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NEW ZEALAND.

DEPARTMENT OF LANDS:

REPORT ON THE DUNE-AREAS OF NEW ZEALAND,

THEIR GEOLOGY, BOTANY, AND RECLAMATION.

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Presented to both Houses of the General Assembly by Command of His Excellency.

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INTRODUCTION.

(*a.*) GENERAL REMARKS.

WHEREVER there are loose deposits of sand liable to be moved by the wind, those mounds and ridges known as dunes are to be found. The most familiar are those of the coast-line, but the great deserts of the world show examples on a much vaster scale. Were such hills of sand stable and not liable to move, except for their peculiar physical and chemical qualities, they would not merit any special attention. But the material of which they are composed, so capable of easy transport to a longer or shorter distance according to the velocity of the wind, leads to their excessive instability, and makes a soil on which plants can only be established with extreme difficulty, and one moreover which, driven *en masse* by the prevailing wind, frequently overwhelms fertile lands, burying not merely the meadows but even forests and human dwellings.

So far as New Zealand is concerned, dunes are an extremely frequent character of the sea-coast. They also occur inland to some extent, as in the neighbourhood of certain of the rivers of the Southern Alps, on the volcanic plateau of the North Island, and especially near Lake Tekapo and in Central Otago.

It is the coastal dunes, however, which are of prime moment, as, in the first place, they form a natural defence to the land against the encroachment of the sea, and, in the second place, *their movement inland is a national concern*, since through their advance much valuable land has been ruined in the past, while yearly further destruction takes place, the evil at the same time becoming more difficult to suppress.

Such depredation, confined as it is to a limited and little-visited area, and appearing to be the affair merely of the few whom it affects, is apt to be overlooked, while the comparative slowness of its action tends to make its extreme importance for mischief underestimated. Nor is it generally known how large an area in New Zealand is occupied by these more or less moving sands and virtually a desert, but which, judging from the experiences of Europe, might be rendered not only harmless, but a source of wealth to the nation. *Roughly speaking, there are in the North Island 290,000 acres and in the South Island 24,000 acres.* Figures such as these bring home at once the importance of the dune question. This has indeed to some extent been recognized by the passing of the Sand Drift Act of 1907, but which has not as yet been put into force. Also, a bonus is given to such lessees of Crown dune-areas as plant them with certain specified plants, but this arrangement as now existing is not likely to lead to any useful results.

Towards the end of the year 1908 the Minister of Lands, the Hon. Mr. McNab, and a little later, his successor, the Right Hon. Sir J. G. Ward, thoroughly recognizing the importance of the question, decided that, as a preliminary to further advance, a scientific study of the dunes of the Dominion should be made, so that a more complete knowledge of their present condition could be gained and an examination of their capabilities made, while, as a result of such field-work, suggestions could be offered as to their reclamation and future treatment. For this purpose my services were engaged by the Department of Lands and Survey.

The field-work was commenced in November, 1908, and continued until the 8th February, 1909, during which time the dune-areas of western Wellington and part of Taranaki were examined, as also the Waikouaiti dunes, those near Normanby (South Canterbury), and the coastal planting carried out by Dr. Truby King at Karitane.

Previously, on my own account, I had studied the dunes in many parts of New Zealand (northern Auckland, Southland, Martin's Bay, Stewart Island, Chatham Island, the Auckland Islands, &c.), but this was rather from the botanical standpoint alone than with any idea of formulating a scheme for their reclamation. More in accordance with this latter was my keeping a private experiment garden for a period of some twelve years on the dunes near New Brighton, Canterbury, at about a distance of one mile from the sea, but for which experience I would never have undertaken the important duty of preparing this report.

As the outcome of the above studies my first report on the dune question was published by the Lands Department in June, 1909 (Cockayne, 91). It dealt with the scientific aspect of the matter only; since it was clear, as the Under-Secretary of Lands (Mr. W. C. Kensington, I.S.O.) explained in his letter of transmission to the Minister, that "a sound knowledge of general principles as well as of local conditions is a necessary preliminary to any attempt to cope practically with the sand-drift evil." So important, indeed, is a clear understanding of all matters pertaining to the formation of dunes, their movements, and their occupation by plants, that it has been decided to reproduce my original report in an amended form. Thus there is under one cover, for the information of all interested, a fairly full account of sand-dunes from both the scientific and practical standpoints. The botanical part of the first report dealt only with the dunes of western Wellington. Here, on the contrary, the whole dune-area of the New Zealand biological region, from the Kermadec Islands to the Auckland Group, is considered. The treatment, however, is comparatively brief, and the less-interesting details are omitted. Part II, dealing with the reclamation of dunes, is altogether new, and goes into the matter with some degree of thoroughness for the first time in New Zealand.

In December, 1910, by direction of the Right Hon. Minister of Lands, Sir J. G. Ward, my examination of the dune-areas was continued, and I was able to visit the extensive areas of western Auckland, as also Central Otago, Ocean Beach (Dunedin), and Southland as far east as Waikawa. Earlier in 1910, on my own account, I had examined the Otago dunes to the south of Dunedin and

those in the vicinity of Westport. From the above it will be seen that I have inspected nearly all the important dune-areas of the Dominion, and am consequently in a much better position to make definite statements *re* dune-reclamation than was the case when my former report was written.

Although certain owners of dune-areas are fully aware of the sand-drift evil, and are making brave efforts to overcome it, these are in no few instances misdirected (see Photo No. 16). Others, again, are doing nothing; they recognize the need for action, but have no idea as to the methods to be pursued. Some even hold the most strange or dangerous views, such as that the sand did not originally come from the sea-shore, or that a belt of shrubs will stop a wandering dune. Even where the best successes have been won there has been only a planting of marram-grass (*Ammophila arenaria*) or tree-lupin (*Lupinus arboreus*), which is at most but a makeshift, except under special circumstances. *The final treatment of dunes should assuredly be afforestation,* and yet by many this is thought to be impossible, and, except in a few specially favourable localities, nothing of the kind has been attempted.

The dunes of New Zealand are of special scientific importance. Those of the Old World have been materially changed by the many centuries of man's occupation. Their reclamation was for the new and unnatural conditions. But in New Zealand there is an opportunity of observing what nature, quite unhindered, has done for their fixation. The native dune-plants are also of much interest, since some are endemic and also of quite remarkable form, while their value as "sand-fixers" is by no means generally appreciated.

During the progress of my work I have received valued assistance and encouragement from so many that only quite a few can be specially mentioned. To all those whose names do not appear I here tender my sincere thanks. I am also indebted to the following gentlemen who have assisted me in various ways, and but for whose aid, generously given, interesting material and observations of moment would have been neglected, and I thank them most heartily: Drs. Truby King and L. Talbot; Messrs. A. W. Amon, D. L. Blyth, K. W. Dalrymple, J. Handley, J. H. Herrold, R. Hoe, and W. Waide. I must also specially thank Mr. H. Carse, who put his intimate knowledge of the far north of Auckland at my disposal; Mr. W. H. Field, M.P., for some most excellent photographs of the dunes near Waikanae, and for assistance and advice; Mr. R. Speight, M.Sc., F.G.S., who has contributed the section on the origin and material of dune-sand; my son, A. H. Cockayne, Government Biologist, who has given me much assistance in dealing with the subject of grassing the dunes; and Mr. T. F. Cheeseman, F.L.S., who gave me important information regarding the dune-flora of Auckland, and discussed with me various critical matters. For help from outside New Zealand I here tender my grateful thanks to Professor J. W. Harshberger (University of Pennsylvania), Professor L. Diels (University of Marburg), Mr. A. S. Hitchcock, Agrostologist (United States Department of Agriculture), and Dr. B. T. Galloway, Chief of Bureau of Plant Industry (United States Department of Agriculture). Finally, I must express my great indebtedness to Mr. W. C. Kensington, I.S.O., the Under-Secretary of Lands, who has assisted me most materially and offered various important suggestions which are embodied in this report.

(*b.*) OBJECTS OF DUNE-CULTURE.

It seems needful to state briefly the objects of dune culture or reclamation, since usually in New Zealand the only point considered is the fixing of such sands as threaten fertile land.

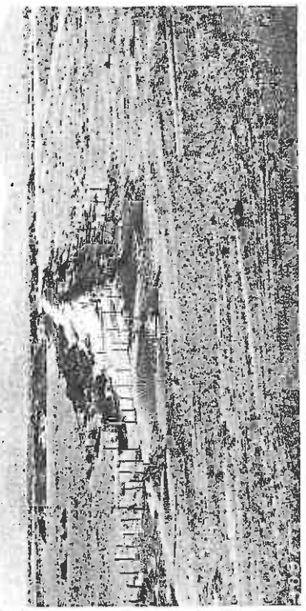
In Europe the culture of dunes has been in progress for more than one hundred years. There the first object is not reclamation at all, but the *protection of the coast-line.* This is a matter which as yet has received little attention in New Zealand, nor has my examination up to the present revealed any pressing need for action in this direction. At the same time, the sea does make encroachments, as at the Ocean Beach, Dunedin; at various points on the coast of western Wellington (see Photo No. 1); near New Brighton, Canterbury; and elsewhere. When really close settlement fills the Dominion the coast-line will need attention. So urgent is this matter in the Motherland that a Royal Commission has recently dealt with the question, and issued a voluminous report.

Closely bound up with coast protection is the obstruction of waterways. This is exemplified by the bars of rivers and estuaries, which, although mostly of marine and fluviatile origin, are strengthened by sand from the dunes. Sandspits crowned by dunes also bear an important relation to harbours (see Photo No. 2).

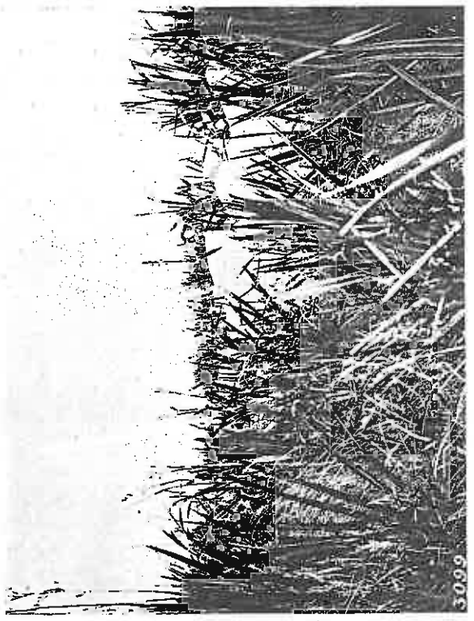
As for the dunes themselves, the damage they do is twofold. On the one hand, at their extreme landward boundary they bury good ground quite free from sand, adding it to the dune-area, and, on the other, they overwhelm a great deal of fairly good low-lying land within the dune-areas themselves (see Photo No. 3). Besides fertile soil, valuable flax swamps are filled and destroyed (see Photo No. 4). Also, watercourses are choked or diverted, and the drainage of the neighbouring country is much impaired (see Photo No. 64).

Finally—and to my mind this is the most important of all, nor has it been approached to any degree as yet—the dune-areas themselves, now simply deserts and always a menace to the neighbouring valuable land (see Photo No. 3), even when supposed to be checked by shelter-strips, should be reclaimed and made productive by afforestation. The methods to be pursued and the trees to be made use of, on account of economic value of one kind or another, are given in Part II of this report. Here a few words will not be out of place as to afforestation of dune-areas in Europe, since there is a belief amongst many that sea-spray is altogether antagonistic, and that afforestation, near the shore at any rate, is impossible. Such forget, or do not know, that natural coastal forests, and even dune forests, exist in New Zealand, and that various trees and shrubs (pohutakawa, *Metrosideros tomentosa*; Chatham Island akeake, *Olearia Traversii*, &c.) grow even on cliffs subject to constant wetting with sea-spray.

The best-known and always-quoted example of afforestation is that of the dunes of Gascony, in France. Here the justly celebrated Brémontier, during the closing years of the eighteenth

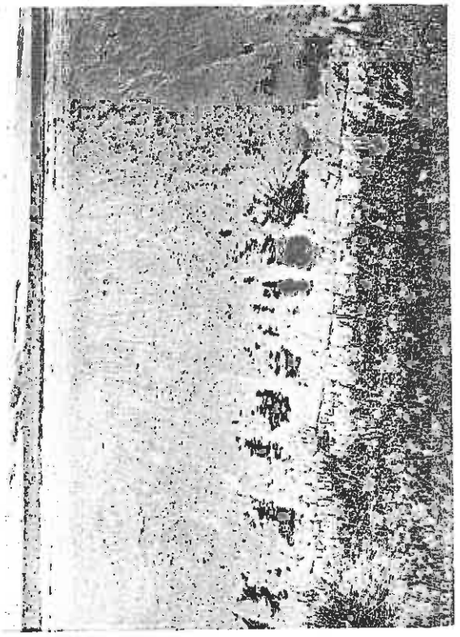


No. 2. Sand-spit, Waikouaiti Bay. In Centre Artificial Foredune; Natural Dunes beyond. [*Photo L. Cockayne.*



No. 4. Sand-drift filling up Phormium Swamp. Dunes of Western Wellington. [*Photo L. Cockayne.*

No. 1. Breach in Foredune made by Sea, North of Rangitikei River. Drift-wood carried Inland. On Right the Pingao (*Scirpus frondosus*). [*Photo L. Cockayne.*



No. 3. Dune-fall of Wandering Dune gradually filling up a Fairly Fertile Hollow. [*Photo L. Cockayne.*

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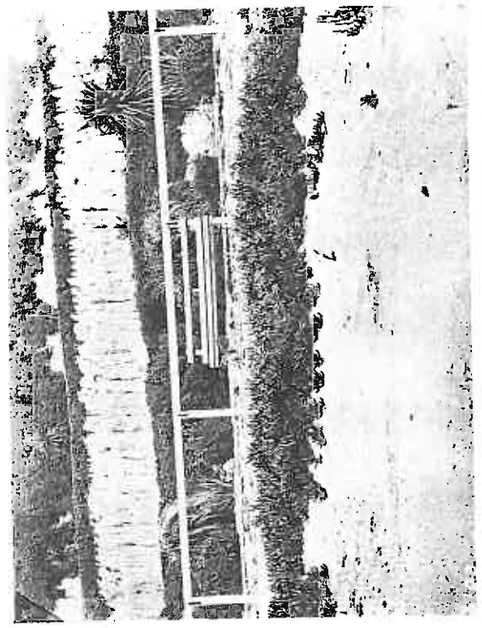
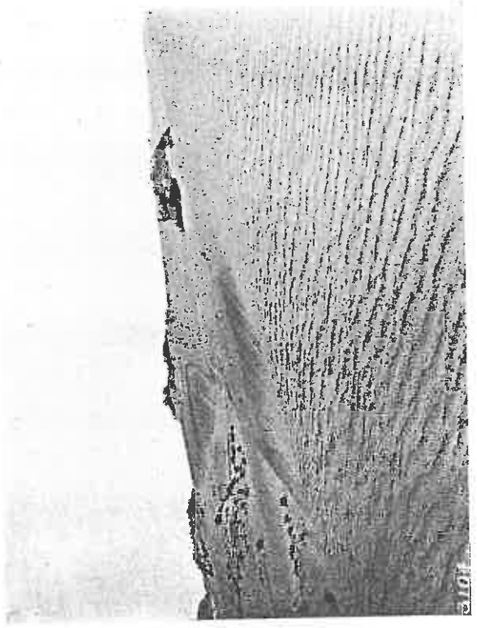
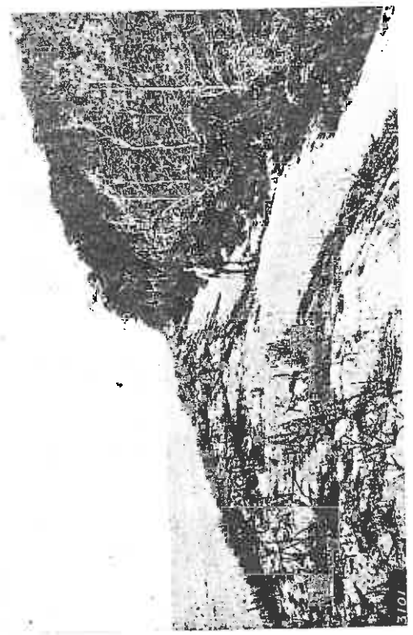


No. 6. Foreshore, Caroline Bay, Timaru, formerly gravelly, now covered with Sand. Embryonic Dune built by planting Mesembrianthemum. [*Photo L. Cockayne.*



No. 8. Conversion of Dune-complex into Wandering Dune, which is advancing, burying Hills and adding to its Volume. [*Photo L. Cockayne.*

No. 5. Wind-trough caused by Eddy from Face of Mound raised by planting Marram-grass. [*Photo L. Cockayne.*



No. 7. Plantation of Scotch-pine (*Pinus sylvestris*), established for more than Twenty Years, just behind Artificial Foredune on Baltic Coast. [*From photo in Handbuch des deutschen Dünenbaues.*

century, using methods which have since been modified and improved, covered extensive areas with the maritime pine (*Pinus pinaster*), which have yielded large quantities of turpentine.

More important still, because the work has been accomplished in the face of greater difficulties, has been the afforestation of the German dunes. Without going into details, the various photographs in Gerhardt's splendid work on dune-reclamation (18) are most illuminating, as may be seen from the one reproduced (Photo No. 7). And it must be impressed upon the reader that the climate of North Germany is not in the same category with ours, since there the severe winter forbids the use even of gorse (*Ulex europaeus*), let alone tree-lupin (*Lupinus arboreus*), and many other plants which are hardy with us.

(c.) Previous Investigations of New Zealand Dunes.

Up to the time of my first report comparatively little had been published as to the geology, botany, or economic possibilities of New Zealand dunes, so that a detailed account of what has been done would be of no moment. The geological writers usually mention dunes as existing in the locality dealt with, but supply no details. McKay's paper (116), however, is an exception, as it describes at some length the dunes of northern Auckland, which form such a striking feature, especially on the west. Various botanical writers—Kirk, Cheeseman, Petrie, and others—have enumerated more or less fully the dune-plants for certain parts of the New Zealand botanical region, and their distribution is probably now approximately known. Between the years 1873 and 1890 a few papers dealing with the economic aspect, but suggestive rather than instructive, were published by Messrs. Whitcombe, Crawford, Travers, and others, Mr. Crawford giving details as to the cultivation of marram-grass, which he was probably the first to introduce into New Zealand. A list of the various papers in which New Zealand dunes are mentioned, even if only casually, is given at the end of this part of the report.

(d.) The Dune-areas of New Zealand.

(i.) Auckland. (Area of Dunes, about 183,940 Acres.)

Commencing on the west at 3 miles south-east of Cape Maria van Diemen, the dunes extend southwards for a distance of 1·7 miles, with an average width of 1·7 miles. Then the coast is rocky to Scott's Point, when a vast stretch of high sandhills forms a belt 47 miles long, with an average breadth of 3 miles (1 mile to 5½ miles), as far as Ahipara Bay. Reef Point then forms a break,* but south of it is a small area 3 miles long by 3 miles broad at the widest part. A small tract lies at the mouth of the River Herekino. Between the Hokianga Harbour and Whangape Harbour lies a belt 7½ miles long, and varying in width from ½ mile to 2½ miles. Between Kawerua and Maunganui Bluff is a narrow belt of dunes. North of Kaipara Heads a broad belt extends northwards for 29 miles, with a width varying from ½ mile to 3¼ miles; and south of Kaipara Heads is a still larger area of 30½ miles long, with an average width of 1¼ miles (1 mile to 4 miles). Then comes a rocky coast to the Manukau Harbour, south of which is a patch of considerable size near the lighthouse, and thence, with a short break, dunes extend for 16 miles to the mouth of the River Waikato, having an average width of 1 mile. South again are dune-areas at the entrance to Aotea Harbour; between the latter and Kawhia Harbour, extending 6 miles, with a width of 1 mile; south of Kawhia is an area 2½ miles long by 1½ miles in the widest part, and on the north shore, at the entrance to Whaingaroa Harbour. On the north coast is an area 8 miles in length at Spirits Bay, and smaller tracts at various places. On the east coast dunes composed of a glistening white sand extend, with one or two small breaks, from the North Cape Isthmus to Rangaumu Bay, having a length of 17 miles, and varying from ¼ mile to 2 miles wide. There is a small area at Henderson Bay and another between Grenville Point and Perforated Point. South from Houhera is a strip 6 miles long and averaging ½ mile in width. Finally there is a long strip on the shore of the Bay of Plenty, from Tauranga Harbour to the Waiaua River beyond Opotiki, 92 miles in length, with an average breadth of 37 chains.

(ii.) Taranaki. (Area of Dunes, 6,333 Acres.)

From south of the mouth of the River Mokau are scattered areas extending to New Plymouth, with an area of about 11,621 acres. From about 8 miles north of Cape Egmont are also scattered areas extending to Patea, having an acreage of about 4,712 acres.

(iii.) Hawke's Bay. (Area of Dunes, 5,345 Acres.)

The dune-areas are mostly small. They are situated at the mouth of the River Waiapu; on the shore of Poverty Bay; at Pukenui Beach, 6 miles north of Table Cape; near the Township of Mahia; a strip 5 miles in length on either side of the mouth of the River Nuhaka, having an average width of ¼ mile; on the beach at Waimarama, 8 miles south of Cape Kidnapper; at the mouth of the Porangahau River; near Cape Turnagain.

(iv.) Wellington. (Area of Dunes, 92,270 Acres.)

A belt extends right up the coast from Paekakariki to Patea, a distance of about 170 miles. From the mouth of the River Manawatu to that of the Wangaehu there is an average width of about 2½ miles and a greatest width of about 6 miles. There are also small areas on the shores of Wellington and Porirua Harbours, and at Lyall, Haughton, and Island Bays.

(v.) Nelson. (Area of Dunes, 4,515 Acres.)

The most important dune-area is at Farewell Spit, with a length of 14 miles and an average breadth of ½ mile (see Napier Bell, 73). There are also small areas at West Wanganui Inlet, Cape Farewell, Golden Bay, Tasman Bay, and for some distance north and south of Westport.

* This will not be the case in a few years' time, as the sand has crossed right over the point and descended to some distance on the northern side.

(vi.) Marlborough. (Area of Dunes, 1,500 Acres.)

A narrow belt extends from the Ure River, 14 miles south of Cape Campbell, for a distance of 12½ miles, having an average width of 7 chains. Another narrow belt extends from the mouth of the River Clarence for 3½ miles to Waipapa Point.

(vii.) Canterbury. (Area of Dunes, 8,755 Acres.)

The most important area extends for a distance of 24 miles from 3 miles north of the River Ashley to the Sumner Estuary. Ancient dunes lie inland to the west of this belt, and divided from it by the Avon and Styx Rivers. There are small areas at Gore Bay, near Lake Ellesmere; at certain bays of Banks Peninsula; and at about 3 miles south of Timaru, near the Normanby Station. Inland is an area near Lake Tekapo.

(viii.) Otago. (Area of Dunes, 5,325 Acres.)

The most extensive dunes are scattered areas from Taiaroa Head to near the mouth of the Taieri River, comprising 1,310 acres. Smaller areas are at Waikouaiti, Waitati, and Purakanui. There are important areas in Central Otago—notably on the banks of the Clutha River, at Tarras (700 acres), at Lowburn (200 acres), at Cromwell (700 acres), and scattered areas between Alexandra and Clyde, extending for about 6 miles by an average breadth of 2 miles.

(ix.) Southland. (Area of Dunes, 4,910 Acres.)

The dune-areas are—near the mouth of the Waikawa River, at Haldane Bay, between Black Point and Waipapa Point (920 acres), from Waipapa Point to Toetoes Bay (1,390 acres), from the New River Estuary to Orepuki (1,800 acres).

(x.) Westland.

A quite narrow belt faces the shore for miles in many places, but the sand-supply is very limited, and the dunes are of little moment so far as sand-drift is concerned.

(xi.) Stewart Island.

I have no details as to areas. There are extensive dunes at Mason Bay on the west, various small areas on the east, and a remarkable series of ancient dunes in the valleys of the Rivers Freshwater and Rakiahua and inland from the Mason Bay dunes.

(xii.) Chatham Island.

Wherever the coast is not rocky there are dune-areas, those of the east coast especially being of considerable extent, and fed by an abundant sand-supply. (See Cockayne, 85.)

(xiii.) The Subantarctic Islands.

Dunes, and these of no great extent, are found only facing the sandy shore of Enderby Island, near the boat-shed for use of castaways.

PART I.—THE GEOLOGY AND BOTANY OF THE DUNES.

I. GEOLOGY.

(a.) GENERAL.

In contradistinction to the infinite slowness which generally marks the evolution of land-forms, that of those of the dune-area is sufficiently rapid to be witnessed by an observer in a limited time. A certain definite series of changes can be recognized, leading to a fixed goal, while at the same time retrogression is in progress.

