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Sand Movement and Sand-binding Plants on Kaitorete Barrier, Canterbury

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In studies of sand dune environments, the importance of plants in dune building has been acknowledged by several writers (Willis et al 1959a, 23; Ranwell 1972, 6). Sand-binding species have frequently been compared in tests of plant-habitat relationships. Such species have wide tolerance ranges, suffer extreme conditions of highly variable temperatures and strong winds which cause both salt and sand blasting. In addition, plants of coastal areas must withstand either rapid burial or undercutting of their highly mobile substrate sand, which results in an austere environment for plant growth. However, previous studies have indicated that different sand-binding species, although thriving under similar environmental conditions, may result in marked variations in sand dune form.

Norman (1980, 21-2) described the impact of one such sand-binding species, *Ammophila arenaria*.

> Environmental changes brought about by the exotic stabilising grass species European beach grass (*Ammophila arenaria*, sometimes called marram grass or Holland grass), ... include exaggerated foredunes, and deflation planes, sand-starved inland dunes and temporarily prograded beaches.

Esler (1970) has examined the interplay of plants and habitat in the changing topography of Manawatu sand dunes. He compared three sand-binding species, *Spinifex hirsutus*, *Desmoschoenus spiralis* and marram, and suggested strong variations between their influences on sand dune morphologies. Marram appeared to form a higher steeper more irregular dune relative to both *Spinifex* and *Desmoschoenus*, which Esler related to marram's erect growth form and clump habit.

Hesp and Hyde (1978) extended the study of plant-habitat relationships by examining airflow modification around two pioneer sand dune plants, *Festuca littoralis* and marram. They endeavoured to explain the variations in developing bedforms by studying the relationships between plant morphology, airflow behaviour, and bedform evolution. These studies indicated that sand-binding plants may play a far more important role in sand dune dynamics than previous plant-habit studies had suggested.

In this paper the extent of plant interactions with blowing sand in the development of sand dune landscapes will be determined for the sand-binding species *Desmoschoenus spiralis* (pingao) and marram grass. The influence of each species on patterns of sand movement, as well as their relative sand-trapping abilities will be described. Their mechanisms of interaction and airflow modification, will be examined and related to plant morphology and growth behaviour. These findings should enable relationships to be established between the two species and the geomorphic process of sand dune building. This interaction may account for observed variations in dune form.

Data Collection

Data collection was carried out on the sand dunes of Kaitorete Barrier and involved measuring sand movement and analysing variations in landscape features. Quantities and patterns of sand movement were measured with 30cm lengths of no.8 fencing wire firmly buried to a depth of approximately 10cm. The exposed sections of these pins were measured over a period of time to provide net sand movement. The pins were situated around plants under varying environmental conditions: locality on foredune; plant size and plant density and arranged in two patterns: cross-shaped and linear.

Three major terrain features were compared for each species: slope irregularity; profile shape; and sand size distribution. Slope irregularity is a measure of the small-scale variations in dune topography associated with each species, providing an indication of surface roughness. Profile shape involved measuring ten dune profiles colonised by each species with an Abney Level. These data were analysed with a standardising statistical procedure to determine average slope profiles. Sand samples were collected from the lee of ten plants of each species and from unvegetated dune sites. These were sieved and analysed following the Wentworth grain size classification.

The experiments determining airflow modification were carried out in the University of Canterbury, Mechanical Engineering Department's Wind Tunnel. Individual plants of each species were consecutively secured in the wind tunnel under controlled conditions. Each plant was approximately 50cm in height, with a 20cm base diameter. The air velocity was maintained at 4.2m/sec simulating a gentle breeze and anemometer measurements were made of windspeeds at 25 and 50cm heights, for distances up to 5m leeward of the plants. A smoke generator and video camera were also used to record patterns of airflow around the plants.

Landscape Variations, Sand Movement, Airflow Modification

A. Landscape Indices

The landscape indices were developed in an attempt to measure dune landforms on Kaitorete Barrier and to relate them to plant morphology and the consequent aerodynamic properties of both sand-binding species.

