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COASTAL DUNE STABILIZATION-AN ENGINEER'S VIEW

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The Coastal Engineer

Civil engineers have been connected with coastal works since the formation of the profession in the 1770s. Works designed to control erosion of the coast or coastal dunes fell within the domain of the civil engineer from that time and such works have continued to be of concern to the profession. Indeed the present day techniques of sand dune stabilization have their origins in methods invented by two 18th century French engineers.

Development of Dune Stabilization

Credit for the discovery of a technique to arrest the movement of dunes is given to Nicolas-Thomas Brémontier, a French civil engineer. Although Brémontier has the honor he was not the true discoverer. The credit should go to Charlevoix Baron de Villers, engineer of the French Navy and the Colonies. Villers had been in the service of the King since 1743. He was 22 years a captain, had been wounded in the frigate 'Star' and was 15 years engineer-in-chief of the Navy. He came from St. Dominic. During the years 1778-1779 he wrote four reports on the proposed construction of canals in Gascony, near Bordeaux, and in connection with these schemes he outlined a method of fixing the dunes through which the canals had to pass.

Brémontier was born at Tronquay, near Bayeux. He started his professional life as a clerk, then became professor of mathematics at the Naval Artillery School at Toulon after which he entered the administration of the department of Roads and Bridges. He was an under-engineer at Perigueux, an under-engineer at Bordeaux in 1770, being promoted to engineer in this town which he left in 1780. He returned in 1784 as engineer-in-chief, was promoted Inspector General in 1802 and went to Paris. He died in 1809.

During the ten years 1770-1780 he was naturally conversant with the various projects for the construction of canals. He took a great interest in these and certainly he was in possession of Villers's reports on the subject. Contemporary accounts of him state that he had a talent for flattering the Chief Administrator, being subtle, clever and ambitious. He was also said to be cunning and sly. Others said, "Well, after all, is he not a Norman?" He had a shrewd appearance, a long nose and a large mouth with thin lips giving him an air of slyness.

Trials on the dunes of Gascony began in 1786 and larger experiments were started in 1787. Brémontier's method was to erect brush fences or palisade fences around the area to be treated and to sow the seeds of maritime pine, (Pinus pinasta), a tree native to the area, within these fenced parcels of dune. An improved technique, whereby the fences were replaced with branches spread over the sand, was soon adopted. The work was completely successful, the dunes today being covered with a thick forest of magnificent pines, where formerly there had been a vast desert of sand which had engulfed houses, roads, churches and entire villages over the centuries. (Buffault,1942).

On the windward side of the pine plantations and on the dunes near the sea plantations of marram grass were sown. This grass is native to Europe, particularly to the area around the Baltic Sea. The vernacular name of this grass, marram, is given in this form by Sir J.E. Smith in his "English Flora" of 1824. Hooker spells it marrem whilst in Sowerby's"English Botany"it is called murram. Here we learn that, according to Dr. Prior, the name is derived from the Gaelic muram, or the Danish marhalm, sea haulm, or straw. Other names are mat-grass, beach-grass, sea-weed, and sea-mat reed. Old botany texts give it the botanical name *Psamma arenaria*. Modern texts describe it as *Ammophila arenaria*. The story of the use of this grass in Australia is not without interest.

In the latter part of the 19th Century at Port Fairy, Victoria, and along the adjacent coast, the sand dunes became denuded of shrubs, grasses and other vegetation through the grazing by sheep and cattle, and the sand began to drift over the adjacent rich and valuable soil at a most alarming rate even to the extent of overwhelming the houses and gardens. Strenuous exertions were made to stem the advancing tide of destruction, but with no success until the Port Fairy Municipal Council consulted Baron Von Mueller, who suggested that marram grass might prove effective. He provided some seeds for experimental sowing in 1883 (Molineux,1902). Mr. S.T. Avery, the Borough Council's Ranger, had charge of the work. He developed the method of planting out the grass in rows, it being easier, quicker and cheaper to propagate from plants than seeds.

Von Mueller visited Port Fairy on 12 April, 1895 to examine the work. What he saw amazed him. In his own words "he clapped his hands with joy" on witnessing what he destined to be a work of world-wide benefit. The Baron remarked that not even in Belgium or France had he seen or read of so much success, and Port Fairy would remain entitled to the great credit of introducing to the Southern Hemisphere one of the most valuable products which Divine Providence had granted for this purpose. The whole Southern Hemisphere would have reason to compliment the Port Fairy Borough Council for their supply of this most wonderful plant and the members of the corporation would always have the satisfaction of feeling that they had been instrumental in doing much good to their fellow creatures. (Broadsheet. News Print, Sackville Street, Port Fairy, 1895?).