Hand-in-hand with the building of dunes under natural conditions, and assisting in the work, goes their occupation by plants, these helping too, in various ways, to hold the loose substratum in position, and so keep the hills intact. Such vary from extremely unstable to quite firm structures, on which the erosive power of the wind has no effect. But such stability is at the present time often the exception rather than the rule, certain dune-areas being for the most part made up of bare stretches of sand, protected by a very scanty plant covering, and liable to be displaced by the wind. Man, with his introduced grazing-animals, fires, and methods of cultivation, has further assisted to bring this about, upsetting the equilibrium of the dunes and rendering them still more desert-like.

A general knowledge of the changes that dunes undergo, and their causes, is evidently an essential fundamental towards any scheme for dune-fixing—that is, for modifying the process of nature in a definite manner.

(b.) THE MATERIAL OF DUNES, AND ITS ORIGIN.

[*By R. Speight, M.Sc., F.G.S., Lecturer on Geology, Canterbury College.*]

(i.) Origin of Dune-sand.

The formation of the sand of dunes commences on our mountain-sides, where, by the disintegrating action of frost, variations in temperature, and other causes, solid rock is broken into fragments, forming screes, and those vaster *débris* masses locally called "shingle-slips." While these fragments are being carried seawards by the rivers into which they fall, attrition goes on constantly, and additions to the load of the transporting streams are made unceasingly by the country through which it passes, especially in time of flood. Materials of all grades of fineness are thus produced, from boulders of huge dimensions down to almost impalpable powder. Although the term "sand" is usually restricted to those grains varying in diameter between $\frac{1}{100}$ in. and $\frac{1}{10}$ in., there is no real difference as far as mode of formation is concerned between gravel and sand, the one passing into the other by insensible gradations. There is a difference, however, in composition, gravel being usually a collection of minerals cemented and joined together to form a mass of rock, while sand consists in general of the harder and more refractory units of that mass.

Sand is also formed by the erosive action of the sea (see Photo No. 25). On every coast, between high- and low-water mark especially, wear-and-tear is constant, material is torn away from its place and reduced in size by the continual friction, as fragments are dashed against cliffs, or are rolled over one another by waves and by strong tides and currents. Sand is thus formed by the sea itself, but the sea also performs an important function in distributing it, however it has been formed. When poured into the sea by streams some of the sand helps to form estuarine and delta deposits and shallow-water marine deposits near river-mouths; but a great deal is caught by the shore current, added to that produced by marine erosion, and carried along a narrow belt a little distance from the beach, within which the influence of the waves on the sea-bottom is distinctly felt. While moved along by the shore current, waves and tides carry a part seawards, where it forms permanent marine deposits; they also carry a part landward, where by the aid of prevailing winds it is swept beyond reach of the sea and formed into dunes. This action is more marked during storms, for then the sea-bottom is affected to greater depth, and the shore current is usually stronger, so that a greater load can be carried, and additions to the beach, and ultimately to the dunes, are much greater. This is especially the case when dunes are forming at the head of a bay with gently shelving beach. In fact, shoal water gradually deepening off shore seems essential to the formation of extensive dunes on an exposed coast-line. The amount of sand lying at such a depth that waves can move it readily is, under those circumstances very great, and vast quantities are gradually brought landward by the waves and ultimately form dunes, especially when the area left by the ebbing tide is extensive and has time to dry before it is covered again by the succeeding tide.

When a promontory or obstruction bars the course of the shore current and turns it into deeper water the load is dropped and piled up in front of the obstruction, but usually with an intervening space kept clear by eddying currents. If, however, waves and currents are strong they carry the finer particles round the obstruction, and form a beach and its consequent sandhills in its lee. This is occurring in Caroline Bay, near Timaru. The breakwater stops the coarse gravel, but fine sand travels round the end, and is building up a beach with small dunes on the northern side of the breakwater (see Photo No. 6).

If, however, the shore current crosses a shallow bay it forms a spit. This is at first beneath sea-level, but it is gradually built up, and plays its part as a beach, and is finally crowned with dunes. A deep channel is usually maintained close alongside the headland towards which the spit stretches, especially when there is a tidal basin of considerable area, which fills and empties through

the opening. Sometimes the opening is completely closed, and drainage is effected by percolation through the bank. Spits frequently tie islands to the mainland. Excellent examples of this can be seen at Ocean Beach, near Dunedin; at Lyall Bay, near Wellington; and far north of Auckland, where the ancient mountain-headlands lying between Cape Maria van Diemen and the North Cape are joined to the solid land near Mangonui by the best-developed sandspit and sand-dunes occurring in the Dominion.

(ii.) Material of Dunes.

The material out of which dunes are built consists for the most part of small particles of the more resistent constituents of the rocks of the land surface. Quartz-grains usually form 90 per cent. of the whole. This is due to two main causes.

(1.) Quartz is a very widely distributed mineral in rocks of the earth's crust. It forms the greater part of all sandstones, and is an important constituent of many other rocks.

(2.) It is a mineral not susceptible to the action of weathering-agents; it resists the action of all acids occurring naturally, and it is extremely hard. Owing to this cause its importance is always increasing as a constituent in the waste of the land; other minerals suffer decomposition, or are worn away, but quartz survives, and so its percentage becomes greater as the products of erosion are subjected to further disintegration and weathering.

Other minerals play an important though subordinate part in the formation of dunes—viz., feldspar, iron-oxides, hornblende, augite, and limestone, and with these occur occasionally the rarer minerals, zircon, rutile, and tourmaline. Their power of resisting decomposing-agents explains their presence also. But account must be taken of the character of the rock which has furnished the material of dunes when speaking of the mineralogical character of the individual grains.

A sandstone or quartz rock produces sand consisting almost wholly of quartz-grains. As the main mountain-ranges of the North Island and of the eastern part of the South Island are composed principally of sandstones, greywackes, and slates, the sands on the eastern shores of the South Island and of the south of the North Island contain a high percentage of quartz. Slates weather into very fine particles, and usually form mud.

Granites, gneisses, and schists produce a sand with predominating quartz-grains, unless the parent rock is of basic type. Feldspar and mica are of subordinate importance, for the reason that, although they may be predominant in the solid rock, they are less able to resist attrition and decomposing-agents. Mica is a very important constituent of river-sand, but it becomes rapidly shredded out into thin films, and is finally carried away when exposed to wind-action in a dune. Sands of this type occur on the beach at St. Clair, derived in all probability from the Central Otago schists by the agency of the Clutha and Taieri Rivers, and carried north by the strong shore current running up the coast.

The sands from volcanic rocks depend in composition on that of the parent rock. Pumiceous and scoriaceous varieties are extremely common in the North Island, and the titaniferous ironsands of the west coast are largely derived from the breaking-down of the volcanic rocks of Mount Egmont and of the Central Plateau. Little or none of this sand is found farther east in Cook Strait than the mouth of the Rangitikei River. That on the shore between there and Porirua owes its origin to the disintegration of the quartziferous rocks of the Ruahine and Tararua Mountains, and magnetite is absent. One point should be noted here. The black sand of the Taranaki coast contains a good deal of hornblende and augite grains, both dark in colour, but of no value as a source of iron. These minerals have also been weathered out of the volcanic rocks, and at first sight are indistinguishable from the magnetic ironsand, but they detract very much from its value as an ore, and will have to be separated before it is treated metallurgically.

Similar magnetic sands occur in smaller quantities on other stretches of coast. Small patches of fairly pure titaniferous magnetite are to be found on some of the beaches of Banks Peninsula, derived from its basic volcanic rocks; and also on the west coast of the South Island, weathered out of the metamorphic rocks and basic volcanics of Westland.

It is stated by P. G. Morgan (122, p. 110), "The beach-sands of Westland consist mainly of quartz. Magnetite is a noticeable constituent, whilst garnet and zircon are fairly common, the former being especially abundant on the beach near Ross. More or less fine gold is always associated with the magnetite." This mineral forms an important constituent of these sands because of its hardness, its resistance to chemical decomposition, and its tendency, owing to its weight, to accumulate in masses by the ordinary process of water-concentration.

A cursory examination of specimens of New Zealand dune-sands shows that they are largely composed of quartz, with subordinate magnetite, hornblende and augite, and feldspar, in that order of importance; but subsequent examination may lead to a modification of this statement. Limestone formed from shell-fragments is very common in some places, and at times forms the main bulk of the sand. Its presence is a distinct advantage, as it forms a valuable cementing-agent, and thus tends to fix the position of dunes.

(iii.) Form of the Sand-grains.

The sand-grains of dunes exhibit certain peculiarities of form which distinguish them from ordinary river and sea sands. The latter are angular or subangular in shape, as they have not been subjected to the abrasion which dune-grains have to endure. Although stones and gravel are invariably rounded by the continual friction as they are rolled along by river or sea, the smaller particles are more or less protected by an enveloping film of water, which, as they become smaller, prevents that close contact necessary for rapid abrasion. However, the corners and edges of the grains get worn off in process of time. But when sand accumulates as dunes, and there is no protecting envelope

of water round each grain, abrasion is very rapid, and thoroughly rounded grains result from the backward and forward drift in varying winds, or even by the constant onward drift in a prevailing wind. For this reason desert-sands are always rounded. Nevertheless, it is frequently very difficult, if not impossible, to decide on the origin of sand-grains, judging from their contour alone. Long-unconsolidated sands carried for long distances in river or sea, also those derived from old sandstones by the removal of the cementing-material, will also exhibit this peculiarity. In fact, some of these old consolidated sandstones may have been formed from the dunes of geological ages long past, and perhaps represent accumulations in an old Triassic desert or on the shore of an old Jurassic sea. It occasionally happens that such sand-grains have developed the regular outline characteristic of crystals while forming a part of the solid rock, and have again been rounded when removed from their fixed position, two ages of rounding being thus observed in the same grain.

It may be definitely stated, in concluding this section, that sharp-edged and subangular grains rarely form part of dunes, and, even when they do, have been but recent additions to the sand of which the dunes are built.

(c.) DUNE-BUILDING ON THE COAST.

(i.) General.

On sandy beaches not completely covered with water at high tide there will be a foreshore consisting of quite loose sand, into which the foot sinks at every step. This material forms the supply out of which the dunes are built, its amount being kept up by fresh sand continually brought from the sea by the tide under the influence of the waves.

It is only a small proportion of the sand moved by the waves which, having become dry, is finally added to the supply of the foreshore; the greater part is borne back to the sea, while some is deposited between the water-marks, building up the lower shore, or the "sea-wall," as it is sometimes called. Other portions are deposited in the shallow water, forming sandbanks, which may be quite bare at low water, and over which the sea breaks. After the turn of the tide, if the weather be fine, the sand wetted by the furthest wash of the sea at high water commences to dry, but this process is frequently very slow, owing to the moisture of the sea wind; and in the absence of sunshine it will be still more retarded, so that *there are many days in the year when little or no additional sand reaches the foreshore from the sea.* Until the sand is quite dry there is no movement, and it is usually but a narrow strip of beach which is affected. The limit between the wet sand and that which may dry is known to every frequenter of a sandy shore, who finds there a path for walking, or for vehicles, above or below which the sand becomes gradually less firm and the foot sinks.

The breadth of the belt of loose sand varies greatly at different parts of the coast. On the long stretch of sandy shore between Ahipara and Cape Maria the sea at high water almost reaches to the foot of the dunes. On the beach of eastern Canterbury, on the contrary, the belt is so wide that a well-fixed foredune has been built upon it opposite the seaside town of New Brighton. Between the north Kaipara Head and Maunganui Bluff the sea reaches in many places right to the foot of the cliffs, on the summit of which the present dunes lie. *The sand-supply thus varies greatly on many parts of the coast, and this variability is of much moment with regard to the ease or difficulty in dune-reclamation.*

(ii.) Movement of Sand by the Wind.

The wind blowing inland from the foreshore carries with it, according to its velocity, more or less sand. The sand-grains move in three ways. The coarsest are rolled along the ground; those somewhat finer are raised just above the surface for very short intervals, but constantly fall and progress hopping, as it were; finally, the finest particles are blown bodily into the air. From the summit of a wandering dune during a high wind the sand may be seen rising in a great cloud just like smoke. Such flying sand may be carried long distances, as in Central Otago, where the sand from the Tarras drift is sometimes conveyed in the air for more than twenty miles. The air-borne particles, since they do not fall all at once in heaps, but are scattered over wide areas, usually play no primary part in dune-building, the rolling and hopping sands being alone of moment in that regard. All the same, high gales may have an average carrying-power, and thus it is that sand from the Cromwell flat is being accumulated at certain spots on the hills across the Kawarau River.

At a certain point, depending upon the velocity of the wind, the weight of the sand becoming greater than the wind can carry, a certain amount is deposited upon the ground, and by gradual accumulation a heap of sand—*i.e.*, a small dune—is formed. Very frequently, however, some obstacle, such as a mass of seaweed, a piece of driftwood, a living plant, or an incipient dune itself, arrests the drifting sand and forms a nucleus on which the dune is built. Such a hill will have a long and gentle slope to the windward, up which the sand is pushed, the velocity of the air increasing with the height: but the leeward side is much steeper; there is no pressure of wind down its slope; on the contrary, there is an eddy of greater or less power, and the sand falls by gravity alone.

(iii.) Sand-ripples.

Very frequently the sand forms ripples as it moves—*i.e.*, small waves similar in appearance to those so well known on the wet shore made by water-movements. The formation of sand-ripples has been experimentally investigated by Dr. V. Cornish (7, p. 279), who in his admirable paper shows that where the sand-grains are all of an equal size no ripples can be formed, but that when coarser grains are added rippling at once commences if the wind be suitable. The explanation of this depends on the fact that when the wind strikes upon a solid obstacle an eddy is formed on its lee side, and rippling takes place when this eddy in the lee of the larger grains is of sufficient strength to lift the smaller. Conversely, if the wind be strong enough to lift the larger grains, so that they do not remain stationary,

there will be no ripples, a state of affairs which frequently occurs during high winds, especially on dunes such as those of east Canterbury, where the grains are small and fairly uniform. On the windward side of the large grains a long but gentle slope is formed, up which the grains travel, but at the summit the larger ones are arrested by the eddy and build up the ridge of the ripple, while the vertical motion of the eddy scours out a trough in the loose sand, raising the finer grains, some of which, together with those passing up the long slope, are blown to leeward. The ridges advance by the larger grains falling by the influence of gravity over the crest of the ridge, thus building up a steep lee-slope at the natural angle of rest of the particular sand-grains. Thus the ripples are continually advancing, a ridge taking the place of a hollow, and so on. The rapidity of advance varies with the force of the wind. During a violent east wind I have observed the ripples of an east Canterbury dune moving at the rate of an inch a minute. The ripples frequently merge into one another, on account of the different rate of movement of different parts, a matter depending on the height of a ridge, the higher this being, the slower the movement. From the above it may be seen the wind exercises a distinct winnowing or selecting power, the sand-grains being sorted according to size, the smallest advancing fastest inland. This sorting of grains is well shown in the case of the ironsands, the black heavy grains forming the ridges and the lighter-coloured ones the hollows. Ridges of black grains an inch or more above the level of the hollow are quite common (see Photo No. 8), and much higher ridges are formed under certain conditions, which differ little from dunes, but the former are evanescent, while the latter, owing to the greater amount of sand, can never be wholly moved during the period of any special wind. Also, dunes are generally acted on by more than one wind, and are usually more or less governed by a plant covering.

Specially coarse sands, such as those of Fortrose, form very large ripples, but the most striking are to be found on those inland dune-areas of Central Otago, where all the sand except the coarsest has been blown clean away by the violent westerly gales. In such cases, as Photo No. 11 shows, there are frequently two series of ripples, one much taller than the other and not to be moved except by the very highest wind, but otherwise to be added to and so become dune-chains in miniature.

As ripples are formed at right angles to the wind producing them, and as all further motion is arrested by even a gentle shower, they are evidently self-registering wind-gauges of the particular wind which accompanied the rain, as Jentzsch has shown (18, p. 54).

(iv.) Plants as Dune-builders.

It is very rare indeed that a dune in course of formation is quite destitute of plant-life; indeed, the majority owe their progress and existence to the presence of some "sand-binding" plant, which, in the first instance having stopped the sand-drift, assists further deposits to collect, while at the same time its own growth is accelerated, it and the sand rising up together. Juvenile dunes occupied by plants are extremely common, both on the upper strand itself, on "sand-plains" within the dune-area, and even on decaying hills, the pingao (*Scirpus frondosus*) and the silvery sand-grass (*Spinifex hirsutus*) acting as dune-builders. Further details on this subject are given in the botanical section.

A typical dune is a hill with a long windward slope at a variable angle (frequently about 4°) and a steep lee side which corresponds to the natural angle of rest of the particular sand out of which the dune is built, a matter depending on the form, size, specific weight, &c., of the sand-grains—*e.g.*, the "sandfall" of a wandering dune may be at an angle of 30° or even more. Near the summit and on the upper part of the windward slope grow sand-binding grasses and sedges, while the leeward side may also have a plant covering or may be bare sand occasionally trickling downwards through its weight. Shrubs also may play an important part in dune building and maintaining (see Photo No. 22).

It is astonishing how quite a scanty plant covering checks the wind and adds to the stability of the dune. Even where the tufts of grass or sedge are only a foot tall, and where more than two-thirds of the surface is unprotected, it is remarkably stable.

(v.) Effect of Obstacles.

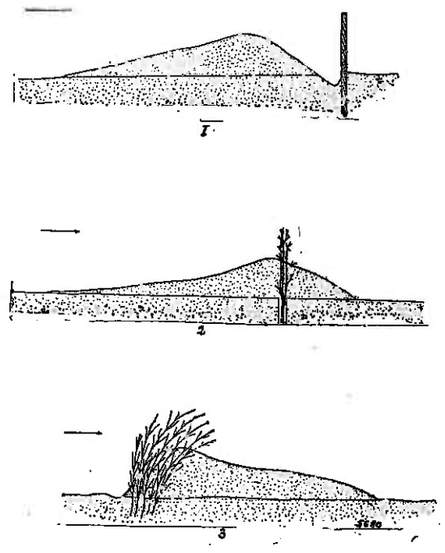
(α.) *General.*

An obstacle opposed to the sand-drift functions in different ways, according to its physical state. Three main classes need mention, but they are connected by intermediates. A knowledge of the effect of obstacles is of great importance in artificial dune-reclamation, for on their proper use depends the erection of suitable protection-fences, &c.

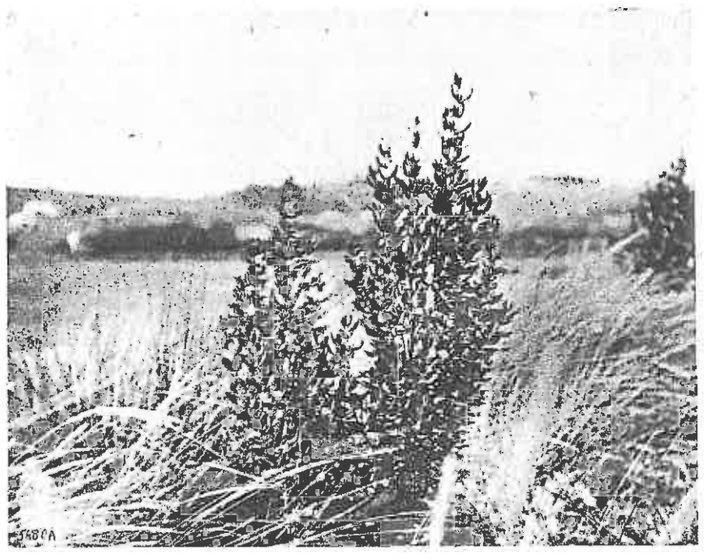
(β.) *Solid Obstacles.*

These are very frequent, and may consist of a piece of driftwood, a cliff, the steep face of a dune itself, a wall of any kind, &c. The wind striking on such an obstacle is reflected, an eddy is formed, the sand at the base of the obstacle is scooped out, and the advancing sand cannot pile up against the obstacle, but forms a heap at some distance in front (see Photo No. 9). If the wall is low—*e.g.*, a paling fence—the sand rises level with its summit, and then, beyond the reach of the circumference of the eddy, is blown over the fence, collecting on its leeward side, while contemporaneously the eddy ceases, the hollow becomes filled with sand, the fence being finally buried and forming the nucleus of a bare dune should the sand-supply continue. An isolated house may have the sand heaped up not only in front but opposite its sides, owing to the lateral eddies.

The effect of such obstacles as the above are very marked in any dune-area, and lead to the partial or complete burying of fixed dunes and other solid bodies and the cutting or forming of wind-troughs, &c.



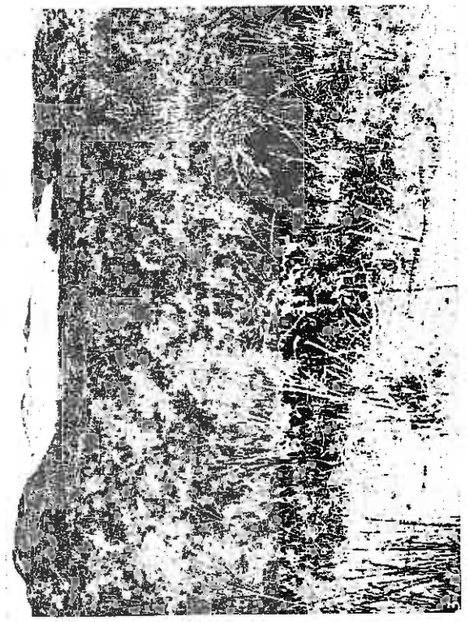
No. 9. (1.) Effect of a Solid Obstacle. (2.) Effect of an Inflexible Open Obstacle. (3.) Effect of a Flexible Open Obstacle, such as a Bunch of Marram-grass. (After Gerhardt.)



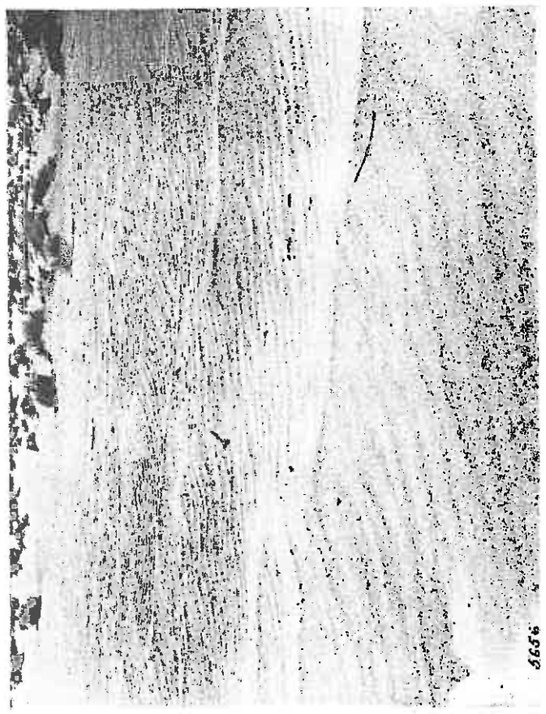
No. 10. The Chatham Island Akeake (*Olearia Traversii*) planted by Mr. Tannoch on the Dunes, Ocean Beach, Dunedin.

[*Photo L. Cockayne.*

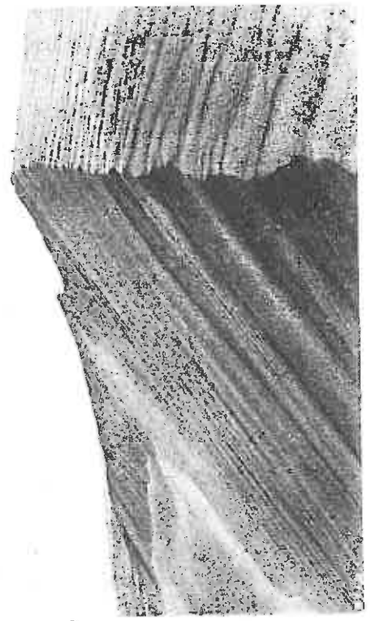
To face page 10.]



No. 12. Dune naturally fixed reverting to the Active Stage at Summit. Shrubs in Front chiefly *Cassinia leptophylla*. [*Photo L. Cockayne.*



No. 11. Wind-ripples, Primary and Secondary, in Coarse Sand. Cromwell Dunes. [*Photo L. Cockayne.*



No. 14. General View of Wandering Dune, formerly Good Grazing-land, showing Ridge at Summit of Sand-fall. [*Photo L. Cockayne.*

No. 13. Natural Foredune near Waikanae held by the Silvery Sand-grass (*Spinifex hirsutus*), forming an Excellent Protection to the Coast. [*Photo W. H. Field.*

(γ.) *Flexible open Obstacles.*

A typical and frequently observed obstacle of this class is a bunch of the pingao (*Scirpus frondosus*) or of marram-grass (*Ammophila arenaria*). Here the sand is blown into the calm interior of the bunch, which it fills, but as further sand strikes from the windward it creeps over the interior sand and on the leeward side of the obstacle forms a tongue-like mass. On the stony plains between the mouths of the Wangaehu and Waitotara Rivers the long tongues of sand collected on the leeward side of the small wind-swept shrubs of *Coprosma acerosa* are very noticeable (see Photo No. 41).