1. Slope Irregularity

The mean results are presented in Table 1, along with their standard deviations and coefficient of variation. The coefficient suggests a difference in dispersion between the two species, with marram possessing the higher value. Results of a Student 't' test indicate that this difference is significant at the 5% confidence level. This measure of topographic

Table 1. Slope irregularity - measured as distance from cross-bar to ground (cm)

	MARRAM			PINGAO		
	MEAN	STANDARD DEVIATION	DISPERSION	MEAN	STANDARD DEVIATION	DISPERSION
SAMPLE NO. 1	76.0 (cm)	2.0	0.03	75.5	2.0	0.03
2	73.9	2.0	0.03	72.2	3.3	0.05
3	73.9	3.4	0.04	73.5	2.4	0.03
4	73.6	3.9	0.05	67.8	4.5	0.07
5	79.3	4.9	0.06	68.4	3.7	0.05
6	77.7	2.7	0.03	73.1	2.2	0.03
7	73.7	2.2	0.03	75.3	2.8	0.07
8	69.1	3.5	0.05	72.8	2.8	0.03
9	85.4	7.2	0.08	74.6	3.2	0.04
10	71.8	6.7	0.09	73.0	2.4	0.03
GRAND MEANS	75.4	3.9	0.05	72.6	2.9	0.03

variation supports the observed trend noted by Esler (1970), that marram communities have more irregular dune landscapes than those of pingao.

2. Profile Shape

Comparisons were made of the average slope profile under each species and the results are summarised in Figure 1. Marked differences in profile shape are evident between the two species, with marram covered dunes being associated with concave slopes and pingao with convex. These variations in the sand dune landscape may be attributed to interactions between the species and blowing sand.

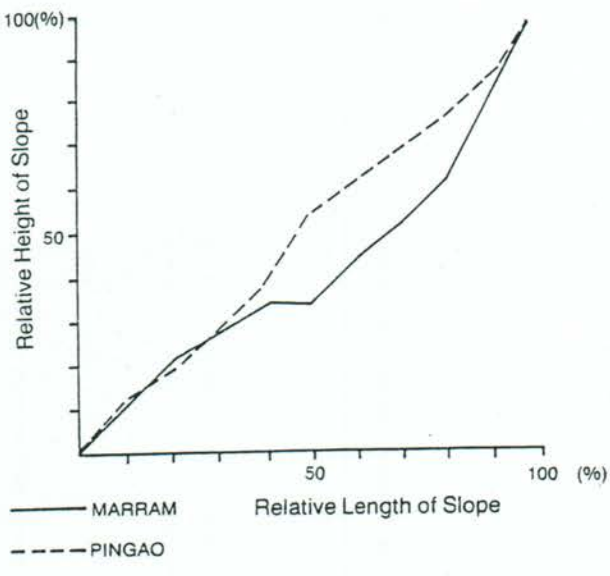

Figure 1: Standardised slope profiles for marram and pingao.

3. Sand Size Distribution

The results are summarised in Appendix I and reinforce the contrast between the coarser sand of the unvegetated and the finer sand of the vegetated dunes as well as the variations in sand size of dunes colonised by the two species. As finer sand is transported more readily than coarse sand, the relative amounts of sand in the finer size range may be a good indication of the ability of each species to retain trapped sand. Pingao is associated with marginally finer sand which suggests a greater sand-trapping efficiency in comparison to the more evenly distributed size range for marram.

B. Sand Movement

The cross-shaped pattern of pins revealed net change in the volume of sand surrounding individual plants from December 1980 to September 1981. The seven marram and six pingao plants studied were assigned to three size categories: small, medium and large. Means and standard deviations of net gain or loss were calculated and are summarised in Figure 2, with marram possessing the greater sand accumulation for all size categories. Net sand movement by distance from the base of each plant is summarised in Figure 3 with marram again showing the greater sand accumulation. These graphs illustrate the general trends in sand accumulation and through the large values of standard deviation emphasize that considerable variations can occur. Student 't' tests were therefore used to determine whether significant differences existed between the various means. The null hypothesis tested, that marram is not significantly different to pingao in amounts of sand accumulated around the individual plants, was rejected.

Only marginal differences in sand movement rates occurred between the localities of each plant species, as recorded by control pins, and these proved not significantly different. This suggests that overall, differences in sand accumulation between the two species are not accounted for by external conditions of sand supply, but are due to the influence of each species.

