year.

In general, there is little seedling mortality in the nursery. In a trial at FRI Nursery, seedlings pricked out into PB 2 polythene planter bags were, after 15 months, up to 50 cm high and had 91% to 100% survival for the seven provenances tested (Table 2).

The cost of seedlings is a significant proportion of the total cost of restoration of dunes especially where voluntary labour associated with Beach Care or Coast Care planting programmes is available. In general, 18 month old seedlings raised in Hillson rootrainers or similar size containers have been available from several North Island nurseries for 90 cent to $1.20 each (excluding GST). Seedlings in larger containers that are 2 years old or more are over $2.50 plus GST each. The cost of freight is considerably less for the seedlings in smaller containers and they are easier to move to the planting site and plant.

PINGAO PLANTING TRIALS

Nuhiti Beach trial

Trial site:
The first major FRI pingao planting trial was at Nuhiti Beach on the East Coast of the North Island. The 1.5 km beach comprises a narrow dune system. A stable dune on the landward side is covered in short grasses, particularly Indian doab (*Cynodon dactylon*) and harestail (*Lagarus ovatus*). The foredune has steep banks with a sporadic cover of spinifex. Sand sedge (*Carex pumila*) was common on the foredune. Some 3300 pingao seedlings were planted in groups of 30 in August 1990 (Herbert & Bergin 1991).

Treatments:
The trial was designed to measure differences in survival and growth in a factorial design incorporating seedling type, habitat type and fertiliser and hydrogel applications.

Five seedling types were tested. They were based on container size and size of seedling.
- large seedlings raised in polythene planter bags PB 2's ex Whanganui seed,
- medium-size seedlings raised in polythene planter bags PB 0.75's ex Whanganui seed
- small seedlings raised in Hillson rootrainers ex Whanganui seed
- large seedlings raised in Tinus rootrainers ex Whatipu seed

The latter seedling type was severely hardened-off at the nursery before planting by placing seedlings in the open during the last few months of growth. No fertiliser was applied.

Seedlings were planted in 30-seedling groups. The habitat types compared were unstable foredunes that had sparse vegetation, and stable vegetated inland dunes that were generally more sheltered.

The fertiliser treatment was 30 g of slow-release fertiliser (Magamp, medium granule) incorporated with the sand when each seedling was planted.

A post-plant application of fertiliser (Magamp, medium granule) was applied to each pingao seedling in selected groups 11 months after planting. This fertiliser was placed in a 5-8 cm deep channel scooped out in a 25 cm radius around each seedling. The channel was infilled.

The hydrogel treatment consisted of 150 ml of Broadleaf P4 hydrogel applied in hydrated form around the root system of each seedling.

Assessment was carried out 8 and 20 months after planting. Leaf length (leaves were extended to obtain this measurement) and root-collar diameter were recorded at the 8 month assessment. At the 20-month assessment, survival, subjective assessment of health and colour of foliage and the number of plants with multiple shoots was recorded.

Results:
The Nuhiti Beach planting trial demonstrated clear differences in the performance of seedlings subjected to different treatment and site factors.

Leaf length was not a very useful measure of growth for pingao as mean leaf length declined for seedling types in all treatment groups as a result of tip dieback (Table 3). Although root-collar diameter increased for most seedling types, the most suitable measure of growth and plant vigour seemed to be the number of seedlings in treatment groups that had developed multiple shoots.

Significantly more pingao survived on the unstable dune (71%) than on the stable dune (64%) 20 months after planting (Table 3). Neither fertiliser nor hydrogel had any significant effect on survival of planted pingao. Similarly, a post-plant application of slow-release Magamp fertiliser 11 months after planting had no significant effect on survival on the unstable site.

With a single exception, all planting stock showed high survival at Nuhiti Beach 20 months after planting. Less than one-third of the small Whatipu provenance seedlings, which were severely hardened-off before planting, survived.

