Management and Retention of Pingao (*Desmoschoenus spiralis*) in Stable Back Dune Sites

By

Dean Nelson

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of

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Executive Summary

Title
Management and retention of Pingao (*Desmoschoenus spiralis*) in stable back dune sites.

Investigator
Dean Nelson

Study sites
Dunes in Sandfly Bay, 'Wharekakahu' Beach and Victory Beach, Otago Peninsula.

Objectives
- To provide an overview of the ecology, status and cultural significance of pingao.
- To describe the past and current role of pingao on the Otago coast.
- To review other studies that have relevance to management of pingao.
- To conduct field trials to determine the relative importance of root and shoot competition and soil nutrient status to the growth of pingao as a means of investigating methods of managing and maintaining pingao in stable back dune areas on the Otago coast.
- To make recommendations for future management and further research.

Methods
A stratified randomised block design was applied on six clumps of pingao to investigate the effects of removal of root and shoot competition and the value of application of fast release nitrogen fertiliser to managing pingao in stable back dunes. To simulate removal of competition, plots were either sprayed with the grass specific herbicide Gallant or all other vegetation was clipped off at ground level. Based on a review of previous relevant studies, the parameters that were chosen for measurement were numbers of new leaves on selected shoots, numbers of seed heads in each plot and length of seed heads.

Treatments were established in the winter and spring of 1999 and measurements were taken at the beginning of March 2000, coinciding with observed tapering off of leaf growth and the beginning of seedfall.

Acknowledgements

This project is dedicated to Josh. His generation and others to follow have inherited the problems created by my generation and those preceding it.

I would like to thank Janice Lord, my supervisor, particularly for helping set up the first plot and for putting up with sporadic visits and contact until the mad rush at the end. Thanks Janice for your patience, help with statistics and many comments on drafts.

David Bergin gave heaps of advice and time, and also commented on several drafts.

Thanks also to Henrik Moller for encouraging me to look at a project that has absolutely nothing to do with yellow-eyed penguins, although I have spotted pingao amongst nesting material in a penguin nest at 'Wharekakahu' Beach.

The members of the Pingao Recovery Group, especially Tui Williams and Mike Hilton, have all helped to engender my enthusiasm for this wonderful plant. Dave Blair has been a source of inspiration in the Group and as leader of the Conservation Corps who have done so much work for this species over the last 8 years. Paul Pope is to be congratulated for his efforts to bring pingao to the attention of the Dunedin City Council and the wider community.

Thanks to the Yellow-eyed Penguin Trust for permission to do trials in 'Wharekakahu' Beach and also to the above group along with the Dunedin City Council and Te Runanga Otakou for allowing me to work in the Okia plots. The Department of Conservation gave time and resources to complete the study. Brian Sargeant and Greg Hawker helped with the map and photos. Thanks to the announcers of Radio Sport who helped keep me sane during the measurement of numerous pingao seed heads and the counting of leaves.

Last but not least my undying gratitude goes to Sandy and Josh for all their support and encouragement.

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1. Introduction

The indigenous sand binder pingao (*Desmoschoenus spiralis*)[i] was a major component of the foredune vegetation along the Otago coast up until the early 1900's. Since then major modification of coastal ecosystems as a result of increased development and use has occurred including the spread of the introduced sand binder, marram (*Ammophila arenaria*), that along with lupin (*Lupinus arboreus*), was often planted to improve dune stability. As a result many indigenous species have declined in sand dune areas including pingao.

This project evaluates a range of practical management options for maintaining and enhancing the existing scattered clumps of pingao that occur in the stable back dunes of the Otago coast as a resource for ongoing efforts to restore pingao to the foredunes.

2. Objectives

- To provide an overview of the ecology, status and cultural significance of pingao.
- To describe the past and current role of pingao on the Otago coast.
- To review other studies that have relevance to the management of pingao.
- To conduct field trials to determine the relative importance of root and shoot competition and soil nutrient status to the growth of pingao as a means of investigating methods of managing and maintaining pingao in stable back dune areas on the Otago coast.
- To make recommendations for future management and further research.

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[i] Plant nomenclature follows Allan (1961), Moore and Edgar (1976), Webb *et al.* (1988) and Edgar and Connor (2000).

3. Overview

3.1 Ecology of pingao

Pingao (*Desmoschoenus spiralis*) is an endemic sedge that naturally inhabits the active foredunes (Fig. 1). Sometimes referred to as the golden sand sedge (Herbert and Oliphant, 1991) due to its yellow-orange appearance, the coarse, curved leaves of pingao (pikao in southern Maori dialect) grow from long thick rhizomes which spread out across the sand. In an undegraded dune system, pingao, together with spinifex (*Spinifex sericeus*) and other indigenous species such as sand tussock (*Austrofestuca littoralis*), sand convolvulus (*Calystegia soldanella*) and *Carex pumila*, forms communities that are able to maintain stability in the foredune areas and initiate the process of trapping sand and dune building (Bergin and Herbert, 1998).

Fig. 1 The golden line above high tide. Healthy pingao thriving on foredunes at Sealers Bay, Whenua Hou (Codfish Island)

Pingao needs moderate amounts of sand movement to thrive but excessive accumulation of sand and/or erosion by strong winds can cause die back (Bergin and Herbert, 1998). It has two comparatively distinct habits; a sprawling horizontal growth of rhizomes and a more erect version that more closely resembles tussock in form. Courtney (1983) suggests that the two forms are dependent on environmental conditions, particularly sand deposition, and that there is a continuum of growth forms between the two extremes. However more recent studies have also shown that the two forms can be a result of provenance differences (Bergin and Herbert, 1998).

In spring dark brown inflorescences (flower heads) appear and are borne in a spiral pattern (hence the scientific name) on stems ranging from 30 – 90 cm long (Courtney, 1983). These ripen and the seed is shed along with copious quantities of husk in early to late summer depending on the latitude. Seed dispersal is dependent on the wind.

Natural regeneration from seed has not often been seen (Bergin and Herbert, 1998) but the seed can lie dormant in the ground for quite long periods. In several sites in Otago without nearby existing plants, pingao has become established after disturbance of thick ground cover on sandy substrate (pers. obs., 1997). This is despite a noted decrease in seed viability over time (Courtney, 1983).

3.2 Distribution and decline

Pingao was once widespread throughout New Zealand and the Chathams (Cockayne, 1967) but the effects of European settlement have seen its distribution reduced dramatically. Many dune areas have been severely modified or lost as a result of agricultural and residential development, and sand mining (Partridge, 1992). A national inventory of dunelands has shown that there has been a 70 % loss of dune areas across the country since about 1950 as a result of afforestation, subdivision and development (Hilton *et al.,* in press).

Other agents of destruction have been fire, browsing by introduced animals such as hares and rabbits, grazing and trampling by domestic stock (Walls, 1998), vehicles in dune areas, harvesting and the introduction of competing plants, particularly the sand binder marram (Partridge, 1995). Coastal erosion can also be a problem. Thirty three vigorously colonising pingao plants documented by Johnson (1993) on Waikarara Beach, Otago Peninsula were completely destroyed by the changing position of the mouth of Hooper's Inlet (pers. obs., 1994).