The linear traverses enabled net sand movement to be measured under varying densities of each species: low, medium and high. Eleven traverses, five through marram and six through pingao were pegged. Approximately half were located on the windward and half on the leeward dune face, but not all density categories were found for each species. Again the hypothesis that no significant difference in amounts of net sand accumulation between marram and pingao was tested.

The results in Table 2 show that no significant difference was found between the species, although pingao does possess the marginally greater values in total. By location, pingao has a significantly greater rate of sand accumulation on the protected leeward face and marram

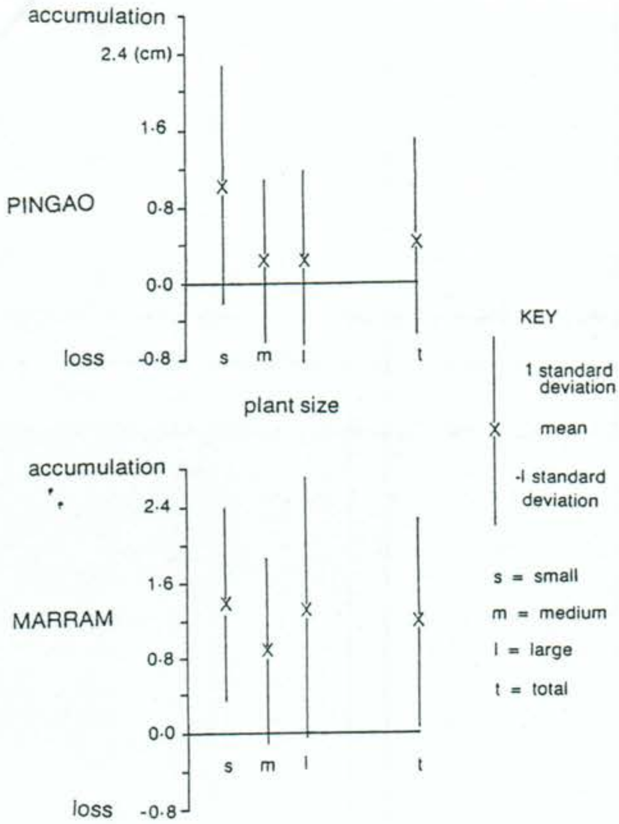

Figure 2: Patterns of sand accumulation/loss around individual plants: by species and size.

Table 2. Sand accumulation in single species stands, by species and locality

A.	Marram	Pingao	t
mean total	0.35cm	0.39	0.44

B.	Marram	Pingao	t
leeward	0.14	0.47	2.06*
windward	0.59	0.34	2.27*
	Marram leeward	Pingao windward	t
	0.14	0.34	1.67
	windward	leeward	t
	0.59	0.47	0.27

C.

	Orientation					
	Leeward			Windward		
Plant Density	Marram	Pingao	t	Marram	Pingao	t
Low	0.36	0.72		-	-	
Medium	0.23	0.41		0.21	0.38	
High	-0.16	0.22		-	-	

*Significantly different

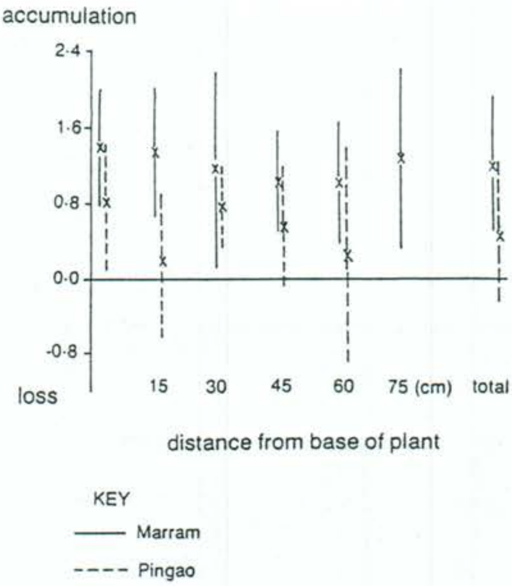

Figure 3: Patterns of sand accumulation/loss around individual plants at various distances from base of plants.

is significantly greater on the exposed windward dune face. These trends indicate that location has an important influence on the sand-trapping efficiency of each species.

In Table 3 the windward locality emerges as the area with the greatest overall sand accumulation. This is understandable because dune growth relies on a continual supply of sand and the windward dune face will consistently have greater sand movement.

