Interaction Between Pingao and Marram on Sand Dunes

Completion of Permanent Plot Studies

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CONTENTS

1. General Introduction

This report constitutes the completion of a larger study, mostly finished in 1991, on the interaction between the native sand binder pingao (*Desmoschoenus spiralis*) and the introduced sand binder marram (*Ammophila arenaria*) (Partridge 1991). In that report it was stated that part of the study, involving monitoring the interaction between the species in permanent plots, required a further two years data before accurate conclusions could be drawn. These measurements have now been completed, and the results are interpreted in this report. It is important that this report be considered in conjunction with the previous study (Partridge 1991), where other important aspects of the problem are covered. The work described here is an extension of Study 2 and Study 4, which are presented again in their entirety.

2. Study 2: The Process of Pingao Replacement by Marram

2.1 INTRODUCTION

It is clear that throughout New Zealand, and especially in the South Island, sand dunes once occupied by pingao are now covered in marram. What is not always clear, though, is the process by which this change has taken place. For instance, a statement frequently heard is that marram has displaced pingao by building dunes of steeper slope. Such statements are usually unsubstantiated; indeed, Esler (1978) illustrates the different dune profiles (his fig. 33), but nowhere does he state that this involves a displacement process, nor does he suggest that different dune-building processes are responsible.

For many of New Zealand's dune systems, and especially those built out of finer sands, evidence seems to suggest that the two species may never have been in contact (Cockayne 1911). In these situations, induced instability removed the entire pingao vegetative cover to create bare sand, upon which marram was later planted. In other situations, however, it is clear that the two species came into contact, and that pingao is being replaced by marram.

This study attempts to answer some important questions regarding the physical process of replacement, using permanent quadrats, put in place in 1988, i.e., following changes over a four-year period. Firstly, does marram replace pingao wherever they come into contact, or can pingao and marram co-exist in certain situations? If they can, then identification of these situations is crucial for optimising active conservation efforts. Secondly, how fast does the process take place, and what is the mode by which marram invades and by which pingao departs?

2.2 STUDY SITES

Plots were set up at three locations: Kaitorete Spit and New Brighton Beach, Canterbury, and at Hannah's Clearing, Haast, South Westland. At New Brighton the dune system is dominated by marram, with only a few small areas of pingao on the front face of the foredune. This situation is similar to many North Island dune systems, where pingao occupies only small areas above the strand line on dunes dominated by either or both of spinifex and marram (Partridge 1991). At Haast, the beach has a poorly structured system of very low dunes with about an even mixture of marram and pingao. Rather than building tall dunes, the binders create hummocks, the system grading into short forest/scrub behind.

Three parts of the extensive Kaitorete dunes were chosen for examination. In the north-east, near Birdling's Flat, there is a low two ridge dune system with a hollow between. On the seaward ridge a front of marram meets the pingao at a very obvious boundary. Additional small outliers of marram have also established in the pingao along the strand line. Although close to doing so in a number of places, marram has not yet reached the stable inner ridge by vegetative spread. At the south-western end, near Black Huts, the dune system consists of a single low dune ridge, with a long back slope down to Lake Ellesmere. The narrow base of the foredune has pingao, then marram to the dune crest, while the back slope has large "islands" of marram with narrow bands of pingao between. The third area is that which has been used for sand mining and adjacent unmined dunes, and has been described in Study 1 (Partridge 1991).

2.3 METHODS

The sites for location of the permanent quadrats were chosen to represent as many different situations involving mixtures of pingao and marram as possible. At New Brighton, one plot (6 m x 2 m) was set up and passes along the beach from dense marram, through a zone of pingao, to dense marram again. At the time of setting up there were areas of bare sand between the two species on both sides. At Haast, six plots were set up. Two were also used as controls for a marram pulling experiment reported on in Study 4. Unfortunately, one of these (plot 5) was mistakenly weeded of marram in May 1990. Plot 1 (8 m x 6 m) covers a section of the narrow dune system from bare sand to the margin of woody vegetation behind. Plot 2 (4 m x 3.5 m) was set up in a mixture of equal amounts of pingao and marram, with the two species in contact. Plot 3 (5 m x 5 m) was set up on a flat area where pingao seedlings were establishing, but where marram was beginning to spread from the side. Plot 4 (6 m x 2 m) consisted of two patches of pingao on sloping sand with marram spreading towards one of the patches. Plot 5 (3 m x 3 m) was set up in dense vegetation consisting of slightly more marram than pingao. Plot 7A (4 m x 2 m) (plots 6 and 7B were used for the weeding study) was set up in dense marram with only a little pingao remaining.