Fertiliser had a highly significant effect on the growth of pingao. Sixty-nine percent of plants in fertilised plots had multiple shoots compared with 50% in plots with no fertiliser (Table 3). Groups fertilised at planting had significantly more plants with multiple shoots than unfertilised plots on both unstable and stable sites after 20 months but particularly on the stable site. This probably reflected the competition for nutrients by the other vegetation on the site, particularly Indian doab and hares tail. However, there was no measurable response to the addition of fertiliser 11 months after planting on the unstable site.

There was also a significantly greater number of seedlings with multiple shoots on the unstable dune (69%) than on the stable dune (49%).

Whanganui plants in planter bags continued to be more likely to have a greater number of multiple shoots than Whatipu plants in rootrainers after 20 months. There was a significant growth response to fertiliser for all but one planting stock type. In general, seedlings with a well-balanced shoot and root system were more suited for planting on dunelands than excessively large seedlings.

Health was significantly better for seedlings planted on the unstable dune compared to seedlings on stable dunes (Table 3). Seedling health scored better and foliage colour scored greener for fertilised seedlings compared to unfertilised pingao.

Seedlings excavated 8 months after planting showed massive root development and extension of more than 40 cm. Where hydrogel had been applied, some hydrated gel was still visible with root hairs penetrating the gel. However, application of hydrogel had no effect on survival or growth.

The poor performance of hardened-off relatively smaller pingao seedlings indicates that stock does not need to be exceptionally hardened off before planting on exposed foredunes (Table 3).

Waikawau Bay trial

Trial site:
The 3 km beach at Waikawau Bay on the Coromandel Peninsula is managed by the Department of Conservation as a recreation area and has an extensive fenced off dune system. Scattered small patches of vigorous pingao plants occur naturally along the foredunes amongst spinifex.

Treatments:
Some 1400 pingao seedlings were planted in groups of 25 in August 1990 at the northern end of the beach. Treatments similar to the Nuhiti Beach trial were also tested at this site.

The three seedling types planted were:
- small seedlings raised in Hillson rootrainers ex DOC Nursery, Taupo
- small seedlings raised in Hillson rootrainers ex FRI Nursery, Rotorua
- small seedlings raised in Hillson rootrainers ex Tairawhiti Polytechnic Nursery, Gisborne.

All seedlings were raised from local Coromandel sourced seed.

Fertiliser and hydrogel was applied to selected seedling groups as for the Nuhiti Beach trial.

The trial was assessed for survival and growth 4 months and 20 months after planting.

Results:
Rabbits severely browsed nearly all planted pingao seedlings at this site. Consequently, there were no significant differences in leaf length and survival of pingao 4 months after planting (Table 4). The only major differences detected were for colour of foliage and to a lesser extent seedling health. Seedling type raised at the FRI Nursery produced more seedlings with yellow foliage than the other seedling types. Seedlings on the unstable dune habitat tended to have

greener leaves and be healthier than those on the stable habitat. As for the Nuhiti Beach site, fertilised seedlings were greener than unfertilised seedlings but hydrogel again had no effect on seedling performance.

Only 19% of seedlings planted on the sheltered site at Waikawau Bay survived 20 months after planting. Growth of surviving plants was severely retarded, mainly because of poor recovery from initial rabbit browsing. However, browsing during the second year did not appear to be as severe as during the first year.

On the exposed site only a few plots remained after a change in the course of a river channel. Most of these remaining plots were subsequently affected by major accumulations of sand leading to high mortality of pingao. Up to 60 cm of sand accumulated on some plots and it was likely that some of the missing plots were submerged under greater depths of sand.

Whiritoa Beach trial

Trial site:
Trials testing the three sand binding species were established at several sites at Whiritoa Beach on the Coromandel Peninsula in 1994 and 1995.