Table 3. Sand accumulation in marram and pingao stands, by location

A.	Location		
	Leeward	Windward	t
Marram	0.14cm	0.59	4.09*
Pingao	0.47	0.34	5.65*
TOTAL	0.61	0.93	1.8 * (one-tailed)
	Leeward	Windward	t
	Low	Low	
Pingao	0.77	0.33	1.76* (one-tailed)
	Medium	Medium	
Marram	0.23	0.21	0.15
Pingao	0.41	0.38	0.13
	High	High	
Marram	-0.16	0.97	4.1*

* Significantly different

Table 4. Sand accumulation in marram and pingao stands, by density

Density	Marram			Pingao		
	Leeward	Windward	Total	Leeward	Windward	Total
Low	0.36	-	-	0.77	0.33	0.47
Medium	0.23	-	-	0.41	0.38	0.40
t	0.80	-	-	1.29	0.28	0.5
Low	0.36	-	-	0.77	-	-
High	-0.16	-	-	0.22	-	-
t	1.93	-	-	1.53	-	-
Medium	0.23	0.21	0.22	0.41	-	-
High	-0.16	0.97	0.40	0.22	-	-
t	1.50	4.75*	1.5	0.58	-	-

Table 4 presents sand accumulation results in relation to plant density and it can be seen that there appears to be no significant difference between categories.

These results have demonstrated the comparative influence of each sand-binding species on sand movement. The mechanisms of plant interaction with wind will now be described to determine how the two species interact differentially with sand.

C. Airflow Modification

It was hypothesised that, owing to differences in plant morphology, airflow modification would differ significantly between the two species and account for part, at least, of the observed variations in dune form. The results of the anemometer measurements are presented in Figures 4 and 5. The effects the plants have on airflow are best illustrated by the dramatic decrease in wind velocity at 25cm height in the centre, immediately leeward of the plants, (marram = 0.44m/sec, and pingao = 0.35m/sec) which would effectively halt sand movement. Velocity decreases further, at 45cm leeward of the plants, before increasing gradually from 55cm onwards. These results clearly indicate the existence of a zone of limited flow, as wind velocities at this position remain much lower for up to several metres in the lee of the plant. Downwind recovery rates appear to be different for each species with pingao initially displaying the greater windspeeds. However, after 105cm downwind of the plants, marram shows higher wind speeds which suggests that the influence on airflow close to the plant is relatively stronger and weakens with distance.

Consequent sand movement patterns for the two species should reflect these differences in airflow. Sand accumulation immediately leeward of marram should be higher as airflow is slowed and increases more slowly initially with increasing distance from the plant. A marram-induced bedform should therefore be more clumped, due to the stronger dumping tendency near the plant, whereas pingao should exhibit a lower bedform feature since its influence on airflow is relatively smaller.

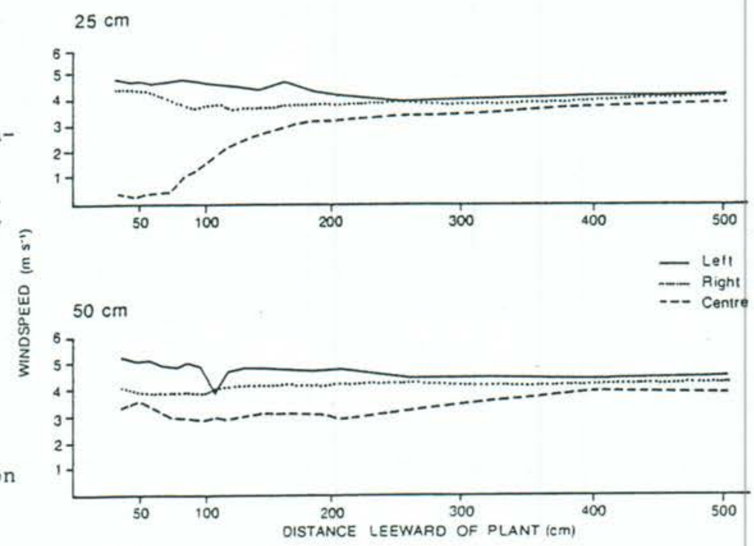

Figure 4: Windspeed modification leeward of marram at 25 and 50 cm heights.