(δ.) *Inflexible open Obstacles.*

In this third case the wind-current is checked to some extent in passing through the obstacle; there is no eddy, consequently the sand is piled up on both sides. Obstacles such as these are formed naturally by certain stiff shrubs, which consequently fill with sand. They are also used artificially for sand-catching or drift-arresting.

It can easily be seen that obstacles of various kinds assist materially in dune-building, and that when plants grow upon dunes their height may be considerably increased, while their stability is maintained so long as the obstacles remain unburied. In the case of dead obstacles this must eventually happen, also in living ones which cannot grow upwards at a rate to correspond with their burial, as in the case of all true sand-binding plants. Even these, when the supply of sand becomes too great, are frequently overwhelmed and killed, the dune then becoming the sport of the wind (see Photo No. 32).

(vi.) Stratification of Dunes.

The size of the sand-grains moved varies according to the force of the wind, which, as seen in the case of sand-ripples, has a distinct winnowing action, an exceptionally strong gale moving even pebbles and small stones. So, too, is there an ever-variable transporting-power passing up the inclined plane of the windward surface, so that the layers of sand differing in coarseness, and consequently in water-holding power, are deposited and overlie one another. This leads to an irregular stratification, plainly to be seen when a dune is so laid bare by the wind that a horizontal section is exposed. Old soils, &c., also form layers beneath the sand, and in some cases are important food-material for any trees, &c., which may be planted. The sand-planter, then, should carefully examine his dunes as they are laid bare or cut into by the wind.

(vii.) Effect of Climate.

Sand, as already noted, can only move when dry, the cohesion of the particles when wet being too powerful for the wind to disturb. Quite a gentle shower will fix the sand; in fact, owing to its great power of absorption, the heaviness of the downpour is of little moment, whereas the duration is everything. It is not the rainfall of a district, but the number of days yearly during which rain falls, and their distribution throughout the year, that, besides the perennial supply of sand, governs the magnitude of a dune-area, the wind factor being considered constant. The dunes of Enderby Island, in the Auckland Group, are virtually stable notwithstanding the absence of sand-binding plants, owing to the almost daily rain and constantly cloudy skies (see Cockayne, 86, p. 237). The sand on the summit of the dunes dries more rapidly than that below, and so is the first to be moved after rain. Irregular drying of a flattish sand-surface leads to irregular low deposits of sand extending in the direction of the wind. Wind, especially that from the south-west, is in certain parts of New Zealand accompanied by a downpour,—and its subsequent effect is correspondingly lessened. A wet season will lead to a general flattening and lowering of the dunes, and a dry one to their raising. Indirectly, also, dry weather leads to extension of dune-areas, since the owners burn more of the plant covering.

Sunshine plays its part in sand-drying, summer being more favourable for dune-building than winter, while cloudy skies are adverse.

Wind, the most potent factor with regard to dune-development, is fully dealt with under other heads.

(*d.*) THE FOREDUNE.

The dry sand of the foreshore is blown inland by every sea-breeze, but either through its own weight or on account of meeting with an obstacle, such as the driftwood or a strand-plant, it is eventually piled up in a continuous ridge which follows in every case the contour of the shore-line, no matter whether the prevalent wind be at right angles or oblique. This ridge is early captured by *Scirpus frondosus* in the southern botanical province of New Zealand, or by this sedge or the silvery sand-grass (*Spinifex hirsutus*) in the northern and central.

Where the supply of sand is fairly uniform a very even ridge may be formed with a gently sloping flattish top, well covered with the grass or sedge or with both. The lee side is generally more or less bare sand.

In some parts of the coast this front line of dunes, here called the foredune, forms such an even, unbroken, and well-established wall—as near Waikanae, for instance—that one might easily believe it to be an artificial structure (see Photo No. 13).

A well-shaped and plant-fixed foredune is a land-form of the greatest importance, since it not only cuts off in part the sand-supply of the shore from the land, but it forms a natural protection against the inroads of the sea, thus safeguarding the coast. Owens and Case (47, p. 143) call attention to the value of the foredune for coast-protection, and point out it has not received the recognition in England that it deserves, and "that, unfortunately, it is therefore necessary to look abroad if we wish to make a careful study of the matter and benefit by the knowledge which practical experience alone can give."

The natural foredune is not always so even as that just described, but may be cut into by the wind or washed away by the sea, when at once destruction begins in the dune-complex, and in time a general flattening takes place. Where a well-made natural foredune does not exist, in the best European procedure an artificial one is constructed. This has been done in a few places in New Zealand, either by design or accident. There is one at Waikouaiti Bay, but which is not altogether satisfactory (see Photo No. 2). At New Brighton, Canterbury, and Ocean Beach, Dunedin, are much better examples, the former having quite checked the once very troublesome drift from the shore.

(e.) GENERAL TOPOGRAPHY OF A DUNE-AREA IN NEW ZEALAND.

Where there is a sandy shore with more or less bare sand at high tide the dunes will commence at a variable distance beyond the limit of the highest tide. Where the supply of sand is small, as in the case of either a small belt of dry sand or a shore where there are more pebbles than sand, there may be only a foredune, and this of the smallest dimensions; but usually behind the foredune are numerous chains of sandhills of quite irregular form, which are generally divided in places by basin-like hollows of greater or less extent. Frequently the ridges are at right angles to the prevailing wind, but in New Zealand there are nearly always one or two other more or less common winds, which operate to no small degree in regulating the position of the hills, in altering their form, in determining windward and leeward slopes, and in modifying the slope-angles. There are also many openings through the chains, hills at all stages of decay or growth, basins in process of being hollowed out or filled up, and comparatively flat masses of sand where the dune-chains have been destroyed. In short, there is usually a bewildering maze, especially where winds blow from several quarters, the actual origin of which could be traced only with the greatest difficulty and uncertainty. Such a collection of dunes is called by Cowles the "dune-complex" (12, p. 194), a term well suiting the case.

The dune-area varies from a foredune, or merely a few low mounds of sand, to a width of several miles, the maximum being about seven miles, between the Rivers Wangaehu and Rangitikei, in western Wellington. It is easy to overrate dune distances, for traversing them on foot is very laborious.

Large tracts of land such as the above are not worthless by any means: they include low-lying wettish flats clothed with nutritious grasses, streams, shallow lakes, and extensive swamps. The hills themselves are not generally bare, but possess a plant covering varying from a few tufts of sand-binding grass or sedge to a close turf overlying a deposit of loam, and affording fairly good pasture. It frequently is at the extreme inland boundary where the wandering dunes, huge masses of bare sand slowly moving, are encountered (see Photo No. 14).

Generally speaking, the view from an eminence in a wide dune-area is that of a sea of sand, the ridges stationary billows, and the scanty vegetation showing only as small yellowish or dark patches on the general white or greyish groundwork.

Some important dune-areas in New Zealand have no connection with the coast sand at the present time. This is the case with those dunes which extend in many places inland from the summit of coastal cliffs, as generally in Taranaki and between the north Kaipara Head and Maunganui Bluff in Auckland. Here the distinction between dune chains, hollows, and so on, is not nearly so well marked, and in some cases does not exist. Dunes of this description were in general covered with vegetation when the settlers arrived; but now some of them are wandering dunes of the worst description.

In western Auckland these present cliff-dunes overlie ancient sandhills, now consolidated into rock of a most variable degree of hardness. Between the north Waikato Head and the south Manukau Head the sea is cutting into and has removed a good deal of these ancient dunes. From Tewahiaroa northwards the old line of dunes marks an ancient shore-line, but at the foot of this is now a mile or so of low recent dunes extending to the sandy shore. Between Cape Maria and Reef Point there are several chains of consolidated dunes, forming the bulk of the narrow land-surface, and in some places they extend right to the western shore. Beneath them in many places lie the remains of kauri forest and even lignite, and this is the case also with some of the ancient consolidated dunes on Reef Point. From the above it is evident that there have been various changes in the altitude of northern New Zealand, while possibly some of the changes have been quite local; but a consideration of these matters would be out of place in a report dealing chiefly with the economic aspect of dunes.

The dunes differ much in height in different parts of New Zealand. The foredune may be from 8 ft. to 25 ft. high or more; but dunes more inland are very variable, those at Mason Bay, in Stewart Island, attaining the great height of possibly 300 ft. Generally 20 ft. to 50 ft. is a common height; but hills of 100 ft. and more are not infrequent, especially on the more fixed and inland dunes, whose instability was so little suspected in the early days of settlement that some of them received names (Mount Amon, Mount Jacob, &c.), and were made the sites of trig. stations.

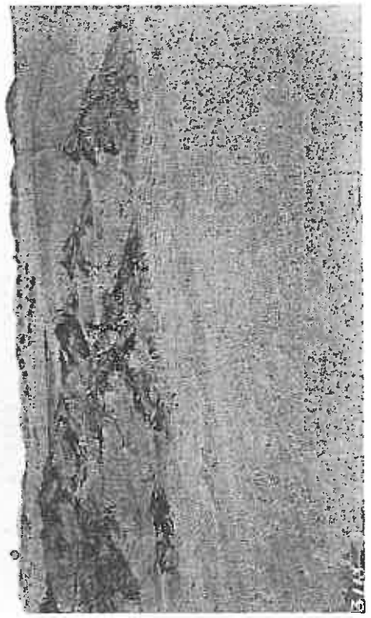
Some of the dunes look far higher than they really are, so far as the depth of sand goes, owing to their being underlain by rock or by the above-mentioned ancient dunes now consolidated into varying degrees of hardness. Even the great wandering dune at the north Waikato Head is in many places quite thin, and near its summit at more than one place a stream of water trickles over the sand, coming from the solid ground below.

(f.) MOVEMENTS OF DUNES AND DUNE-SAND.

(i.) General.

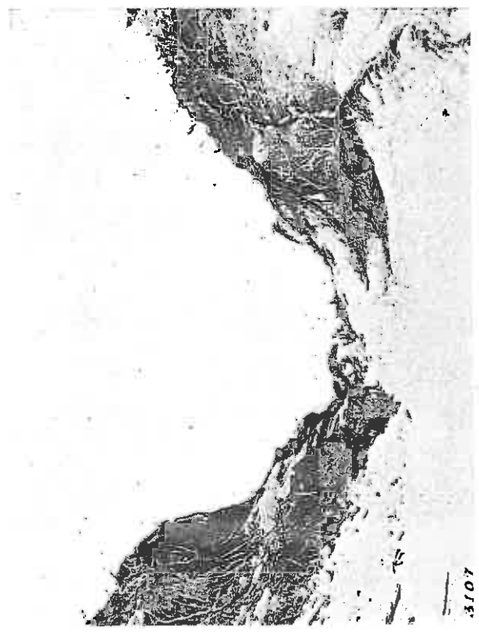
It is easy to see that, built of so unstable a material as sand, a dune-area is in a constant state of change. Just as the ridges of ripples and the hollows alternate, so do dune-ridges and sand-plains. The dune having reached maturity, it is at once attacked by the wind, gashes are made in its surface, slight depressions are changed into deep gullies, plants are uprooted or buried, and high hills are finally

No. 16. Marram-grass planted to arrest Drift has built Hills, which have led to Wind-channels and Fresh Destruction in consequence. [*Photo L. Cockayne.*



No. 18. Wandering Dune in process of Formation. In Centre Wrecks of *Scirpus frondosus* Dunes. [*Photo L. Cockayne.*

No. 15. Marram-grass planted in a Wind-channel formed by Two Hills has been killed. Here Growth impossible without Protection. [*Photo W. H. Field.*



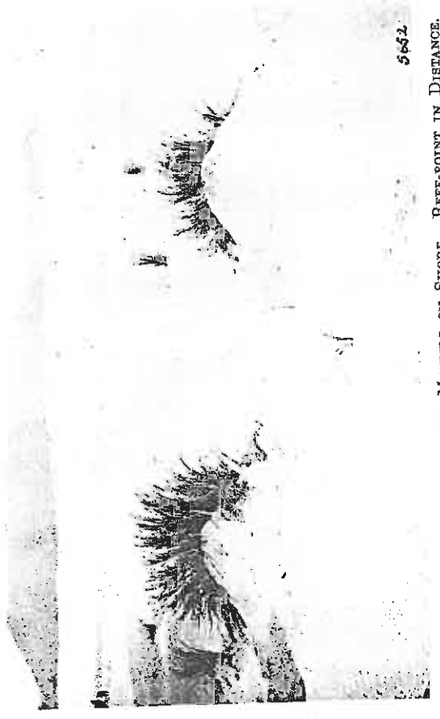
No. 17. Wind-channel between Two Hills, showing Destructive Effect of Mounds raised by Sand-binding Plants. [*Photo L. Cockayne.*

To face page 12.]

No. 20. Sand-drift from Shore killing Grass in Dune-hollow. In Centre and to Right *Marisca ustulatus*. [*Photo L. Cockayne.*

No. 22. The Sand-collecting Shrub *Coprosma acerosa* building a Small Dune. On Left almost buried. [*Photo L. Cockayne.*

No. 19. Advance of Wandering Dune stopped by River Turakina. Well-fixed Portion of Dune above. [*Photo L. Cockayne.*



No. 21. *Scirpus frondosus* building Mounds on Shore. Reef-point in Distance. North-west Auckland. [*Photo L. Cockayne.*

blown away. Also, as Shaler has shown, the rubbing-together of the sand-grains leads to the formation of dust, which will, with much very fine sand, be blown away from the dune-area altogether (55). But with the destruction dune-building goes hand-in-hand, new dunes arise, and fresh chains of hills are formed, these in turn to be destroyed. All this round of destruction and regeneration is the work of the wind, modified by the plant-life.

(ii.) Wind as a Destructive Agent.

So long as the wind brings a sufficient sand-supply, and the sand-binding plants form a close-enough and even-enough covering, will the dunes remain intact. But with increasing stability of the surface so does the sand-supply decrease, while in any case the tendency of the plants is to raise prominences and hillocks, nor do they usually in a state of nature grow closely, there being many isolated tufts or tussocks.

The wind performs a dual function: it transports material, and it erodes. When there is less than a certain amount of material brought the erosion will predominate. So, too, will this be the case with winds of abnormal intensity. Where a high wind blows over a well-fixed area it transports little, but attacks every bare spot.

A certain velocity of wind does not act everywhere with uniform power; on the contrary, it is a variable factor, depending on circumstances. First of all, the nature of the ground-surface is a matter of great importance, all irregularities tending to break the force of the wind, as the observations of King and Olsson-Seffer have shown, the experiments of this latter author demonstrating that *the velocity of wind over a smooth surface is at least 34·7 per cent. greater than on uneven ground* (44, p. 560). Grassy ground, then, can be seen to have a powerful influence in restraining the wind, while the effect of rows of sticks, &c., fixed in the soil, small as it might be thought, is very great indeed, and on such depend some of the methods of sand-reclamation discussed in Part II of this report. When the wind strikes on a solid object, such as a dune, its power is greater at the sides than in front, while in the lee an eddy is formed varying according to the force of the wind. Each obstacle, then—every sand-mound and isolated tussock or shrub—favours erosion. Still more is the erosive power of the wind increased by the proximity of two objects, as two adjacent mounds, making a channel (see Photos Nos. 15 and 17). Through such the compressed air blows with increased erosive power, making ever-deepening cuts into the sand, until finally what were at first but bare sand-patches become gullies, these latter varying from merely saddles to miniature gorges. In such wind-channels there is nothing but bare sand; the sand-binding plants are uprooted in the first place, and it is impossible for them to gain a foothold again without shelter (see Photo No. 15). Nor is it simply a direct wind-current which operates when the wind strikes a solid obstacle: there is always the lee eddy playing a powerful part, and there is a vertical as well as a horizontal stream of air; in fact, an air-current is a most complex matter (see Langley, 37). Moreover, as shown before, air-vortices are caused by impact upon certain obstacles. The erosive power of the wind is therefore frequently much intensified, and a dune unprotected, or partially protected, by vegetation is by degrees cut into deeply, and finally may be quite blown away, the only trace of its former presence being dead rope-like rhizomes of the pingao (*Scirpus frondosus*). Dunes in all stages of destruction may be seen in any area, from a tiny bare sand-hollow between two tussocks to a sand-plain without a trace remaining of the former dune-chain which occupied the ground.

From the above it may easily be seen that the natural fixing of sandhills by tussock-forming plants or by shrubs may lead finally to the destruction of what one would expect to be stable dunes, any irregularity of surface favouring the erosive power of the wind. Irregular planting of marram-grass, or its spontaneous spreading from seed, may for the above reason not only be useless but dangerous (see Photo. No. 5). The frequently expressed opinion that any plant is useful on the dunes is an erroneous conception, based on ignorance of the behaviour of plants with regard to erosion. "Well-fixed" summits of hills are not infrequently a source of danger. An interesting example was afforded in the planting of the foredune of the Kurische Nehrung (Gerhardt, 18, pp. 343–44) with the Caspian willow (*Salix caspica*), a plant which tolerates sea-spray and wind, and is an excellent sand-binder. For a number of years the plant grew excellently, doing all that was required, but finally its irregular growth led to the forming of thickets and mounds and the resulting wind-channels, so that the dune became subject to erosion, the willow causing the very destruction it was planted to check. In consequence, at great expense, the whole of the willows were uprooted, and a new beginning had to be made with other material.

The erosive power of the wind leads to the forming of various land-forms in the dunes. Thus there are the saddles and gullies mentioned above. Hills may be quite wasted away below, the plant-covered summit remaining, mushroom-like. There may be rounding of ridges, or hills may be cut vertically, exposing the strata. Various hollows may be cut in the sand, of which "wind-troughs" formed by eddies, as already explained, are frequent (see Photo No. 5). When a strong wind is blowing, the eddy on the steep lee side of a high dune is very powerful, whirling the sand high into the air, scouring out its base, and probably increasing the steepness of the slope. Such eddies may be met by the strong current of a wind-channel, when a combination of the two forces leads to the building-up of slopes, the heaping-up of mounds, the formation of appendages to the main dune, the cutting of channels, or erosion of basins, whose origin, if viewed during a period of calm or when a contrary wind is blowing, would seem inexplicable, so complex is the effect of the diverse currents. Spots where this complexity of wind-action takes place are extremely critical with regard to dune-cultures, and the conditions require modifying artificially before a successful planting of sand grasses or trees can be undertaken. The most important form perhaps is the wind-basin. Here the wind, having removed the dune piece by piece, continues its work of hollowing out the dry sand into a shallow basin-like hollow, until finally the ground-water is neared, the sand becomes damp, and all further erosion ceases

as by magic. Large areas may be so eroded, the hills having been blown quite away, and flat "sand-plains" result. These may be seen in all stages of formation; and though it seems hard at first to believe that comparatively fertile plains of large extent were once the seat of dune-complexes, remnants of hills marked chiefly by rhizomes of the pingao in some instances mark the position of former sand-hills (see Photo No. 18).

Owing to the proximity to the water-table, sand-plains are fairly moist all the year round, though during dry weather a sandy crust will lie on the surface. In winter, water collects in pools in many places. Even shallow lakes may arise, the aquatic vegetation making humus, which forms in time a more impermeable bottom than does the sand.

Though hardly present, so far as I have noted, in the New Zealand dune-areas, a quicksand may be formed on the sand-plain near the base of a high dune, owing to the special water-supply from this latter being added to the subterranean water of the plain.

Sand-plains within the dune-complex may remain for many years undisturbed, as evidenced by the age of their vegetation and the presence of a humus-layer, and in places they become occupied by good pasture plants. But sooner or later there may be a sand-invasion, and a new dune-complex or dune-chain occupy their site.

(iii.) Dune-wandering.

The wind blowing up the long windward slope of a dune carries with it the rolling and hopping sand to the summit, which, as before noted, falls down the leeward slope, leading to its gradual advance. Where the incoming sand-supply is small, as is that of a dune-chain on the leeward side of a grass-covered or "rush"-covered sand-plain, then there is a comparatively rapid advance, the wind carrying the sand of the windward to the leeward slope whenever it blows, and bringing no fresh material to supply the constant waste. Generally speaking, there is a gradual but usually very slow advance of the unstable dunes, the sand-plains being buried at their seaward and extended at the landward boundaries. The movement landwards is much checked where there are powerful antagonistic land winds, and it is not unusual to see a dune advancing in two directions. Great quantities of sand may blow back into the sea, as I observed on the shore between the Rivers Manawatu and Rangitikei, where all day a constant cloud of sand looking like smoke blew along the shore into the water.

The rate of movement is governed by a number of factors. The shape and height of the dune is of great importance, a high dune, other things being equal, moving more slowly than a lower one. Climate in general, specific gravity of the sand, size and shape of sand-grains, velocity of wind, plant covering of the dunes, disturbance by grazing animals—all these affect the rate of movement. Where the dune is absolutely bare sand the question is less complex; but here the height of the hill, and whether its advance is checked by trees or shrubs, much affect the case. A stream, again, may stop a dune altogether (see Photo No. 19). So far as New Zealand is concerned, there are few statistics as to dune-advance. On the dunes of east Canterbury I have measured a lee slope, 10 ft. high, which moved horizontally 2 ft. in ten hours with a very powerful east wind; but such rapidity of movement would only take place a dozen times or so in a year. Mr. Hoe, of Woodhill, in the Kaipara district, Auckland, was able to furnish me with some accurate particulars regarding the dunes of his locality, based on measurements made during certain surveys. Thus, one wandering dune, the position of which was fixed in 1866, had advanced 132 yards by the end of 1910—*i.e.*, an advance of 3 yards a year.

Speaking generally, my investigations show that in certain seasons the dune-movements are greater than in others, and that where a plant covering is present they are usually very slow—perhaps a foot or two yearly. Foreign statistics give very variable results. They concern chiefly the wandering dune, which, according to them, may move in some places only a few feet and in others many yards yearly.

Dune-wandering is especially dangerous, since it is slow and insidious; but in its very slowness lies the security to those who *recognize the danger*, since it gives abundance of time for permanent reclamation-work. So slow is it, indeed, in certain cases that a semi-sand-binder (see botanical section) such as *Arundo conspicua* (toetoe) can gain a footing and establish itself on a dune-fall. Its presence, however, does not indicate that the dune is stationary, as many suppose, but rather that the upward growth of the grass is equivalent to the sand-supply.

(iv.) Sand-drifting.

By sand-drifting, as opposed to dune-wandering, I mean the blowing of a flat layer of sand along the ground-surface. It is sand-drifting which leads to dune-building, dune-wandering being a secondary phenomenon.

During gales extensive drifts take place, the sand coming from naked dunes, and also from hollows where the wind has full power (see Photo No. 20). These drifts are particularly dreaded by owners of sand-areas, since when merely an inch or two in thickness they quite destroy any grassy sward on which they fall. The drift also, when once it has commenced, continues to advance with even moderate winds, the distance reached being determined by the sand-supply. Contrary to the advance of a wandering dune, the sand drift is extremely rapid, acres at a time being covered with a layer of sand, thus killing all the grass during one heavy gale. Sand-drifts, though the worst-dreaded form of invasion, are of considerably less moment in the long-run than dune-wandering, and can be much more easily stopped. *It is the stopping of these which is nearly always shown us an example of how to control dunes in general—a quite misleading object-lesson.*

(g.) Land-forms of the Dune-area.

(i.) Dunes.

(α.) *Dune-ridges.*

The foredune is a typical example of a dune-ridge, and has already been described. Partly sheltered by the foredune, lie the interior dune-ridges. These are most irregular in form, and much cut into and denuded by the wind. They are the *Kupsten* of the German writers, a word derived from the Lithuanian "kùpstas," meaning a small hill. These chains of hills resemble miniature mountain-ranges with their prominent or rugged peaks, rounded tops, saddles, deep or shallow gullies, and at times quite precipitous faces. Frequently the parallel chains have lateral connections. Near the coast they are generally but semi-stable, the plant covering usually only occupying half their surface, and in many places they are so bare as to be a transition to the wandering dunes. Ridges absolutely fixed by nature are to be found at the inland termination of a dune-area, where they are frequently a considerable distance from the shore, or crowning old consolidated dunes, though in this case it is the rock beneath rather than the sand above which forms the ridge or chain of hills. They are generally much more rounded and offer less play for the wind than the ridges just described. Possibly in many instances they are of considerable age, dating back to a time when the land was lower, the sea coming farther inland.

(β.) *Isolated Hills.*

Sandhills not forming chains may be either portions of such separated by wind-action, or they may have originated directly on a sand-plain, or elsewhere, after the primary hills were destroyed or had wandered on. Sand-binding plants are chiefly responsible for the origin of these secondary hills. Sometimes they are formed upon a decaying dune itself, which in this manner may be rejuvenated. The curious isolated hills called "barchans" are noted further on.

(γ.) *Mounds* (see Photo No. 69).