At the southern end of the beach the trial site consisted of a curved beach extending for approximately 200 m, adjacent to an Urupa situated on the inland dune. The gently sloping beach was mostly bare sand with very sparse spinifex and sand convolvulus (*Calystegia soldanella*). Knobby club rush (*Isolepis nodosa)* and sand sedge occurred on lower lying flat sites.

Treatments:
Approximately 1000 pingao seedlings were planted in Spring 1994 and Autumn 1995 using the standard group planting techniques with 20 seedlings in each group. Selected groups were fertilised at planting with Magamp fertiliser.

Post-plant applications of fast-release Urea and DAP fertiliser were also tested at Whiritoa Beach and involved broadcast applications of fertilisers to selected established pingao groups at the rate equivalent to 400 kg of N per ha. This application rate is recommended for boosting growth of natural spinifex stands in restoration projects in Australia (Barr & McDonald 1980; Barr *et al.* 1983).

In addition to assessing survival, a wide range of growth parameters were used to assess performance of planted pingao approximately 18 months after planting for the Autumn 1995 pingao and 2 years after planting for the Spring 1994 seedlings.

Results:
There was a significant difference in survival between spring planted (78% survival) and autumn planted pingao (41% survival) (Table 5). Although, spring-planted seedlings may be vulnerable to late spring-early summer dry spells, they do have sufficient time to become well established before the onset of the following winter. In contrast autumn-planted seedlings may fail to establish sufficiently well in the 1-2 months before the onset of winter to survive the inevitable winter storms and mass sand movement that may accompany them. Based on the range of performance parameters assessed, surviving autumn plants showed similar rates of growth and vigour to spring planted seedlings.

This trial has clearly demonstrated a significant increase in all growth parameters with application of Magamp at planting (Table 5). Compared to unfertilised pingao, fertilised pingao were on average 18 cm higher, had almost 3 times the root collar diameter, had over twice the plant cover, were more vigorous and had over twice as many shoots. At the plot level, the subjective assessment of vegetation cover was 3 times greater for fertilised plots (53%) compared to unfertilised plots (18%) with greater sand accumulation on fertilised plots for the 1.5-2 year period since planting for fertilised plots (13 cm) compared to unfertilised plots (4.7 cm).

As for the earlier planting trial at Nuhiti Beach, fertiliser did not significantly affect survival.

Although the sample size was too small to statistically test the effects of post-plant applications of DAP and Urea, there is some evidence that DAP has caused a substantial increase in all measured plant growth and plot parameters. The responses appear to be similar to those resulting from at-planting applications of Magamp. In contrast, post-plant applications of the fast-release high N Urea to established plants resulted in a considerably less response in seedling growth and vigour with virtually no difference in height growth, plant cover, vigour and root collar diameter compared to unfertilised seedlings.

South Brighton Beach

Trial site:
This front slope trial was on a sandy slope devoid of vegetation at a slope of about 1:4 to a height of about nine metres above mean sea level. The top of the slope comprised a partially vegetated crest dominated by marram grass (*Ammophilia arenaria*). This slope was exposed to the full force of the prevailing easterly winds.

Treatments:
Plots were established on the seaward face of the foredune on bare sand. The trial was planted with pingao seedlings in April 1995 (Bergin *et al.* 1996). Three hundred pingao seedlings were planted in a 3 m diameter clusters of twenty. Each cluster was allocated one of three treatments:

- control - no fertiliser
- Magamp slow release fertiliser incorporated into the planting hole at planting
- Elite slow release fertiliser applied as for Magamp

Approximately 30g of fertiliser (one handful) was applied to each seedling. It was incorporated into sand at the upper level of the hole during planting.

Results:
Assessed one year after planting, there are no significant differences in survival and growth of pingao at this exposed South Brighton foredune site (Table 6). Both unfertilised and fertilised pingao (Magamp or Elite applied at planting) had a similar height growth (mean 68 cm), plant cover (mean 1.25 m^2), a very high plant vigour score (mean 4.9) and number of shoots per plant (range 12-19.7).