Pingao is currently classified as an 'M' species in the species priority ranking system used by the Department of Conservation (Molloy and Davis, 1994). This classification defines the species as being rare and localised, and of cultural importance to Maori.

3.3 Cultural use and significance

The story of pingao describes the conflict between Tane Mahuta (God of the forest) and Takaroa (God of the sea) where Tane's eyebrows, rejected by Takaroa as a peace offering between the two, now grow as pingao. The plant's struggle for survival in a harsh environment is symbolic of the tension that exists between land and sea (Walls, 1998)

Maori consider pingao a taonga (treasure). The brilliantly coloured leaves, which do not require any enhancement, are used in tukutuku (wall panels) where the gold of the pingao is contrasted with the darker and lighter colours of harakeke (*Phormiun tenax*), kiekie (*Freycinetia banksii*) and toetoe (*Cortaderia richardii*) (Herbert and Oliphant, 1991). Pingao leaf is also woven into kete (baskets), whariki (mats) and other functional and decorative items. South Island Maori warriors were said to have worn pingao chest protectors in battle. In early times, the sweet and palatable inner shoots were collected and cooked and the use and harvesting of pingao was governed by tikanga or strict rules which effectively conserved the resource in its natural habitat. This often involved placing a rahui or restriction on harvesting, in areas that were becoming depleted (Paneke Conservation Team, 1990).

In many parts of the country there are no longer sufficient resources of pingao to permit harvesting for traditional use (Bergin and Kimberley, 1999).

The need for access to cultural materials under Treaty of Waitangi settlements, the revived interest in traditional crafts and the increased recognition of the value of indigenous plant species in restoration of dunelands has seen a number of projects set up to re-establish pingao on our coast. The obligations under the 1991 Resource Management Act of having to protect and preserve the natural character of the coastline has resulted in some resource managers consciously moving away from the use of exotic species in beach management (Bergin and Herbert, 1997). Of note in Otago is the decision by the Dunedin City Council to require a company to use pingao to restore disturbed foredunes at Island Park as a condition of a resource consent (Paul Pope pers. comm., 1999).

4. Review of previous studies relevant to management of pingao

Much experimental work has been completed by the Forest Research Institute on restoration of pingao including trials on germination, seedling establishment and response to slow release fertiliser at planting (Bergin and Kimberley, 1999). Similar trials have been conducted on spinifex, which is the other major native sand binding species in the North Island and northern part of the South Island. In addition, research has been undertaken on established spinifex where it dominates foredunes at Matarangi and Whititoa beaches on the Coromandel Peninsula (Bergin, 1999). The results clearly indicated that spinifex responds to fast release nitrogen fertiliser for up to three years after application. After two years at initial application rates of 200 – 400 kgN/ha, average spinifex cover at Matarangi increased from up to 52 – 61 %. The fertiliser increased the growth of exotic weeds where they were present but spinifex was able to maintain its dominance. Formal trials on pingao dominated dunes have not been completed but anecdotal evidence indicates that pingao responds to urea at similar rates of application (David Bergin pers. comm., 2000).

Removal of marram using the grass specific herbicide Gallant has been trialed since the late 1980s by Department of Conservation staff in Southland (Jul, 1998; Barnes *et al.*, 1999). It is now established that Gallant applied at a dilution rate of 15 ml/litre by a variety of methods is very effective at removing marram without harming existing pingao. On foredunes where marram has formed the typical high profile, there is an issue of some dune instability as a result of marram eradication. However the dead marram takes two - three years to break down, thus helping to maintain stability of the dunes while pingao re-establishes its dominance (Barnes *et al.,* 1999).

Courtney (1983) found significant differences between leaf and seed head length and width, length of the lowest bract on the seed head, number of bracts and spikelets per seed head and number of flowers and fruit per spikelet of pingao in foredune and reardune-grassland sites. He concluded that sand movement was the causal factor for the differences between the two zones. With regular inundation by sand, the growing tips of pingao rhizomes will push upwards leaving the zone of root development down within the moister sand layers. In back dune sites, as the growing tip reaches the surface, it is more likely to then grow horizontally across the ground and the development of roots into the dry upper layers of sand is less likely to be successful. Consequently the plant is more likely to become stressed due to insufficient water uptake and have less vigour.

Courtney (1983) found that natural regeneration was rare which concludes with Bergin and Herbert's (1998) findings. The only places he found seedlings were areas where there was sufficient moisture for them to establish. However it is interesting to note that Bergin and Herbert's (1998) trials with Hydrogel, a water storage agent, did not improve the growth or survival of planted pingao in their first season.

Much has been made of the effects of marram displacing pingao. Partridge (1995) studied the interaction between pingao and marram on sand dunes on Kaitorete Spit, New Brighton Beach and at Haast. He suggested that marram can either co-exist with pingao or displace it depending on conditions. He suggested that the two can coexist on the front dune face because marram is restricted by its comparable lack of tolerance of salt, in situations where moisture in the upper layers of sand is not limiting, and where both species are struggling due to a lack of new sand. He stated that replacement of pingao by marram was most likely to occur on stable dunes where moisture was a limiting factor in the upper layers, and concluded that the displacement process was not related to the dune building process or the shapes of dunes.

Partridge also noted that hand weeding of marram was effective only if carried out regularly and poor weeding may actually rejuvenate its growth.

However Esler (1970) found that marram builds higher and steeper angled dunes than the more rounded and dynamic dunes formed by pingao. He also found that marram tended to cause higher and more stable back dunes. The higher marram dunes could contribute to the moisture limitations for pingao trying to compete. The high foredunes created by marram have a tendency to get eroded by high tides and storms, with the result that they often blow out. However recolonisation is generally quick due to the remnants of marram roots left in the sand.

At Masons Bay on Stewart Island, Jul (1998) disagreed with some of Partridges findings on marram displacement of pingao particularly in relation to salt intolerance and geomorphic processes. She found that marram is invading in a phalanx fashion, i.e. movement of a tight invasion front where the vegetative reproduction of marram contributes to it forming dense areas that are progressively marching up the coast and inland. She concluded that the interaction between pingao and marram is still not well understood and that in time, marram would displace pingao in almost every situation in southern New Zealand.

Sykes (1987) looked at the influence of environmental factors on the distribution of a variety of sand dune vegetation, including pingao and marram, at four sites in the South and Stewart Islands. He found that climate, related to east or west coast orientation was the over-riding factor that affected distribution, but also concluded that on a local scale, proximity to the sea affecting salinity, elevation, fertility, pH and moisture was important.

He noted that total nitrogen at all sites was extremely low even through the semi-fixed dunes. As an associated part of a sand burial trial, he found that mature plants of marram lived almost twice as long (mean of 116 days) in the dark as pingao (67 days). Relating this to sand burial, he suggested that marram was able to out compete other species because of its ability to survive darkness longer while buried.