The Port Fairy Council certainly developed a wide market for the grass. Consignments were sent to all the Australian mainland colonies, Tasmania, New Zealand, Cape Colony (Sth. Africa), Great Britain, India, Brazil and Southern Asia. The cost never exceeded 40/- per ton. In recognition of his services Mr. Avery was honored by the right to use the letters F.R.H.S. Eng. after his name. An amusing story is told of the occasion when a consignment of grass was sent to Newcastle, N.S.W. There was some delay in its delivery and it reached Mr. Zerwonki, the engineer, in a very dry condition. The town clerk of Port Fairy received a telegram reading: "Grass arrived; totally useless, nothing but straw". To which the clerk confidently replied: "Plant out straw as directed". Mr. Zerwonki did so; and when reporting the grand results of the experiment, presented the town clerk, Mr. Mandeville, with a gold case, and the ranger, Mr. Avery, with a set of studs. (Broadsheet,1895?).

Sand

Sand, of which marram is such a lover, is a peculiar substance. Alone of all the materials on the earth's surface it has the ability to coalesce into mounds or dunes when acted upon by the wind. All other granular substances when blown by the wind are scattered. The physics of this curious phenomenon was elegantly solved by Brigadier Ralph A. Bagnold and his work was published definitively, in a book which has become a classic of scientific literature. (Bagnold, 1941). In the finest wind-blown sands the predominant diameter is never less than 0.08 mm. Usual values lie between 0.3 mm and 0.15 mm.

Sand Flow

The movement of sand grains under the action of wind is called saltation, a term coined by G.K. Gilbert around 1910. (Bagnold, 1979). Saltating grains rarely rise beyond a metre above the gravity bed and the greater part of the flow occurs within 10 cm of the surface. The sand flow q, (the mass of sand moving along a lane of unit width past a fixed transverse line in unit time), is found in air to depend only on the velocity gradient of the wind above the mean level of saltation and on the size grading of the grains. Mathematically it can be expressed as

$$q = 1.5 \times 10^{-9} \ (v - Vt)^3 \text{ in C.G.S. units}$$

q = mass of sand in gm./cm./sec.

v = velocity at ht. of 1 metre

Vt = velocity at ht. k' (400 cm/sec of k' = 1 cm)

It will be seen from this formula that the flow of sand is proportional to the third power of the excess wind velocity above the threshold velocity. This makes for an enormously rapid increase in the weight of sand moved when the wind rises appreciably above the threshold. For instance a strong wind blowing at 16 metres/second, or 35 m.p.h., will move as much sand in 24 hours as would be moved in three weeks by a wind blowing steadily at 8 metres/second or 17 1/2 m.p.h.

Sand Dunes

Sand dunes occur along sea or lake shores, on the banks of rivers and in deserts. About one-fifth only of deserts is covered with sand whilst the desert areas themselves occupy one-fifth of the world's land surface (Holmes, 1965; Glennie, 1970). Coastal dunes exist generally in a temperate habitat and are much modified in form by vegetation. They are also accessible to the feet of animals and of men which interfere seriously with both the structure and the natural movement of their surfaces. The result is a general formlessness; in so much that the average mind associates a sand hill with something essentially chaotic and disordered. But in desert areas free of vegetation "instead of finding chaos and disorder, the observer never fails to be amazed at a simplicity of form, an exactitude of repetition and a geometric order unknown in nature on a scale larger than that of crystalline structure". (Bagnold, 1941).

The word dune in English dates from 1790 and is an adaptation of the modern French dune. The word means a mound, ridge or hill of drifted sand. The antecedents of this word are the Old Dutch duna, the Old English dun, and the gaulois or gallic words dounon, dunum. The word dun, or doon, is found also in Irish and Gaelic whilst in Welsh it is din. Dun, and its variants, means a hill, an ancient hill-fortress or a fortified eminence. This word occurs in many place names in the British Isles associated with neolithic sites and monuments and in modern place names such as Dunkirk, the site of a notable retreat in World War II, which means simply the kirk (or church) in the dunes. The French word dune occurs in official Government Acts from at least 1703. (Buffault, 1942). There are many regional names to describe hills of sand. In Scotland they are commonly called links which name suggests their frequent use for golf. In East Anglia the name meals or meols (melr, Old Norse for sandbanks) is commonly in use. In the West Country the term burrows (beorg, Old English for hill) is employed e.g. Braunton Burrows, Devon, and towans is a name used in Cornwall. (Salisbury, 1952). In the Landes of France (the region around Bordeaux) one finds truc or tuc, Gascon or Basque words which are no longer in general use. (Buffault, 1942).

The Dunes Between Barwon Heads and Black Rock, Victoria

For some years the author has been engaged on sand drift control adjacent to coastal roads within the Geelong Division of the Country Roads Board, now called, since the 1-7-83, the Road Construction Authority. A considerable amount of work has been done on the dunes bordering the road between Barwon Heads and Black Rock and I will outline some aspects of this work. (Fig. 1).