Sand accumulation was high (range 13 -23 cm) for all plots during the 12 month duration of the trial compared to the Whiritoa Beach trial site (range 4.7-14.5 cm) where seedlings were planted for up to two years.

Brighton Spit trial

As for the foredune site at South Brighton, pingao was planted and spinifex seed sown on a bare foredune site in May 1995. The top height of backdunes at this site was only about 6 m above mean sea level with the trial located near the toe of the dune just above high water mark. The slopes planted were about 1:10 or flatter, devoid of vegetation and exposed to prevailing onshore winds.

Of the 300 pingao seedlings planted with and without fertiliser treatments, only 3 plants were found one year after planting. All plants were heavily browsed within days of planting by rabbits. The area was poisoned soon after the pingao were planted and some recovery of browsed plants were observed 3 months later. However, continued rabbit browsing and excessive accumulation of sand (up to 1 m deep) along parts of the foredune have contributed to the very poor survival of the planted pingao.

Port Waikato

Trial site:
Pingao was established on sand dunes at Port Waikato in collaboration with Environment Waikato, Franklin District Council, Department of Conservation and the Port Waikato Dune Care community group in May 1994. This was the first trial to be established on the west coast of the North Island where, compared to the east coast, there is a more severe climate and considerable sand movement on foredunes. As a consequence, dune blowouts are common, especially where there is disturbance. High recreational use coupled with a carpark and the Surf Club at the south end of the beach had resulted in a narrow foredune with virtually no vegetation immediately adjacent to the carpark. Several large blow-outs occur within 500 m to the north of the Surf Club, probably as a result of high recreational use and the casual development of undefined accessways from nearby roads.

Treatments:
The trial comprised a total of 28 plots of pingao seedlings with 20 seedlings per plot. Two sites were tested; one site immediately adjacent to the carpark on a steep foredune with little existing vegetation, and the other on two blow-outs immediately north of the Surf Club building where sand is highly mobile.

SEED SOWING AND GERMINATION

Method:
Raising large numbers of spinifex seedlings in the nursery has proved difficult both in New Zealand and Australia. At the FRI Nursery, large losses of seedlings occur at most stages of nursery handling. Compared with pingao or sand fescue, large losses invariably occur when spinifex seedlings are repotted from one container into another. Several techniques were evaluated for germination of spinifex seed. These included:

- burying of whole seedheads to mimic natural foredune processes of sand burial of stranded seedheads. Up to six seedheads were pressed down on seed trays containing standard peat/pumice potting mix and covered with sieved potting mix.
- broadcast sowing of separated spikelets containing sound seed and large amounts of seedhead chaff and debris
- upright sowing of separated spikelets containing sound seed directly into containers. Spikelets were placed vertically into the potting mix with the seed pushed 2-3 cm into the medium and the spine facing upward. One or two seeds were placed into each container.

An alternative approach of sowing individual seeds into final-size containers was designed to reduce handling induced mortality of spinifex. This method obviates the need for pricking-out newly germinated seedlings from seed-raising boxes or repotting seedlings into larger containers. Direct sowing of seed into the final container is only feasible were sound seed has been sorted from the large quantities of empty seed characteristic of spinifex.

Results:
The time taken for spinifex seed to germinate is correlated with the season of sowing. Seed sown in early winter took up to 3 months to germinate whereas seed sown in spring generally took 1-2 months (Table 8).

Germination tests for 1995 collections clearly indicate that seed sown individually in upright positions germinated in about half the time of that broadcast or 'whole spike' sown.

Harty & McDonald (1972) carried out a detailed study of the germination behaviour of spinifex seed. Laboratory experiments showed that germination of seed was significantly inhibited by light, with only 14% germination in light compared to 56% in the dark. This suggested that spinifex seed must be buried in the sand before appreciable germination will occur. Upright sowing methods in the FRI experiments were probably more effective in burying the seed compared to the other sowing methods.