5. Status of pingao in Otago

The dunes of coastal Otago are a prime example of pingao surviving only in small discontinuous patches (DoC, 1992). Thomson (1944) notes that in the 1880's a local custom of picking up stranded frostfish from beaches in winter indirectly lead to the decline of pingao. On cold winter nights, to relieve boredom and keep warm, people used to set fire to the "native grass" and soon the dunes were becoming eroded because of the removal of the sand binder. In 1897 Thomson began sowing marram and lupin on a number of beaches north of Otago Harbour to arrest the destruction of the dunes and the covering of the land behind them in sand.

Johnson (1992) in his sand dune inventory of the South and Stewart Island notes that marram and lupin dominate the Otago area with few occurrences of pingao. It has primarily been displaced from the fore dunes and struggles to survive, often in a moribund state, in the stable back dunes in competition with marram, pasture grasses, weeds, lupin, gorse (*Ulex europaeus*) and other woody species. Two sites on Sandymount where pingao still survives are at approximately 240 metres elevation (pers. obs., 1999). This situation is quite unlike pingao on the North Island beaches where it predominantly inhabits the front dunes (David Bergin pers. comm., 1999). The only local places where pingao still exists naturally on mobile foredunes, albeit dunes dominated by marram, are Tahakopa Beach in the Catlins and Ryans Beach on the Otago Peninsula.

In recognition of this situation the Department of Conservation in conjunction with local runanga set up a recovery group in 1992. At the same time a recovery plan was written which had as its primary goal the restoration of pingao to the Otago Coast for conservation and cultural purposes (DoC, 1992).

The recovery group has continued its activities since then with participation from the Dunedin City Council, the Otago Regional Council, Conservation Corps and other interested parties. Four local runanga have built shadehouses and work with pingao in partnership with the recovery group. Relatively small numbers of plants have been produced and planted out in a number of sites, some of which are purely for demonstration and advocacy purposes. The pingao in some of these sites has thrived but the limited resources of planting material have prevented any attempts at full-scale restoration of degraded dunes. The recovery group is attempting to seek funding to allow the mass production of plants for such an exercise. The only attempt at large scale removal of marram by spraying with the herbicide Gallant was begun in late 1999 (Cheryl Mudford pers. com., 1999).

To maintain a supply of seed from local sources (to maintain genetic purity and diversity) it is necessary to attempt to manage all existing pingao resources in situ at least until planting and marram control programmes have established large self-sustaining pingao populations on a number of Otago beaches. These predominantly back dune sites are not ideal pingao habitat and in the natural course of succession, would develop a range of other species consistent with the degree of stabilisation and build up of litter and humus.

This project therefore investigates methods for conserving and enhancing the existing scattered populations of pingao along the Otago coast. It has involved selecting a range of typical sites where pingao is struggling to survive amongst a range of introduced species and testing a range of treatments to improve survival and growth. The long-term aim is to ensure sustainable populations of pingao including local seed sources for both natural regeneration and for raising of seedlings to enable planting in sites where pingao has been severely reduced or gone.

6. Study sites

Six sites on three beaches located on the Otago Peninsula where pingao survives on stable back dunes were selected for the study (Fig. 2). The three beaches, 'Wharekakahu', Victory Beach and Sandfly Bay are representative of the variety of different back dune situations that pingao exists in on the Otago coast.

6.1 'Wharekakahu' Beach

This beach is not named on NZMS series maps and Johnson (1992) just refers to it as being south of Cape Saunders. The author calls it 'Wharekakahu' as it lies opposite the island off the coast of that name and other local names include Miller's Beach and Third Beach (Fig. 3).

Johnson (1992) describes this beach as being small with marram common on small dunes along with white clover (*Trifolium repens*), sweet vernal (*Anthoxanthum odoratum*), catsear (*Hypochoeris radicata*) and hawkbit (*Leontodon autumnale*). He notes that pingao is more abundant here than at any other Otago site. It merges with silver tussock (*Poa cita*) where the sand meets the loess soils of the hillside.

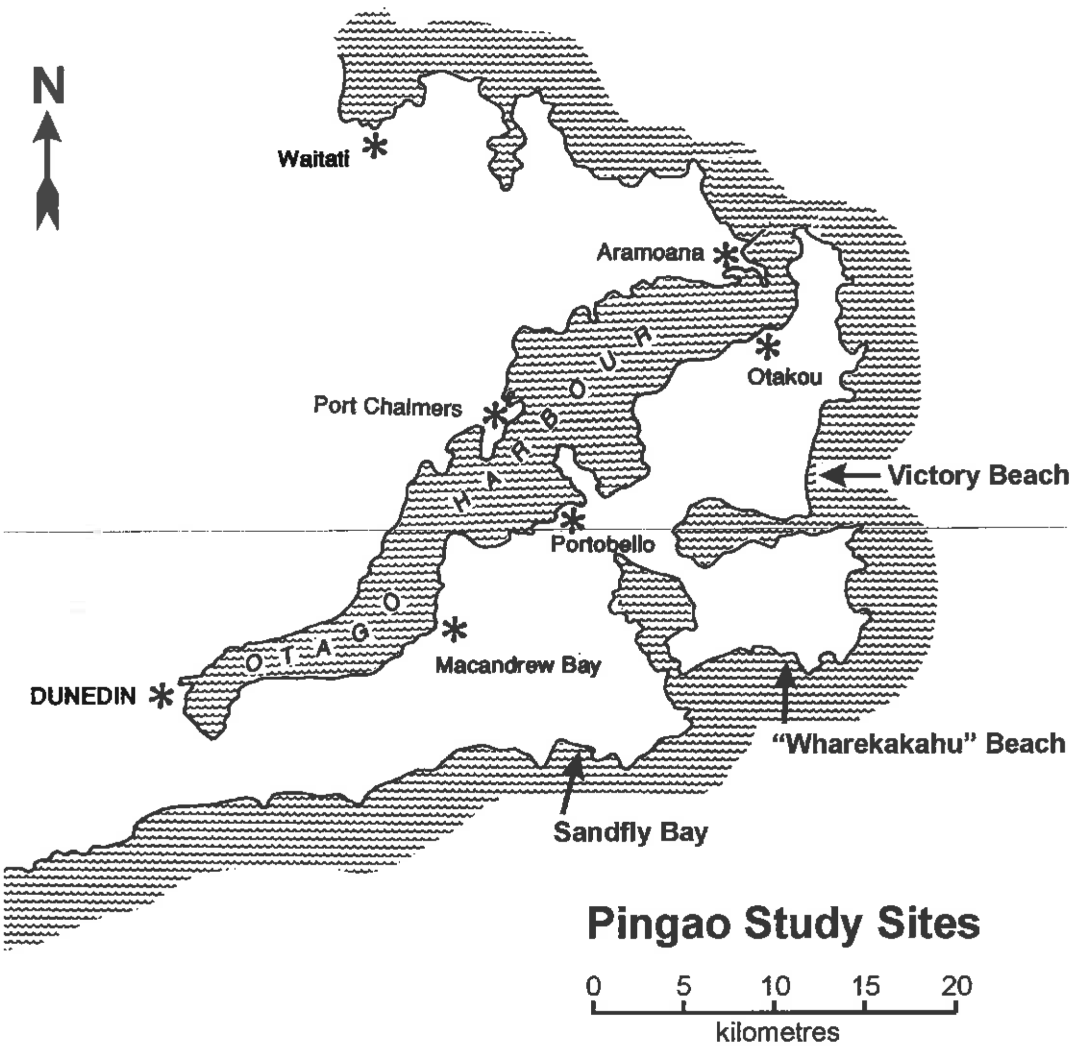

Fig. 2 Map of study sites.