At the Birdling's Flat part of Kaitorete two plots (each 5 m x 3 m) were set up both straddling the pingao to marram boundary. At the Black Huts site plot 1 (4 m x 3 m) was set up to straddle the seaward pingao marram boundary, while plot 2 (7 m x 2 m) on the back slope extended from dense marram, across a zone of pingao that extended from the shore to the lake, and back into marram again. Eight plots were set up in the vicinity of the mined area at Kaitorete. Plots 1 and 2 (each 5 m x 3 m) straddle the pingao to marram boundary on unmined dunes. Plots 3 and 4 (each 4 m x 4 m) were set up on the strand line in equal mixtures of pingao and marram). In plot 3 the two species occurred mixed together, while in plot 4 they commenced as discrete clumps. Plot 5 (5 m x 5 m) was set up on an area previously dominated by marram that had been mined in the 1960s and again in 1987, and was being colonised by pingao seedlings and by a few marram plants from stem fragments. Plot 6 (5 m x 5 m) was also set up in an establishment area, but that had previously supported pingao without any marram. Plot 7 (4 m x 4 m) was on an area of dunes mined in the 1960s and now dominated by marram with some remnant pingao. Plot 8 (6 m x 6 m) was on an area mined in the 1970s and consisting of patchy pingao with some more recently established marram.

Pegs were placed to locate plot boundaries, tapes were placed across the plots at 0.5 m intervals, and sample points were established at each 0.5 m along these tapes. At each point presence of all plant species was recorded in a 10 cm x 10 cm square. In the plots set up to examine seedling dynamics, the position of each seedling was plotted. The plots were revisited annually in November and species frequencies were recorded.

2.4 RESULTS

2.4.1 *New Brighton*

There was little change at this site from 1988 to 1990. However, a major storm in early 1991 eroded back the dunes, causing both species to decline and pingao to eventually disappear. Marram is gradually filling in the resulting gap (Table 1).

TABLE 1 ANNUAL SPECIES FREQUENCY, NEW BRIGHTON.

	1988	1989	1990	1991	1992
pingao	17	14	12	2	-
marram	45	48	46	14	18

2.4.2 *Haast*

Plot 1

In this large plot there have been major changes not only in pingao and marram but in other species as well (Table 2). The greatest changes were between 1988 and 1989, when most species showed a considerable increase in cover. Only tree lupin (*Lupinus arboreus*) declined, owing to attack by the fungal pathogen *Colletotrichum* which devastated this species throughout New Zealand at that time (Molloy et al. 1991). The slowest-increasing species was pingao. Between 1989 and 1990, however, the process stabilised for many species, including both marram and pingao. Sheep sorrel (*Rumex acetosella*) continued to increase, while shore bindweed (*Calystegia soldanella*) suffered a decline. Again in 1991 there was a spread, especially of marram, although both *Carex pumila* and *Rumex acetosella* declined. In 1992 the plot had once again stabilised. Overall there was a trend of increasing pingao and marram, with marram the more rapid, while other species fluctuated.

TABLE 2. ANNUAL SPECIES FREQUENCY, HAAST PLOT 1.

	1988	1989	1990	1991	1992
pingao	18	22	21	24	25
marram	19	35	37	45	53
Carex pumila	27	35	35	18	1
Calystegia soldanella	13	25	16	15	20
Lupinus arboreus	11	-	1	-	-
Rumex acetosella	4	22	29	17	15
Rubus fruticosus	-	4	3	3	2
Ulex europaeus	-	-	-	-	2

Plot 2

Between 1988 and 1992 pingao has remained essentially constant (Table 3), while marram has undergone a steady increase to occupy more than half the plot and dominate by a ratio of 4:1 (from an initial 1:1).

TABLE 3. ANNUAL SPECIES FREQUENCY, HAAST PLOT 2.

	1988	1989	1990	1991	1992
pingao	14	11	13	15	14
marram	14	25	32	47	57

Plot 3

Colonisation has been remarkably slow (Table 4). Few of the pingao seedlings survive for long, and those that do show little growth. The largest pingao plant in 1992 had grown to only 55 cm, from a seedling in 1988. Each year the number of new seedlings declined, and their chances of survival became lower. All plants have been severely browsed. Marram, absent in 1988, has slowly invaded along one side and is now well established.

TABLE 4. ANNUAL SPECIES FREQUENCY, HAAST PLOT 3, AND THE NUMBERS OF PINGAO SEEDLINGS.

	1988	1989	1990	1991	1992
pingao	1	1	2	1	2
marram	-	2	4	10	12
pingao (total seedling)	11	17	10	7	4
1988	11	8	5	4	3
1989		9	1	1	-
1990			4	1	1
1991				1	-
1992					-

Plot 4

The amount of pingao has been relatively stable (Table 5). Initially pingao occurred alone, but marram rapidly grew into the plot from one corner and came into interaction with the pingao in 1991.