Spinifex seed appears to retain viability for at least 6 months after collection where seed in kept in cool dry storage. On one occasion, seed from two provenances collected in 1994 that had been stored for up to 19 months after seed was collected still germinated (Table 8).

RAISING SEEDLINGS

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

- direct sowing of seed into final containers as described above (FRI Nursery, Rotorua).
- propagation from seed using standard nursery practices. Unsorted seed collections are sown in seed boxes and, following germination, are pricked out into containers (FRI Nursery and several others).
- setting of cuttings taken from stolons of mature plants (Christchurch City Council nursery, Linwood).

Direct sowing in containers: For sorted seed sown upright in containers, moderate to high survival (55-75% after 7 months) was achieved for all but one provenance seed collection made in 1994 and 1995 (Table 9). Where pairs of seed were sown into each container, four of the six provenances tested had at least one live seedling in 80% of containers after 19 months. For the 1995 collection, where seedlings were assessed 18 months after sowing, survival had significantly declined for all seedlots. Although this method looks promising, there is still mortality of seedlings at all stages of the nursery operation. Consequently, fewer live seedlings carry the total production costs.

Standard nursery practice: Seedlings potted-on from broadcast sown seed in trays or from buried whole spikes had variable survival. Of 300 seedlings potted into PB 0.75's in 1994, only 26% of the seedlings were alive 12 months after

Six weeks after sowing, there was no germination of spinifex seed and seedheads. Seedlings were first observed almost 4 months after sowing with a handful of seedlings ranging in height from 30-200 mm. The poor viability of seed used in the trial probably contributed to the poor germination rate.

Whiritoa Beach trial (Urupa site)

Treatments:
The spinifex trial was established in the same location as the pingao planting trial at the south end of the beach adjacent to an Urupa (Bergin & Spence 1994). A range of establishment treatments were tested:

- Planting - approximately 200 nursery-raised spinifex plants were planted in Spring 1994 and Autumn 1995.
- Seeding - up to 3 seedheads were placed into 10-15 cm deep spade holes similar to methods used in New South Wales (NSW Public Works Department and Soil Conservation Service 1987). Twenty seed spots were evenly located within 3 m diameter circular plot with a central identification peg.
- Stolons - stolon tips approximately 60 cm long were cut from nearby established colonies and transplanted immediately into 10 cm deep channels with 5-10 cm of the tip left exposed. Five transplanted stolons were placed within a 3 m diameter plot.

Magamp fertiliser was applied at planting to the nursery seedling treatment involving incorporating 30-40 g of fertiliser into the planting hole for each seedling.

Results:
Planted nursery-raised seedlings had at least 80% survival up to 2 years after planting (Table 11). There were no differences between autumn and spring plantings and no significant effect on survival from application of Magamp fertiliser applied at planting. There were no significant differences in height growth between autumn and spring plantings and no effect of fertiliser. Mean overall height after two years was 41.2 cm.

However, the application of Magamp fertiliser at planting did have a significant effect on other aspects of plant growth with increases in plant spread, root collar diameter and average length of runners (Table 11). Vigour was also significantly better for fertilised compared to unfertilised plants. As with the earlier established pilot spinifex trial near the Surf Club, fertilised spinifex seedlings at the Urupa site were noticeably greener and considerably larger than unfertilised seedlings. They also showed a greater accumulation of sand.

Despite use of local Whiritoa seed collections (14% sound seed in the 1994 collection and 25% sound seed for the Whiritoa G collection in 1995) (Table 7), less than 10% of the spots where 2-3 seedheads had been sown had germinated seedlings (Table 12). Nearly all spots where seedlings had germinated had only one seedling. Growth of seedling was also generally poor. Germination began within 2 months of planting for the spring sown seed in contrast to autumn sown seed which did not germinate for several months until early spring. Although numbers of germinated seedlings are too low to allow statistical testing of performance, spinifex germinated from spring sowing tended to be larger and have greater survival than seedlings from autumn sown seed.