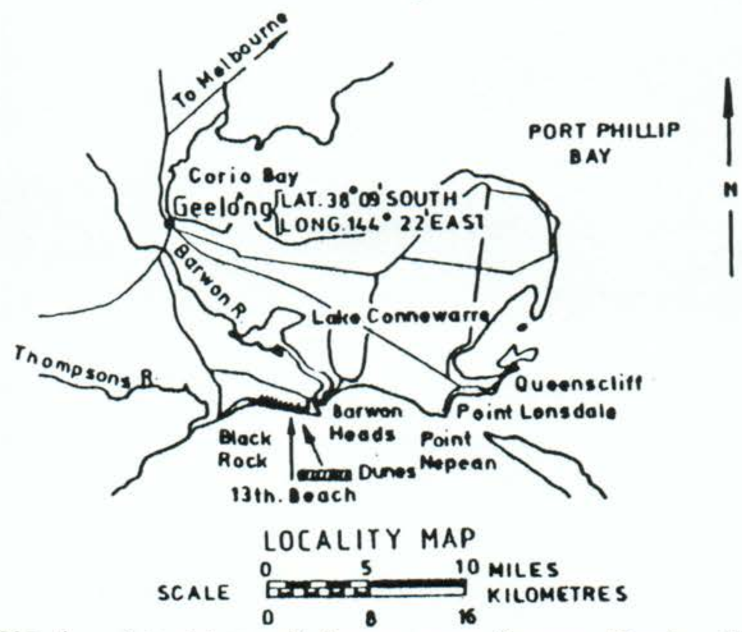
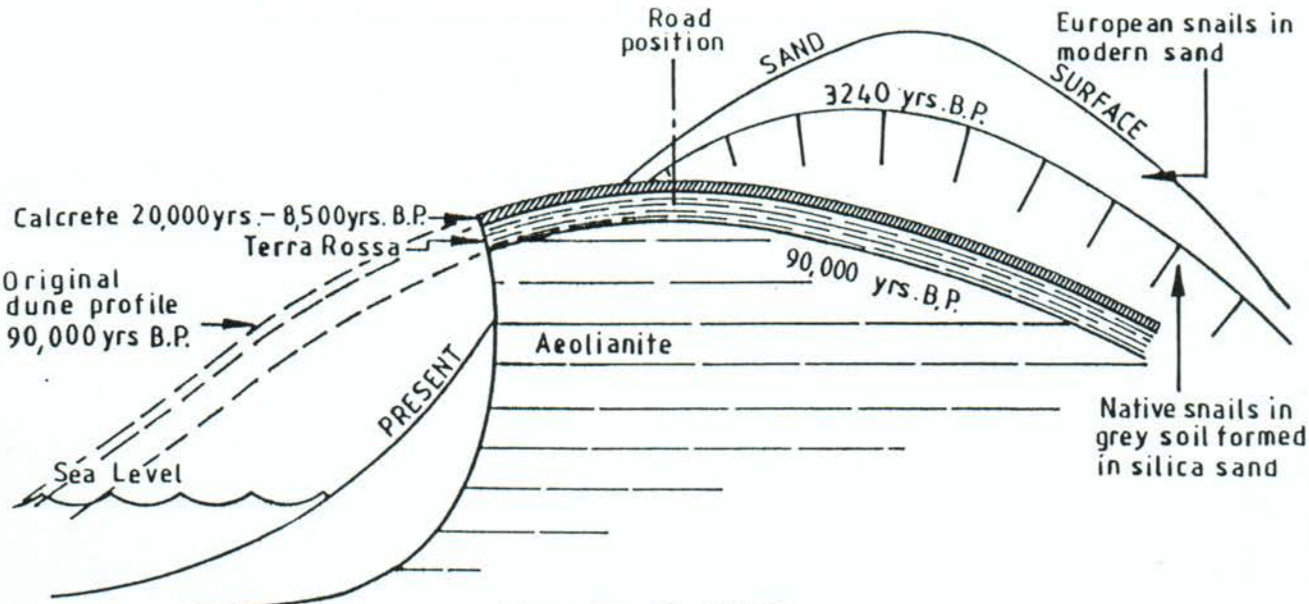


Fig. 1. Location of dunes near Barwon Heads, Victoria

Geology

This section of the coast consists of a low cliff of aeolianite which dates about 90,000 years B.P. when the sea was three metres below its present level. Overlying this is a terra rossa soil above which is a layer of calcrete the latter indicating an arid climate which lasted from 20,000 years to 8500 years B.P. approximately. (Alsop, 1981; Gill, personal communication). Above this there is a deposit of grey soil formed in silica sand. This soil which contains native snail shells *Austrosuccinea australis* has been radiocarbon dated at 3240 years B.P. (Gill & Alsop, 1983). Overlying all these strata are the dunes of the present day which contain the European snail *Theba pisana*. Most of the silica sand comes from the decomposition of the aeolianite cliff and has been deposited over the last 6000 years, the period during which the present cliff has been formed. (Fig. 2).