The pouring of sand into a sand-plain by means of a rapid drift sometimes leads to a remarkable hummocky surface, made up of numerous low mounds built through the rapid growth of silvery sand-grass (*Spinifex hirsutus*). Isolated mounds, generally formed by *Scirpus frondosus*, are common on sand-plains and also on a wide sea-shore (see Photo No. 21), where in both positions they may eventually build isolated hills or dune-chains. Mounds of a more temporary character are formed by the aid of the sand-coprosma (*Coprosma acerosa*) and other shrubs (see Photo No. 22).

(δ.) *Wandering Dunes.*

The wandering dunes are the greatest feature of the dune landscape, and the land-form to be most dreaded. It is they which in populous lands have devastated the adjacent country, burying villages, and even churches, as in Norfolk, Cornwall, Aberdeenshire, Gascony, and elsewhere.

Wandering dunes are broad, high masses of sand extending over many acres, so gently sloping on the windward side as to be apparently flat in places, where they are quite firm to the tread. On the leeward they are very abrupt; so much so, where absolutely sheltered from the wind, as to merit the title of "sandfall," the extremely loose sand moving with the slightest touch, or, when wind moves the surface of the dune, forming long trickles which fall to and accumulate as talus on the ground. The quite smooth surface, destitute of all plant-life, stretching for hundreds of yards, and more or less of a glistening whiteness, forms a striking spectacle. The surface is here and there traversed by wind-troughs, or secondary dunes may be built upon the surface, but over wide areas there may be a quite even surface, broken only by long lines of sand-ripples. At the angle formed by the ascending slope and descending sandfall is often a sharp ridge, the result of the eddy (see Photo No. 14). In other cases the angle may be rounded, a sign of contrary winds.

Wandering dunes have a twofold origin. On the primeval dune-area they arose from the coalescence of a number of dune-ridges (see Photo No. 8). It can be seen that this is an easy matter; the unequal rate of advance of contiguous dune-ridges will bring it about, for one thing, the lowest portions moving the fastest and leading to a crescent-like form, the horns advancing in the same direction as the wind. Then, too, winds from different directions causing irregularity of the direction of the movement play their part. A rapid undermining of plants on the windward side of a dune also (Photo No. 23) causes an accumulation of loose sand, thus giving material for burial of plants and filling up of hollows. According to Jentzsch (18, p. 81), it takes 100 dune-chains, each 6 metres high, to build a wandering dune 60 metres in height. With the general flattening and increase of sand-surface there is less shelter than in the area of sand-ridges and isolated dunes: the wind catches the surface fairly, increasing in intensity as it ascends, and the natural establishment of even sand-binding plants becomes impossible, while those present are rapidly exterminated. *It is therefore useless to attempt artificial planting on many wandering dunes without shelter of the proper kind.*

Between the true wandering dune and the dune-complex are all kinds of transitions, many of the dunes of the latter, although quite small, being altogether unstable, and both wandering and drifting. A dry season, burning the vegetation, the presence of cattle—these, singly or combined, may easily convert an unstable dune-complex into a wandering dune. So, too, does a breach in the foredune by the sea lead to destruction of the dune-complex, whose members become undermined by the wind, and the increased sand-supply helps to bring about a flatter condition, hollows being filled, and extensive sand-drifts resulting.

Frequently the wandering dune is quite unconnected with the dune-complex and with the perennial sand-supply of the shore; in which case, as no fresh sand is arriving, and as waste is ever present, either

from superficial drifts, from the sand borne away high in the air, or from that kept firm by wet ground, the dune must finally by degrees lose its power, come to rest, and be occupied by vegetation. But before this can happen it buries all before it as it advances—meadow-lands, swamps, crops, and even dwellings, if such should lie in its path—leaving behind a desolate sand-plain or an exposed rock-surface, the buried trees, &c., being again uncovered as it continues to advance.

So far as New Zealand is concerned, the wandering dunes as now met with inland are not an evolutionary product of dune-change, destined when finally fixed by nature and covered by scrub or forest to be the climax of dune-development; on the contrary, they are a *reversion* from perfectly fixed sandhills, held in position not only by shrubs or grass but by loam, to the original wandering state. Their origin is traced further on, under another head. Here it need only be pointed out that they are indistinguishable from the primary wandering dune, except insomuch as they are frequently continuous with loam-fixed grassy hills. Also, as they are often quite unsheltered by contiguous chains of sandhills, being cut off from the general dune-mass by wide flats covered with manuka or grass, the wind can attack them with full force, and their power for mischief is consequently great.

The most remarkable wandering dune in New Zealand, and one of the wonderful natural objects of the Dominion, is that which at the mouth of the Waikato River extends from the shore to the Maioro Stream, a distance of about three miles, and occupies an area of nearly 3,420 acres. In its highest part it can hardly be lower than 250 ft., but this is due to the sand overlying rock. The view from the summit is that of an undulating tableland of bare sand as far as the eye can reach, with long low ridges and rounded advancing parasitic hills which have crescentric dune-falls. All is brown in colour, save where long stripes of black mark the innumerable ripples. In some places there are long rows of huge secondary ripples—low ridges, in fact, giving the sand the appearance of a furrowed field. There are no plants of any kind. A few flies creep along the surface, and rise in the air for a short distance when disturbed: these are the only signs of life on this desolate spot. As the actual shore is approached there are sand hollows and gullies which contain a scanty vegetation. The sand finally pours into the Waikato and the neighbouring swamp.

Very frequently in New Zealand the wandering dune advances in more than one direction, since it will be fully exposed to all the common winds.

It is the fixing of wandering dunes which is the most difficult problem in dune-reclamation, and, as they vary much in character, various cases will obviously require different treatment.

(c.) *Cliff-dunes.*

(a.) *The Under Cliff-dune.*—Wherever there is a wall-like obstacle, such as a cliff, a dune will be built some distance in front by the eddying wind, as described in section (*c*). Dunes similar in origin are formed in front of high sandhills, or even on dunes themselves. For ridges of this character I propose the name of "under cliff-dune." An excellent example of such a dune on the Taranaki coast is shown in Photo No. 24. Another well-known case occurs at Sumner, Canterbury, at some considerable distance from the actual shore.

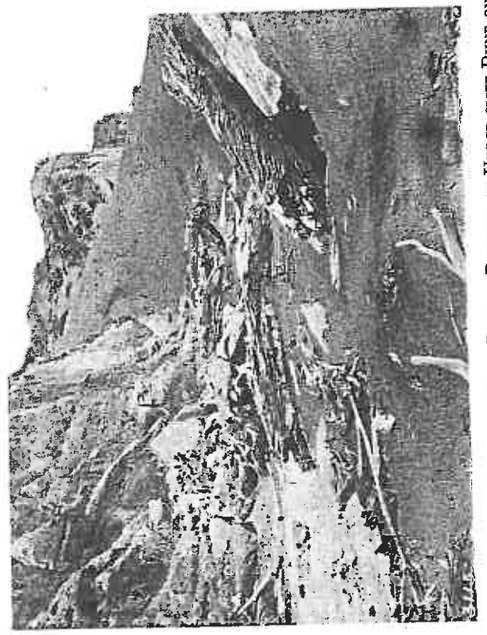
(b.) *The Upper Cliff-dune.*—Dunes are very common on the summit of cliffs at many parts of the New Zealand coast. The origin of such may be twofold. Where the cliff-face abuts on a sandy shore the whirlwind caused by the stroke of the wind raises the sand high in the air, depositing it upon the ledges of rock, and finally on the summit of the cliff, where a line of dunes will be formed. These are the upper cliff-dunes. According to Jentzsch (18, p. 74) sand-grains can be raised 30 metres (118 ft.) into the air by the strong winds of an open coast. Cornish (7, p. 301) thus describes the phenomenon: "A cliff facing the wind deflects the current of air, which rises in a billow above the edge of the cliff. Below the billow is an eddy, which assists in bringing down the sand borne by the wind. Thus a cliff may be capped with blown sand which deposits in a position apparently exposed, but in reality well sheltered." It seems to me very probable that many upper cliff-dunes in New Zealand had their origin at a time when the land was lower and the sand travelled from the shore in the usual manner. Personally I have had no opportunity of witnessing the effect of a high wind on the foreshore at the base of cliffs. Where there are gullies in the cliff, even though very steep, the sand ascends by their aid to the summit (see Photo No. 24), and such a drift may be considered a combination of upper and under cliff-dunes. Reef Point, north-west Auckland, 700 ft. in height, is an excellent example of sand from the shore covering a rocky promontory. There the southern side is almost completely covered by wandering dunes and drifts, which pass over almost the highest point and are descending on the northern side towards Ahipara, burying the forest in their descent. Watercourses have been dammed up, deep gullies filled with sand, rocks fantastically cut, and the face of nature completely changed (see Photos Nos. 64 and 31).

(ii.) Sandspits.

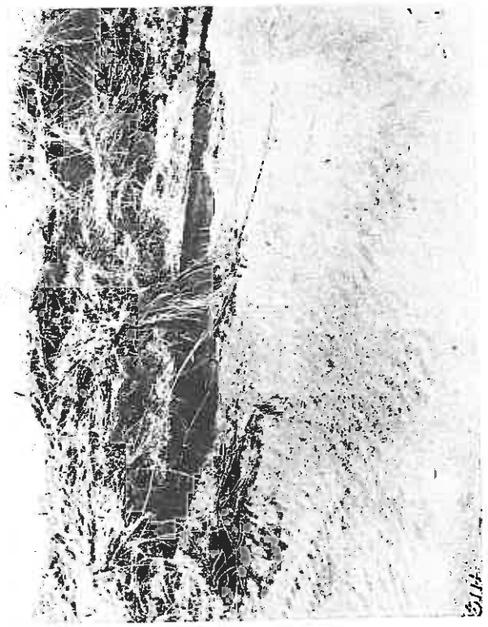
Sandspits are of great economic importance, insomuch as they may enclose harbours, and, when crowned by fixed dunes, prevent the drifting sand from filling up these waterways. Their origin has already been sufficiently described. In the case of a tidal river its course may be much diverted, a growing spit forcing the river to run parallel with the coast for a considerable distance, as in the case of several of the rivers of western Wellington.

(iii.) Sand-plains.

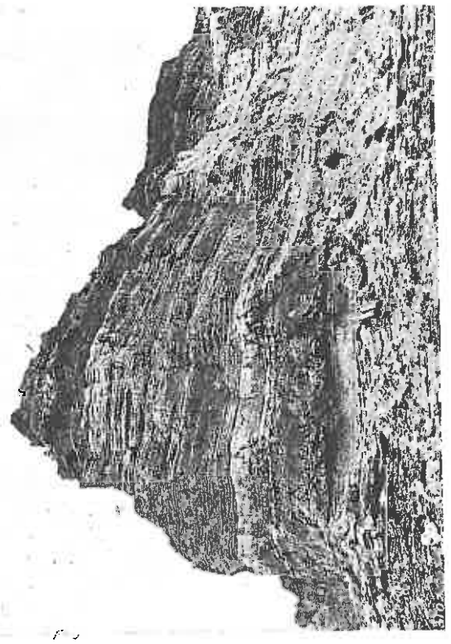
The origin of these has been already explained, and further details are given in the botanical section. They are the most important part of the dune-areas from the farming standpoint, and their treatment is gone into at considerable length in Part II.



No. 24. Base of Coastal Cliff, Patea. Portion of Under-cliff Dune on Right, and Ascent of Sand by Gully to Summit of Cliff. [*Photo L. Cockayne.*

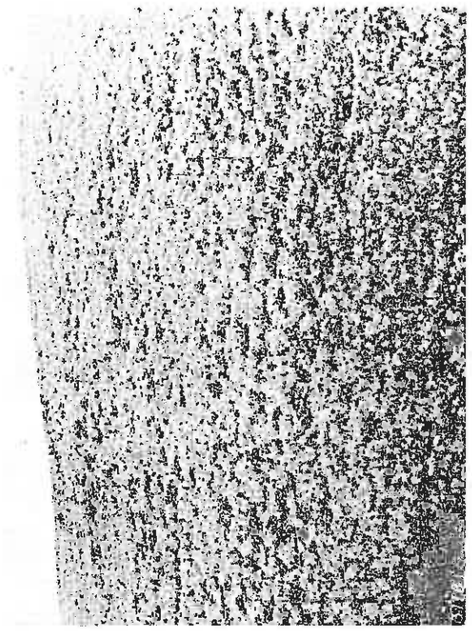


No. 23. A Planting of Marram-grass which had succeeded well being now undermined on its Windward Side. [*Photo L. Cockayne.*

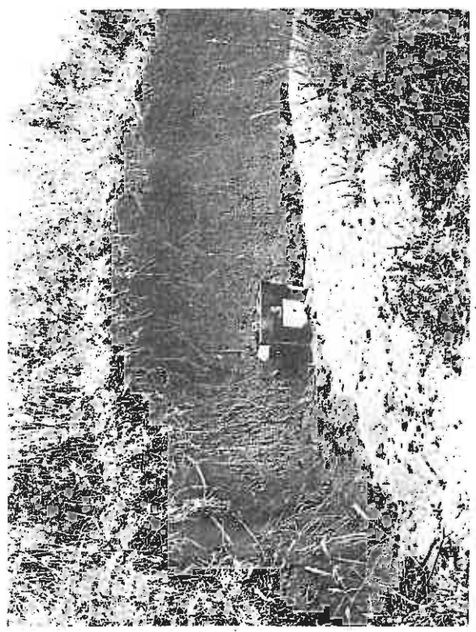


No. 25. Coastal Cliff North of Wanganui, near the Ototoka Stream. [*Photo L. Cockayne.*

To face page 16.]



No. 27. Crop of Rape on Ancient Fixed Dune. Dunes of Western Wellington. [*Photo L. Cockayne.*



No. 26. First Stage in History of a Wandering Dune: Hole made by Sheep. 5 by 4 Camera-case for Scale. [*Photo L. Cockayne.*

No. 28. Lee-face of a "Barchan." Dunes of Alexandra, Central Otago. [*Photo L. Cockayne.*

(iv.) Quicksands.

Where a stream passes over a sand-plain, or where the wind has cut almost to the water-table, there may be a superabundance of water and the wet mass be so fluid as to be no longer a solid, but governed by the laws of hydrostatics Generally, there is too little water for the formation of quicksands, but the water-content may be much increased by the flow from the body of a wandering dune. Quicksands are not at all common in the dune-areas. The worst occur on the Aupouri Peninsula, Auckland. So far as human beings on foot are concerned quicksands are of little moment, but when on horseback, or for horses themselves, they are dangerous enough.

(v.) Swamps.

Swamps are formed either by a shallow lake becoming occupied by vegetation, or through the natural drainage being blocked or checked by the sand-movement. In some places there are hundreds of acres of swamp right in the centre of a dune-area, but generally it is nearer the landward than the sea boundary.

(vi.) Lakes and Ponds.

Dune-lakes originate in exactly the same manner as swamps, being really an earlier stage of the latter's development Both lakes and swamps assist in checking the sand-advance for a time, but finally the surface becomes dry, the sand drifts over the site of the swamp, and no trace of it remains visible.

(*h.*) THE VIRGIN DUNES.

At the present time it is not altogether easy to present a picture of the virgin dunes of New Zealand. Excepting on the sand-grass dunes themselves, and perhaps some of the semi-stable shrub dunes, there are few places where man, his fires, and his grazing animals have not wrought great changes. These changes have been twofold: they have brought about a state of very much greater instability, and they have altered the composition of many of the plant associations. This latter is most marked in the plant covering of the stable dunes, whether that be heath or grass.

The opinion expressed by many that the present instability of the dunes and their wandering is entirely the work of man, due to using the dunes as grazing-land, is certainly incorrect. Even before the white man arrived, the Maoris lived much among the dunes, as remains of dwellings, heaps of shells, stones, and ancient burial-places testify. Their presence would conduce to considerable dune-movement.

But, apart altogether from man, the dunes could never have reached their present breadth had not their wandering been of long duration. The presence also of the endemic sand-binding plant *Scirpus frondosus* is significant, since its well-being depends upon the coming of drifting sand, and its endemism proves that such a drift has been taking place for a long period.

The distance a dune-area can penetrate inland depends upon the general topography of the coast-line, the extent of the sand-supply, and the counteracting effect of land winds. At any rate, a point is finally reached where the velocity and erosive power of the wind so much decrease that non-dune plants can get a foothold, increase in number, and finally absolutely fix the dune, giving it by their decay, in course of time, a coating of loam. Thus the virgin dune-areas were well fixed and beyond the power of the wind to disturb, while the general plant covering of the dunes as a whole would prevent drifting sand to a much greater degree than is at present the case.

(*i.*) EFFECT OF MAN, ETC., ON THE DUNES.

Apart altogether from the natural struggle between sand, wind, and plants, which resulted not only in a steady movement of sand inland, but also in its ultimate fixation, man, by the aid of animals, fires, and cultivation, on the one hand, has brought about most powerful dune-movements; but, on the other hand, he has to some extent counteracted these by the planting of various sand-fixing plants.

The early settlers, tempted by the numerous extensive well-grassed sand-plains, made use of them as grazing-grounds. Also, in order to make room for better growths, they burned the "rushes" and shrubs which appeared to be occupying good ground. Moreover, the cattle and sheep did not confine their attention to the flats, but, as food got scarce, wandered over the dunes, breaking the surface, and pulling up some of the sand-binding plants. The result was soon manifest. The unstable hills were turned into wandering dunes, the fertile flats were buried with sand, and desert conditions grew apace. Introduced plants also made their appearance, but economically were generally of a worthless kind.

With the stable dunes it was worse. These were clad with various indigenous grasses, shrubs, and bracken-fern, and beneath a layer of loamy sand. Burning the shrubs, &c., helped to lay bare the sandy surface and to destroy the accumulation of humus, its most important possession. Later on, overstocking played its part, and, notwithstanding their quite stable character, the fixed dunes gradually began to revert to the active conditions (see Photo No. 12).

It is quite astonishing how little will set even the most stable dune in motion. A sheep rubbing its back, irritated with ticks, against the surface soon lays bare a patch of sand, which, attacked by the wind, may rapidly develop into intense activity. Such a hole as that shown in the photograph (Photo No. 26) would, if not checked, set in time the whole hillside in motion. Rabbits also work considerable harm. It is worst of all when the damage commences in a gully, where, as shown before, the wind has special erosive power. Such gully wounds are most difficult to heal (see Photo No. 15), and on that account are neglected after one or two failures, and so the contiguous slopes are undermined,

and in no very long time a revivified wandering dune, itself originally good ground capable of growing rape or oats, as the photograph shows (Photo No. 35), is invading and burying land of much greater value. At the present time *the neglect of wounds in the turf by the farmer is perhaps the greatest source of danger to the adjacent fertile lands*. These wounds seem trivial, but they are capable of the most profound mischief, and their neglect must already have cost the Dominion thousands of pounds.

New Zealand is not alone in having once more set in motion the dunes fixed and made not only harmless but valuable by nature. The moving dunes of Cape Cod, in North America, had originally three-fourths of their area covered with trees, the destruction of which, through fire and the pasturing of stock on the sand-area, led to a state of affairs endangering a most important harbour, and "the problem of controlling the drifting sands has concerned the municipal, State, and national authorities for two hundred years" (Westgate, 65, p. 10).

The wandering dunes of the Kurische Nehrung, too, were forest-clad, and the felling of this forest for timber has cost Germany vast sums of money, and a considerable annual outlay is still expended in refixing the dunes so well fixed by nature.

In Holland, according to a most interesting communication from the British Vice-Consul at Flushing, the dunes have been rendered unstable in some places through potato-growing on the sand-plains, the ground having been finally abandoned and left to the mercy of the wind. The Dutch dunes are also used as a drink-water reservoir for the many adjacent towns and villages. "Long canals traverse the inner dunes, and the water is pumped from them into large basins and afterwards to the drink-water towers in the towns. All the towns near the coast get their water from the dunes (Amsterdam, Haarlem, Leyden, The Hague, Delft, Middelburg, Flushing, &c.), and the result of this water-withdrawal is sinking of the water-table in the dune-area."*

(*j*.) INLAND DUNES.

(i.) The Volcanic Plateau.

Drifting sand made of pumice, scoria, and ash is quite a common feature of the flat, bare parts of the volcanic plateau (see Cockayne, 89, Photo No. 24). Except where the coach-road crosses the Rangipo desert the drifts do no harm. The dunes are low, often isolated, and frequently held firmly by vegetation. Sometimes wide breadths of the flat surface may be slowly advancing and burying an older surface.

(ii.) The Canterbury Plain.

Small isolated dunes or dune-chains appear in some of the wide river-beds or at some distance away on an older river-bed on the plain itself. They are generally quite fixed by vegetation, and are of no moment as agents of damage.

(iii.) Central Otago (see Photos Nos. 46 and 63).

The dune-area of Central Otago lies in the upper valley of the Clutha, chiefly in the neighbourhood of Alexandra, Clyde, Cromwell, and Tarras. The source of the sand is the Clutha itself, where the terrace against which the streams abut, or did abut, has been cut into either by the river itself, water-channels from above, or drifting sand. The great flood of 1878 is said to be responsible for the main drifts, though doubtless, as Park points out (129, p. 35), "the terrace on which Cromwell is built contains a large amount of drift-sand mixed with the gravels, and a constant supply of this sand, derived from the terrace-faces between Lowburn and Deadman's Point, is carried by the wind across Cromwell flat." The supply at Alexandra is, I believe, considerably augmented by the dredging operations in the Clutha. The commencement of what may become a formidable drift, if not stopped soon, may be seen on the bank of the River Kawarau, near Bannockburn, the sand blowing across the river from the Cromwell flat having cut into the terrace. Sand and gravel drifting from the above wound cuts deep into the soil of the flat above, which in its turn is broken up, its particles being driven along the ground. The finer sand and dust is also raised high into the air, and is finally deposited upon the Carrick Range.

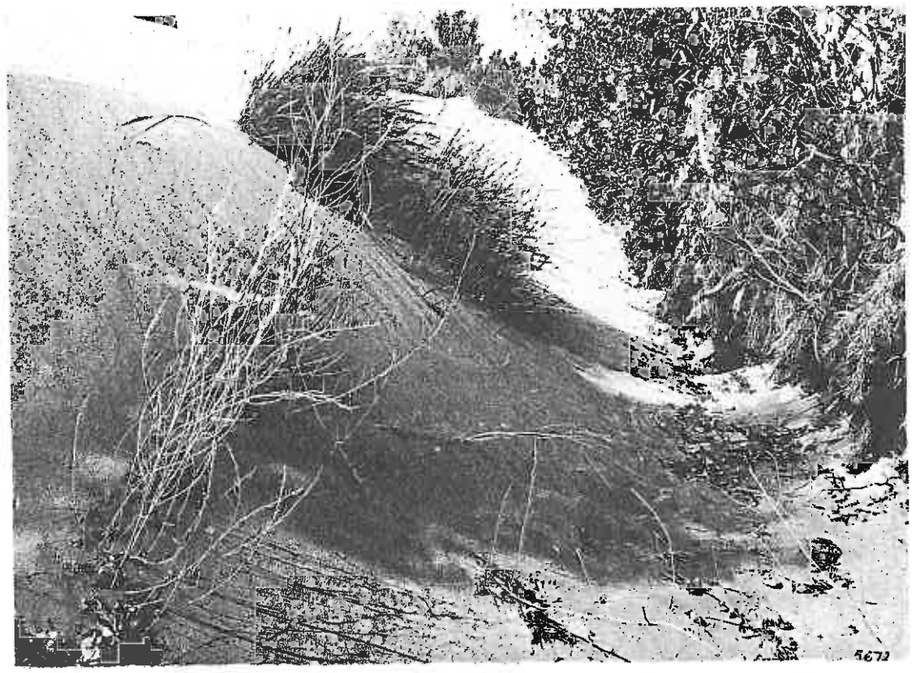
As for the areas themselves, the dunes at Alexandra are the most active. They are of true barchan form—*i.e.*, they are low, with a crescentic dune-fall terminating in two horns, while the body of the dune is convex (see Beadnell, 1A, p. 386). Isolated barchans are present (see Photo No. 31), but generally they are joined together, and their true nature is more or less hidden. The advance of the isolated dunes is in the same direction as the wind, while the united hills are at right angles to the wind.

At Cromwell the principal dunes are the result of high catching-fences, which they have either buried or are in process of burying (see Photo. No. 29). As well, there are many low dunes, sand-ridges, and deep or shallow layers of sand on many parts of the plain, there being a special advance towards the River Kawarau between Cromwell and the Bannockburn Bridge.

At Tarras there are few dunes, but, instead, a very powerful drift along the ground.