Sheep and cattle grazed this area until mid 1997 when it was fenced for restoration of yellow-eyed penguin habitat. Cattle were often overwintered in the area and tended to be very destructive towards the pingao, ripping it out of the ground in large chunks (Fig. 4).

Fig. 3 'Wharekakahu' Beach. The pingao involved in the study site is in the middle of the extreme right hand side of the photo.

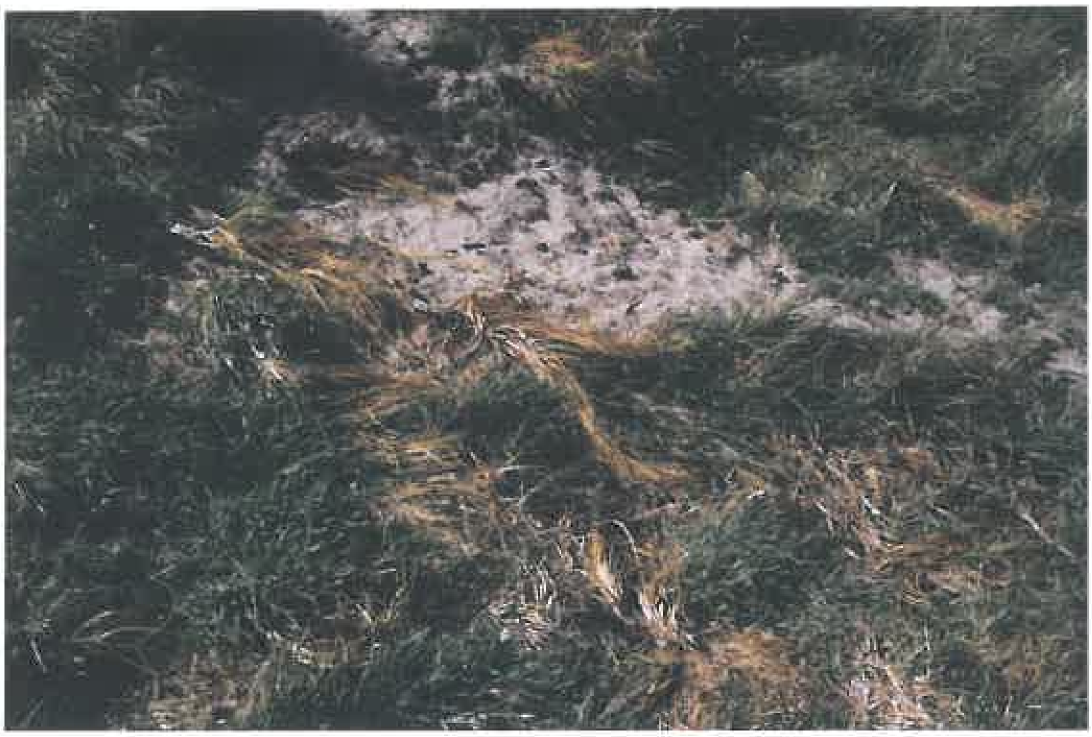

Fig. 4 Cattle damage to pingao at 'Wharekakahu' Beach. Note the relatively loose nature of the sandy substrate and the short grass.

Sheep also seemed to graze on the pingao and together the stock had the effect of keeping the area open and the ground disturbed with the result that pingao has been able to survive in quite large clumps. Since being fenced off the grass and marram has become rank and thick with result that pingao has become overgrown and in danger of being out-competed (Fig. 5).

Fig. 5 'Wharekakahu' pingao showing dense growth of marram and pasture grasses since the area was fenced in mid 1997.

This area has been topdressed on a regular basis as part of farming operations (Des Neill pers. comm., 1999) so fertility in the past has probably never been a limiting factor. The tenure is partly Department of Conservation managed land and part freehold land owned by the Yellow-eyed Penguin Trust.

Two separate clumps in this area were used in the study. In the results section these two sites are referred to as Wharekakahu 1 and 2.

6.2 Victory Beach (Okia Reserve)

This long curved beach has marram on low dunes at the southern end but the northern half has eroded back to tall dunes (8-10 m. high) which are covered mainly in lupin, bracken (*Pteridium esculentum*) and Muehlenbeckia australis (Johnson 1992). The southern third of the dunes was planted in *pinus radiata* in approximately 1983 (Tony Perrett pers. comm., 2000) and despite relatively poor growth due to the salt conditions, the pines now dominate the dunes with little or no understorey vegetation (Fig. 6). Pingao survives as scattered clumps, predominantly on the crests of dunes and generally overgrown with marram, grasses and lupin.

Fig. 6 Victory Beach (Okia Reserve). Two study sites are in the dunes amongst the pines and the third is approximately half way along the beach.

Two out of the three clumps used in this area have a history of management. One was sprayed with Gallant to control marram in 1994 and the existing pingao had some supplementary planting around it. The most northern of the 3 clumps used was predominantly one and a half year old plants planted around existing pingao clumps in

August 1996. These plants were planted with additional slow release nitrogen fertiliser and have had no management in the form of weeding or fertiliser since (David Blair pers. comm., 1999).

These sites are referred to as Okia 1, 2 and 3, and are all within the Okia Reserve, which is jointly owned by the Yellow-eyed Penguin Trust and the Dunedin City Council. The reserve is managed by a committee, which includes representatives of the owners, the local runanga and the Department of Conservation. The management plan specifically states that the regeneration of pingao will be encouraged (Okia Management Committee, 1998).

6.3 Sandfly Bay

This beach has an extensive area of sand extending over 1 km inland towards the summit of Sandymount to the north-east with large steep foredunes dominated by marram (Johnson, 1992). The prevailing southerly wind keeps the massive sandblow active (hence the name Sandfly Bay) and provides what appears to be ideal pingao habitat (Fig. 7). However pingao only grows in scattered small clumps. Several patches of pingao have been planted in this area using a variety of exposed open sand sites and sheltered back dune habitat. Despite difficulty in surviving in the open due to either being eroded out or being covered with excessive amounts of sand, some planted pingao has become well established. For this study a patch of pingao planted as one-year-old plants in June 1994 (David Blair pers. comm., 1999) in one of the back dune sites was chosen. This site had some initial treatment with a variety of fertilisers (Osmocote, Urea and Biogold) as part of an informal experiment and the plants responded quite well. However the pingao has since become overgrown with marram and weeds and has generally become moribund. This is despite occasional deposition of sand as the site is only one dune down wind of unconsolidated sand in the prevailing southerly.