TABLE 5. ANNUAL SPECIES FREQUENCY, HAAST PLOT 4.

	1988	1989	1990	1991	1992
pingao	23	20	26	23	22
marram	-	2	8	22	28

Plot 5

There has been a slow increase in pingao between 1989 and 1991 (Table 6), although the 1992 value shows what may be the start of a decline. Marram has increased rapidly, its failure to do so in 1990 probably resulting from the accidental weeding during that period. In 1992 marram dominated virtually the whole plot, but pingao was still plentiful.

TABLE 6. ANNUAL SPECIES FREQUENCY, HAAST PLOT 5.

	1988	1989	1990	1991	1992
pingao	29	33	41	41	37
marram	39	59	63	73	82

Plot 7A

This is the most stable Haast plot in regard to the sand binders, even marram having become stable after an initial large increase in 1989 (Table 7). Between 1990 and 1991 parts were invaded by sheep sorrel and by gorse (*Ulex europaeus*).

TABLE 7. ANNUAL SPECIES FREQUENCY, HAAST PLOT 7A.

	1988	1989	1990	1991	1992
pingao	22	18	20	16	18
marram	76	87	80	84	89
Rumex acetosella	-	9	38	29	36
Ulex europaeus	-	4	9	16	4

2.4.3a *Kaitorete - Birdlings Flat*

Plot 1

In this densely vegetated plot the replacement of pingao by marram is very clear (Table 8). The spread of marram is matched by a decline in live pingao and an increase in dead pingao plants (recorded as such where the whole plant was dead). Also of note is the decline of the annual grass *Lagurus ovatus* following the advance of marram.

TABLE 8. ANNUAL SPECIES FREQUENCY, BIRDLINGS PLOT 1.

	1988	1989	1990	1991	1992
pingao (live)	49	44	38	26	22
pingao (dead)	13	32	26	25	26
marram	45	56	66	74	83
Lagurus ovatus	53	47	39	31	26
Hypochoeris radicata	-	-	-	3	3

Plot 2

Between 1988 and 1989 marram spread rapidly into the plot, and there was a decline in both pingao and *Lagurus* (Table 9). This trend slowed considerably between 1989 and 1992.

TABLE 9. ANNUAL SPECIES FREQUENCY, BIRDLINGS PLOT 2.

	1988	1989	1990	1991	1992
pingao (live)	64	52	45	39	38
pingao (dead)	8	18	21	29	26
marram	45	65	71	73	77
Lagurus ovatus	78	57	61	55	57
Rumex acetosella	10	14	19	26	26
Hypochoeris radicata	3	1	1	3	3
Bromus diandrus	-	-	-	4	6
Acaena agnipila	-	-	-	-	1

2.4.3b Kaitorete - Black Huts

Plot 1

The positions of the plants and the species composition remained remarkably stable over the four years (Table 10). There was also a clear and consistent separation of the two binder species by a distinct bare zone.

TABLE 10. ANNUAL SPECIES FREQUENCY, BLACK HUTS PLOT 1.

	1988	1989	1990	1991	1992
pingao	16	21	17	21	19
marram	32	32	33	37	38
(overlap)	-	-	-	-	-
Lagurus ovatus	10	6	14	13	8
Calystegia soldanella	5	13	3	8	13
Salsola kali	-	1	-	1	-

Plot 2

On one side the marram was dense and the two binder species intermixed, while on the other side it was of lower density and the two species were separated by a bare area. Species composition (Table 11) remained stable, however.

TABLE 11. ANNUAL SPECIES FREQUENCY, BLACK HUTS PLOT 2.

	1988	1989	1990	1991	1992
pingao	24	19	21	19	23
marram	55	56	57	55	55
(overlap)	8	7	5	4	7
Lagurus ovatus	8	3	1	7	9
Lupinus arboreus	-	-	3	-	-
Hypochoeris radicata	3	1	4	3	3
Rumex acetosella	-	-	-	1	4

2.4.3c Kaitorete - Central

Plot 1

Marram spread rapidly through the plot (Table 12) and after four years only a little pingao was left. The spread of *Acaena agnipila* was the result of growth of a single large patch, but this declined in the face of marram advance, as did most other minor species.

TABLE 12. ANNUAL SPECIES FREQUENCY, KAITORETE CENTRAL PLOT 1.

	1988	1989	1990	1991	1992
pingao (live)	40	39	30	18	10
pingao (dead)	5	8	12	15	22
marram	40	52	62	69	79
Lagurus ovatus	29	25	18	8	9
Calystegia soldanella	8	5	5	1	-
Hypochoeris radicata	4	3	3	3	3
Acaena agnipila	3	5	9	5	4

Plot 2

In contrast to plot 1, the replacement process was very slow (Table 13). Marram seems to be advancing only very slowly, and its effect on pingao seems equally slow. The greater than usual frequency of associated species is due to the plot's location on the back dune system.