GEOLOGY OF DUNES

Fig. 2. Geology of coast between Barwon Heads and Black Rock

Morphology

The present area of the dunes is 295 hectares of which 63 hectares are occupied by the Barwon Heads golf links, 95 hectares are on private land and 137 hectares are within a Public Purposes Reserve. The surface features appear essentially chaotic but a contour survey has revealed that the crests of the seaward dunes are aligned on the on-shore resultant of sand driving winds at S 44° 10' W; the crests of the landward dunes are aligned on the off-shore wind resultant at N 29° W and at the Black Rock end of this coast there are some dunes aligned on the resultant of all sand driving winds at S 69° W. (Alsop, 1981).

The Barwon Heads Torquay road runs parallel with the coast 50 metres from high water for six kilometres and is constructed on top of the aeolianite cliff which is now largely submerged by the modern sand. By 1966 large blowouts had developed through this mantle of sand on the seaward side of the cliff and large drifts from these crossed the road periodically. Much of the sand on the seaward side of the road was devoid of vegetation. Under these conditions sand was being taken from the beach by the wind, transported through the blowouts and passed on to the road or across it. At any rate, sand was being lost from the beach which was being lowered progressively and the sea was entering the blowouts during winter storm surges.

The remedial works, started in 1967, attempted to renourish the beach by inducing sand to be deposited in the blowouts, gradually filling them with wind deposited sand, which was planted with marram grass. The result has been a general raising of the level of the upper beach next to the frontal dune by between 1½ and 2½ metres over the sixteen years between 1967 and 1983.

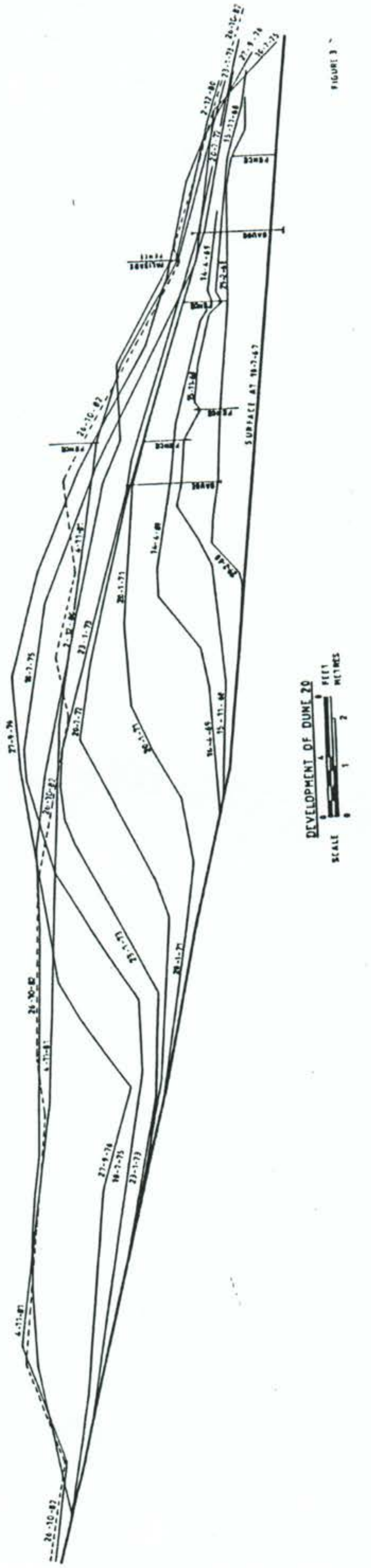
Accretion Techniques

The methods that were adopted for stilling the flow of sand have been described in other papers. (Alsop, 1973, 1975, 1981). It will be sufficient to say here that various styles of permeable fencing have been used across blowouts and along the seaward face of the frontal dune. For the most part these fences have consisted of timber slats (3' x 1" x ½") sewn 1" apart, timber palisades consisting of individual timber planks 6" x 1" standing 3 feet to 4 feet high which are raised periodically as the sand accumulates around them and plastic fences of several types but latterly paraweb fencing which has horizontal straps 50 mm wide at 50 mm spacing. These fences have been used in association with reshaping of the frontal dune to an aerodynamic shape, brush matting of the frontal dune, planting the dunes with marram grass and occasionally building brush fences from one to 1½ metres high.

Because of the high wind speeds encountered along this southern coast, some form of permeable fence across blowouts has been found to be necessary to form a mound of sand in the lee of which marram could be planted rather than planting out the blowout directly with grass. Speeds of 35 to 50 knots are not infrequent. Wind travelling at this velocity and accelerating through a blowout erodes the sand from around the hills of planted grass, exposing the roots or wrenching it completely out of the sand.