This site is referred to in the results as S F Bay. The Department of Conservation manages the area.

Fig. 7 Sandfly Bay sandblow. The study site is down near the sea on the left hand side of the photo.

7. Methods

7.1 Requirements

It is clear from the brief review in section 4 that one of the main factors yet to be fully determined in studies of pingao is the role of competition with other species, and the nature of that competition. Several studies have suggested root competition for moisture is a significant factor in pingao decline (Esler, 1970; Courtney, 1983; Sykes, 1987; Partridge, 1995), whereas competition for nutrients is also suggested by Sykes (1987). This project aimed to separate these components of competition, so that the effect of root competition, shoot competition and nutrient status could be independently assessed.

7.2 Release Treatment

The treatment selected to test removal of root competition was spraying with the grass specific herbicide Gallant, as this have been proven to be effective in eradicating marram on Stewart Island and Southland Beaches (Barnes *et al.*, 1998; Jul, 1999), and Partridge (1995) found that hand weeding of marram had the potential to rejuvenate its growth. For this study, due to the relatively small treatment areas, gallant was applied by knapsack sprayer. The herbicide mix (15 ml/l) was sprayed directly over the whole treatment area as due to Gallant's selectivity; it leaves the pingao unharmed (as it is a sedge) but kills marram and grasses. Unfortunately it does not take out broadleaf weeds.

However the use of herbicides for management purposes can be controversial. Therefore to test the effect of removal of shoot competition, all vegetation apart from pingao was clipped off at ground level with a pair of shears. This effectively left the roots of a number of competitors intact to grow during the study period. While this maintained an element of competition for moisture, it was likely to be less than in the control plots as there would be less moisture loss from the system due to evapotranspiration.

The spraying and hand clipping treatments were compared with non-released control plots where no vegetation was disturbed.

7.3 Fertiliser treatment

To test the effect of competition for nutrients, it was decided to investigate whether the broadcasting of a fast-release nitrogen fertiliser would improve the health and vigour of pingao in a back dune situation. If this was the case then the existing pingao could continue to compete with other species and still produce adequate supplies of seed for collection.

Based on the actual amount of nitrogen in urea (46 %), the amount of nitrogen applied to each $1m^2$ plot was the equivalent of 200 kgN/ha. This was considered adequate for boosting growth of pingao as has been found for spinifex (Bergin, 1999). The urea was broadcast by hand over the selected plots. Fertilised plots were compared with non-fertilised control plots.

7.4 Trial design

At each of the sites selected, pingao colonies that ranged from individual plants to large clumps were used for the treatments, which were applied in a stratified randomised block design. Only six blocks were used due to the difficulty of finding sufficient clumps of pingao of adequate size to accommodate the experimental design, which requires a clump of at least rough dimensions of 2.5 m. x 4 m. Consequently it was necessary to use two blocks that were based around pingao planted at least three years ago. Unfortunately due to the limitations of the clump sizes, treatment replications were unable to be done within each clump so the individual sites had to serve as replicates. This further illustrates the issue of the sparse nature of surviving clumps of pingao on the Otago coast.

Each selected clump of pingao was designated a block and was divided into three down-slope $1m^2$ plots that were fertilised and three up-slope unfertilised plots. This was to avoid any runoff effect from the fertiliser onto unfertilised plots. A minimum buffer zone of 0.5 m. was allowed between each plot, the boundaries of which were marked by short wooden pegs (Fig. 8).

Fig. 8 An established block with boundary pegs of 1 m^2 plots.

The three treatments, spraying, clipping and a control were randomly allocated within the fertiliser treatments.

7.5 Assessment

This project set out to trial the effects of competition between other species and pingao, and its relationship to managing and maintaining pingao in a back dune situation. The primary requirement was to have some easily measured indicators of pingao health and vigour at the end of the trial. A number of the studies mentioned in section 4 were looked at for parameters that might be suitable for measuring. Measurement of above ground biomass as used by Courtney (1983) was rejected as being too expensive and also too destructive on what is a relatively limited local resource. Leaf length was considered too variable and time consuming to be of much use.

New growth of leaves, and number and length of seed heads were considered suitable parameters to measure as Courtney (1983) had found them effective in distinguishing variations between foredune and reardune-grassland inhabiting pingao.

Fig. 9 A clipped, marked shoot.

In each plot, three shoots were selected from separate plants where possible and all new light green leaves were clipped right back as far as possible without affecting the growing tip of the shoot (Fig. 9). These clipped shoots were marked with aluminium tags for later measurement of new growth.

One plot in Wharekakahu was set up in late May but the others were set up in August and September. This fitted in with the peak growing period of October to February that Courtney (1983) found in his study on Kaitorete Spit. A potential problem with this design was the possibility that pingao has differential flowering seasons due to environmental influences as is the case with tussocks (Janice Lord pers. comm., 2000). In this study, the factors determining flowering may have occurred well before the treatments were applied. However Bergin (pers. comm., 2000) has not observed variations in seed head production over a number of years of study but noted that spinifex does exhibit considerable variation of seed head quality between site and season and that this aspect of pingao may require further study. The other problem was that the treatments have had longer to take effect in the plot established earlier than the rest.

7.6 Measurements

All plots were measured from the 2nd to the 4th of March. At this time seed was just beginning to fall in most of the plots so there would be no further growth of seed heads. It also coincided with tapering off of leaf growth found by Courtney (1983) at Kaitorete Spit in Canterbury.

Measurement involved three things. Firstly all seed heads that originated from within each 1 m.^{2} plot were identified and clipped off with secateurs. Next each seed head was measured, the distance taken as that between the point of origin of the lowest bract on the stem and the tip of the apical spikelets (Fig. 10). Lastly each marked clipped shoot was found, the clipped leaves identified and all new leaf growth beyond these was counted. Any of these marked shoots that had produced seed heads were discounted due to the fact that as part of the inflorescence development, growth of the leaves that are borne on top of the stem becomes arrested and they then become the bracts on the flower head (Courtney 1983). Also two shoots had died with no new growth beyond the clipped leaves and one had insect damage which had killed the growing tip so these figures were discarded.

The full table of measurements and treatment times is attached as appendix 1.