Although stolons were established in both autumn and spring using methods successfully used in Queensland, overall survival from a total of 100 transplanted stolons was less than 5% in the 18 months to 2 years after the trials were established. Attempts at establishment of spinifex using stolons was time consuming in both the collection of runners and setting them into holes or trenches. Although much of the work was easily carried out by volunteers in locally based Beach Care groups, the very poor survival clearly demonstrates that this method is unrewarding.

South Brighton

A spinifex seeding trial similar to the Whiritoa Urupa trial site was set up on South Brighton beach. Here, up to three seedheads were placed into 10-15 cm deep spade holes (Bergin & Herbert 1996). Seed was sourced from the nearest existing spinifex population north of Kaikoura. Germination was not recorded until 6 months after sowing. Of the 10 plots comprising 10 spots each with sown seedheads, less than 5% of the spots had one or more germinated seedling. Seedlings were only 1-5 cm high in the October 1995 inspection and within 2 months had disappeared. Excessive sand movement on the relatively steep site and strong easterly winds in late spring were the probable cause.

In spring 1996, the Christchurch City Council Coast Care Unit established 100 18 month old spinifex seedlings in front of the South Brighton Surf Club within a fenced area. They were raised from cuttings at the Council's Linwood Nursery. Approximately 30 g of Magamp was applied to all seedlings. Inspection 2 months after planting indicated very high

The application of Magamp fertiliser clearly had a positive effect on growth of sand fescue. At the Urupa site, Magamp at planting significantly boosted plant survival, and all measured growth parameters (Table 14). Fertilised seedlings were 25 cm taller, had at least five times the plant cover, almost twice the vigour rating, had at least twice the root collar diameter and three times the plot cover compared to unfertilised seedlings. Although statistical comparisons of reduced seedling numbers at the Estuary site in not possible, growth trends indicated a positive effect to the addition of fertiliser at planting.

Seasonal differences in performance of sand fescue were apparent at the Urupa site with significantly larger root collar diameters and greater plot vegetation cover for autumn planted seedlings.

South Brighton trial

Plots of sand fescue with and without Magamp were established among the pingao plots at the South Brighton Beach site. This is a steep, relatively exposed foredune site and these conditions have contributed to the mean survival of only 47%.

Fertilised seedlings were taller (45.5 cm) and plant vigour was rated greater (4.5) compared with unfertilised seedlings (height 23.4 cm and vigour score 2.8) (Table 15). Results of the other growth parameters indicated a tendency for better growth and survival of fertilised seedlings with differences in plot cover and sand accumulation very nearly significant at the 95% level.

Brighton Spit

At Brighton Spit, only one seedling out of total 100 planted seedlings survived. Most seedlings were severely browsed by a high infestation of rabbits at this site within a few days of planting.

IMPLICATIONS FOR RESOURCE MANAGERS AND LOCAL BEACH/COAST CARE GROUPS

Planting nursery-raised seedlings has proven to be the most effective technique for establishing the three indigenous sand binding species on dunes in New Zealand. However, rehabilitation of any ecosystem by planting is always expensive. Nursery-raised seedlings will cost at least $1 each and planting is labour intensive. Planting for rehabilitation of a degraded site should, therefore, be a 'last resort' option. On degraded sand dunes, other options to protect and enhance existing vegetation remnants should be considered before launching into a planting programme. These include use of fencing and accessways in high public use areas, implementing education programmes and erecting sign posts to inform users of the importance of dune vegetation, excluding grazing stock and controlling wild animals such as rabbits, and where appropriate, improving the vigour of existing vegetation by, for example, fertilising. On some sites, the combined use of artificial barriers with a revegetation option may be a worthwhile option.