Here the sand, much of it extremely coarse, came in the first instance from the broken river-terrace, over the summit of which it was at times driven with such strong velocity that in its progress it cut into the surface soil, exposing by degrees the stones, gravel, and sand of the old river-bed. Thus an ever-increasing source of sand was added until, at the present time, the flat above the river, and not the face of the terrace itself, is almost the sole supply of sand. But this supply is decreasing, since owing to the laying-bare of the large stones and the depth of the sand beneath the surface, the upper layer having been removed, the power of the wind to raise the sand has much decreased. It is drifting sand rather than true dunes which distinguish the sands of the Clutha valley. When the powerful westerly winds blow with their full might the drifting is excessive. Not only sand, but gravel and

* [illegible] Department from the British Vice-Consul at Flushing.



No 29. Catching-fence in process of being buried. Dunes, Cromwell. Fence originally 15 ft. tall.
[*Photo L. Cockayne.*

No. 30. Grazing-land turning by Drifting Sand into River-bed. Ancient Flood-plain of River Clutha. Tarras Drift.
[*Photo L. Cockayne.*

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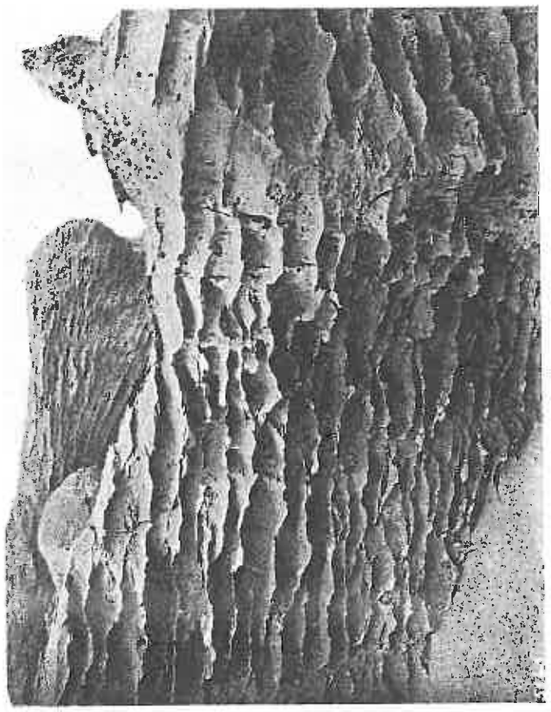
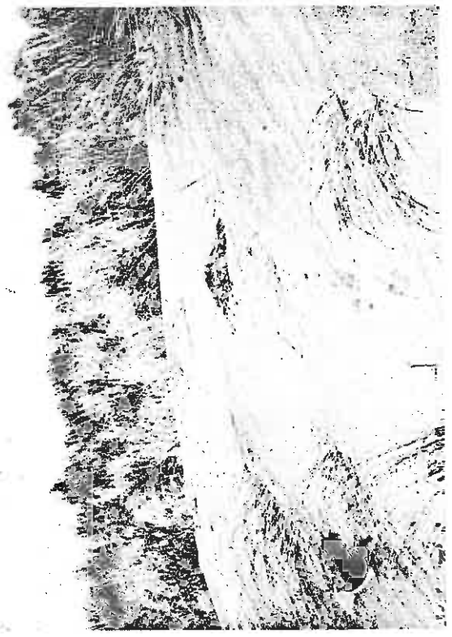


No. 31. Rock cut by Wind-borne Sand. Reef Point, North-west Auckland. [*Photo L. Cockayne.*

No. 33. Fixed Dune, which had become Active through Damage by Sheep, getting naturally reclothed by Plants. [*Photo L. Cockayne.*



No. 32. A Close Growth of Marram-grass in process of Destruction by a very active Sand-drift. [*Photo L. Cockayne.*

even small stones are swept along the ground or borne in the air, while the fine sand is carried for miles, darkening the sky, and finally deposited here and there on the distant hills. Thus it may be seen that unless there is a constant supply of sand the drifts will finally cease to be. This is the case with the earliest sand-sweep at Tarras; its site is well marked, but its activity and power for destruction is gone. And this seems to be happening at the other localities. In many places, where the ground is not swept bare, coarse sand and gravel alone are present. The ground itself is cut into deep furrows, while at Tarras both the present and extinct sand-sweeps are marked by their area having almost entirely reverted to river-bed (see Photo No. 30), the vegetation first, and then the surface soil, being altogether swept away. It is most interesting, geologically, to see how in so short a time the face of the landscape can be changed by a cause—a flood in a river far below, which might well be thought to have no possible relationship with the ancient flood-plain high above that it had laid down and abandoned many thousands of years before. The three areas—Alexandra, Cromwell, and Tarras—show three stages in the progress of the work: Alexandra, with its barchans and dune-masses, being the youngest; Tarras, the oldest, with its dunes almost gone, except in the sheltered lee of certain terraces, and its active sand and gravel sweep; and the one now extinct, its surface rejuvenated river-bed.

II. BOTANY.

(A.) ECOLOGICAL BOTANY.

(*a.*) GENERAL REMARKS.

The study of the dune-vegetation is of the greatest moment with regard to the economic treatment of sandhills. Not only does it show what plant forms* and structures are most fitted for growing on the moving substratum, but the investigation of the evolution of a fixed dune—*i.e.*, an inquiry into the dynamics of the plant covering—shows exactly how nature acts regarding dune-fixation, and the methods she has applied with more or less success.

The dune-flora proper consists partly of plants specially attuned to sandhill conditions, and partly of those found, and sometimes abundantly, in other formations, but whose "adaptations" fit in with such conditions—*i.e.*, tolerate the peculiarities of the environment. This toleration is exhibited by different species to a much varying degree, and so, as the dune conditions relax, does a greater number of plants enter in. This fact must not be lost sight of, since otherwise quite a wrong conception may be gathered as to the capabilities of dunes as a whole for reclamation, for false and dangerous generalizations may easily be made from a study of some particular sand-area. Near Paekakariki, for example, the tree-lupin grows well right up to the foreshore, whereas in many places in the same position it would be overwhelmed, and a moving dune be the result.

The flora of the unstable and semi-stable dunes is remarkably uniform throughout New Zealand, its physiognomy being much the same from the north of Auckland to Stewart Island and the Chathams, notwithstanding considerable differences in climate between the extreme points. In other words, the climatic factor is of less moment than the soil factor. At the same time, some species occur only in certain localities, and, although there is a common groundwork, additions or the contrary take place in passing from one extreme to the other. The dunes of the Auckland Islands have a special flora of their own, and that of the ancient dunes of Stewart Island is also quite distinct from that of a typical fixed dune (see Cockayne, 86).

(*b.*) CONDITIONS FOR PLANT-LIFE.

(i.) General.

The conditions governing the plant-life of a dune-area are extremely severe, and bring about a state of affairs very similar to that of a desert. But between this latter and the dune there is the important economic difference that the one can be made fertile only by irrigation, whereas the other has a sufficient rainfall, and *the sand-drifting propensity has alone to be dealt with.* Also, it must be remembered that the dune region offers very dissimilar plant stations, with its wandering dunes, naturally fixed dunes, and sand-plains, a fact hitherto altogether overlooked by New Zealand writers on dune-reclamation.

(ii.) Climatic Factors.

(*a.*) *Wind.*

Wind is by far the most important of the climatic factors. According to the position of the seashore with regard to the prevailing wind, so is the average intensity very different. For instance, the oblique south-west wind at Ocean Beach, Dunedin, is much less to be dreaded than the direct but less intense east wind of New Brighton, Canterbury.

The effect of a sea wind is frequently counterbalanced in part by a land wind, as in the case of the north-west, south-west, and east winds of the Canterbury coast, or the south-west and north-west of western Wellington—a matter, if not directly connected with plant-form, affecting the distribution of the species and the associations. An occasional excessive velocity will cause a sudden drift, but such is generally of less moment than is a much lighter but continuous sea wind, while a very high wind may remove the dry upper layer, exposing the moist sand beneath, when all movement will cease.

* It is surprising what absurd plants have been suggested in certain cases owing to want of knowledge of the life-forms of true dune-plants and of their physiological requirements.

The wind factor acts as follows :—

(1.) It moves the sand, laying bare the roots of plants, and causing damage or destruction.

(2.) It causes sand-drifts or a dune to advance, thus overwhelming whole plant associations.

(3.) It makes the surface so unstable that none, or only a few species specially endowed, can gain a footing.

(4.) Sand carried by wind strikes on the plants, cutting, bruising, or otherwise damaging their tender parts. How damaging such sand-laden wind can be is amply shown by its eroding and cutting action on rock (as shown in Photo No. 31, taken high up on the dunes of Reef Point, north-west Auckland). The size of the wind-borne grains of sand is a matter of great importance, large grains being much more destructive than small ones. At Tarras, in Central Otago, an oat-crop facing the drift is frequently cut for many feet as if with a stripper.

(5.) Plants not actually broken are bent in a direction contrary to the wind, and their foliage is "wind-shorn," but this is no more marked than on non-sandy coasts or in exposed alpine localities.

(6.) The soil is cooled (this frequently beneficial), and rapid evaporation takes place from the ground.

(7.) Transpiration is much accelerated, thus leading to desiccation (Warming, 63, p. 38), and strong xerophytic structure is thereby demanded, or plants may be wholly or in part killed.

(8.) Various plants depend for their pollination on the wind; also seeds are carried in the air or blown with the sand-grains along the ground. This may lead to the irregular planting of tussocks, &c., and so indirectly to dune-movement.

The wind-shearing mentioned above is in part due to the mechanical action of the wind, and in part to the physiological conditions induced by excessive transpiration.

The salt gales of the coast of part of Wellington and Taranaki, which occur every few years, make their effect felt at more than twelve miles inland by damaging deciduous trees, *Eucalypti*, and some conifers, while other species, especially Norfolk Island pine (*Araucaria excelsa*) and African boxthorn (*Lycium afrum*) are undamaged. How far the salt carried by the wind has a physiological effect I do not know, but the chief damage is probably due to the quite abnormal transpiration from the leaves during such gales.

The average number of days per year during which strong gales occur on all parts of the coast are comparatively few; were it not so, many of the species of the exposed dunes, where the rainfall is not excessive, could not exist. In the south of the South Island, and especially in Stewart Island and Auckland Island, strong gales are much more numerous than elsewhere, but their effect is, to a greater or less degree, modified by the excessive number of rainy days.

(β.) *Heat (partly considered in Conjunction with the Soil).*

The climate of the whole sand-area is distinguished by the absence of extremes of heat and cold. Certainly there is a gradual decrease of temperature in passing from north to south, but even in the Auckland Islands the difference between winter and summer is comparatively insignificant. Auckland and Dunedin, the latter being 630 miles south of the former, have, according to Marshall (119, p. 229), a difference of 8·7° Fahr. in their average mean temperature. The average temperature of the hottest month (December) in Auckland is 65·5°, and of the coldest (July) 51°; and in Dunedin the hottest (February) is 57·2°, and the coldest (August) 40·5°. More than a few degrees of frost are quite rare on all parts of the coast, excepting that of Canterbury, where, owing to the cold air sinking from the Southern Alps, the temperature may occasionally drop to 15° Fahr. Were it not, indeed, that the summer climate is remarkably low, if the latitude be considered, a considerable portion of the coast-line would be truly subtropical. As it is, one can hardly apply that term to any part, unless it be to the coast north of Hokianga and to the Kermadec Islands. But the lack of frost in the north and the equable climate certainly permit a considerable selection of what may be called subtropical trees for purposes of afforestation.

Notwithstanding what is said above, sudden changes of temperature are not uncommon in some parts. This is especially the case in Canterbury, where the well-known hot wind coming from the north-west is suddenly succeeded by a cold and violent wind from the south-west, perhaps accompanied by rain. In such a case the temperature may drop in a very short time some 30°.

Sand has a low specific heat. The upper dry layer becomes excessively hot under a cloudless sky. At Levin, on the surface of the foredune, on the 4th February, at 11.30 a.m., an ordinary mercury thermometer registered 120° Fahr. to 127° Fahr.; and on the black ironsand of the Nukumaru dune-complex, on the 16th December, at 11 a.m., the heat at a depth of 3 in. was 92° Fahr., while the air-temperature was 66° Fahr. The daily variation must also be considerable, since the rapidly heated surface layer will cool very quickly when the sun goes down.

The colour of the sand is a matter of ecological importance; the black sand of Taranaki, the yellow sand of eastern Canterbury, and the dazzling white sand of north-east Auckland differ considerably in their powers of absorption and of radiation.

The wet sand absorbs heat much more slowly, and as at a depth of a few inches below the surface the sand is always moist, the plant-roots descend into cool soil very quickly. This is a most important matter, since it renders possible the cultivation in pure sand of quite short-rooted plants.

The heat is rendered still more powerful by the strong reflection from the sand, so vegetative parts high above its surface are, during sunshine, exposed to a much greater heat and also more powerful illumination than are denizens of a meadow with the same air-temperature. This has an effect on increasing transpiration, and also on ripening fruits and accelerating flowering.

The general dryness, in conjunction with heat and intense light, leads to rapid oxidation of all dead organic matter, and prevents the formation of humus. The common belief that all dune-plants are "making soil" is to some extent unwarranted.

(γ.) *Light.*

No data are available as to the intensity of the illumination. On the frequent cloudless days of the north especially, and of eastern Canterbury, insolation must be powerful. The glare of the sand as one walks for hours over the bare dunes is an experience hardly to be forgotten. The yellow colour of certain dune-plants belonging to different unrelated families is doubtless correlated with excess of light, and seems to me a possible example of heredity of an acquired character. Shade conditions are virtually absent, so far as the open vegetation of the unstable and semi-stable dunes are concerned. Just as with heat, so with light, there is generally a considerable decrease in the far south of the region; and in the south and west of the South Island, as also in Stewart Island and the Chatham and Sub-antarctic Islands, cloudy skies and correspondingly dull light are frequent.

(δ.) *Moisture.*

The rainfall and number of rainy days of all the New Zealand dunes is amply sufficient to support a rich forest-vegetation, but except under certain exceptional circumstances such is absent.

Considerable differences in rainfall do not affect the dune-flora in the least. Martin's Bay, on the west coast of the South Island, with a rainfall of considerably more than 100 in. yearly, has a dune-vegetation no richer than the sandhills of eastern Canterbury, with their rainfall of some 25 in. or less. An extreme number of rainy days combined with cloudy skies, however, does bring a change, as seen in the low mixed forest on the lee side of the high dunes at Mason Bay, Stewart Island, and the dunes of Enderby Island, in the Auckland Group, where there are no true sand-binding plants; and, notwithstanding, the sand does not drift to any extent.

Quite apart from the rainfall, at a distance of only a few inches below the surface, even on the summits of dunes some hundreds of feet high, and in the driest climate, the sand is moist. This state of affairs has usually been explained as being due to capillary attraction, but that as a full explanation has experimentally been shown to be impossible. Jentzsch has shown (18, p. 103) that in all probability there is an internal formation of dew within the dune. The matter is thus explained: The air between the grains of sand at the base of the dune, in close proximity to the water-table, is saturated with moisture, and its absolute humidity corresponds with the yearly mean temperature of the layer of soil. At a depth of 60 m. (196 ft.) this temperature is only 2° C. (3·6° Fahr.) higher than the mean temperature of the air at the surface. Through diffusion of gases the air of the upper and colder sand-layers becomes saturated with water-vapour, but, since these layers are colder, their saturation-point is lower, and dew will be deposited. The slight difference between the two temperatures is hardly sufficient to account for much deposition of dew, but the diurnal and nocturnal variations of temperature are considerable, and sufficient to cause periodical condensation of water in the sand.

It seems to me possible to account for the perpetual moisture within the dune on the supposition that a sandhill from its very beginning is always wet within, that the rain from time to time sinks into the sand, wetting the upper layers as they are formed, and that drying to any considerable depths is alway hindered by the upper layer of dry sand. But this explanation, though it may suit the moist climate of New Zealand, will not explain the moisture in a desert dune.

Rain-water falling upon the sand descends to a depth proportional to its amount; none runs off the surface, and so all is absorbed. But evaporation, as soon as the rain is over, dries the surface with great rapidity, but only for a trifling depth, since the loose surface sand acts as a dry mulch, and checks evaporation from below to a most marked degree. After a period of drought a dune will be much wetter than the adjacent clay land, notwithstanding the water-capacity of the one is 90 per cent. and the other 30 per cent., or even much less. It must, however, be borne in mind by the dune-planter that by no means is *all* the water present available, and that sand at best can offer only a scanty although a perennial water-supply. The water-content of sand plains and hollows is quite different to that of the hills, since the water-table is in close proximity to the surface, so close indeed in some instances as to be antagonistic to ordinary land plants.

(iii.) The Soil Factor.

This has already been partly dealt with under some of the preceding heads. Equally with the wind is the sand a most important factor, and to the two combined do the special dune-plants owe their distinctive characters, and the associations their distribution and physiognomy.

The rate and ease of movement of the sand by the wind depends upon its coarseness, and so also does its water-content, coarse sand being drier than fine, the rate of percolation increasing with the coarseness. In any case, sand will hold less water than any other soil except gravel or scoria; consequently it cannot support, under ordinary circumstances, a continuous covering of meadow-grasses or typical herbaceous plants. Flattening the dunes, if it does not increase the water-supply, decreases surface evaporation by reducing the wind's drying-power, the sand remaining moist for a longer period. Humus is frequently altogether absent, except on the surface of the ancient fixed dunes, or in certain hollows and sand-plains. But in some places old humus soils have been buried, and such may be found at variable depths, as evidenced by layers of dark-coloured sand. Further, where the sand covering is shallow, roots may penetrate to a richer or moister soil beneath.

The chemical composition, theoretically of much moment, is actually of little account so far as regulating the occurrence of species is concerned, though a pure quartz-sand, according to Warming (63, p. 59), is sterile, one containing feldspar, mica, or lime being more nutritious. Where broken shells are present there is more plant-food, and the celebrated ironsand of Taranaki should affect the plant covering, but in point of fact it does nothing of the kind; while, so far as I have observed, the same general uniformity of vegetation occurs on all the New Zealand unstable dunes, those of the Auckland Islands and the Kermadecs excepted.

Theoretically, sand contains very little available plant-food; but from analyses of soils in general very little is to be learnt regarding their nutritive qualities. So far as the New Zealand sands are concerned, it is surprising, if only there be shelter, what a variety of plants will thrive, including massive trees, and especially if water can be supplied; but, as shown above, there may be more nutritive matter than is suspected.

Massart (41, pp. 156–165) lays great stress on the effect of the above-mentioned lack of nutritive salts in producing poverty of vegetation and stunted growth of plants of sand-hollows in the Belgian dunes, supporting his views by most careful observations and soil-analyses. His statements regarding not only reduced growth in the land plants of the hollows, but in the aquatic plants of the dune ponds are of great interest, and suggest detailed examination of New Zealand material.

In the immediate neighbourhood of the sea there will doubtless at times be a little salt on the surface, but it is now considered that the salt-content of dunes has been altogether overestimated, and that the soil has no excess of salt (see Kearney, 31, and Darbyshire, 126A, p. 297). An analysis of New Zealand sands is wanted to settle the point, so far as our dunes are concerned. At any rate, many meadow-plants, which could not tolerate excess of salt—*e.g.*, the daisy (*Bellis perennis*), white clover (*Trifolium repens*), &c.—grow on or close to the shore itself. On the other hand, the plants of dune-hollows, where the ground-water is fresh and comes to the surface, are in part those of brackish water and salt meadows—*e.g.*, *Leptocarpus simplex*, *Selliera radicans*—an interesting fact, since it demonstrates how these so-called halophytes are really not salt-demanding plants at all.

(iv.) The Topographical Factor.

As seen from the paragraph dealing with the general topography of the dunes in the geological section of this report, a considerable diversity of stations are offered for plants in the hills, mounds, sand-plains, and so on, so far as water-content, stability of surface, shelter, shade, and even soil are concerned. A dune itself offers quite different conditions on the windward and lee slopes as regards steepness, velocity of sand-motion, exposure to wind, depth of water beneath the surface, and firmness of the sand. The height of the hills and their relative position have, as already seen, a strong bearing on the erosive power of the wind. The relationship of the dune-area to the sea-shore—*i.e.*, to the sand-supply—its position with regard to the sea, its relation to the prevailing winds, and the character of the underlying soil; these matters have a strong bearing upon the nature of the plant covering, and must be especially studied when dealing with dune-reclamation.

(v.) The Plant-covering Factor.

Wherever there is a plant covering the force of the wind is more or less broken, though adjacent tussocks or shrubs which are at some distance apart may lead to a wind-channel being formed, and consequent denudation. Where the plants are not far apart, and occupy a patch of ground, even though there are bare spaces between them, the sand will not move, and within the plant zone the principal dune condition is eliminated, and xerophytes other than sand-binders can flourish. A plant covering, too, helps to conserve the moisture, and adds a little humus to the soil. This is of slight moment on the unstable dunes, but becomes of considerable importance in the hollows, and even on the hills after these become stationary. In fact, given a long enough period of repose, a soil is finally developed on which mesophytic species can settle. Generally the plants are far apart, and their presence does not hinder the settling-down of other species; and this to some extent takes place, various European weeds, not dune-plants at all, entering into the association—*e.g.*, *Bromus hordeaceus*, *Trifolium arvense*, *Hypochoeris radicata*, &c.

(vi.) The Animal Factor.

The animal factor, except as regards insects and their pollinating-power and birds as seed-carriers, was a minus quantity in primitive New Zealand. Human settlement has changed all that. The matter, however, needs no discussion here; it has been already dealt with to some extent, and receives further notice in more than one place. At the present time it is one of the most important factors in retarding dune-reclamation.

(vii.) Fire.

Fire is dealt with in Part II, and its effects for evil need no emphasizing. It too was a factor not affecting the primitive vegetation.

(c.) THE MOST CHARACTERISTIC PLANTS, THEIR GROWTH-FORMS AND ADAPTATIONS.

(i.) General.

Were it not for the instability of the dunes caused by the drifting sand, no special "adaptations" would be required by their plants other than those demanded by excessive wind, dry soil, strong insolation, &c., and which are possessed by xerophytic plants of various other formations.

The dune-plants proper—*i.e.*, those which not only tolerate but *benefit* by a partial sand-burial—are almost as highly specialized for their mode of life as lianes, which in some respect they resemble in their great length of stem. This latter enables them to spread over wide areas, and to increase rapidly by vegetative means, a great advantage under conditions so antagonistic to the welfare of seedlings. But it is the special power of the shoot-apex to grow upwards as it is buried which enables this growth-form to cope with the constant increase of sand. This peculiarity possessed by dune-plants of all regions has already been mentioned under the term "sand-binding," and is present to a

greater and lesser degree in different species, so that one may speak of *major* and *minor sand-binding plants*. This "sand-binding" form is so admirably in harmony with the conditions of life that one may well conclude it has risen by degrees in ordinary rhizomatous plants subject to a sand-burial, while the presence of the form to a most intense degree in an endemic subgenus in New Zealand, an isolated land-mass, can be better explained as an hereditary acquired character than it can by either the principles of mutation or natural selection. All sand-binding plants are perennials.

Other dune-plants only catch the sand, or at best can lengthen their shoots to some limited extent, and either are finally buried and die or the sand is blown away. These may be called *sand-collecting plants*. These latter may really seem as if adapted for the purpose, as in the case of certain low-spreading shrubs resembling thick mats or cushions made of many wiry or flexible branches; or they may simply arrest the sand, as do certain plants of the tussock-form (see, however, p. 33).

Finally, there are the plants of moist hollows, which have no special dune "adaptations"—though one (*Gunnera arenaria*) is very characteristic of the above station—but are merely species of other wet or moist stations without the dune-area.

As for the plants of the stable dunes, the heaths, swamps, and lakes, their growth-forms, &c., have evidently nothing to do with dune conditions, and so receive no treatment here. A brief mention of their growth-forms is given, however, for comparative purposes, along with the more specialized species, in the list of dune-plants, as well as for the information of those not well acquainted with the New Zealand flora. Further, it is obvious that a knowledge of the growth-forms of the indigenous plants give important suggestions as to what foreign species can be used for cultivation on the dunes.

In what follows a brief account is given of each characteristic species, there being altogether too few to allow of generalizations as to growth-forms and plant-organs. Here it need only be said that the New Zealand dune-plants—though several belong to genera unknown in most dune-areas of the world, and the leading sand-binding plant *Scirpus frondosus* belongs to *Desmoschoenus*, an endemic section of the genus—for the most part possess growth-forms and "adaptations" similar to those of dune-plants elsewhere. The species peculiar to dune-areas are marked with an asterisk.

(ii.) The Leading Dune-plants.

(α.) *Sand-binders.*

(a.) Major.—**Spinifex hirsutus* (Gramineae); **Scirpus frondosus* (Cyperaceae); **Euphorbia glauca* (Euphorbiaceae).

(b.) Minor.—**Carex pumila* (Cyperaceae); **Calystegia Soldanella* (Convolvulaceae); *Arundo conspicua* (Gramineae).

(β.) *Sand-collectors.*

(a.) Major.—**Coprosma acerosa* (Rubiaceae); **Pimelea arenaria* (Thymelaeaceae); *Cassinia leptophylla* (Compositae); *Cassinia fulvida* (Compositae); **Cassinia retorta* (Compositae).