TABLE 13. ANNUAL SPECIES FREQUENCY, KAITORETE CENTRAL PLOT 2.

	1988	1989	1990	1991	1992
pingao (live)	34	31	31	26	23
pingao (dead)	22	22	27	19	19
marram	45	51	56	60	68
Lagurus ovatus	60	68	66	57	51
Bromus diandrus	12	13	18	12	10
Hypochoeris radicata	6	5	4	4	5
Rumex acetosella	5	10	1	8	3
Acaena agnipila	-	-	1	-	-

Plot 3

At this active establishment zone both pingao and marram have spread vigorously (Table 14), although pingao was showing signs of a decline in 1992. During the first year they barely came into contact, but by 1992 they were well mixed together.

TABLE 14. ANNUAL SPECIES FREQUENCY, KAITORETE CENTRAL PLOT 3.

	1988	1989	1990	1991	1992
pingao (live)	30	38	40	46	42
pingao (dead)	-	-	-	-	2
marram	21	32	38	53	59
(overlap)	1	6	11	21	23
Calystegia soldanella	14	19	10	14	9
Lagurus ovatus	1	6	9	7	7
Hypochoeris radicata	-	1	1	1	2
Acaena agnipila	-	-	-	1	1
Salsola kali	1	-	-	-	-

Plot 4

Although the overall totals for pingao remained rather stable, while those for marram increased (Table 15), these figures somewhat obscure two processes that were taking place. Originally the marram was a dense patch surrounding some pingao, while other pingao was present around the periphery. This central pingao declined from 8 sample points in 1988 to 5 in 1989 to 2 in 1990, and none in 1991. Around the margin pingao spread has compensated for this loss, but these too came into contact with marram in 1990, although there was no sign of displacement in the following two years.

TABLE 15. ANNUAL SPECIES FREQUENCY, KAITORETE CENTRAL PLOT 4.

	1988	1989	1990	1991	1992
pingao (live)	20	20	21	17	19
pingao (dead)	4	6	10	6	6
marram	33	43	49	57	67
(overlap)	6	5	1	1	5
Lagurus ovatus	4	-	2	6	7

Plot 5

Initially this plot contained a large number of pingao seedlings and a few marram patches established from rhizome fragments (Table 16). The area had been mined in 1987, so these plants had only recently established. The numbers of new pingao seedlings declined with time, and survival was poor. In contrast, marram survival was good, and the plants were spreading. Surviving pingao plants were showing signs of severe grazing, most probably by rabbits and hares, which are common on the dunes. By 1992 the plot seemed destined to become pure marram. However, following the recommendations of Partridge (1991), the Department of Conservation in late 1992 constructed a rabbit-proof fence around the area, planted pingao seedlings and sprayed the marram clumps. By mid 1993 the pingao seedlings had grown rapidly, and were close to the size that will no longer be grazed. Marram spread has been halted, so competition will not take place.

TABLE 16. ANNUAL SAMPLING FREQUENCY, KAITORETE CENTRAL PLOT 5, AND THE NUMBERS OF SEEDLINGS OF EACH SPECIES ACCORDING TO THEIR YEAR OF ORIGIN.

	1988	1989	1990	1991	1992
pingao	4	1	-	-	-
marram	2	6	7	17	21
pingao (total seedling)	18	8	4	2	1
1988	18	2	1	1	1
1989		6	1	-	-
1990			2	-	-
1991				1	-
1992					-
marram (total plants)	5	6	6	6	6
1988	5	4	4	4	4
1989		2	2	2	2
1990			-	-	-
1991				-	-
1992					-

Plot 6

The number of pingao plants has remained rather stable, those lost each year being replaced by new recruits (Table 17). However, recruitment has declined over the four years. The plants are spreading slowly, and the trend suggests that they will slowly come to dominate the plot.

TABLE 17. ANNUAL SPECIES FREQUENCY, KAITORETE CENTRAL PLOT 5, AND THE NUMBERS OF SEEDLINGS OF EACH SPECIES ACCORDING TO THEIR YEAR OF ORIGIN.

	1988	1989	1990	1991	1992
pingao	2	3	5	6	9
pingao (total seedling)	14	16	14	10	10
1988	14	9	6	5	4
1989		7	5	3	3
1990			3	1	1
1991				1	1
1992					1

Plot 7

Neither pingao nor marram has spread into bare sites or into areas occupied by other species (Table 18). The plot contains two clumps of marram, one of pingao, and one where the two occur together, but with little sign of displacement.