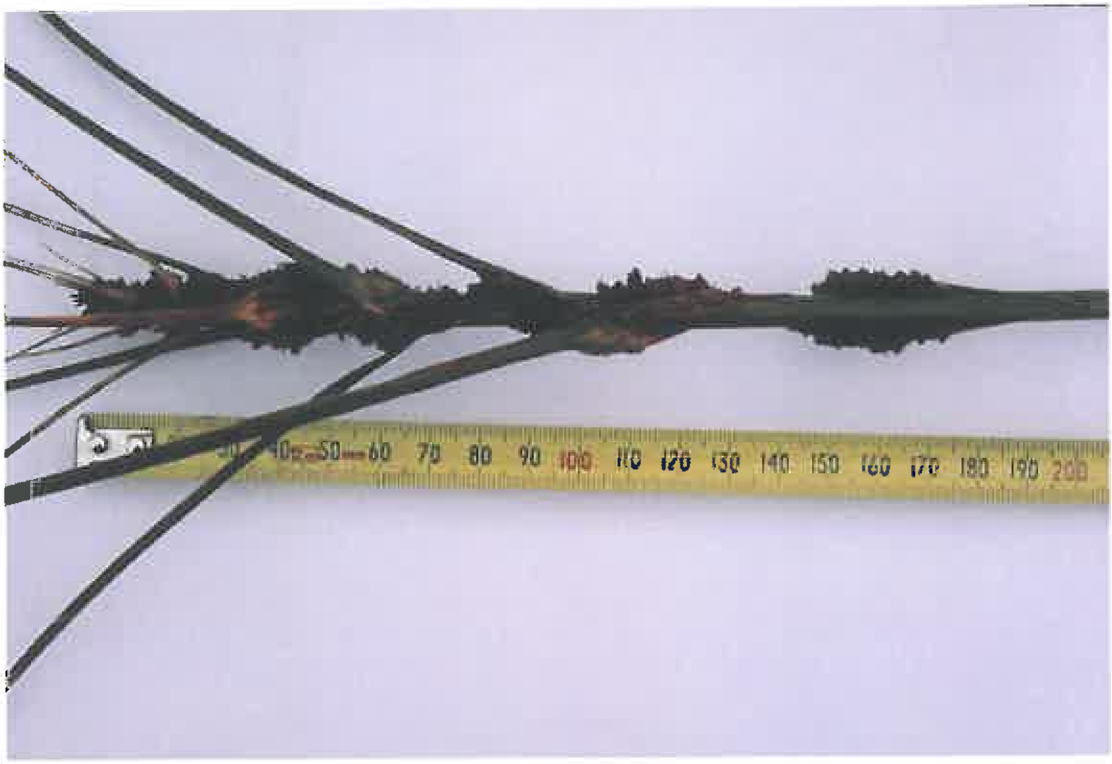

Fig. 10 Measurement of a seed head. This example measures approximately 20 cm.

7.7 Statistical analysis

Due to the small size of pingao clumps in the study sites, replicates were not able to be located within each block, therefore individual sites had to act as replicates. Firstly a one-way Analysis of Variance (ANOVA) was performed to see if there was any effect between sites (replicates) on the mean number of new leaves per marked shoot, the mean length of seed heads and the number of seed heads in each plot

If there was no significant difference between sites for a particular measure then the effect of treatments was tested using a factorial two-way ANOVA, with one factor being +/- fertiliser, and the other being the three release treatments (spraying, clipping and control), with the sites acting as replicates. If a significant difference existed between sites then the effect of the treatments on the particular measure were tested using two separate nested ANOVA models:

1. +/- fertiliser was nested within site, and release treatments were used as replicates;
2. release treatments nested within site, with +/- fertiliser used as replicates (this is not ideal, as the replicates are in reality pseudoreplicates due to the blocked design of the experimental layout).

Data were tested for equality of variance prior to analysis. A posteriori comparisons of means were conducted using Scheffe's tests.

A test for a significant relationship between the length of treatment and the different measures was done using Pearson's correlation.

8. Results and discussion

8.1 Results

There was no significant difference between sites for mean number of new leaves ($F_{5,29} = 0.87$, $P > 0.05$) and mean length of seed heads ($F_{5,34} = 0.59$, $P > 0.05$). However as was to be expected with the Okia 1 and 3, and S F Bay sites having young plants, there was a distinct difference between sites for the number of seed heads per plot ($F_{5,35} = 7.18$, $P < 0.001$) (Table 1). The mean number of seed heads per plot in Okia No. 1 and S F Bay were 5.6 and 8.8 respectively while all other sites averaged 18 or more per plot. To analyse the effects of fertiliser and competition on numbers of seed heads it was necessary to change the model to remove the effect of the age of plants. Consequently analysis of variance was done within sites (Table 2). This showed that the removal of root and shoot competition had no significant effect on the number of seed heads produced ($F_{12,35} = 0.47$, $P > 0.05$) but that that there was some effect as a result of the application of fertiliser ($F_{6,35} = 3.02$, $P < 0.05$).

Table 1. ANOVA results for the effect of replicates (sites) on the mean number of new leaves per marked shoot, the mean length of seed heads and the number of seed heads per plot of pingao. Marked shoots producing seed heads and dead shoots were excluded from the analysis.

	(a) Mean number of new leaves per marked shoot					(b) Mean length of seed heads				
Source	d.f.	SS	MS	F	P	d.f.	SS	MS	F	P
Between	5	2986.2	597.2	0.87	>0.05	5	21.8	4.36	0.59	>0.05
Within	24	16385.8	682.7			29	212.9	7.34		
Total	29	19372.0				34	234.7			

	(c) Number of seed heads				
Source	d.f.	SS	MS	F	P
Between	5	2981.2	596.2	7.18	< 0.001
Within	30	2490.6	83.0		
Total	35	5471.89			

Closer analysis using a Scheffe comparison of means unexpectedly showed that the non-fertilised plots produced the greatest mean number of seed heads (22.05) compared to only 15.83 for the fertilised plots ($F = 4.26$, $P < 0.05$).

Table 2. ANOVA results for the effect of removal of root and shoot competition (a) and application of fertiliser (b) on the production of pingao seed heads within sites. In both cases the effect of the main factor was treated as nested within site and tested using the other factor as the error term

Source	d.f.	SS	MS	F	P
(a)					
Site (A)	5	2981.2	596.2	5.66	<0.005
Comp (B)					
A* B	12	593.6	49.5	0.47	>0.05
Fert (C)					
A*B*C	18	1897.0	105.4		
(b)					
Site (A	5	2981.2	596.2	10.08	<0.001
Fert (B)					
A*B	6	1071.3	178.5	3.02	<0.05
Comp (C)					
A*B*C	24	1419.3	59.1		
Total	35	5471.9			

As there was no significant difference between sites for new leaf growth or seed head length, it was possible to use the sites as replicates in the analysis of variance performed on the effects of fertiliser and competition on these two parameters (Table 3). This showed that both the addition of a quick release nitrogen fertiliser ($F_{1,29} = 5.18$, $P < 0.05$) and the effect of removal of root and shoot competition ($F_{2,29} = 3.79$, $P < 0.05$) had a significant effect on the production of new leaves. However neither of these treatments had any significant effect on seed head length.

Table 3. ANOVA results for the effect of application of fertiliser (Fert) and the removal of root and shoot competition (Comp) on (a) the production of new leaves and (b) the length of pingao seed heads across all sites. Marked shoots producing seed heads and dead shoots were excluded from the analysis. * 6 cases missing due to death or flowering of shoot (see methods section).