(b.) Minor.—**Festuca littoralis* (Gramineae); **Calamagrostis Billardieri* (Gramineae); *Scirpus nodosus* (Cyperaceae).

(γ.) *Wet-ground Plants.*

Leptocarpus simplex (Restionaceae); **Gunnera arenaria* (Haloragaceae).

(iii.) Descriptions of Plants.

(a.) Spinifex hirsutus (*the Silvery Sand-grass*).

Found in New Zealand in the northern and central floristic provinces only. Also indigenous in Australia and New Caledonia.

The special sand-drift "adaptation" of *Spinifex hirsutus* is the extremely long, quickly growing, much-branching rhizome, which, if all the branches of an old plant were taken, would measure many yards; indeed, it seems capable of quite unlimited extension. Normally, the rhizome creeps over the surface of the ground, putting forth roots at the nodes; but it is soon buried by the drifting sand, in which case its apex may again emerge, but more usually branches or leafy shoots pass upwards to the light. Such a stem creeping on the surface is a runner rather than a rhizome, since it roots at the nodes, also putting up erect shoots, each of which is virtually an independent plant. These creeping stems, which frequently extend to the flat ground along a windward dune-slope unbranched and perfectly straight for many feet, are soft and juicy for their three or four apical internodes, but elsewhere hard, smooth, woody, and of a pale-brown or yellowish colour. The soft portion is well protected from damage by the strongly developed leaf-sheaths closely pressed to the stem, the sheaths themselves being also protected by a close almost tomentose covering of adpressed silky hairs.

The path of a subterranean stem is indicated by the bunches of leafy branches which at intervals pierce the sand, the leaves reaching a variable height above the surface; they are not crowded together, as are those of marram-grass (*Ammophila arenaria*), but sand is always visible through a bunch of leaves. The leafy shoots may descend 20 in. or more to the rhizome from which they branch, and such, rooting and deeply descending, binds the sand to an extraordinary degree. The leaves consist of blade and sheath; they are of two kinds, protecting leaves and ordinary leaves, the former having much broader sheaths and very short blades, and function as already described. An ordinary leaf has a blade about 19 in. long and $\frac{1}{16}$ in. broad; it terminates in a fine, tapering, but usually dead point. In texture it is flexible, coriaceous, and thick; the margins are much incurved, so much so as to frequently make the apical half or third into a pipe. Both surfaces are thickly covered with adpressed silky hairs. The sheath is about 5 in. long, pale-coloured, thick and fleshy, especially at the base, and rather brittle. The flowers are dioecious. Frequently extensive patches are all of one

sex, in which case probably there may be only a few plants. The male spikes are arranged in a terminal umbel; the spikelets are two-flowered, and about ⅓ in. long. The pollen is being shed from the middle of November to the beginning of December. The female inflorescence is a large globose head sometimes 1 ft. in diameter; the usually one-flowered spikelets are at the base of long sharp-pointed spines, each about 5 in. long, and spreading out radially. The roots are of great length, and descend deeply into the sand.

(β.) Scirpus frondosus (*the Pingao*). (For rhizome-development see Photo No. 17.)

Found only in New Zealand, occurring on dunes in all parts, except on the Kermadec and Subantarctic Islands.

The important features of this plant with regard to drifting sand are: (1) The great power of vegetative increase by means of the much-branching, stout, excessively long rhizome; (2) the tendency of the growing point to seek the surface—*i.e.*, the light—and the rapid lengthening of the stem; (3) the protection afforded to the very tender growing point, young stem, and leaves by the overlapping of the broad leaf-bases and their fastening together by a resinous exudation; (4) the leaf-texture so suitable to withstand the sand-blast; (5) the close packing of the inner leaves, owing to the concave upper surface; (6) the arching of the leaves so as to bring the convex undersurface, which is strengthened by abundant stereome, into opposition with the wind.

The rhizome is stout (about ⅝ in. diameter), somewhat woody, stiff, much-branching, covered with old leaf-sheaths, and many yards in length. Normally, it creeps close to the surface of the ground, branching near the apex into leafy shoots given off rather closely, but it is soon buried, finally forming a complete network of rope-like stems reaching to far down within the dune. The leaves are in bunches, tightly bound together at the base by their sheaths, the diameter there being about ⅞ in., but they gradually open out, also curving gently inwards. Each leaf consists of sheath and blade. The sheath is about 4 in. long and 2 in. broad at the base, somewhat triangular in shape, moderately thick in the middle, but translucent and membraneous at the margins, and everywhere sticky with a resinous exudation. The blade is about 2 ft. long by ¼ in. broad, tapering very gradually to a long trigonous point; the texture is very thick, coriaceous, stiff but flexible. It is concave on the upper surface and convex on the under. Its colour is rather dark glossy green near the base and on the undersurface, but on the upper it is frequently orange or reddish, especially above. The branches are given off quite close together, so that the separate leaf-bunches touch, making tussocks or lines. The inflorescence is 4 in. to 8 in. long, and consists of clusters of sessile reddish-brown globose spikelets spirally arranged round the stem, each cluster subtended by a linear bract similar to the leaf above described. The roots are of great length, very numerous, as may be seen when the wind lays them bare, and descend deeply.

Juvenile plants growing in hollows or sand-plains, show little trace of the far-creeping rhizome, whose extreme development depends upon an abundant sand-supply.

(γ.) Euphorbia glauca (*the New Zealand Spurge; Wairuatua*).

Found in all parts of New Zealand along the coast, except in the Kermadec and Subantarctic Islands. Also occurs in Norfolk Island.

Euphorbia glauca is a tall herbaceous plant, forming considerable colonies, and capable of much extension through its far-creeping rhizome.

The stout, terete stems stand erect above the sand for 3 ft., more or less, and descend for a variable distance. They are naked for the lower two-thirds, but marked with old leaf-scars; above they are covered closely with leaves. The naked portion of the stem is red or green, the former colour depending on excess of light. The leaves are alternate, of obovate type, but differing in width, 2 in. or 3 in. long, entire, sessile, and fleshy. All the parts are full of milky juice. The roots are long.

(δ.) Calystegia Soldanella (*the Shore-convolvulus, or Bindweed*).

Found on all parts of the coast-line, except in the Subantarctic Islands; elsewhere it occurs throughout the Temperate Zones. As well as on the dunes proper, it grows on sandy and even gravelly shores.

There is a long creeping rhizome, very variable in thickness, attaining a maximum of about ⅜ in. in diameter, frequently many feet in length, very flexible and cord-like, and branch abundantly, the final slender branches bearing many leaves. The leaves have long stout petioles 1 in. to 3 in. long, which raise the blades above the sand. The blades are reniform, broader than long, being 1 in. long by 2 in. broad, more or less. They are bright glossy green, thick, fleshy, brittle, and the basal lobes are frequently brought close together, rendering the leaf funnel-shaped. The leaves all touch, and together with the prostrate stems form a close mat (see Photo No. 61) about 3 in. in depth, which absolutely prevents any sand moving. Such mats are frequently several square yards in area, and small dunes may be quite covered, forming green oases absolutely stable in a moving waste of sand. The flowers are on stalks about equalling the leaves. The corolla is very showy, being 1 in. or more in diameter, and pale lilac in colour, but paler still in throat, with a band of this colour down the centre of each division of corolla. The roots are numerous, and when given off from the stems help to bind them to the sand; but many of the trailing stems are for the most part without such roots.

(ε.) Carex pumila (*the Sand-sedge*).

Found on dunes and sandy shores of the North and South Islands, the Chatham Islands, and Stewart Island. Also indigenous in Australia, temperate South America, and eastern Asia.

Carex pumila is a small sedge, which, like other sand-binding "grasses," can increase enormously by vegetative means. Its low stature and the bending downwards of its leaves does not enable it to withstand the drift of the dune proper, though very useful for wind-resisting, and it is in consequence confined to the sand-plains. It is also possible its water-requirements may be greater than those of the preceding plants.

There is a slender rhizome about ⅛ in. in diameter, which may extend for many feet, giving off small bunches of four to six fully developed leaves at intervals. The leaves are grass-like, sheathing at the base, the sheaths overlapping. The blade is thick and coriaceous, 1 ft. or more in length, but frequently less, and ⅛ in. or more in breadth. It tapers gradually to a fine point, is glaucous-green in colour, deeply concave on its upper surface, at first erect and then curving until its apex almost meets the ground. The roots are long and slender. The culms are short, stout, and about 6 in. tall. The utricle is large, turgid, and about ¼ in. long.

(ζ.) Arundo conspicua (*Toetoe-kakaho; New Zealand Reed*).

Found only in New Zealand, on almost all dune-areas of any magnitude. Also a very common plant without the dunes, occurring from sea-level to about 1,000 ft. altitude, chiefly in wet ground, including actual swamps. It is absent in the Kermadec and Subantarctic botanical provinces.

Arundo conspicua is a very tall grass, forming enormous dense tussocks after the manner of the pampas-grass (*Gynerium argenteum*). There is a stout short rhizome which can grow upwards as it is buried. The leaves are long, narrow, coriaceous, flat or involute, and their nerves strongly developed. When in bloom the plant is very showy with its long shining yellowish-white panicle, 1 ft. to 2 ft. in length.

(η.) Coprosma acerosa (*the Sand-coprosma*).

Found only in New Zealand, where it occurs on all dunes, excepting in the Kermadec and Subantarctic Islands.

Coprosma acerosa is a low-growing shrub, which forms flattened cushions (see Photo No. 22), or thick mats, 2 ft. or so in depth and 1 or 2 yards in length, made up of wiry, interlacing twigs, conspicuous through their orange or reddish colour.

The main stems are extremely flexible and rope-like, $\frac{1}{10}$ in. or more in diameter, prostrate, and covered with thick brown bark. Such are generally buried in the sand, marking a former surface; or, at any rate, they are quite concealed by the interlacing twigs. The stems forming the cushion are very wiry, flexuous, and flexible. The branching is at right angles or thereabouts, and frequently only from the flanks of the stem. The ultimate twigs are almost straight, and from ½ in. to 3 in. or more long. The leaves are in opposite pairs on much-reduced branchlets, pressed closely to the stem, an equal amount of naked stem being between them. They are linear, about ¼ in. long, thick, coriaceous, pale or yellowish green. The roots are extremely long, but short adventitious roots are frequently given off from the peripheral twigs, the plant in that case being able in some degree to rise above the drifting sand. The flowers are dioecious. The drupe is fleshy, globose, ¼ in. long more or less, translucent, white stained with pale blue.

(ι.) Pimelea arenaria (*the Sand-pimelea; Aute-tawanga, Torohekе*).

Found only in New Zealand; common on dunes everywhere, except in Stewart Island, the Kermadec Islands, and the Subantarctic Islands.

Pimelea arenaria is a close-growing, much-branched, low shrub, its final branchlets erect and forming close masses.

The main stems are cord-like, but not as flexible as in *Coprosma acerosa*, frequently several feet in length, thus having the faculty of lengthening as they are buried. The shrub is leafy at the periphery only for a depth of about 2 in. to 4 in. The prostrate branches finally give off erect, straight twigs, which branch corymbosely at a narrow angle, thus giving a flattish top to the shrub. The ultimate and subultimate twigs are alone leafy. The leaves are of a broadly ovate type, about ⅜ in. long, closely covered beneath with appressed silky hairs, as are also the final twigs. The buds fit in with the station, the hairs of the leaf affording special protection. The flowers are in close heads at the tips of the branches, and are polygamo-dioecious. The drupe is white and fleshy. The roots are of great length, and adventitious roots are fairly abundant from the uppermost branches, the rest of the shrub being beneath the sand to a variable depth.

From the preceding description it may be seen that both *P. arenaria* and *Coprosma acerosa* are sand-binders to a limited degree, and can with a slow drift continue to grow upwards and rejuvenate themselves, thanks to the power of putting forth adventitious roots from the subultimate twigs.

(κ.) *The Dune Species of Cassinia.*

Cassinia retorta, *C. leptophylla*, and *C. fulvida* are found in the northern, central, and southern botanical provinces respectively, but the last-named also occurs in the central province. None are exclusively dune-plants, but *C. retorta* is almost so, while *C. fulvida* ascends to the subalpine belt. All are readily reproduced from seed, and have extended their range since the settler arrived.

Cassinia leptophylla may be taken as the type of the dune cassinias. It is a shrub of the ericoid habit, from 3 ft. to 5 ft. tall, or even more.

The main stems are few, naked, and not much branched at first, but above they branch abundantly into slender leafy twigs, which finally give off at a narrow angle flexible straight branchlets, which are covered with a moderately loose cottony greyish tomentum. These final shoots form close masses of leaves, but those of one branch are distinct in themselves, and do not mingle with those of the next. The leaves are very small, narrow, linear or linear-spathulate, $\frac{1}{12}$ in. to ⅛ in. long, patent or semi-imbricating, coriaceous and moderately thick, bright shining green on the upper surface but tomentose beneath, the tomentum being slightly tinged with yellow. The bud-leaves imbricate;

they are resiny, and the tomentum of the leaves also affords protection. The flower-heads are numerous, white, and in small terminal corymbs 1 in. or more in diameter at the ends of the branches.

C. retorta and *C. fulvida* are very similar to the above; the former has white tomentum, and the latter is almost of a golden colour from the tomentum on the undersurface of its leaves and final slender branchlets.

It is simply the xerophytic adaptations of the above shrubs which has enabled them to settle upon the dunes, though at the same time the stimulus of the moist sand causes sometimes the putting forth of adventitious roots.

(λ.) Festuca littoralis (*the Sand Fescue-grass*).

Found in all parts of the coast of New Zealand, except the Kermadec and Subantarctic Islands; also indigenous in temperate Australia.

Festuca littoralis is a "steppe-grass," forming close-growing tussocks about 2 ft. tall and 5 in. or so through at the base.

The underground stems can lengthen upwards to some degree as buried, new roots arising from near the base of the leaves, and plants may rise in this manner 1 ft. or more, thus withstanding a slow burial. The leaves are narrow, strongly involute, green when young or in the shade, but frequently yellowish. The leaf-sheath is pale-coloured and thick. The lamina is 16 in. long or thereabouts, its upper surface furrowed and waxy. The roots are numerous, wiry, brown, furnished with many short filiform rootlets, and frequently spread out laterally for a distance of 3 ft. The panicle is dense, spike-like, and the spikelets turgid.

In certain parts of Southland this grass builds dunes of considerable size right on the foreshore.

(μ.) Calamagrostis (Deyeuxia) Billardieri.

Common on New Zealand coast, except in the Kermadec Islands and the Subantarctic Islands; also indigenous in Australia.

Calamagrostis Billardieri is a tufted perennial grass forming small green patches about 1 ft. long by 6 in. broad.

The underground stem is pale, slender, wiry, creeping, and furnished with a great number of slender roots about 6 in. long. The leaves are shorter than the culms, and the blade is bent outwards from the sheath, spreading semi-vertically; it is about 3¾ in. long by $\frac{5}{16}$ in. broad, bright green, flat, membraneous, and tapers to a short point. The panicle is 6 in. to 10 in. long, as broad as long when fully expanded; its branches are hair-like, arranged in whorls, and branch trichotomously.

(ν.) Scirpus nodosus (*the Stiff Club-rush*).

Common in New Zealand, except in the Subantarctic Islands, but not confined to the dunes; also indigenous in temperate Australia, Norfolk Island, South Africa, South America, St. Helena, and Amsterdam Island.

Scirpus nodosus forms close tussocks about 30 in. tall, made up of terete, stiff, flexible, pale-green stems arranged closely together, and given off from a short, straight, woody rhizome ⅜ in. in diameter.

The leaves are represented by sheathing scales at the base of the stems, which latter function as leaves. The roots are wiry and of medium length. The inflorescence is a solitary globose head ⅜ in. in diameter, of numerous crowded spikelets subtended by a rigid bract, 1 in. or more in length, continuous with the stem.

The tussock form, stiff isolateral stems, and absence of leaves fit this plant for very dry stations, and so it is very common on the dunes themselves, but is quite absent where the sand drifts to any extent, since it has no sand-binding properties and gets buried.

(ο.) Leptocarpus simplex (*the Yellow Rush*).

Found only in New Zealand; common on the coast, except in the Kermadec and Subantarctic Islands; occurring principally in salt marshes and sand-plains.

Leptocarpus simplex forms dense tussocks of quite erect, slender, terete, stiff, wiry, flexible, rush-like stems of a dull green, but more frequently reddish or yellowish colour, according to the intensity of the light, being at times, when fully exposed, bright red or orange.

The leaves are reduced to short blackish sheathing scales clasping the stem at distances of 1 in. to 4 in. The rhizome is stout, woody, creeping. The roots are wiry and of medium length. The flowers are dioecious, the male inflorescence panicled, and the female arranged in compact rounded glomerules.

(π.) Gunnera arenaria (*the Sand-gunnera*).

Found only in New Zealand; extending along the coast, but confined to dune-hollows, or wet cliffs, from the northern floristic province to Stewart Island.

Gunnera arenaria is a very low-growing herb, forming large round flat patches a yard or more in diameter, the leaves flattened down to the ground.

The rhizome is stout and much-branching. The leaves are of the ovate type, 1 in. or 2 in. long, including the petiole, thick, coriaceous, and of a dull-green colour. The flowers are monoecious. The female peduncle lengthens as the fruit ripens, finally becoming 2 in. or 3 in. in length, and so much raised above the foliage. The drupes are yellowish-red, and crowded on the upper part of the peduncle.

(*d.*) METHODS OF SPREADING OF DUNE-PLANTS.

The distribution of the special dune-plants takes place most likely by means of coastal currents, for, no matter how far separated are the dunes, their typical flora has gained small dune-areas remote from others, and isolated islands where the amount of sand is trifling. Perhaps succulent fruits may be carried by land-birds, but these latter are rare on dunes, there being little to attract them.

As for the spread of the plants on the dune-area itself, this is chiefly the work of the wind. Especially are the ball-like infrutescences of *Spinifex hirsutus* suitable for wind carriage. Caught by the breeze, these hop over the sand on their long spines as if endowed with life, until eventually, falling to pieces, they come to rest, and the seeds are buried ready for germination. In this manner originate the embryonic dunes of the upper foreshore.

The "seeds" of *Festuca littoralis*, *Carex pumila*, *Calystegia Soldanella*, *Coprosma acerosa*, and *Pimelea arenaria* are cast in great numbers near the bases of the plants, and can there germinate, or are more frequently driven when dry along with the surface sand. Generally speaking, however, there are very few seedlings on the sandhills themselves. It is in the hollows that seeds, even those of the sand-binding grasses, germinate, the seedlings of these, on receiving a sand-supply, building dunes. On the hills seedlings are extremely scarce, the increase there being almost altogether by vegetative means, which amply suffices, under favourable conditions, to cover the ground.

(*e.*) THE PLANT ASSOCIATIONS OF THE NEW ZEALAND SAND-DUNES.

(i.) General.

The words "New Zealand" are here used in the plant-geographical and not the political sense, and include, besides the two main islands and Stewart Island, the Kermadec, Chatham, and Subantarctic groups, but the tropical appanages of the Dominion (Cook Islands, &c.) are excluded. The term "plant-association" is restricted to the usage proposed by Warming (63, p. 145), the associations as a whole being parts respectively of the sand-dune formations of the entire earth. This conception of plant-formation and plant-association seems to me scientifically sound, although, in more complicated arrangements of vegetation than that of dunes, difficult, if not impossible, to act up to in the present state of knowledge.

The comparative simplicity in the progress of dune-development, its rapidity, and the ease with which it can be observed, as stated already when dealing with the geology of dunes, makes a genetic study of the vegetation of a dune-area much more easy than that of a series of land forms whose evolution is extremely slow. Beginning with the foredune and ending with the fixed dune, a gradual change may be noted in harmony with the increasing stability of the sand, a condition which is in large part the work of the plants themselves. Also certain stages enter in where a new class of associations branch off, which may be either transitory and doomed to obliteration, or become permanent, their persistence depending upon the stability of the dune-area as a whole. *The above is important from the economic standpoint, since where nature has brought stability and inserted shrubby associctions in the midst of dunes originally unstable, so too can afforestation be artificially carried on, but with greater ease*, or the better land be used without danger for certain agricultural purposes.

The various plant associations may receive either a physiographic or a botanical name, the two exactly coinciding, each association forming a definite step in the progress of events whose final goal is stability. The treatment also does not go into minutiae which are of little importance, an attempt only being made to give a clear general idea of the associations, which necessarily will not be absolutely true for every part of the district.

The associations, taking on account of its practical significance a physiographic classification rather than a botanical, may be divided into those of the *dunes* and the *dune-hollows*, including amongst the latter the most extensive sand-plains, lakes, and swamps. Between the associations as described below there are all kinds of gradations, even those of dunes and dune-hollows having at times the closest relationship. Where the dunes abut on river mouths and estuaries there are salt meadows and marshes, but these are here excluded.

Many portions of the dune-area are not typical—*i.e.*, there is no sand-supply from the shore, nor a general procession of events such as here described, which is only to be observed on the broader dune-areas. This arises from their being situated on cliffs, while their movement is due to destruction of their plant covering. Other areas again form but a narrow belt along the shore, and there are few evolutionary stages to be observed. In what follows, fuller details are given of typical dune-areas than of these more ancient rejuvenated dunes, which, if undisturbed, would generally represent the fixed dune—*i.e.*, the climax association of dune-development. Nor do the smaller areas receive more than a very brief treatment at best, while many are not dealt with at all, since their economic importance is trivial.

(ii.) Dune Associations Proper.

(*a.*) *Sand-grass Dunes* (see Photo No. 61).

These are distinguished by their instability and by the presence of some sand-binding grass or sedge. They occur along the sandy beach, where, if continuous, they build a long low ridge (the foredune), and extend inland for a variable distance, depending on the position of the shore with regard to the prevailing winds. At first they are clothed with the pingao (*Scirpus frondosus*) and the silvery sand-grass (*Spinifex hirsutus*), one or both, the latter occurring only on the dunes of the northern and central botanical provinces. The sand-grass dunes may remain at this stage, and frequently do so near the shore; but by degrees there come in, first, the minor sand-binders, then the sand-catchers, many of them shrubs, until finally a shrub dune is established.

Generally the sand-grass dunes are by no means closely covered by tufts of the *Spinifex* or *Scirpus*, there being as many or more bare patches than vegetation. At the junction of foredune and shore in the northern and central botanical provinces the long bamboo-like stems of the *Spinifex* may extend over the loose sand of the foreshore, as may also the rhizomes of the *Scirpus*. Also, both plants not uncommonly build small dunes on the foreshore itself, pioneers of a new line of foredunes. Frequently one or other of the above species is dominant, *Spinifex* giving a silvery and *Scirpus frondosus* a yellow colour to the ridges. Sometimes the two plants grow side by side, but they are usually not intermixed. *Spinifex hirsutus* rarely extends inland for any considerable distance, its presence being a sign that

the shore is near; but *Scirpus frondosus* is to be found wherever there is moving sand, even on the retrogressive fixed dunes at the landward boundary of the area.

Calystegia Soldanella, *Euphorbia glauca*, *Festuca littoralis* (this actually building primary dunes on the shore in certain parts of Southland), *Scirpus nodosus*, and *Calamagrostis Billardieri* are also in part plants of the moving dunes, but they do not confer such stability as the dominant sand-binding plants. The *Calystegia* (Photo No. 36), with its shining green leaves and, in their season, showy lilac flowers, forms a refreshing contrast to the grasses or sedge. It forms dense masses on the sand, sometimes quite covering small dunes, but, the mats being only a couple of inches deep, a heavy drift will soon overwhelm them. All the same, it is remarkable for how long such closely covered dune-summits persist in an area where the *S. frondosus* dunes are blown flat, the absolutely covered sand defying the wind, the dune itself creating an eddy, and a channel being formed in front of the advancing sand. *Euphorbia glauca* is by no means a common plant everywhere, but when it is present it forms colonies of considerable size, the pale-green colour of the leaves and erect habit rendering it conspicuous.

The sand-coprosma (*Coprosma acerosa*) is a very early comer, and belongs to this association. Where the wind is not excessive the great tussocks of the toetoe (*Arundo conspicua*) especially on the Auckland dunes, are a conspicuous feature; in fact, Carse considers it the leading dune-plant in the Mangonui County (81). The fleshy-leaved sowthistle (*Sonchus littoralis*), generally a rock plant, occurs on the sand-grass dunes of Stewart Island; and here, too, as also in Southland, are bushes of *Pimelea Lyallii* flattened to the sand, together with rosettes of the small *Geranium sessiliflorum*, which thrives, thanks to its very stout, deeply descending, woody root. In Southland also several species of piri piri (*Acaena novae-zealandiae*, *A. microphylla*, *A. species* with sessile flower-heads), *Hydrocotyle novae-zelandiae*, and *Myosotis antarctica* var. *Traillii* are fairly common in some places.