A decision to re-establish foredune communities, or to enhance existing remnant vegetation by planting, may be taken on the basis of desire to restore naturalness, or for cultural, historical, amenity, landscape or practical reasons, or for any combination of these reasons. In this case it is important to acknowledge that at this early stage the scale on which rehabilitation of dunes using indigenous species can be practically achieved is relatively small. Despite the local success of some foredune plantings using indigenous sand binders, the scale of rehabilitation envisaged for any indigenous species rehabilitation project is considerably less than large-scale sand stabilisation programmes undertaken in the past using marram grass (Wendelken 1974). As noted by Cockayne (1911), marram grass is often more vigorous and is less susceptible to disturbance than the indigenous sand binding species on similar coastal sites.

Rehabilitation programmes using indigenous species should initially be focused on relatively small areas with high ecological, cultural or community values where there is a desire by the local community and managing agencies to enhance natural character and dune stability by using local indigenous species. Participation of local community groups such as Beach Care and Coast Care initiatives in partnership with local authorities in such rehabilitation programmes is resulting in worthwhile restoration of degraded dune systems in several regions throughout the country.

Although results clearly indicate that pingao, spinifex and sand fescue grow best in the mobile sand characteristic of foredunes, it is not always easy to identify optimum sites. Foredunes are subject to a range of adverse weather and sea conditions including occasional very high tides, storms, strong winds from different directions, extremes in temperature and impact of human use or introduced animals. Failures are expected from time to time. Often the degree of damage from storms or human impact can vary over short distances and from one year to the next. Rehabilitation strategies that spread the risk both over time and spatially are more likely to succeed. Where planting is considered for rehabilitation of a dune system, the aim therefore, should be to produce large numbers of seedlings at low cost, to plant up key areas, to be accepting of setbacks and, once effective cover has been achieved, to be prepared of ongoing maintenance of storm damaged areas.

Restoration of degraded dunes will not succeed without ongoing maintenance and monitoring of past management practices. Regular inspection and follow-up work to maintain fences, signs, accessways, replanting damaged sites and fertilising is essential. Measuring the success of restoration programmes is only possible through a monitoring programme such as regular inspections of restored sites to determine vigour and extent of vegetation cover. This is essential so that maintenance is carried out when required and where necessary, management practices can be modified to improve the goals of restoration.

Experience from trials established on a wide range of foredune sites and climatic conditions in both the North Island and the South Island indicates that mortality of planted seedlings of the indigenous sand binders plants pingao, spinifex and sand fescue can vary from 10-60% within the first year of establishment. It is recommended that trials are designed with sufficient seedlings to allow for possible large losses of seedlings within a year of planting on these difficult foredune sites. The design should incorporate a minimum of five replicates with at least 10 seedlings planted in discreet groups with plant spacing within groups of 50-60 cm. Treatment (e.g., application of fertiliser at planting) should be applied to all seedlings in one group. A centrally located numbered peg placed at a known height above the sand allows subsequent measurement of sand movement as well as providing plot identification. Planting a set number of seedlings within a known small diameter circle of the central peg has made efficient relocation of planted seedlings.

Assessment of grasses and sedges is always difficult and a range of parameters were used at each trial. Early trials indicated that measurement of leaf length was an unreliable indicator of plant performance. Preferred parameters used in most trials include survival, number of leaders for pingao, number and length of runners for spinifex and plant spread (length x breadth).

With operation-scale planting programmes, intensive monitoring of plant performance is not practical but some monitoring should be carried out to determine whether programmes are successfully meeting the aims of resource managers and local communities in the restoration of degraded dunes. Simplified procedures incorporating some of the design and assessment parameters proven to be successful in trials should be considered by resource managers and community groups in monitoring their restoration programmes.

Seed preparation

- Store seedheads of all species temporarily in hessian or paper bags and where necessary allow to dry out for a few days before longer-term storage or separation of seed.

- Store unsorted pingao and sand fescue seed dry in a refrigerator for several months. Spinifex seedheads are best stored in hessian sacks and will maintain viability for at least 6 months. Protect from rodents.