Fig. 3 shows a cross-section of a blowout normal to the coast. The progressive accretion induced by the use of slat and palisade fences in this blowout is shown from 1967 to 1983. The cumulative growth of the resulting dune is shown in Fig. 4 whilst its rate of growth is shown in Fig. 5. An initial rapid fall in the growth rate in the first year, 1968, has been followed by a slow decline in the rate until the recent drought during which sand movement has been considerable. Table 1 gives the figures upon which Figs. 4 and 5 are based.

Another technique that has been used is to reshape a dune to an aerodynamic profile and to plant it densely with marram grass. This work is described in a previous paper. (Alsop, 1981). During a ten year period, (1970-1980), one such dune 61 metres long grew from 6000 cubic metres to 8000 cubic metres whilst it's rate of growth declined from 24 cubic metres/metre/year to 13 cubic metres/metre/year. This accumulation has taken place over a distance of 37 metres from the seaward toe of the dune to the slip face adjacent to the road.


DEVELOPMENT OF DUNE 20
SCALE
FEET
METRES
FIGURE 3

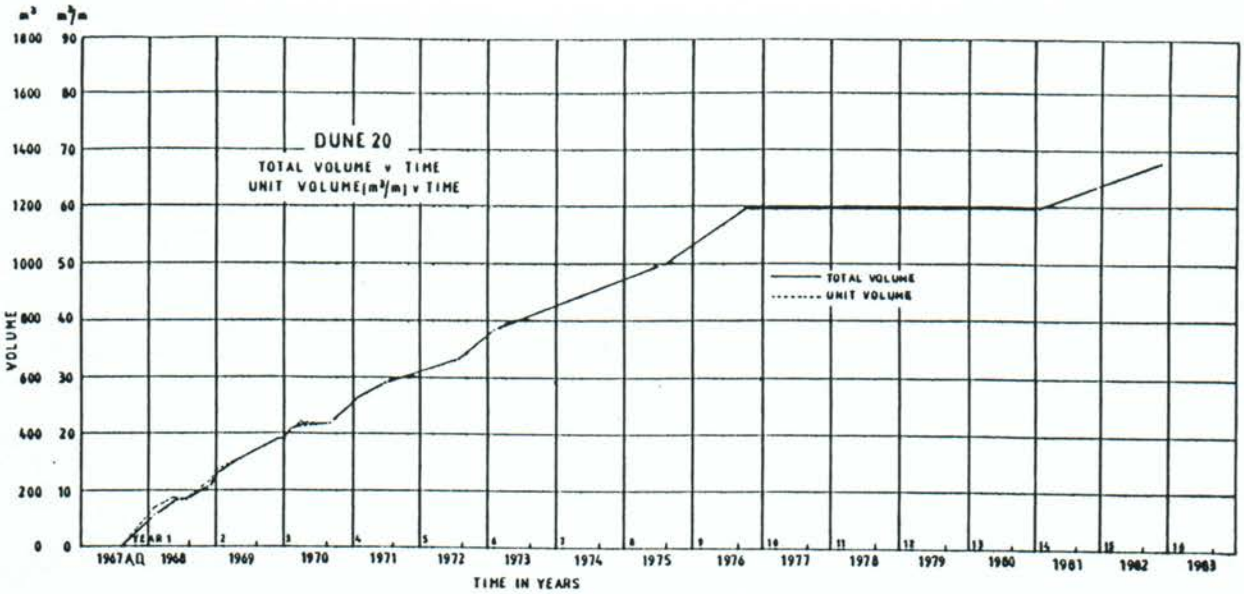


FIGURE 4

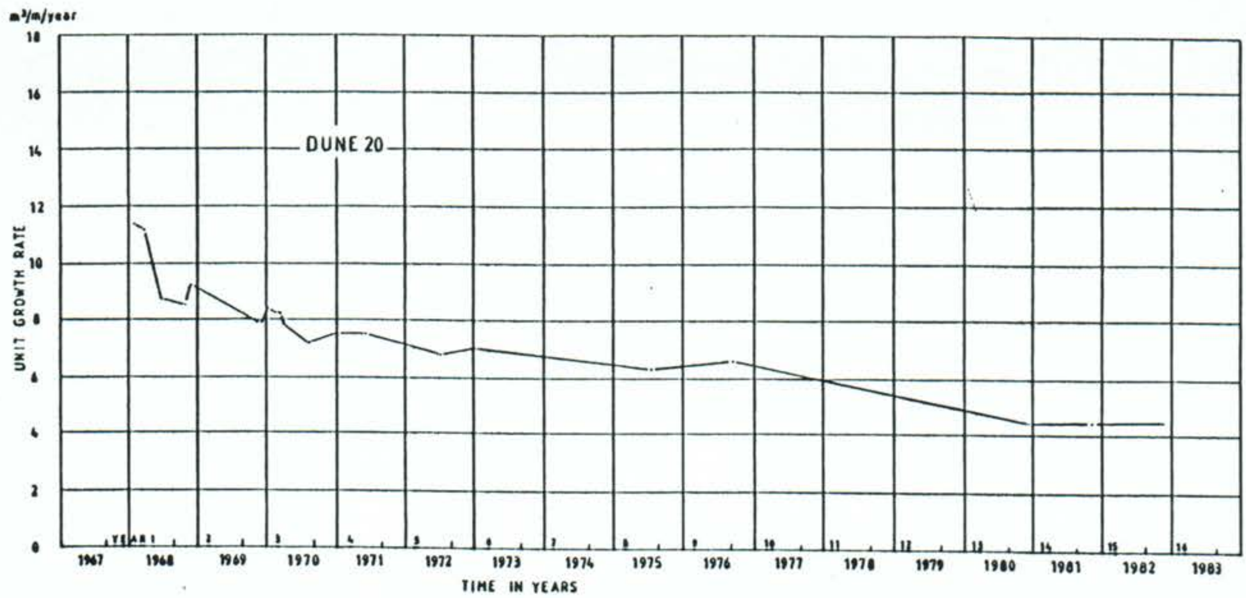


FIGURE 5

Table 1

Growth of Dune 20

Date	Days	Years	Volume m^3	m^3/m	$m^3/m/yr$
18. 7.67	0	0	0		
29. 2.68	225	0.62	113.2	7.0	11.4
17. 4.68	273	0.75	156.3	8.3	11.1
21. 5.68	306	0.84	163.1	8.6	10.2
19. 7.68	364	1.00	163.4	8.7	8.7
15.11.68	497	1.36	218.5	11.6	8.5
31.12.68	542	1.48	259.9	13.7	9.2
14. 4.69	646	1.77	305.8	15.4	8.7
27.11.69	872	2.39	379.4	18.9	7.9
4.12.69	878	2.40	382.3	19.0	7.9
8.12.69	881	2.41	385.1	19.2	8.0
14. 1.70	907	2.48	419.1	20.8	8.4
17. 2.70	940	2.57	427.5	21.3	8.3
24. 3.70	974	2.67	442.8	22.0	8.2
29. 4.70	1009	2.76	435.4	21.6	7.8
24. 6.70	1064	2.91	438.9	21.8	7.5
20. 8.70	1120	3.16	441.7	22.0	7.2
20. 1.71	1272	3.48	526.7	26.2	7.5
2. 6.71	1404	3.84	581.2	28.9	7.5
20. 7.72	1789	4.90	672.8	33.5	6.8
23. 1.73	1975	5.41	768.1	38.2	7.1
10. 7.75	2872	7.86	999.9	49.7	6.3
27. 9.76	3279	8.98	1194.2	59.4	6.6
2.12.80	4815	13.18	1184.8	59.0	4.5
4.11.81	5152	14.10	1260.0	62.6	4.4
26.10.82	5508	15.08	1354.0	67.3	4.5

N.B. The volumes shown are cumulative. The rate of growth is shown as m^3/lineal metre of fence and also as m^3/lineal metre of fence/year.

Planting of Marram Grass