TABLE 18. ANNUAL SPECIES FREQUENCY, KAITORETE CENTRAL PLOT 6.

	1988	1989	1990	1991	1992
pingao	14	14	14	12	12
marram	35	36	36	38	36
(overlap)	1	1	1	2	1
Lagurus ovatus	32	30	26	31	35
Hypochoeris radicata	5	2	4	5	4
Calystegia soldanella	14	17	11	7	9
Erodium cicutarium	6	6	9	5	4
Raoulia australis	11	10	11	11	12

Plot 8

Pingao occupies only a small proportion of the plot, but is stable and probably moribund (Table 19). Much of the area between the isolated tufts carries scabweed (*Raoulia australis*), a species indicative stable sand substrates.

TABLE 19. ANNUAL SPECIES FREQUENCY, KAITORETE CENTRAL PLOT 6.

	1988	1989	1990	1991	1992
pingao	8	8	8	6	6
Raoulia australis	13	14	15	15	15
Erodium cicutarium	7	8	5	5	7
Lagurus ovatus	3	5	1	2	5
Bromus diandrus	4	7	6	7	3

2.5 DISCUSSION

The results show that when pingao and marram interact only two of the three possible outcomes eventuate - stability, and pingao being displaced. Nowhere was there evidence that pingao was able to displace marram. Indeed, in brief examinations of dune systems in New Zealand (Johnson 1992, Partridge 1992), only one situation was cited (Pakiri Beach, North Island) in which marram was being displaced by pingao, and that was on a dune where marram had been recently planted on to the strandline.

A number of situations were evident in which the two species can co-exist, and these can be divided into stable and dynamic.

Stable situations involve either spatial separation or close mixtures of the two species. An example of the first is at New Brighton, where small patches of pingao occur on otherwise marram-dominated dunes. Similar situations exist throughout New Zealand, where such patches of pingao occur on the front face of foredunes otherwise dominated by marram, or more frequently by spinifex. Pingao has been shown (Sykes & Wilson 1989) to be more salt-tolerant than marram, and patches such as these may persist on the strandline because of this attribute, the less tolerant marram being kept further back. This stability at New Brighton was, however, only temporary, as demonstrated by its disappearance during a storm. The strandline and front face of the foredune constitute a risky environment in which pingao, by its confinement there, is especially vulnerable. In the situation that exists at New Brighton little can be done to manage the system so as to preserve or enhance pingao. Plantings of pingao have been rewarded with some success, but the potential for instability, especially during an erosion phase, leaves the plant very vulnerable. That it has been able to remain at all is indicative of pingao's ability to re-establish provided a seed source is available. On the New Brighton dunes, however, there is so little pingao left that even this ability is threatened.

Other patterns of spatial separation can be seen in the Black Huts plots at Kaitorete, where the entire dune vegetation of both pingao and marram appears to be stable. It has generally been regarded that pingao and marram occupy the same ecological niche, that is, any site that is suitable for one is suitable for the other. Ecological niches are best envisaged as a set of environmental gradients along which the particular species can survive. The realised niche is the part of the gradient along which the species is actually found, once interactions with other species are taken into account. Where their niches overlap, the two species actively compete for the same resources and thus the same site. Where such competition strongly favours one species over the other, displacement or exclusion may take place. However, the Black Huts sites suggest that niche overlap is not complete, and that there are situations to which pingao is better suited than marram. There is little doubt that the situation there is relatively stable, as there is no sign of recently dead pingao amongst the marram, nor is there evidence of marram spreading into the pingao. Sea water is frequently washed on to the seaward face of the foredune and down the narrow, low-lying areas to the lake, these being the areas occupied by pingao. It is difficult to envisage much sea water reaching the areas occupied by marram on the back face of the dune. Pingao is more salt-tolerant than marram (Sykes & Wilson 1989), so it seems that this limits spread of marram and maintains zones of pure pingao. This difference in salt tolerance therefore maintains the spatial separation of the two species. There is no need to control marram provided the present situation persists.

The two species also co-exist by spatial separation in the mined area at Kaitorete. In many of the areas sampled pingao appears to be stable, and indeed moribund, but at Kaitorete Central plot 7 marram appears moribund as well. In the earliest mined areas sufficient sand was left for dune building, and on these dunes marram has colonised at the expense of pingao (plot 5). On the dunes that were mined in the 1970s, however, there is limited sand available, so the marram and pingao mixture has stabilised at an earlier stage of colonisation. On the nearby plot 8, where marram is absent, dune-building has stopped even earlier, there being now scattered clumps of pingao barely beyond the seedling stage, but moribund and in poor health. Between the plants the surface has lost all movable sand, and is now a pavement dominated by scabweed. The absence of any interaction in plot 7 is therefore the result of both species being trapped by an inability to spread and come into contact. This suggests that for active displacement to occur, there needs to be sufficient sand within the system for at least marram to spread. Again, in this situation there is little need for active management of marram as this species has lost its ability to spread. This applies not only to mined dunes but to situations where sand supply is very limited.