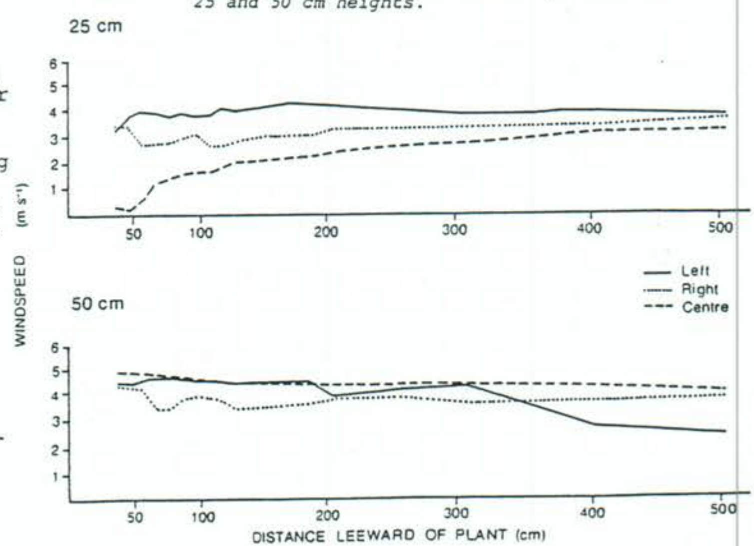

Figure 5: Windspeed modification leeward of pingao at 25 and 50 cm heights.

Marked differences in airflow modification between the species are also found laterally around the plants. The 25cm high anemometers on the plant flanks were not directly sheltered and showed an increase in windspeed for marram and a decrease for pingao. Although some variation could be accounted for by possible positioning error of the anemometers, the differences are considered to be the result of the erect, tufted growth form of marram in comparison with the open texture of pingao. Whereas pingao will allow air to penetrate the plant lower edges, marram provides a more solid obstacle, causing the airflow to be strongly altered and, consequently it displays an increase in velocity around the plant flanks. These differences in airflow patterns may be expected to affect sand movement patterns. The increase in velocity around the flanks of marram could cause scouring of sand and accentuate the clumped patterns of deposition described previously, as well as producing irregular topography. Airflow results for pingao, however, are consistent with the suggested patterns of lower bedforms and smoother topography.

Patterns of smoke disturbance are presented in the following series of photographs. Figures 6 to 12, clearly illustrate the trends measured by the anemometer recordings. Figure 6 shows the eddies and turbulence created around the edge of the plants. This airflow modification immediately in the lee of each plant can be compared in Figures 7, 8, 9 of pingao and 10, 11 and 12 of marram. These show actual reversals of wind direction as eddies are formed in the lee of the plant. This accounts for the anemometers recording higher wind velocities at 35cm downwind of the plants, than 45cm, because wind direction is reversed at the 45cm point and results in the wind speeding up closer to the plant. The eddy patterns differ between the two plant species. With the smoke probe at a height of 20cm, marram deflects the air higher and extends the eddy further leeward, whereas eddies around pingao do not appear as distinct and are smaller by comparison. These results are consistent with those of the anemometer measurements. The initially higher windspeeds around the marram plant, with very low recordings in the centre, account for the stronger eddy characteristics, whereas the decreased windspeed around the pingao plant results in weaker eddies occurring. These eddies, strongly influenced by lateral airflow, have the effect of transporting sand from the outer edges of the plants to the central position leeward of the plants. With the decline in windspeed at this point sand movement is halted and bedforms develop. As eddies formed in the lee of the marram plants become stronger, so sand deposition my be greater and the consequent bedform more clumped in comparison with that formed by pingao plants.

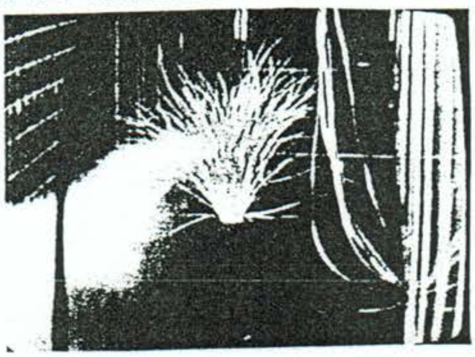

Figure 6: Eddies and turbulence created by airflow laterally around pingao.