Marram grass was planted along this coast at the turn of the century. Little success was achieved with planting within 50 metres of the high water mark but good growth occurred on the dunes at greater distances than this on the landward side of the road. Over the years the grass was subjected to much interference and damage and this led to restoration work being started in 1967.

Statistical trials of grass planting techniques were conducted by the late Mr. Gerard Sluiter and myself. Mr. Sluiter, then an officer of the Soil Conservation Authority, later of the Port Phillip Authority and subsequently of FAO, Amman, Jordan, was my principal guide and mentor in the early phases of the work along this coast. Two of his published papers were influential in the development of coastal dune protection works. (Sluiter, 1964, 1966). Mr. Sluiter retained an interest in this work up to his death this year and I record here my appreciation of the help this fine scientist gave me. The trials proved that there was no statistical significance at the 5% level in growth between pruned and unpruned grass or between broadcast fertilized grass plantings and unfertilized plantings. (Sluiter & Alsop, 1974).

In the late 1960s when relatively large areas of sand were being hand planted with marram the grass was soaked in a water bath for a day before it was planted. Nowadays when only small areas are planted this soaking has been eliminated. Planting has been on grids of 0.6 m x 0.6 m, 0.6 m x 0.9 m and 0.9 m x 0.9 m depending upon the severity of exposure to SW winds. Planting depth is 0.3 m. On the frontal dune the native grass Spinifex hirsutus is gradually gaining ascendancy over the marram.

Planting of Trees

A plan of this coast done in 1854 by A.J. Skene shows the dunes occupying a band extending no more than 200 m to 240 m from the shore. The land behind the dunes was marshy and immediately beyond this the country was thickly wooded with tea-tree and she-oak. These trees were cleared for farming, to supply fuel and to provide bark for tanning leather. The destruction of these trees left the dunes exposed to the northerly winds. It appears to be a universal phenomenon that where trees are removed from the landward side of coastal dunes those dunes will erode and migrate inland. (Marsh, 1864).