The unstable dunes of Central Otago are occupied in many places by tussocks of *Poa caespitosa*, which becomes under these conditions a minor sand-binder. So efficacious is it in this regard that it is planted at Cromwell to stop sand-drift.

Juvenile sand-grass dunes are met with on the foreshore, on sand-plains, on dunes themselves, and indeed anywhere if there is a supply of moving sand and a sand-binding "grass" to arrest its progress. During a period of calm weather, or in some spot where there is no movement, such as a moist sand-plain, the seed of *Spinifex hirsutus* or *Scirpus frondosus* germinates, a young plant arises, and if it can attain a few inches in height may hold its own. Vast numbers of seedlings must perish, but an occasional one here and there will serve for dune-building. The young plant catches the sand, which then forms a tongue on its lee side; into this the growing rhizome extends, and, with increase of size of plant, through much branching of rhizome and development of leaf-branches, more and more sand is held, this stimulating the growth of the plant. Thus grass and sandhill increase in size at the same time, the former looking like many independent plants, and the latter acting now as the obstacle, catch the windward drift, which is finally arrested by the leaf-branches, each tuft of leaves building a tongue of sand on its lee side, as did the original young plant. Thus in a few years a dune several feet in height will arise from one young plant of the *Spinifex* or *Scirpus*, which, through its extensive branching, might well be thought to consist of a colony of separate plants.

Natural planting, such as the above, leads to the formation of mounds and ridges, and ultimately on that account to more or less destruction of the dunes, as already explained in the geological portion. But in an artificial plantation extending over a flat area, where the plants are regularly arranged, the building of mounds is more or less suppressed, and a stable plant-association will result; but where this is subject to a windward supply of sand it is sometimes destroyed (see Photo No. 32).

The number of species present on a sand-grass dune depends entirely on the wind factor. Where strong sea winds are frequent only *Spinifex hirsutus* and *Scirpus frondosus* are present, but where the wind is weaker, sand-shrubs, minor sand-binders, and sand-holders will appear, and, where weaker still, ordinary wind-tolerating shrubs and even certain introduced plants; in short, *the plant covering is an exact index of the wind-force.*

(β.) Pes caprae *Dunes.*

These only occur on Sunday Island, in the Kermadec Group. They are covered with *Ipomaea pes caprae*, a creeping herb with prostrate stems some feet in length which root here and there. The leaves are large, 2-lobed, dark yellowish-green, and firm in texture (R. B. Oliver, 127, p. 133). Growing amongst the *Ipomaea* are the grasses *Imperata Cheesemanii* and *Eleusine indica*, the stiff club-rush (*Scirpus nodosus*) and the wild celery (*Apium prostratum*). These dunes are of no moment except from the scientific standpoint.

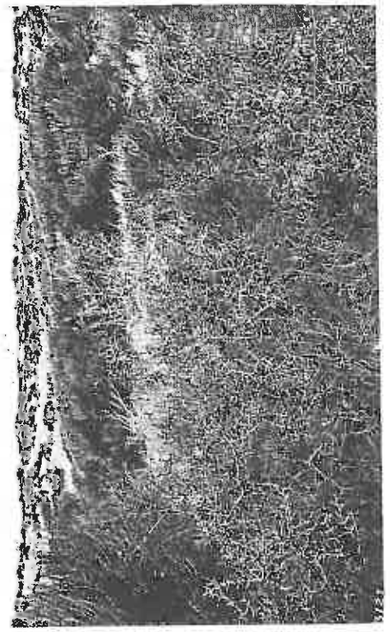
(γ.) *Dunes of the Auckland Islands.*

Dunes occur only on Enderby Island. The most important feature, as I have explained elsewhere (Cockayne, 86), is a negative one—the absence of special sand-binding plants. All the same, the dunes were originally quite stable, owing to their surface being kept constantly wet by the almost daily rain. The plant covering is, however, by no means close. It consists of *Pratia arenaria*, *Lagenophora pumila*, *Epilobium confertifolium*, *Crassula moschata*, *Ranunculus acaulis*—all low creeping herbs—and a moss of dense habit. On some parts, especially where cattle have caused drift, there is the shore-dock (*Rumex neglectus*), a low-growing herb with stout and far-creeping underground stems. This plant is here to some extent a sand-binder, though elsewhere it is not a dune-plant.

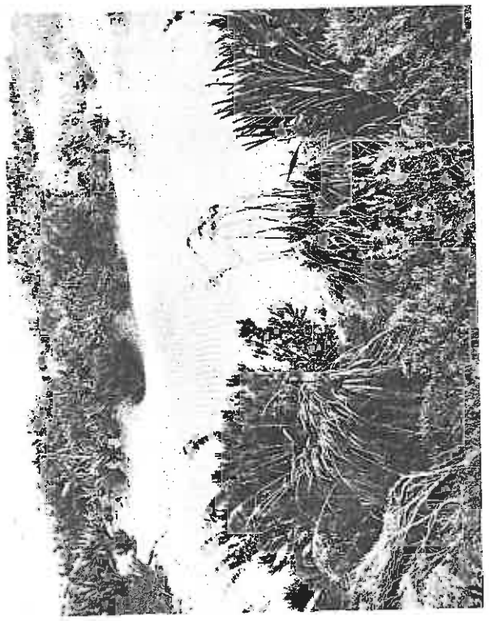
(δ.) *Shrub Dunes.*

(a.) *Sand-shrub Dunes* (Photo No. 38).—Sand-shrub dunes are the second state of progressive dune-evolution. They are occupied only by those shrubs which tolerate drifting sand. Leaving out of consideration the Kermadec and Subantarctic botanical provinces, the actual shrubs vary more or less in different parts of the botanical region. *Coprosma acerosa* occurs throughout. So too with *Pimelea arenaria*, Stewart Island and perhaps Southland excepted, where there is *P. Lyallii* instead. *Cassinia retorta* is confined to the Auckland dunes, *C. leptophylla* to those of the central botanical province, while *C. fulvida*, though chiefly on the dunes of Canterbury, is more or less common in parts of the central province also.

No. 35. Crop of Oats growing on Naturally Fixed Dune-ridge. Dune-area of Western Wellington. [*Photo L. Cockayne.*



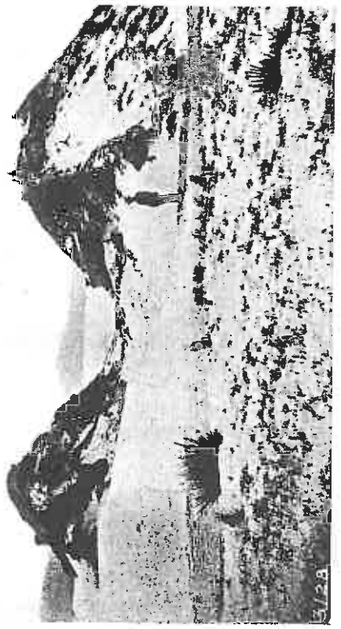
No. 37. Manuka Heath of Sand-plain. In Front are Bushes of the Wild Irishman (*Discaria toumatou*). [*Photo L. Cockayne.*



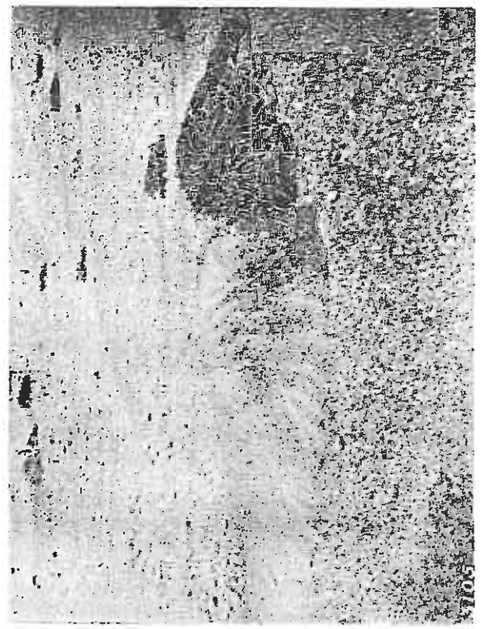
No. 34. Face of Active Dune getting naturally clothed by *Phormium tenax*, *Arundo conspicua*, and *Cassinia leptophylla*. [*Photo L. Cockayne.*

No. 36. The Shore-convolvulus (*Calystegia soldanella*) in bloom, and showing Close Habit of Growth. [*Photo A. H. Cockayne.*

To face page 28.]

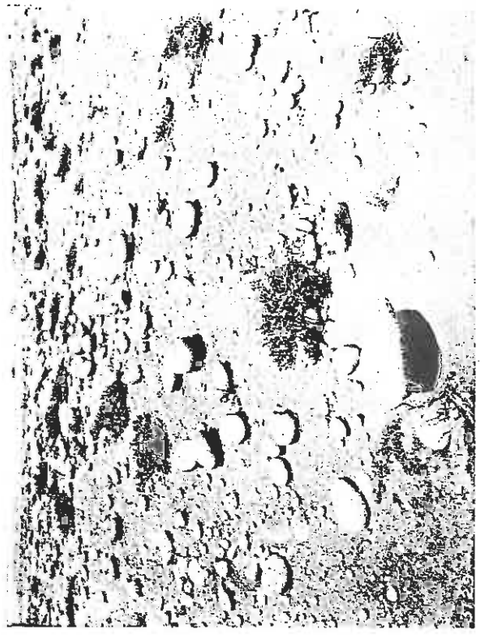


No. 39. Sand-plain in which Drifting Sand is being fixed by *Carex pumila*. Wind-channel and Wrecked Dunes in Centre.
[*Photo W. H. Field.*



No. 41. Tongue of Sand in Lee of Prostrate Shrub (*Coprosma acerosa*) on Stony Desert, South-east of Wanganui.
[*Photo L. Cockayne.*

No. 38. Sand-shrub Dune with Small Portion of Sand-plain in Front. Dunes of Western Wellington.
[*Photo L. Cockayne.*



No. 40. Stony Desert near Nukumaru, South-east of River Waitotara. The Shrub is *Coprosma acerosa*.
[*Photo L. Cockayne.*

As the sand-grass dunes become more stable they afford sufficient shelter for the seedlings of shrubs to establish themselves on the lee side. Thus, as already shown, shrubs occur to some extent on the sand-grass dunes, becoming more abundant with increase of distance from the shore, until finally they dominate, and a shrub association occupies the ground.

Besides capturing sand-grass dunes, the shrubs under discussion are also dune-builders, their form favouring the accumulation of sand. Especially is this the case with the prostrate, spreading, much-branched *Coprosma* and *Pimelea*, which function as veritable sand-traps (see Photo No. 22), the sand accumulating in their interior, but eventually, if the drift continues, burying them altogether. The various species of *Cassinia*, much taller and more erect plants than the two preceding, function somewhat differently. Their closely branching portion is at some feet above the sand-surface. The sand is at first held, but not strongly, by the basal stems, and as the drift continues it mounts up to the above twiggy portion, where it accumulates more rapidly, so that the shrub may be altogether buried, or a few twigs alone project above the sand, which, unlike those of the *Coprosma* or *Pimelea*, cannot lengthen to any noticeable extent. Even in that case the plant is not necessarily doomed, for the loosely held sand at its base is frequently blown away, the stiff naked stems being again exposed, and the shrub none the worse for its burial. On the other hand, sand held in the network of branches of the *Coprosma* or *Pimelea* cannot again be removed, except under very special circumstances. *Cassinias* at all stages of burial and disinterment are a common feature of the shrub dunes.

To a minor degree the sand-shrubs function as sand-binders, since their upper branches sometimes put forth roots, thus enabling the plant to grow upwards with the drift, while the cord-like old stems are buried deep in the dunes. But, generally speaking, all the indigenous shrubs of the New Zealand dunes function as sand-*holders* rather than as sand-*binders*, such as are certain species of Europe or North America, whose upper stems root freely and grow rapidly—various willows (*Salix*), and dogwoods (*Cornus*).

The association is grey or yellow in colour, according to the dominance of the *Cassinia* or *Coprosma*, but generally both colours are in evidence.

Certain other indigenous plants are common in this association. More or less *Scirpus frondosus*, or *Spinifex hirsutus* if near the sea and according to the locality, will be present, especially on the lee slopes, the accumulating of sand there being favourable to their development. Tussocks of the pale-green stems of *Scirpus nodosus* and shining green mats of *Calystegia Soldanella* will be sometimes abundant. The grass *Calamagrostis Billardieri* will be dotted about. Where the wind is not especially strong *Phormium tenax* and *Arundo conspicua* may enter in. On the Southland dunes where the sand is coarse the silvery mats of *Raoulia australis*, so frequently a denizon of stony river-beds, will appear early. There will be usually more or less introduced plants which are able to tolerate a dry station if there be sufficient shelter, *Trifolium arvense*, *Hypochoeris radicata*, *Sonchus asper*, and *Bromus hordeaceus* being especially common.

As for the stability of these *Cassinia-Coprosma* dunes, all depends upon their position—though if stable they belong more properly to the next class—and the degree of covering. Where the shrubs quite cover the sand—a not infrequent occurrence—and if, in addition, the dune is on the lee side of a well-fixed sand-plain, it is quite stable, and would remain so for years were there no advance of sand, or did no animals or fire disturb its surface. This stability is important, insomuch as it shows that *under certain conditions a dune exposed to wind-tearing action may be naturally covered with shrubs and rendered stable without any previous preparation, except such shelter as is afforded by sand-grasses.*

(b.) *Heath Dunes.*—The heath dunes are the third stage towards the evolution of the fixed sand-hill, with its loam-covered surface. They occur at a greater distance from the sea than the sand-shrub dunes, or even quite close to the shore where the wind strikes with less power. They are closely allied to shrub dunes, and differ only in being more stable and containing generally more species.

Very often one or other of the species of *Cassinia* is the dominant plant. In many localities, however, the manuka (*Leptospermum scoparium*) gives the character to the association. The appearance of this shrub is an interesting plant-geographical phenomenon, since it seems at first thought that, the dune-vegetation being correlated with the wind-velocity, manuka must be to a smaller degree wind-tolerating than are the dune-plants proper. But it is nothing of the kind; on the contrary, it can tolerate more wind than almost any other indigenous shrub, as I have shown elsewhere (Cockayne, 92). On a dune-area it is clear that *the presence of the manuka is altogether dependent on the strength of the sand-drift and on nothing else*, not even on excess of sea-spray. *Thus, in selecting shelter-plants for dune-afforestation purposes, tolerance of drifting sand is a matter of prime importance, without which drought- or salt-resisting power are as nothing.*

Besides the above shrubs, other species may make up the association. The great tussocks of the toetoe (*Arundo conspicua*) and the New Zealand flax (*Phormium tenax*) may be present, and in some localities dominant. These two can tolerate a certain amount of sand-burial. The toetoe, for instance, grows upwards as it is buried, and thus ascends a slowly advancing lee slope, finally possibly capturing it and leading to its fixing (see Photos Nos. 33 and 34). If such lee slopes were not interfered with, and beyond the influence of cattle and burning, many which are now advancing, menacing fertile land, would be naturally fastened. Even under the present adverse conditions stability is in some places being established.

In Southland, so far as I have observed, true heath dune is absent, but *Phormium* and toetoe (*Arundo conspicua*) are common on many hills. There in some places the sand-grass dune gives place, on the immediate ridge behind, to fixed dune, which is perhaps grassed or was originally covered with southern rata forest (*Metrosideros lucida*), now replaced by a scrub of species of *Coprosma*, &c. Heath dune seems wanting in Stewart Island, except on the ancient inland dunes.

In north-western and north-eastern Auckland more species enter into the heath than on the dunes of the central botanical province. *Styphelia fasciculata*, flattened close to the ground, is very common. The white tea-tree (*Leptospermum ericoides*), of exactly the same habit as the *Styphelia*, is frequent.

Pomaderris phylicaefolia sometimes occurs in this association. At a greater or lesser distance from the sea, heath is the common feature of these northern Auckland dunes, but it is generally rather on the very sandy soil covering the consolidated ancient hills than on the more recent, and in such a case the florula is much richer. Heath of this character is almost identical with that of the ordinary clay lands, so far as species are concerned, and contains many species not given in my list of dune-plants. Ecologically it is more wind-swept, and various shrubs, normally erect, are flattened to the ground.

(ε.) *Fixed Dunes.*

(a.) *Shrubby and Grassy Dune.*—Even now, short as the time is since the European first settled in New Zealand, it is not easy, or indeed possible, in the majority of cases to say what the vegetation of the fixed dunes was exactly like. The pasturing of stock, frequent burning of the vegetation, and the spread of introduced plants has, in most places, called into existence a plant association quite foreign to primitive New Zealand. But there are certain places, here and there, more or less undisturbed, where probably even yet all the original native species remain, though in a much different percentage from what they were in the primeval vegetation. Heath, as above described, would probably be the important association of many places. *Arundo conspicua* and *Phormium tenax* would play an important part. In Southland certain species of piripiri (*Acaena*) are abundant, and there is a considerable quantity of the round silvery patches of *Raoulia australis*, and of another species allied to *R. Monroi;* also *Gentiana saxosa*, *Gnaphalium trinerve*, *Poa caespitosa*, and *Pimelea Lyallii* are common in certain places—*e.g.*, on the dunes facing Colac Bay. Bracken-fern (*Pteridium esculentum*) is generally present in abundance, but how far heath of this character was a true association in primitive New Zealand is certainly not known. As for turf-making grasses, *Danthonia pilosa*, *D. semiannularis*, *Dichelachne crinita*, *Microlaena stipoides*, and *Zoysia pungens* in the north would be present.

The most important part played by the primitive vegetation in the first instance, and aided afterwards by the introduced plants, was the formation of humus from their decay, the surface thus getting covered by degrees with sandy loam, itself alone an excellent fixing-agent which would render the dune stable unless disturbed. So much so is this the case that in certain places these stable dunes are successfully used for growing crops of oats or rape (see Photo No. 35). But, notwithstanding such a use, the greatest care has to be exercised, for if once the true sand is exposed there is a rapid reversion not merely to semi-stable sandhills, but to the wandering dune itself (see Photo No. 14).

With burning and "stocking" the equilibrium between the species was upset, space was opened up for new plants, so that various grasses, leguminosae, &c., came in, and at the present time a turf, containing white clover, cocksfoot, Yorkshire fog, meadow poa, and even rye-grass, together with many worthless weeds, covers much of the ground of many dune-areas, interspersed with a varying quantity of the indigenous plants mentioned above, and others according to the geographical position of the dunes in question.

(b.) *Dune Forest.*—Dune forest is not a very frequent feature of the coast. It occurs most abundantly where the number of rainy days is excessive. Thus, on the dunes of Chatham Island low forest consisting of the so-called akeake (*Olearia Traversii*) and the matipo (*Suttonia chathamica*) was originally common. Drifting sand has, however, destroyed this forest in many places.

On the lee slope of a portion of the Mason Bay dunes, in Stewart Island, there is a quite luxuriant though low forest, consisting of the broadleaf (*Griselinia littoralis*) as the dominant tree, its thick leaves being in harmony with the dry soil. In some parts the southern rata (*Metrosideros lucida*) is abundant, its dark-green leaves contrasting with the much lighter green of the flat forest-roof. The other trees are *Rupanea Urvillei*, *Aristotelia racemosa*, *Nothopanax simplex*, *Carpodetus serratus*, *Pittosporum fasciculatum*, *Fuchsia excorticata*, *Pseudopanax crassifolium*, and *Dracophyllum longifolium*. (For further details see Cockayne, 92, p. 18.)

On the dunes of western Nelson, south of Westport, there is old forest consisting of the forest-trees of the locality, but I have no detailed notes. It comes quite close to the sea, from which it is separated by the sand-grass (*Scirpus frondosus*) dunes.

Forest occurs occasionally in sheltered gullies on the fixed dunes of both Wellington and western Auckland. The components consist in part of coastal trees, and in part of inland trees found frequently near the coast. The following are some of the members: Karaka (*Corynocarpus laevigata*), akeake (*Dodonaea viscosa*), pohutakawa (*Metrosideros tomentosa*—Auckland only), kawakawa (*Macropiper excelsum*), kowhai (*Sophora tetraptera*), ngaio (*Myoporum laetum*), puriri (*Vitex lucens*—Auckland only), titoki (*Alectryon excelsum*), rangiora (*Brachyglottis repanda*), kohutu (*Pittosporum tenuifolium*), kohekohe (*Dysoxylum spectabile*), and mahoe (*Melicytus ramiflorus*).

The forest of the Southland dunes has been already noted. Also in certain parts of that district, forest, but not necessarily of the dunes, has been buried by sand, the tops of the dead trees still projecting above the surface.

(iii.) Hollows and Sand-plains.

(a.) *General.*

It has been shown how the advancing dune-ridge leaves in its wake level sandy ground, which continues to be lowered by the wind until moisture, rising from the quite adjacent water-table, forbids further removal of sand. It is obvious that such hollows are in themselves quite stable, while their moisture permits an altogether different class of plants to those of the dune proper to establish themselves.

The final destiny of these level areas does not depend, however, upon their own plant covering, but on the stability of the adjacent dunes, and according to the behaviour of the latter so is the subsequent history of the vegetation.

One of two things may happen — there may be an invasion of sand and a reversion to dune conditions, certain transient plant associations arising only to be destroyed; or there may be a

(β.) *The Moist Sand-plain or Hollow.*

In Canterbury, western Wellington, and occasionally in Auckland, the damp sand is early occupied by the curious round mats, 3 ft. to 6 ft. in diameter, of *Gunnera arenaria*, the small, thick, pale-green leaves flattened to the ground. When the short erect racemes of orange-coloured drupes are present in quantity, raised well above the foliage, the plant is both pretty and conspicuous. The sand-sedge (*Carex pumila*), *Scirpus cernuus*, *Epilobium nerterioides*, *E. Billardierianum*, *Cotula coronopifolia*, *Ranunculus acaulis*, and *Crantzia lineata* are more or less common in both main Islands. *Lobelia anceps*, *Myriophyllum Votschii*, and *Limosella aquatica* are abundant in the northern and central botanical provinces.

In places water lies during winter, but these are frequently quite dry in summer, and have at times in western Wellington a surface temperature of 100° Fahr., and probably more, notwithstanding which certain moisture-loving plants grow—*e.g.*, *Epilobium Billardierianum*, *E. nerterioides*, *Cotula coronopifolia*, and *Limosella aquatica*—and remain quite healthy. It seems almost incredible that these plants, whose structure fits them for a wet environment, can tolerate such extremes; but one must remember that the wet sand just below the surface is at a very much lower temperature than the dry crust above, and that it never becomes dry.

Should the hollow continue moist—*i.e.*, should there be no invasion of sand—the salt-marsh plant, *Leptocarpus simplex*, will appear and finally take complete possession, in many places acres occurring at a time, its stiff, erect, yellowish or reddish stems 2 ft. or more tall rendering it very conspicuous. It is quite well known to the settlers under the term "yellow rush," and they set fire to it constantly to make way for more nutritious plants. Other salt-meadow plants also appear, especially the fleshy-leaved and creeping *Selliera radicans*, which has generally more rounded and smaller leaves than the typical form. Tussocks of *Scirpus nodosus* are also common in many localities.

On the dunes of north-western Auckland *Leptocarpus* in many places forms out of its rhizomes great trunks after the manner of *Carex secta* (the niggerhead). The rhizomes, sometimes 10 in. in length, are bunched together and vertical in position, but branch laterally, the branches when above ground curving towards the sand. Masses of *Leptocarpus*, but wanting trunks, growing closely and covering some acres, are a great feature of the Wellington dunes; but I did not see anything of the same extent on those of Auckland. *Schoenus nitens* var. *concinnus* is very common in some of the hollows of Canterbury and Wellington. *Elaeocharis neo-zelandica* forms considerable patches, which catch a little sand, in many parts of the western Auckland dunes, as far south, at any rate, as the Muriwai Stream. It has a moderately stout and wiry rhizome, and erect dark-green stems 2 in. or so tall.

As the sand-hollow becomes drier, and where *Leptocarpus* or other plants do not occupy all the space, there is sometimes, on the dunes of western Wellington especially, even in close proximity to the sea, quite a number of fair fodder plants, especially white clover (*Trifolium repens*), yellow suckling (*T. dubium*), some cocksfoot (*Dactylis glomerata*), Yorkshire fog (*Holcus lanatus*), and meadow poa (*Poa pratensis*). The greater part of the introduced plants are, however, of little or no value — *e.g.*, the melilot (*Melilotus arvensis*), marsh painted-cup (*Bartsia viscosa*), the toothed medic (*Mendicago denticulata*), the sorrel (*Rumex Acetosella*), the soft brome-grass (*Bromus hordeaceus*), the harestail-grass (*Lagurus ovatus*), and the silver hair-grass (*Aira caryophyllea*). In a similar position, abutting right on the sea-shore some miles north of Ahipara, north-west Auckland, I noted *Poa pratensis*, *Festuca bromoides*, *Trifolium repens*, and *Trifolium dubium*—which, with various other introduced and indigenous plants, made a close turf. In other cases where the stability of the sand-plain has been considerable there will be heath.