	(a) Mean number of new leaves per marked shoot					(b) Mean length of seed heads				
Source	d.f.	SS	MS	F	P	d.f.	SS	MS	F	P
Fert (A)	1	2605.9	2605.9	5.18	<0.05	1	0.06	0.06	0.01	>0.05
Comp (B)	2	3816.6	1908.3	3.79	<0.05	2	18.4	9.2	1.24	>0.05
A*B	2	1329.8	664.9	1.32	>0.05	2	0.08	0.04	0.01	>0.05
Site (C)										
A*B*C	24	12071.3	502.9			29	216.1	7.4		
Total	29*	19823.8				34	234.7			

A Scheffe comparison of means of new leaves across all sites showed a significantly greater production in fertilised plots (59.73), with a mean of 42.71 new leaves growing in non-fertilised plots ($F = 4.26$, $P < 0.05$).

A Scheffe comparison of means of new leaves between sites showed that although there was no significant difference, the sites with younger plants (Okia No.'s 1 and 3, and S F Bay) had the greatest mean production of new growth. This was even more obvious when the means of new leaves were compared in the fertilised plots of all the sites (Table 4).

There was a range in treatment times in order to test whether fertiliser needs to be applied well before the beginning of the main period of growth in September as found by Courtney (1983). Wharekakahu No 1 was treated in late May while the other sites were treated from mid August to mid September. Only a weak correlation ($r = -0.239$) was found between the length of treatment and the effect of fertiliser on mean number of new leaves and the correlation was even weaker for the length of seed heads ($r = 0.068$). Although there was no significant difference in leaf production between sites, the site with the longest treatment period (Warekakahu No. 1) had the lowest mean number of new leaves per plot, 29.8 compared with a range of 48.1 – 61.3 for the rest (Table 4).

Table 4. Scheffe comparison of means of mean numbers of new leaves per marked shoot per plot for all plots and fertilised plots. No significant difference between means, $P < 0.05$

	(a)Mean number of new leaves per plot	(b) Mean number of new leaves per fertilised plot	
Site	Mean	Mean	Length of treatment (days)
Okia 1	78.9	61.3	183
Okia 3	73.3	59.3	183
S F Bay	64.2	48.1	172
Wharekakahu 2	56.5	53.6	196
Okia 2	50.6	56.9	184
Wharekakahu 1	34.8	29.8	281

8.2 Observations of trial sites

The spraying with Gallant was very successful with pasture grasses and marram dying off. There was no apparent effect on spraying the pingao. Some of the Okia No. 2 and S F Bay plots had reasonable amounts of dead pingao material but this was obvious before the trial was set up and occurred in all treatments, not just the sprayed plots. This was likely due to the general moribund nature of the pingao in these areas. In the fertilised and sprayed plot in Okia No. 2 the prolific new growth of pingao shoots in amongst the dead material was very noticeable.

Johnson (1992) notes that an event of considerable significance to vegetation on sand dunes was the rapid spread of the fungal disease *Colletotrichum gloeosporioides* in the lupin population since 1987. For a number of years this fungus has reduced the amount of lupins on the Otago Peninsula dunes but in the last two seasons it appears to making a comeback with substantial growth in the many areas (Peter Johnson pers. comm., 2000).

Prior to setting up the Okia No. 2 and 3 plots, a reasonable amount of mature and seedling lupin needed to be removed from the area. Lupin is a nitrogen fixer of potential benefit to dune vegetation, however with vigorous growth it can completely shade out pingao resulting in the plant losing vigour and possibly even dying whereas lupin survives (Fig.10). As the lupin has been showing a greater resilience to the virus, many areas that have been cleared of marram either by hand weeding or by spraying with Gallant, have experienced substantial growth of lupin overtopping the existing pingao (Pers. obs., 1999). This has obvious implications for the future management of the pingao remnants on the dunes.

Fig. 11 Pingao that is struggling to survive due to being shaded out by lupin.

Both of the Wharekakahu sites are in an area that has had some limited development for pasture prior to being fenced in 1987. Since fencing the vegetation has become dominated by tussock, marram and pasture grasses, particularly Yorkshire fog (*Holcus lanatus*) (Fig. 5). Although not obvious in the taller growth, hawkbit (*Leontodon autumnale*) and catsear (*Hypochoeris radicata*) are present. As a result of the clearance of the taller vegetation in the plots by clipping and particularly spraying, hawkbit and catsear became the dominant vegetation in the clear areas in those plots along with a mixture of sheep sorrel (*Rumex acetosella*), white clover (*Trifolium repens*) and *Cerastium glomeratum* along with the occasional Scotch thistle (*Cirsium vulgare*) and the smaller thistle *Carduus nutans* (Fig. 12).

Fig. 12 Hawkbit, catsear, Scotch thistle and other weeds in a sprayed plot after marram and pasture grasses have died.

As was to be expected in the clipped plots, marram and Yorkshire fog have regrown vigorously.

The Okia sites have a different mix of original vegetation (see section 6.2) and having never been developed for grazing, there is not the dominance of pasture grasses with the marram, bracken and lupin. Okia No. 1 site, being a planted plot, still has reasonable areas without pingao and it occupies a fairly dry site on the top of the dune. Consequently the regrowth of marram and grass after clipping and spraying was not as luxuriant as the other Okia and Wharekakahu sites. Most plots had lupin seedlings as well as hawkbit and catsear and a small amount of grass growth. The other two Okia plots were mainly established pingao clumps and had less bare ground and consequently there was less regrowth of grass, hawkbit and catsear, but lupin growth was strong and marram also responded to the clipping and fertiliser treatments. One of the unfertilised clipped plots also had a good cover of the native spinach, *Tetragonia trigyna*.

The Sandfly Bay plot was also of planted origin but being in stable vegetated dunes, quite a bit of clearance of marram was required before pingao was planted (David Blair pers. comm., 1999). Having a pure sand base meant there was a relatively high proportion of bare ground in and around this plot, and the surface cover of pingao was less than the other well established plots. Regrowth in both clipped plots was mainly marram, hawkbit and catsear whereas the sprayed plots had similar species except for marram which was replaced by lupin. Although only spotted in one plot, there was quite a bit of *Senecio lautus* as ground cover in the area.

8.3 Discussion and implications for management

The use of a fast-release nitrogen fertiliser (urea) had a significant effect on the production of new pingao leaves in the study plots in stable rear dune areas, particularly when used in conjunction with the grass specific herbicide Gallant to remove root and shoot competition by marram and pasture grasses. The same treatment did not have a significant influence on either increasing the production of seed heads or the length of seed heads.

In the Otago situation where pingao predominantly survives only in the rear dunes, this is important for the continued management and retention of the resource until restoration and planting programmes can re-establish sufficient self sustaining areas of pingao on foredune areas.