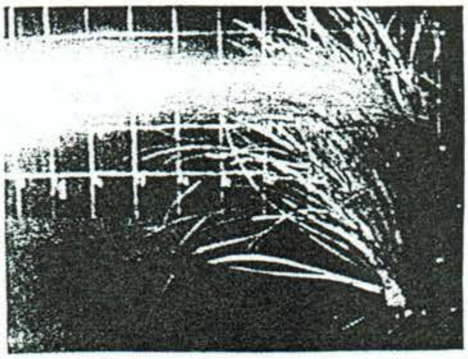

Figure 7: Pingao - smoke probe at 30 cm height.

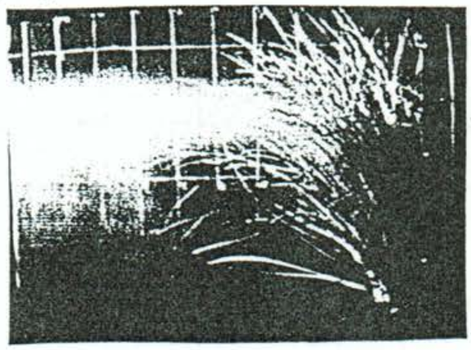

Figure 8: Pingao - smoke probe at 25 cm height.

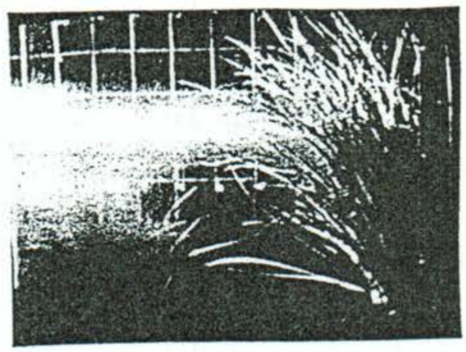

Figure 9: Pingao - smoke probe at 20 cm height.

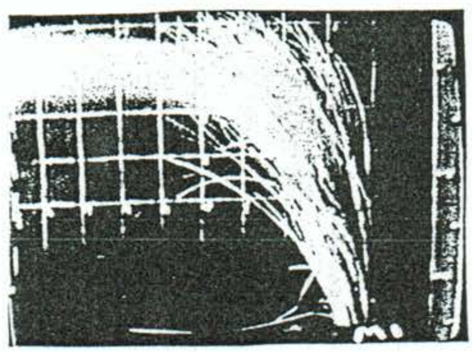

Figure 10: Marram - smoke probe at 30 cm height.

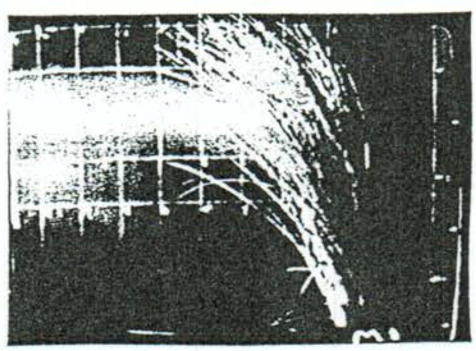

Figure 11: Marram - smoke probe at 25 cm height.

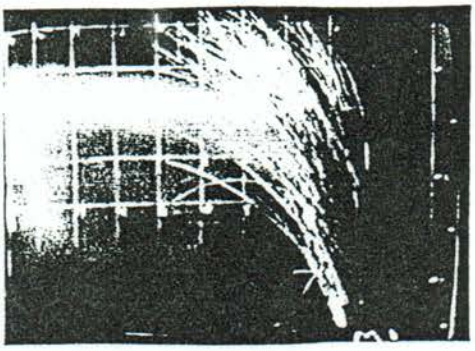

Figure 12: Marram - smoke probe at 20 cm height.

Conclusion

Sand movement studies of marram and pingao covered dunes have indicated marked differences between the two species. At the scale of the individual plant, marram has the stronger influence on sand movement and possesses the greater sand-trapping ability.