On the landward side of the road, at a distance 50 m or more from high water mark and in the lee of some slip faces of frontal dunes a number of trees have been planted. During this phase of the work advice has been received from Mr. G. Sluiter, Mr. Harold Gray who is the Roadside Development Engineer for the Road Construction Authority, Mr G.G. Shepherd, forester at Creswick, Mr. D.M. Thompson, formerly forester at Ballarat, Mr W. Petrie, formerly of the Forests Commission Nursery, Creswick, Mr G.E.L. Vafiopulous, formerly curator of Geelong Botanic Gardens, Mr. Trevor Pescott, President of the Geelong Environment Council and past President of the Geelong Field Naturalist Club, Mr. W.G.D. Middleton, forester at Wail and Dr. D.M. Churchill, Director and Curator Royal Botanic Gardens, Melbourne.

Table 2 shows the species which have been planted, the numbers planted and the year of planting. Up to the end of 1982 9267 trees had been planted. Australian trees predominate but some exotics, such as Pinus halepensis and Pinus pinaster were also used. The sand in which the trees were planted has a pH of 8 and the annual average rainfall, (taken over 68 years to 1971), is 637.284 mm. Table 3 shows the monthly average rainfall and the monthly rainfalls during the drought of 1982-3.

Trees have been planted on 4½ m grids, latterly at 2½ m spacings and in clumps at 2½ to 3 m spacings. In 1972 a count of the trees which had died from plantings in 1970 and 1971 showed the following.

Distance from HWM	Species	% Dead
60-70 m seaward facing slope	A. sophorae	58
	C. arizonica	61
	L. laevigatum	55
	M. armillaris	72
70-80 m seaward facing slope	A. longifolia	63
	M. insulare	73
	C. stricta	74
	E. gomphocephala	44
	H. suaveolens	50
80-100 m landward facing slope	P. pinasta	53 nearest sea 9 furthest from sea

Observations over the last ten years suggest that native species on unprotected seaward facing slopes 60-80 m from the sea continue to have mortality rates similar to those shown. Much better survival rates have been achieved in swales within the 60 to 70 m zone and in the 80 to 100 m zone where the mortality is about half that shown above.

Acacia longifolia and Acacia sophorae which were planted in the early 1970s from nursery stock appeared to remain dormant for some years but within the last seven years these trees have spread considerably attaining diameters of 10 to 12 metres and heights of 1½ to 2 metres, the trees being reluctant to grow above the dune ridges. The prostrate nature of these trees aids their lateral growth as roots are sent down from nodes on the branches lying on the surface.

70 Acacia retinodes is a species which has been grown from seed collected from a tree growing on a sand dune near Torquay. Of the trees planted in 1979 only 30 to 40% died and the survivors are now 0.9 to 1.2 metres high. The trees are spreading by sending out roots 12 mm in diameter just below the surface from which suckers arise. At present these suckers are 0.2 m high at distances of 1.2 to 1.5 m from the parent tree.

Leptosperum laevigatum has had good survival rates. Perhaps 40%

SPECIES	YEAR OF PLANTING/NUMBERS PLANTED														
	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	Totals
1. Acacia Longifolia	50	50	50												150
2. Acacia Retinodes										150					150
3. Acacia Sophorae	50	50	50		100	300			250						800
4. Araucaria Heterophylla			60												60
5. Banksia Integrifolia					100					40					140
6. Casuarina Cunninghamiana				25											25
7. Casuarina Stricta	50	50	100		100	200				40		62			602
8. Coprosma Retusa					100										100
9. Cupressus Arizonica	50	50	750												850
10. Eucalyptus Crenulata				15											15
11. Eucalyptus Diversifolia					100				200	285	200				835
12. Eucalyptus Gomphocephala	50	50	100	100	100	100									500
13. Eucalyptus Leucoxylon var. rosea (macrocarpa)					100				250						350
14. Hakea Suaveolens	50	50	50												150
15. Leptospermum Laevigatum	50	50	50		100	500			150		200				1100
16. Melaleuca Armillaris	50	50	50	50		400			250						850
17. Melaleuca Lanceolata } Same species									250						250
18. Melaleuca Pubescens				100	100										200
19. Myoporum Insulare	50		50			200									300
20. Nerium Oleander (pink)					40										40
21. Nerium Oleander (red)					40										40
22. Nerium Oleander (white)					20										20
23. Pinus Halepensis				200											200
24. Pinus Pinaster	400	300	450	80											1230
25. Populus Yunanensis				100											100
26. Tristania Conferta				4											4
27. Casuarina Glauca												100			100
28. Banksia Marginata													106		106
	850	700	1760	674	1000	1700	-	-	1400	515	400	162	106		9267