The aim of retaining the pingao resource is to have sufficient areas to collect seed from to use for producing plants for restoration of fore dune areas. The longer the seed head, the more the number of bracts it is likely to contain and hence the more seeds it is likely to produce (Courtney 1983). If the remaining pingao resource was very scarce then the lack of influence on the number of seed heads and the length of seed heads (and hence the amount of seed produced) caused by the trial treatments of fertiliser and spraying may be of concern. However there are at least 20 different locations in Otago with varying numbers of plants, mostly existing stock, that produce seed heads for collection. There are also another 8 planted areas as well as garden based plants associated with local marae that are, or soon will be producing seed (pers. obs., 1999). This is more than enough to provide the amount of seed and the genetic variation required for a local restoration project.

Although there has been significant growth of exotic weedy species in the sprayed areas, the rosette-dominated ground cover does not appear to have competed with the pingao to the same extent that marram and pasture grasses have in the clipped areas (where the roots have regrown) and the control plots. This suggests that with fertiliser and spray treatment, pingao would continue to exist and maybe even thrive in managed areas of the back dunes. Some further investigation should be made into selective herbicides that could control the broadleaf weeds without affecting the pingao. If these ground cover weeds that continue to stabilise the sand could also be removed then there is the potential for the underlying sand to loosen up, allowing enough movement for some deposition to take place on the pingao.

Pingao seems to need moderate amounts of sand movement to thrive (Courtney, 1983; Bergin and Herbert, 1998) so another option would be to spray a sufficiently big area around the existing pingao that might allow the wind to stir up the sand enough to create some movement. As dead marram takes several years to break down (Jul, 1999) this process may take some time but this would give existing pingao time to adapt to the changing environment. If the process happened too quickly and violently, excessive wind erosion exposing the pingao roots could have a deleterious effect (Bergin and Herbert, 1998).

The clipping treatment while reducing some competition in the short term does not kill the roots of marram or pasture grasses. These species, particularly in the fertilised plots, grew very vigorously and judging by the results, competed with the pingao for available nitrogen and moisture so there was no significant increase in new leaf growth compared to the sprayed plots. Hand weeding of marram in particular is labour intensive and ineffective in terms of results as the disturbance of the sand allows quick and vigorous regrowth of marram (Partridge, 1995). Therefore it is suggested that hand weeding or clipping should not be used as a management technique.

The plots with younger plants appeared to produce more new growth in response to the application of fertiliser than more established clumps. This may be due to the ability of younger plants to utilise a relatively higher proportion of fertiliser as a result of their smaller biomass. As has been shown by Bergin's (1999) research into fertilising established stands of spinifex, it is probably appropriate to broadcast fertiliser at a rate of 400 kgN/ha, particularly on established pingao clumps.

Treatments were spread out from late May until mid September to ascertain whether timing of management was significant. The longest treatment period did not appear to benefit pingao, rather it produced the least amount of new leaf growth. The application of fertiliser in early winter may have allowed it to become washed away in the sandy substrate much quicker. Consequently it is recommended that application of fertiliser and Gallant herbicide should be undertaken in late winter to early spring (August – September).

Lupin appears to be making a comeback from the effects of the fungal disease *Colletotrichum gloeosporioides* that appeared around 1987 (Johnson, 1992). Typical of legumes, lupin produces copious quantities of hard-coated seed, which can remain viable in the ground until disturbance or increased light permits germination. This has serious implications for the management of pingao in back dune sites as any attempt to loosen up the sand by spraying the marram and pasture grasses will inevitably encourage the prolific germination of lupin in areas where there is seed sources nearby (pers. obs., 1999). If lupin is permitted to grow unchecked, it has the potential to completely shade out pingao, resulting is dramatic loss of vigour or even death (Fig. 11).

At present there is no method used to control lupin apart from hand pulling of seedlings or cutting of larger plants. This is labour intensive and requires regular visits back to each site to monitor and remove new seedlings. For the management of pingao in back dune sites to be effective a more suitable way of controlling lupin is required.

9. Recommendations

1. A combination of spraying marram and grasses around existing clumps of pingao in stable back dunes with Gallant herbicide and broadcasting a high-nitrogen fertiliser over pingao plants will boost growth of pingao.
2. Fertiliser should be applied at a rate of at least 400 kgN/ha on established pingao clumps and the application of fertiliser and Gallant herbicide should be carried out in August to September.
3. Hand clipping or pulling of marram and pasture grasses is not a practical method of releasing pingao.
4. An investigation should be carried out into the use of a broadleaf herbicide to control weed growth on dunes that will not affect pingao.
5. Particular effort should be made to establish pingao-planting programmes on foredune areas, particularly where existing populations are under threat.
6. Trial Gallant spraying over larger areas with the aim that large-scale die off of marram and pasture grasses will encourage the spread of pingao and the re-establishment of dune systems where the indigenous sand binders will dominate and be effective in sand stabilisation.
7. Evaluate control options for lupin where it has proven to be shading out pingao.
8. Integrate the results of this study into the Department of Conservation recovery plan, which is currently in the process of being updated.

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Appendix 1.

Table of measurements of mean number of new leaves per marked shoot, mean length of seed heads and number of seed heads of pingao per treated plot for the six study sites. Length of treatment is included. Treatments are fertilised (F), Non-fertilised (Unf), clipped (cl), sprayed (sp) and control (con). Missing values (m) denote situations where all marked shoots had either developed into seed heads or died.

Site	Treatment	Length of treatment in days	Mean No. of new leaves per marked shoot	Mean length of seed heads	No. of seed heads
Okia 1	F/cl	183	39.3	17.6	16
	F/sp	183	123.6	14.4	6
	F/con	183	74	10.7	2
	Unf/cl	183	26.3	13	5
	Unf/sp	183	63.6	m	0
	Unf/con	183	41	18	5
Okia 2	F/cl	184	76	15.5	24
	F/sp	184	48.3	13.6	5
	F/con	184	27.5	14.4	28
	Unf/cl	184	76	16	37
	Unf/sp	184	m	14.8	34
	Unf/con	184	m	14.7	35
Okia 3	F/cl	183	50.3	13.2	28
	F/sp	183	108.6	18.1	22
	F/con	183	61	20.7	13
	Unf/cl	183	54	13.5	32
	Unf/sp	183	53.3	16.4	26
	Unf/con	183	28.3	16	22
Wharekakahu 1	F/cl	281	41	14.3	13
	F/sp	281	42.5	15.7	33
	F/con	281	21	17.6	22
	Unf/cl	281	m	16.4	51
	Unf/sp	281	m	14.5	32
	Unf/con	281	15	18.4	30
Wharekakahu 2	F/cl	196	37	15.1	11
	F/sp	196	79.6	14	12
	F/con	196	53	24.9	14
	Unf/cl	196	m	16.1	33
	Unf/sp	196	m	14.8	11
	Unf/con	196	45	14.7	27
SFBay	F/cl	172	80	12.8	6
	F/sp	172	82.5	17.5	15
	F/con	172	30	11.4	15
	Unf/cl	172	36.6	13.6	10
	Unf/sp	172	24	17	1
	Unf/con	172	35.5	16.6	6