Conversely, at the community scale this dominance is altered, with pingao appearing to be marginally more efficient. These results imply that differences in plant morphology and growth behaviour have differing effects at these scales of interaction. Marram's tufted, erect bundle of leaves, together with its extensive roots, are in marked contrast to pingao. These growth differences give marram an initial superiority as a sand-trapping plant, thus enabling it to rapidly colonise the bare sand of environmentally harsh areas. Once colonised, however, the developing dunes afford more protection to individual plants. This may lead to changes in environmental conditions resulting in marram no longer enjoying strong advantages over pingao. Pingao's flexible, open-textured form must, therefore, be better suited to sheltered conditions and, as the field results reported here suggest, differences in sand-trapping abilities between individuals of the two species are minimised at the many-plant level.

The results of the aerodynamic studies of each species help explain the mechanisms by which plants interact with sand movement to produce their different effects. The patterns of airflow disturbance clearly illustrate the relationship between plant morphology and resultant sand movement trends. The marram plant appears to exert the stronger influence on air movement, through the creation of distinctive airflow patterns in its lee. Its erect, tufted shape appears to act as a fairly inflexible barrier to airflow, resulting in a sharp drop in windspeed leeward and increased airspeeds laterally. Sand movement around marram follows similar patterns with sand dumped immediately leeward of the plant. Pingao, by comparison, has more flexible leaves and, consequently, associated airflow modifications are less pronounced. This ensures a lower, smoother and more even deposition of sand in the lee of each plant, consistent with measured airflow patterns.

Both sand-binding grasses do have a strong impact on sand movement and play an important role in consequent dune building, resulting in distinctive landscapes. Differences arise, however, between the two species in their influence on geomorphic processes. The initial sand-trapping advantage of marram over pingao declines with the maturing of the plant community due to modification of environmental conditions. These patterns of changing environmental and plant relationships indicate that although marram will be more susceptible to erosive forces it is also more rapid in its dispersal and colonisation compared with pingao. The higher, steeper, and more irregular topography of dunes colonised by marram will be more likely to suffer wind channelling and blow-outs, compared with the more stable, low, smooth pingao-covered dunes. However, the resuls reported here also show that marram has ecological advantages for colonising newly exposed areas under harsh conditions. The initially greater sand-trapping ability and rapid growth of marram give it a strong competitive advantage over pingao. Therefore marram is more likely to be first to inhabit and stabilise an exposed environment.

Where dune stabilisation becomes necessary for the preservation of a coastal system it is essential to understand the vegetation dynamics and environmental changes that will result from the introduction of exotic plant species.

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APPENDIX I

Summary-sand size analysis of dune environment.

Size Range	Unvegetated Dune	Marram	Pingao
V.coarse sand >1.00mm	34.90%	7.60%	6.52%
Coarse sand 0.5-1.0mm	40.81	40.92	35.05
Medium sand 0.25-0.5mm	19.48	40.56	46.17
Fine & V.Fine 0.0625-0.25	4.69	10.73	13.09
Coarse silt <0.0625	0.05	0.10	0.18
TOTAL	99.93%	99.91%	101.01%

NB: Table entries represent the relative importances of sand size categories for the different habitat types studied. Where column totals do not equal 100% experimental procedure explains the differences.

Comparisons of sand trapping ability,
by sand size class, in dune environment.

Size Range	Dune Area					
V.coarse sand	Unvegetated	34.90%	Unvegetated	34.90%	Marram	7.60%
	Marram	7.60	Pingao	6.52	Pingao	6.52
	t	18.70 *	t	19.57 *	t	0.92
Coarse sand	Unvegetated	40.81	Unvegetated	40.81	Marram	40.92
	Marram	40.92	Pingao	35.05	Pingao	35.05
	t	0.08	t	4.06 *	t	4.32 *
Medium sand	Unvegetated	19.48	Unvegetated	19.48	Marram	40.56
	Marram	40.56	Pingao	40.17	Pingao	46.17
	t	17.57 *	t	21.35 *	t	3.77 *
Fine and V.fine sand	Unvegetated	4.69	Unvegetated	4.69	Marram	10.73
	Marram	10.73	Pingao	13.09	Pingao	13.09
	t	7.46 *	t	12.00 *	t	2.54
Coarse silt	Unvegetated	0.05	Unvegetated	0.05	Marram	0.10
	Marram	0.10	Pingao	0.18	Pingao	0.18
	t	0.36	t	1.18	t	0.53

* significant difference at the 0.05 level.