In contrast to these spatially separated situations, the dunes at Haast demonstrate that pingao can co-exist with marram despite rapid spread of the latter. In an examination of the process by which marram can out-compete pingao, Partridge (1991) concluded that the marram was able to extract water from the surface sand layers in which pingao was rooted, thereby depriving it of moisture. Marram is more deeply rooted, and is thus able to exploit water at greater depth than pingao. This would suggest that in situations where surface water is in limited supply, competition would be more severe. At Haast the wet climate probably ensures that there is always sufficient moisture to supply both species, and thus maintain a mixture, whereas at Kaitorete the supply is more limited. The persistence of both species together at Haast may also result from the very dynamic dune environment. There is evidence that on occasions heavy storms flatten the dunes and destroy much of the vegetation. Pingao establishes more readily after such events from the abundant seed that is usually available. Marram establishes mostly from rhizome fragments, and initially there is less. Its faster growth rate means that it will eventually dominate, although it probably does not displace the pingao. So at Haast, marram will take over unless this renewing process intercedes. However, as seen also at Kaitorete, pingao seedlings are very palatable to rabbits and hares, so that in establishing areas grazing can alter the balance in favour of marram at a much earlier phase. Therefore, even though this situation involves co-existence, the long-term prognosis for pingao is not good, and remedial action will eventually need to be undertaken.

The situation of most concern is, however, that in which marram is displacing pingao. It has often been suggested, without evidence, that this process is related to dune building. Invasion by marram is unrelated to differentials in rate of sand accumulation. If indeed marram is able to trap sand at a faster rate, then it has no real influence on the displacement interaction, as seen at the strandline plots at Kaitorete Central, where displacement is slow. The most vulnerable stands of pingao are those that are stable and perhaps moribund. In these situations replacement is fairly rapid. An active front of marram consists of vigorous shoots that start widely spaced amongst the pingao. Other shoots arise from these, and marram density and height increase. Once a dense stand has formed the pingao declines in vigour, to eventually die. The boundary between pingao and marram therefore has four zones: pure pingao, pingao with extension shoots of marram, dense marram with unhealthy pingao, and dense marram with only dead pingao. Irrespective of whether the process is rapid or slow, the whole zone of change typically covers less than 3 metres, an indication of how effective the replacement process is. If, in extreme situations, not only pingao but also marram is moribund (such as on highly stable back faces of back dunes) the replacement process is slowed, neither species growing much.

At Kaitorete, some of the associated species disappeared with the pingao, most notably *Lagurus ovatus*, catsear (*Hypochaeris radicata*) and *Acaena agnipila*, but the displacement of pingao is of greatest concern. Although marram is easily managed while small, its spread poses considerable problems if left unchecked. Even if marram were removed from the dunes, there is little prospect of pingao re-establishing unaided. Areas where marram has been removed show no sign of colonisation by pingao, a situation similar to that on dunes from which tree lupin has been eliminated by disease (Molloy et al. 1991). It is in this situation, in which pingao is being most actively displaced, that most control effort for conservation purposes needs to be placed.

2.6 CONCLUSIONS

- Marram can either co-exist with pingao or displace it, depending upon conditions.
- Stable situations in which the two can co-exist include:

  (a) the front face of the foredune, where marram spread is restricted by its intolerance to salt;

  (b) where moisture in the upper sand layers is not limiting;

  (c) where both species are moribund in areas of limited sand supply.

- Unstable situations can occur in which co-existence is maintained through re-starting of the establishment phase, which favours pingao.
- Displacement of pingao by marram is most severe on stable dunes with moribund pingao, and where moisture supply in the upper sand layers is limiting.
- The replacement process is unrelated to that of dune building and to the shapes of different kinds of dunes.
- As soon as marram invades, pingao starts to lose vigour and dies, leaving pure marram.
- Pingao establishment can be severely restricted by grazing, whereas marram is unpalatable.
- To conserve stands of pingao, effort needs to be put into controlling marram, but at first only where it is actually displacing or threatening to displace pingao.

3. Study 4: Effects of Hand Weeding of Marram as a Control Measure

3.1 INTRODUCTION

The most commonly used technique for the removal of marram from mixtures with pingao is hand pulling. Despite its ability to explore greater depths of sand, marram comes out rather easily, although rhizome material is invariably left behind. Many areas seem to have been weeded once, such as a large stand at Kaitorete, while in other locations, such as at Ship Creek on the West Coast north of Haast, it is known that a single patch is weeded frequently. In the first situation it is hard to tell whether the hand pulling has had any effect; in the second, pulling has had a considerable beneficial effect, but has not eliminated the marram altogether.