	Table 3 - Rain at Barwon Heads P.O.		
Month	Rain mm	No. of rain days 1982-83	Average rain for 68 years to 1971 mm
Jan 1982	27.3	6	29.972
Feb	5.8	4	43.688
Mar	46.4	5	42.418
Apr	46.4	11	51.816
May	51.4	26	65.532
Jun	36.4	12	57.658
Jul	26.0	13	61.468
Aug	10.4	10	66.294
Sep	35.2	14	61.468
Oct	21.2	9	57.912
Nov	5.2	6	53.086
Dec	35.8	6	45.974
Jan 1983	21.0	9	637.284
Feb	1.6	1	
Mar	48.2	11	
Apr	48.4	8	
May	72.8	13	
Jun	56.6	13	
Jul	36.6	17	

of the early plantings died. Later plantings in the 1970s and early 80s seem to have suffered less. They have not spread laterally as quickly or to the same extent as the acacia and like them grow up to the ridge level. The planted trees have seeded and these are now germinating randomly.

The plantings of Casuarina stricta for the most part have been unsuccessful. The early plantings used nursery stock of which perhaps 20% survive. Plantings of this species have been persisted with however as this tree was once plentiful in the region. The plantings in 1979 and 1981 used seeds collected from trees within a kilometre of the dunes and also seed from trees at Wilsons Promontory. These plantings have done slightly better than the earlier plantings. Perhaps 30% have survived but growth is hardly measurable. A few trees have reached a height of 0.6 m.

A fifty year old stand of Casuarina glauca on the Princes Highway between Hoppers Crossing and Werribee had to be removed in 1981 to allow duplication of the highway. These trees had reached a height of 17 m and growth was vigorous. They were in a single line alternating with C. stricta which had only reached a height of 7 m.(Churchill, 1981). The opportunity was taken to cut out some one hundred suckers with short lengths of root stock from the C. glauca and to replant these in a swale some 70 m from the high tide line. These 0.6 m high suckers appeared to die within several weeks of planting but after three or four months new shoots appeared from ground level. These trees were watered twice during the recent drought when the water table fell to 0.23 m below the surface. About 30% of these trees survive but they could hardly be called vigorous.

Banksia integrifolia has been a failure but Banksia marginata may be better adapted. In one group of fifty 98% died but in another group of fifty only 2% died. Both plantings were in 1982 and both groups of 10 cm high seedlings were watered twice during the drought.

Of the eucalypts experimented with, E. diversifolia has been the most successful. The earlier plantings used nursery stock which has not developed quite as strongly as the later plantings of 1979 and 1980 which were grown from seed collected at Cape Nelson near Portland, Victoria. The species grows there in a limestone environment. It is also found on Kangaroo Island, South Australia. Less than 5% of these trees have died. The survivors appear to be healthy though their tips are burnt when their height reaches the level of the dune ridges. This species may well be successful in this area.

Pinus pinasta has suffered a mortality rate of about 70 to 80%. Very little growth occurred in the survivors over a ten year period but within the last few years good growth has occurred and examples can now be found which are between 1.8 m and 3.0 m high. These trees are between 80 and 100 m from the sea but burning and withering of their tips occur when they rise above dune crests. This is common to all the species planted but I do not know if this is entirely due to salt spray. There is a sewer outfall about ½ km away from the pine plantation. Its presence allows at least the suspicion that the damage may be due to surfactants, (domestic and commercial detergents), in the sewage. (Pittman, Powden and others, 1977).

The losses that have occurred in the tree planting programme have not been entirely due to natural causes. Losses of the order of 5% to 10% have been caused by the depredations of the public on horses and trail bikes and in dune buggies and a variety of four wheel drive vehicles.

Conclusion

The essence of this class of work is to use the energy of the wind to build a frontal dune rather than to destroy it. The best way to do this is to exclude man, his cattle and his machines from this sensitive zone. Restoration of frontal dune shape and vegetation can be assisted by using permeable fencing and replanting with appropriate grasses and trees. Minimum work with minimum interference to the general character of an area is appropriate in the upper beach and frontal dune zone which is subject to rapid change from the variable forces of wind and wave. The cost of transplanting marram grass by hand rose from $1500/ha in 1970 to $6000/ha in 1982. This fact alone should convince the restorer that efficient designs and effective use of materials are needed. That the procedures outlined here are effective is shown by the fact that in fifteen years, from 1967 to 1981, 41,000 cubic metres of sand have been added to the beach and frontal dune over length of 640 m and a width of 30 to 40 m. This accretion and the growth of marram and spinifex grass on it has prevented the former movements of large sand drifts beyond 50 m from the high tide line. Beyond this zone sand sheets and dunes have been stabilized with marram grass and subsequently with a variety of trees. The most effective species have been *Acacia longifolia*, *Acacia sophorae*, *Acacia retinodes*, *Leptospermum laevigatum* and *Eucalyptus diversifolia*.

(+ other names p.31)

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