- Pingao seed can be easily dislodged from seedheads by scraping with fingers or a blunt instrument. Sand fescue seed is easily removed from seed head stalks by hand.

- To obtain viable spinifex seed for sowing separately into containers, break spinifex seedheads in half and sort out spines with sound seed by pressing the base of each spine between thumb and finger; firm contents indicate a sound seed; cut a small sample to check seed is being identified correctly. For bulk sowing, break seedheads up by hand to give a mixture of seed attached to spines and seedhead debris.

Sowing and germination

- For pingao and sand fescue, sow seed along with chaff and debris onto standard seed-raising mix such as equal proportions of peat and pumice in a seed box and cover with 2-3 mm of finely sieved soil.

- Germination takes 3- 6 weeks for pingao, 6-12 weeks for spinifex and 3-4 weeks for sand fescue. Germination times are shorter in warmer seasons.

- Prick germinated pingao and sand fescue seedlings into containers when seedlings are 5-7 cm high. Seedlings can be successfully transferred between seed bed and final planting containers or smaller containers such as paper pots for later potting on to larger containers.

- Spinifex seedlings appear to be damaged by standard potting on procedures. To avoid the need for repotting, sow sorted sound seed in pairs into the final planting container. Sowing two seed per container increases number of containers with at least one live seedling being produced. Sow two seed upright into each container by placing seed at least 3 cm into the mix with spine standing upright.

Raising of seedlings

- Seedlings of pingao and sand fescue can be raised in commercial nurseries or alternatively, by local residents or interest groups using minimal facilities. Aim at producing low-cost 18 month old seedlings up to 50 cm tall. Larger seedlings have not performed better than well grown 18 month old seedlings.

- Optimum planting size of seedlings of all three species ranges from 30-50 cm raised in PB 0.75 planter bags or Hillson rootrainers. Alternative containers for local community raising of plants include used plastic yoghurt pots and paper milk cartons.

Establishment on dunes

- Plant seedlings at several key areas along the beach wherever possible to spread risk for failure due to infrequent but inevitable storms and high seas.

- Plant in small blocks or, where numbers of plants are restricted, in small groups where seedlings can give mutual protection and act together to trap sand and build a small dune. Plant seedlings a minimum of 50 cm apart. To enhance natural vegetation patterns, avoid planting in straight lines.

- Apply a slow-release granulated NPK fertiliser such as Magamp to all seedlings at planting. Incorporate approximately 30-40 g (one small handful) of the fertiliser into the sand as the seedlings are planted ensuring fertiliser is evenly distributed around the seedling root zone. Do not use fast release nitrogenous fertilisers at planting.

Transplanting spinifex stolons

- Not recommended for wide scale use at this stage as survival and growth of stolons in trials to date have been poor.
- Indications from FRI trials, and from operational-scale projects in Australia, favour autumn transplanting when, in comparison with spring, there is a greater abundance of good material available for transplanting. However, autumn-planted cuttings are exposed to winter storms before they have had a chance to establish.
- Trial on a small-scale basis only. Use 60 cm long runners from parent plants cut immediately before transplanting into 10-15 cm deep trenches. Leave up to 10 cm of the growing tip exposed.

Direct seeding of spinifex

- Not recommended for wide scale use at this stage due to poor germination and development of seedlings. There has been limited germination from direct seeding trials by FRI. Direct seeding is successfully used in Queensland and NSW.
- Trial on a small-scale basis only. Use the New South Wales method of burying a handful of seedheads (2-3 seedheads) into a spade hole up to 15 cm deep. Use seedheads that have a reasonable proportion of sound seed, preferably greater than 20%.

Monitoring and maintenance

- Monitor survival and growth of all planting programmes and modify new programmes accordingly to improve performance. Maintain planted areas by repairing fencing and signposts and replanting failed areas where practical.

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