The aim of this study is to gain a more accurate idea as to the effects of pulling by monitoring various plots in which marram is removed at varying intervals.

3.2 METHODS

At six sites (four at Kaitorete and two at Haast), pairs of permanent plots were marked out and the frequency of marram, pingao, and other species was plotted as in the interaction study described (Study 2). All plots are 3 m x 3 m except for Haast site 7, which is 4 m x 2 m. The pairs were chosen to be as even as possible, and were in most instances adjacent. At each site one of the pair was randomly assigned to be weeded. The two plots at Haast were weeded in 1988, then again after 1 year in 1989, and then at 6-monthly intervals in 1990 and 1991, giving six weedings over 4 years. The four plots at Kaitorete were divided into two weeding frequencies, yearly and 6-monthly; the first have therefore received four weedings in 4 years, and the second eight. Species frequencies were recorded before weeding in November, the other weeding being in May.

3.3 RESULTS

3.3.1a Haast: Plots 5 and 6

The unweeded plot 5 was accidentally weeded between the 1989 and 1990 readings. The first weeding made little difference, marram continuing to increase in the plots (Table 20). The 6-monthly weeding frequencies show a considerable difference from the annual weedings, however, with little marram left in the weeded plot, though still present after 4 years. Weeding seems to make little difference to the pingao.

TABLE 20. ANNUAL SPECIES FREQUENCY, HAAST PLOTS 5 AND 6.

	1988	1989	1990	1991	1992
Plot 5: unweeded					
pingao	29	33	41	41	37
marram	39	59	63	73	82
Plot 6: weeded					
pingao	53	47	45	41	45
marram	43	69	6	10	8

3.3.1b Haast: Plot 7

In 1988 marram covered both plots and remained fairly stable in the unweeded plot (Table 21). The first weeding made no difference, but those that followed have considerably reduced the cover of marram, although it was still present after 4 years. There is no indication that pingao has benefited from the weeding.

TABLE 21. ANNUAL SPECIES FREQUENCY, HAAST PLOT 7.

	1988	1989	1990	1991	1992
Plot 7A: unweeded					
pingao	22	18	20	16	18
marram	76	87	80	84	89
Rumex acetosella	-	9	38	29	36
Ulex europaeus	-	4	9	16	4
Plot 7B: weeded					
pingao	20	13	22	16	22
marram	62	62	16	11	11
Calystegia soldanella	-	11	9	2	2
Rumex acetosella	-	-	-	7	13
Ulex europaeus	-	-	-	11	7

3.3.2a Kaitorete: Plot 9

Annual weeding has made no difference to the dense marram at this site (Table 22) while pingao continues its slow decline. In comparison with annual weeding, the 6-monthly weeding shows a considerable decline in marram between 1989 and 1990. In the first year, however, there was no indication that this decline was likely to happen. Marram has continued at about 20% frequency despite the 6-monthly weeding. Pingao has shown no response to this change.

TABLE 22. ANNUAL SPECIES FREQUENCY, KAITORETE PLOT 9.

	1988	1989	1990	1991	1992
Plot A1: unweeded					
pingao	39	29	16	8	10
marram	55	71	80	92	90
Plot A2: weeded (annual)					
pingao	33	29	20	24	14
marram	59	69	63	82	86
Plot B1: unweeded					
pingao	33	27	18	16	14
marram	49	57	63	80	86
Plot B2: weeded (6 mth)					
pingao	43	39	39	43	37
marram	61	59	18	20	12

3.3.2b Kaitorete: Plot 10

Again, there was no noticeable decline in the marram weeded annually (Table 23). In the six-monthly weeding marram declined, but only in the second year. There is, however, evidence of an improvement in pingao in the plot weeded six-monthly.

TABLE 23. ANNUAL SPECIES FREQUENCY, KAITORETE PLOT 10.

	1988	1989	1990	1991	1992
Plot C1: unweeded					
pingao	39	29	27	18	10
marram	59	69	76	84	86
Plot C2: weeded (annual)					
pingao	29	31	22	24	16
marram	45	59	59	61	71
Plot D1: unweeded					
pingao	33	22	20	14	14
marram	39	51	59	71	78
Plot D2: weeded (6 mth)					
pingao	37	39	39	45	49
marram	51	39	10	4	6

3.4 DISCUSSION

The six sites examined show a remarkably similar pattern of response to weeding. Between 1988 and 1989 weeding had no effect on marram. Indeed, this species frequently appeared even more vigorous the following year, probably because the sand surface was disturbed and because a large amount of dead material was removed. That marram should recover in such a fashion demonstrates its rapid growth rate and the supply of reserves stored in the remaining underground parts. Indeed, it seems that such a treatment may be beneficial to the marram, as it removes the large amount of dead material above ground that shades the newly emerging shoots, allowing them to grow more vigorously. A large portion of above-ground dead material may be the reason that marram so readily becomes moribund in high density, long-established stands.

The second year of hand weeding shows major differences. In the two plots weeded only annually at Kaitorete marram has continued to recover with the same vigour as before, but in the other plots that were weeded twice in the second year the decline in marram has been remarkable. It appears that this frequency of weeding is sufficient to change the balance between reserves created and destroyed. This does not mean that the remaining marram is unhealthy, it simply appears less vigorous. In subsequent years this pattern has been maintained: annual weeding continues to make little difference, while 6-monthly weeding keeps marram at a lower frequency and restricts its spread. Marram does not, however, disappear completely, and it is envisaged that stopping the weeding will result in a return to pre-weeding densities and worse.

The response of pingao to the weeding treatments has been minimal. In plots that were weeded annually, the best that can be expected is a slowing of pingao decline or stability. In plots weeded 6-monthly the response is either stability or a very slow recovery. Therefore, weeding of marram can be expected to have little influence on the ability of pingao to re-occupy areas from which it has been displaced.

Marram therefore needs to be weeded frequently if this is to be successful. Infrequent weeding results in recovered vigour, and there should be no expectation that any response would be visible in the first year.

3.5 CONCLUSIONS

- Weeding of marram is effective only if carried out frequently and continuously.
- Failure to weed properly may be deleterious to the situation, as it rejuvenates marram growth.
- Weeding will not eliminate marram altogether.
- Alternative control measures will need to be examined if marram is to be effectively controlled.

4. General Summary

In a report on the interaction between pingao and marram on sand dunes, Partridge (1991) described the process and presented interim results on the interaction in permanent plots. This report concludes those studies and draws conclusions from them. The conclusions are essentially the same, but now involve a greater degree of certainty, and there are some additional points to be made. The studies have shown that marram can in certain situations not actually threaten pingao, these situations being the result of either spatial separation or of minimal competitive advantage to marram. Spatial separation occurs where marram is restricted by its lower salt-tolerance, or in situations where the dune-building process is artificially held at an early stage by a limited supply of sand. Where moisture is not limiting, marram is unable to displace pingao by starving it of water, so the two species can co-exist as a mixture, although in such situations marram may still be spreading and dominating the dune vegetation. It is imperative that these kinds of situations be understood and identified. Controlling marram where control is not needed can thus be avoided.

When the two species do interact in dry climates, the most likely scenario is that marram will replace pingao, although this process may take place at varying rates. In most situations this involves the deeply rooted marram depriving pingao of moisture in the upper sand layers while it obtains moisture lower down. Where pingao is old and moribund the displacement process occurs extremely rapidly. However, if marram is moribund as well as on extremely stable dunes the displacement is again slowed. Therefore the worst possible scenario for pingao is in a dry climate on slightly active dunes, as this is where the difference in vigour most favours marram. On the foredune both are vigorous, and on the back dunes both may be moribund, so displacement is slower there. In these displacement situations marram spread needs to be controlled. Hand weeding can be effective, but has risks and needs to be carried out frequently and continually.

5. Recommendations

The question that can now be answered from this study is: “What is the best way to manage the marram problem?” Given constraints of staff and finances, the Department of Conservation needs to develop a strategy to attack the problem most efficiently. Firstly, there is a need to identify, both on a national and a regional scale, priority areas for the protection of pingao. The sand dune and beach vegetation inventory of New Zealand (Johnson 1992, Partridge 1992) provides the starting point for this process. Once priority dune systems have been identified, the location and nature of the problem needs to be assessed. Scale is important; on some dune systems the long-term end-point may be elimination, but on others confinement of marram may be the only feasible option. Important here is the need to identify situations that are stable and those where displacement is occurring. Primary action needs to focus on the latter. Once this has been done, zones of maximum effect can be identified; these may be patches of marram along the strandline, or an advancing front. Control measures can then be focused on to these points. Exactly which control technique is to be used will depend upon the situation, but as shown in this study, half-hearted attempts are ineffectual. Once these areas are under control, management can be re-focused where the problem is less severe. Monitoring of the results is important for the lessons it offers. This does not need to be particularly detailed, and should cover the response of marram and pingao and the nature of the treatment undertaken, including timing.

Pingao is under major threat from marram in New Zealand, but a great deal can be done to alleviate the situation. Unfortunately the problem will never disappear altogether, but with careful management we can still look forward to appreciating dunes golden with healthy pingao.

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