(γ.) *Manuka Heath.*

Where the water-content is not too great, or perhaps rather where there is a certain amount of dry sand on the surface, there will be in many parts of the dune-areas a heath association, with the manuka (*Leptospermum scoparium*) as the dominant plant. In such a station there are frequently small dunes, arising from sand-invasion, and the surface is quite irregular. In this case there is virtually little difference between heath of this character and that of the higher hills.

In Auckland many of the ordinary heath-plants will be present, especially *Styphelia fasciculata*, *Leptospermum ericoides*, *L. linearium*, *Pomaderris phylicaefolia*, *Styphelia Fraseri*, and *Pimelea laevigata*. *Cassinia retorta* will be plentiful, but never flattened to the ground like most of the above shrubs. There will probably be *Phormium tenax* and *Arundo conspicua*.

Wetter sand-plains than the last described are common in western Wellington, where the sand-plains are much more extensive than elsewhere in New Zealand—*i.e.*, they are in proportion to the greater breadth of the dune-area. Such an association will contain a fairly large number of indigenous species, of which the following may be the most conspicuous: The manuka (*Leptospermum scoparium*), the cabbage-tree (*Cordyline australis*), the common libertia (*Libertia ixioides*), the New Zealand flax (*Phormium tenax*), *Mariscus ustulatus*, *Hydrocotyle pterocarpa*, *Viola Cunninghamii*, *Elaeocharis Cunninghamii*, *Ranunculus macropus*, *Potentilla anserina* var. *anserinoides*, *Scirpus inundatus*, *Carex secta*, *Carex ternaria*, *Olearia Solandri*, *Macrus pumilio*, and *Coprosma propinqua*.

In Canterbury the heath will be almost pure *Leptospermum scoparium*, or there may be a good deal of wild-irishman (*Discaria toumatou*). (See Photo No. 37.)

I have no notes as to similar heath in Southland.

In Stewart Island the hollows amongst the dunes are filled with a dense shrubby growth of *Senecio rotundifolius*.

This shrubby sand-plain vegetation may arise either directly from bare ground occupied first by *Gunnera arenaria*, &c., followed by *Leptocarpus simplex*, or it may be the concluding stage of a series next to be mentioned, commencing with a shallow lake or pond and followed by a swamp. At any rate, no matter what its origin, when it becomes drier, through the incursions of cattle chiefly, it makes fair grazing-land, and allows a good many grasses and leguminous plants to enter the association.

(δ.) *Lakes and Swamps.*

It is not always easy to trace the origin of the lakes. Although some small ones arise directly from the sand-plain, as already shown, the majority owe their presence to bad drainage conditions, through streams, &c., being choked by the sand. An interesting example is that shown in Photo No. 64, where on the slope of Reef Point a gully with a considerable stream was first dammed up forming a pond, and this latter is now in process of obliteration from a dune-fall. The vegetation of swamps and lakes hardly concerns this report, except for the economic plants they may contain. Thus the swamps are often occupied by a close growth of *Phormium tenax*. In Auckland they will usually contain more or less of the valuable fodder grass, *Isachne australis*, so much relished by cattle. The lakes contain various aquatic plants — to give an example from Wellington, *e.g.*, *Potamogeton Cheesemanii*, *P. ochreatus*, *Myriophyllum elatinoides*, and *M. intermedium*—and on the margin there may be a zone of *Scirpus lacustris*. Next, *Typha angustifolia* may invade the lake, eventually converting it into a swamp, which, with decrease of water, is invaded by *Phormium tenax*. Finally such a swamp, as the vegetable matter accumulates, may be occupied gradually by manuka, and a manuka swamp or even heath result, such as described above. The vegetation of these lakes, swamps, and even manuka heaths has been most briefly dealt with, since they are associations found commonly without the dunes, and, the last-named excepted, do not affect to any great extent the dune economics.

(ε.) *Dry Hollows.*

Where the hollows are dry they are sandy, and liable to drift; also, any sand falling on them remains unwetted. Hollows such as these are early occupied by the sand-sedge (*Carex pumila*) (see Photo No. 39), which increases vegetatively at a great rate by means of its far-creeping, slender rhizome. The whole of a hollow is frequently so covered, the plant building miniature dunes if there is drifting sand. Nor is it confined to the dry sand alone, but occurs in plenty on the wetter ground, as mentioned before, where, if invaded by the sand, it increases rapidly, fixing the drift at the same time.

Carex pumila plays a very important part in dune economics in checking drifting sand, a part which I did not find recognized by any of the settlers, who do not appear to have any special name for the plant. Where it is present in quantity in a hollow there is certainly no need, so far as the moving sand there is concerned, to plant marram-grass, such procedure being in many instances unwise; for the sand-sedge, having fixed the drift, is soon reinforced by certain introduced plants, even white clover eventually appearing, whereas the marram has little value as a food, and may give rise to new dunes liable finally to "wander." Dry hollows where there is coarse sand, as at Fortrose, Southland, contain an abundance of the low cushions or mats of *Raoulia australis*, usually a river-bed or scoria-desert plant. This is of no importance as a fodder plant, but is a rapid former of humus, and so of considerable economic value. The deep-rooting *Geranium sessiliflorum* is a common Southland and also Stewart Island plant.

(ζ.) *Rapid Drift on to Sand-plain.*

Where there is a rapid increase of blown sand *Carex pumila* will be buried, but generally the indigenous sand-grasses appear, and dune-building commences, the further progress of the hollow towards heath or meadow ceasing. *Spinifex hirsutus* in some parts of the Wellington dunes builds up hundreds of small hillocks side by side—a most curious sight. *Scirpus frondosus* also plays its part, and *Spinifex* may be altogether absent. The sand tussock-grass (*Festuca littoralis*) is also a plant of sandy hollows, constructing ephemeral dunes. Here, too, there will be *Calamagrostis Billardieri* and frequently *Mariscus ustulatus* (but not south of Nelson or Marlborough) and *Scirpus nodosus*.

The sand-catching shrubs also occur under these circumstances—indeed, it depends upon the rapidity and volume of the drift whether sand-grasses or shrubs—*i.e.*, heath eventually—are established. But if the drift continue unabated, the embryonic sand-grass dunes will rise higher and higher, and a new dune-chain come into being out of the wreck of those behind.

If the drift is on to a heath—and this is very frequently the case—the shrubs, being at the best poorly equipped as sand-binders, will soon be buried; but *Phormium tenax*, and especially *Arundo conspicua*, will make a brave fight and, rising up as they are buried, perhaps remain holding small dunes for months or even years. This is especially the case not in hollows particularly, but on the shallow sands of the Auckland cliff-dunes, when these are set in motion by cattle, &c. There many almost pure associations of toetoe (*Arundo conspicua*) occupy fair-sized areas.

(η.) *Stony Plain* (see Photo No. 40).

In places not far from the sea, between the mouths of the Rivers Wanganui and Wangaehu, and to the south of the River Waitotara, the cliff has been weathered flat; and a plain results, covered with sand-cut stones of various sizes, a small yellowish gravel, and coarse sand. The remains of the rock is still to be seen, shaped by the flying sand into tables, pyramids, or beehive-like forms, or flattened quite to the ground. Midway between the Wanganui and Wangaehu larger portions remain, showing the ancient surface, and covered with shrubs and stunted trees, part of the original vegetation probably before the weathering took place. Nothing can be more desert-like than this stony plain, especially where it extends for hundreds of acres east of the River Waitotara, from near the sea-cliffs to the dunes some half-mile or more distant inland.

The vegetation reminds one more of the desert near Mount Ruapehu than of that of the dunes. Everywhere there are dotted about the shrubs *Pimelea laevigata* and *Coprosma accrosa* in about equal quantities, and both flattened to the ground. The *Coprosma* has long woody roots running parallel to the surface, a plant 7 in. by 5 in., having a root more than 3 ft. long. The branches are in small wiry mats, with the thick linear leaves pressed close to the stem. In the lee of each plant is a tongue of sand (see Photo No. 41). The *Pimelea* is pale-green in colour, and contrasts with the yellow *Coprosma*. The plants are about a yard apart. Here and there are cushions of the silvery *Raoulia australis*. *Spinifex hirsutus* forms lines in places, as does *Scirpus frondosus*, but this is where the sand is finer. The small grass *Zoysia pungens* forms colonies here and there, its wiry rhizome spreading through the sand and gravel. Other plants present are tussocks of *Festuca littoralis* and small yellowish cushions of *Scleranthus biflorus*. A slight breeze drives the sand along the ground, but in a gale much flies high into the air, striking one's face with stinging force.

The vegetation of the old land-surface, as seen on the summit of table-like hills south of Wanganui, consists of the ngaio (*Myoporum laetum*), the mapau (*Rapanea Urvillei*), the shrubby corokia (*Corokia Cotoneaster*), the akeake (*Dodonaea viscosa*). All are much wind-swept, and the *Myoporum*, elsewhere generally a small round-headed tree, is almost prostrate.

(iv.) Inland Dunes.

(a.) *Central Otago.*

There is little plant-life on the rapidly drifting sands of Otago. As the sand advances over the tussock-clad plain it collects in great tongues on the lee side of the tussocks of *Poa caespitosa* or *Festuca rubra* var., as the case may be, and as the drift continues these tussocks grow upwards, much after the manner of marram-grass. This is the more remarkable as it is no hereditary adaptation on the part of the tussock-form, for that is "adapted" for a quite different end. *The tussock is, in fact, a potential sand-binder.*

Where the soil has all blown away, and an old river-bed once more brought to the surface, the ground is soon thickly studded with the cushions of *Raoulia lutescens*, and as the sand blows away from their sides the cushion-form becomes more accentuated. Further wind-action cuts away the windward side of the cushions, and a few small grasses and stunted sorrel grows in their lee.

(β.) *Canterbury Plain.*

The low dunes near the Rivers Waimakariri and Rakaia are occupied by *Phormium tenax*, kowhai (*Sophora microphylla*), toetoe (*Arundo conspicua*), *Cassinia fulvida*, *Discaria toumatou*, *Scirpus nodosus*, and *Poa caespitosa*.

(γ.) *Volcanic Plateau.*

A full account of the dunes of the volcanic plateau are given in my report on the Tongariro National Park (89, p. 25). Here it need only be pointed out how certain plants with potential sand-binding adaptations build dunes 6 ft. or more tall. The plants are various subalpine and alpine shrubs, which grow elsewhere for the most part under quite different circumstances. When nature has made these desert dunes stable, even the tree *Nothofagus cliffortioides* settles at times upon them, but of course merely as stunted examples.

(δ.) *Ancient Dunes of Stewart Island.*

These, again, are sufficiently dealt with in another of my reports (92, p. 26), so that a brief mention will suffice. Many parts are covered with a heath ecologically equivalent to that, not of dunes altogether, but rather of the boggy or wet heath of the Auckland gumfields. An interesting member of their vegetation is the tiny taxad *Dacrydium laxifolium*.

(ε.) *Ancient Dunes near the Bluff Harbour, Southland.*

Between these ancient dunes and the actual estuary there is a considerable extent of bog. The sand is covered with a steppe or semi-steppe vegetation. Tussocks of *Danthonia Raoulii* are abundant. There is some stunted bracken-fern (*Pteridium esculentum*), a heath-plant. The following plants, few of which are found on dunes proper, are common: *Helichrysum bellidioides*, *Blechnum penna marina* (small creeping fern, generally subalpine), and *Gaultheria perplexa*. Certain heath-plants more or less common on dunes are also present—*e.g.*, *Gnaphalium filicaule*, *Dichondra repens*, *Pimelea laevigata*, and *Styphelia Fraseri*. The instructive feature is, from the point of view of this report, *that increase of humus-content, owing to climate and long stability of dune, permits a non-dune vegetation to flourish naturally.*

(B.) FLORISTIC BOTANY.

(a.) GENERAL REMARKS.

It is not an easy task to decide as to what species should be cited as actually belonging to the dunes, since some occurring there are very rare indeed, and probably only temporary occupants, while others are present only on the border-land of the dune-area and belong perhaps to some adjacent association.

According to my list the number of dune species is 147, of which 82 are endemic, 43 Australian, and 15 South American, leaving out the cosmopolitan element in the two latter cases. Fifty-one families and 104 genera are represented. The most important families are: *Compositae* 20 species, *Gramineae* 16, *Cyperaceae* 12, *Umbelliferae* 7, *Myrtaceae* and *Campanulaceae* 5, *Orchidaceae*, *Onagraceae* and *Halorrhagaceae* 4.

With regard to the species, only about 50 are common dune-plants, of which 15 are confined, or nearly so, to the dune-area, the remaining 97 occurring only occasionally, or being more or less local in their distribution. Within the botanical region the distribution, according to the botanical provinces, is as follows: Kermadec 26, Northern 113, Central 124, Southern 118, Chatham 58, Subantarctic 16. But these figures refer to the distribution generally in the botanical provinces, and not to the dune species alone, of whose numbers the following is an approximation: Kermadec 5, Northern 100, Central 92, Southern 90, Chatham 19, Subantarctic 6. With regard to vertical distribution, 60 species do not ascend above 1,000 ft., of which about 42 may be considered true coastal plants, 22 above 2,000 ft., 26 above 3,000 ft., and 39 are alpine or subalpine and occur at 3,000 ft. and upwards.

(*b.*) LIST OF THE INDIGENOUS SPERMOPHYTA AND PTERIDOPHYTA OF THE NEW ZEALAND DUNES.

EXPLANATION OF ABBREVIATIONS USED.

N = northern botanical province of New Zealand. C = central botanical province of New Zealand. S = southern botanical province of New Zealand. Ker = Kermadec botanical province of New Zealand. Ch = Chatham Islands botanical province of New Zealand. Sub. = the Subantarctic botanical province of New Zealand. Aus = Australian and Tasmanian (one or both). S.A. = South American and Subantarctic, excluding the New Zealand portion (one or both). Pol. = Polynesian. Mal. = Malayan or South Asian (one or both). Cos. = generally distributed in temp. (= temperate) or trop. (= tropical) lands. Plants confined to the dunes, or nearly so, are printed in bold type. Plants specially common on the dunes are marked with an asterisk. 0 = occurring at not more than 1,000 ft. altitude. 1 = occurring at not more than 2,000 ft. 2 = occurring at not more than 3,000 ft. 3 = occurring up to 3,000 ft. and upwards.

Species, Family, &c.	Maori Name.	English Name.	Distribution.				Growth-form.	Remarks.
			Beyond New Zealand, or Endemic.	Within New Zealand.	Altitude.	Plant Association of Dunes.		
FILICES.								
**Pteridium esculentum* Forst. f. (Cookayne)	Rau-aruhe; rahurahu	Common bracken	Aus., S.A.	Ker., N., C., S., Ch., Sub.	3	Heath; grass dune	Fern, with stout creeping underground stem.	
Nephrodium unitum R. Br.			Cos. trop.	N., C.	1	Sand-hollow, moist	Fern, with creeping rhizome	Except for a few localities in the Aupouri Peninsula, is confined to vicinity of hot springs.
SCHEUZERIACEAE.								
Triglochin striata Ruiz & Pav. var. *filifolia* (Sieb.) Buchenau		Three-ribbed arrow-grass	Aus., S.A.	N., C., S., Ch.	0	Sand-hollow, moist	Herb, small, stoloniferous.	
GRAMINEAE.								
Imperata Cheesemanii Hack.			End.	Ker.	0	*Pes caprae* dune	Grass, tall.	
**Zoysia pungens* Willd.			Aus., Mal., E. Asia	N., C., S.	1	Semi-stable dune; sand-hollow; grass dune	Grass, small, matted with long creeping rhizome	Not on dunes of the south.
***Spinifex hirsutus** Labill.		Silvery sand-grass	Aus., New Cal.	N., C.	0	Sand-grass dune	Grass, sand-binder	As far as Gore Bay in the south.
Microlaena stipoides R. Br.		Meadow rice-grass	Aus., Norf. I.	N., C., S.	1	Grass dune	Grass, medium, creeping rhizome.	
***Calamagrostis Billardieri** (R. Br.) Steud.			Aus.	N., C., S., Ch.	0	Sand-grass dune; sand-hollow	Grass, moderate, tufted.	
Dichelachne crinita (Forst. f.) Hook. f.		Long-haired plume-grass	Aus., Norf. I.	Ker., N., C., S., Ch.	2	Grass dune	Grass, tall, tufted.	
Danthonia pilosa R. Br.		Purple-awned oat-grass	Aus.	Ker., N., C., S., Ch.	3	Grass dune	Grass, medium, tufted.	
—— var. *racemosa* Buch.			End.	N., C., S.	1	Grass dune	Grass, medium, tufted.	
**—— *semiannularis* R. Br.		Common oat-grass; danthonia	Aus.	N., C., S., Ch.	3	Grass dune	Grass, medium, tufted.	
Eleusine indica Gaertn.			Cos. trop.	Ker.	0	*Pes caprae* dune	Grass, medium, annual	Also naturalized in central and northern botanical provinces.
**Arundo conspicua* Forst. f.	Toetoe-kakaho	New Zealand reed	End.	N., C., S., Ch.	2	Semi-stable dune; shrub dune	Tussock-grass of immense size, semi-sand-binder.	
Poa pusilla Berggr. var. *seticulmis* (Petrie) Cockayne var. nov. = *P. seticulmis* Petrie in Trans. N.Z. Inst. 34, p. 391, 1902			End.	N., C., S.	2	Grass dune	Grass, tufted, small.	
—— *caespitosa* Forst. f.		Common tussock-grass	Aus.	N., C., S.	3	Semi-stable dune; inland dunes	Tussock-grass, tall, semi-sand-binder	Only on dunes in the south.
***Festuca littoralis** Labill.		Sand-fescue	Aus.	N., C., S., Ch.	0	Sand-grass dune; sand-hollow	Tussock-grass, tall, semi-sand-binder.	
—— **Coxii** (Petrie) Hack.		Chatham Island fescue	End.	Ch.	0	Sand-grass dune; sand overlying rock	Grass, medium, creeping rhizome	Originally probably common, but now almost confined to ledges of rock covered with sand.
***Bromus arenarius** Labill.		Seaside brome-grass	Aus.	N., C.	0	Dune-hollow; semi-stable dune	Grass, small, annual.	
CYPERACEAE.								
**Mariscus ustulatus* (A. Rich.) C. B. Clarke	Toetoe-upoko-tangata; toetoe-whatumanu		End.	Ker., N., C., S.	0	Dune-hollow	Tussock, tall	Not on southern dunes
Elaeocharis neo-zealandica C. B. Clarke			End.	N., C.	0	Dune-hollow	Rush-like, small, semi-sand-binder.	
**Scirpus filiformis* Savi		Nodding club-rush	Cos.	N., C., S., Ch., Sub.	1	Dune-hollow	Rush-like, tufted, small.	
**—— *nodosus* (R. Br.) Rottb.		Stiff club-rush	Aus., S.A., S. Africa, Lord Howe I., Amsterdam I., St. Helena	Ker., N., C., S., Ch.	1	Sand-grass dune; sand-hollow; grass dune	Tussock, rush-like, tall.	
—— **frondosus Banks & Sol.	Pingao		End.	N., C., S., Ch.	0	Sand-grass dune	Sedge-like, sand-binder.	
—— *americanus* Pers.		Three-square	Aus., S.A., N. America, S. Europe	N., C., S., Ch.	0	Sand-hollow	Rush-like, moderate, with creeping rhizome.	
**Schoenus nitens* Poir var. *concinnus* (Hook. f.) Cheesem.			End.	C., S.	2	Sand-hollow	Rush-like, small, with creeping rhizome, semi-sand-binder.	Common on Wellington and Canterbury dunes.
Cladium Vauthiera C. B. Clarke			End.	N., C., S.	1	Heath	Rush-like, tufted.	
**Carex ternaria* Forst. f.		Cutting-grass	End.	N., C., S., Sub.	3	Grass dune; sand-hollow	Grass-like, tall, with stoloniferous rhizome.	
**—— *testacea* Sol.		Slender sedge	End.	N., C., S.	3	Sand-hollow	Grass-like, medium tufted.	
—— *lucida* Boott.		Shining sedge	End.	Ker., N., C., S.	2	Sand-hollow	Grass-like, medium tussock.	
—— **pumila Thunb.		Dune-sedge	Aus., S.A., E. Asia	N., C., S., Ch.	0	Sand-hollow	Grass-like, sand-binder.	
RESTIONACEAE.								
**Leptocarpus simplex* A. Rich.	Oioi	Yellow rush	End.	N., C., S., Ch.	1	Sand-hollow	Rush-like, tall, tussock	Inland only at hot springs on volcanic plateau.
JUNCACEAE.								
Juncus maritimus Lam. var. *australiensis* Buch.		Sea-rush	Aus.	N., C., S.	0	Sand-hollow	Rush, of tussock-form, tall	Inland at certain places in hot-springs district.
LILIACEAE.								
**Cordyline australis* (Forst. f.) Hook. f.	Ti; tikauka	Cabbage-tree; palm-lily	End.	N., C., S.	2	Shrub dune; grass dune	Tuft-tree.	
**Phormium tenax* Forst.	Harakeke	New Zealand flax	Norf. I.	N., C., S., Ch.	3	Shrub dune; sand-hollow	Iris-like, very tall.	
—— *Cookianum* Le Jolis	Whaririki	Hill-flax; mountain-flax	End.	N., C., S.	3	Sand-hollow	Iris-like, very tall	Not common on dunes.
IRIDACEAE.								
**Libertia ixioides* Spreng.	Turutu; maanga-a-huripapa; tukauki	Common libertia	End.	N., C., S., Ch.	1	Sand-hollow	Iris-like, medium, creeping beneath ground.	

(b.) LIST OF THE INDIGENOUS SPERMOPHYTA AND PTERIDOPHYTA OF THE NEW ZEALAND DUNES—*continued.*

Species, Family, &c.	Maori Name.	English Name.	Distribution.		Altitude.	Plant Association of Dunes.	Growth-form.	Remarks.
			Beyond New Zealand, or Endemic.	Within New Zealand.				
ORCHIDACEAE.								
Thelymitra longifolia Forst.	Makaika	Common thelymitra	Aus.	N., C., S., Ch., Sub.	3	Sand-hollow; heath	Grass-like, tuberous.	
Orthoceras strictum R. Br.			Aus.	N., C.	2	Heath	Grass-like, tuberous.	
Microtis unifolia (Forst. f.) Reichen.	Maikaika	Onion-leaved orchid	Aus., Norf. I.	Ker., N., C., S., Ch.	2	Heath; sand-hollow	Rush-like, tuberous.	
Prasophyllum pumilum Hook. f.			End.	N.	0	Heath	? Rush-like, tuberous.	
URTICACEAE.								
Parietaria debilis Forst. f.			Cos.	Ker., N., C., S., Ch.	2	Shrub dune	Herb, low, annual.	
PROTEACEAE.								
Knightia excelsa R. Br.	Rewarewa	New Zealand honeysuckle	End.	N., C.	2	Heath	Tree, tall	On dunes quite a low tree a few feet tall.
POLYGONACEAE.								
Rumex neglectus T. Kirk		Sea-shore dock	End.	C., S., Ch., Sub.	0	Moving dune	Herb, low, far-creeping	Only on dunes of Auckland Islands.
**Muehlenbeckia complexa* (A. Cunn.) Meissn.	Pohuehue		End.	N., C., S.	1	Grass dune; shrub dune	Shrub, low, dense or liane.	
CHENOPODIACEAE.								
Chenopodium glaucum L. var. *ambiguum* (R. Br.) Hook. f.		Oak-leaved goosefoot	Aus.	N., C., S.	0	Sand-hollow	Herb, prostrate, spreading.	
Salsola Kali L.			Cos.	N., C., S.	0		Subshrub, low.	
AIZOACEAE.								
Mesembrianthemum australe Sol.	Horokaka	Ice-plant; pigsface	Aus., Norf. I., Lord Howe I.	Ker., N., C., S., Ch.	0	Semi-stable dune near sea	Subshrub, trailing and rooting	Not particularly common on dunes.
Tetragonia trigyna Banks & Sol.		Climbing New Zealand spinach	End.	Ker., N., C., S., Ch.	0	Grass dune	Subshrub, semi-liane	Only occasionally on dunes.
CARYOPHYLLACEAE.								
**Scleranthus biflorus* (Forst.) Hook. f.	Kohukohu		Aus.	N., C., S.	3	Sand-hollow	Herb, of cushion-form.	
RANUNCULACEAE.								
Clematis marata J. B. Armstrong			End.	N., C., S.	3	Heath	Liane, slender	Dunes of east Canterbury, climbing over *Discaria toumatou*.
Ranunculus recens T. Kirk			End.	C., S.	0	Sand-hollow	Herb, small, rosette-form	Hitherto only found on dunes of western Wellington, Taranaki, and Southland, but not abundant.
*—— *acaulis* Banks & Sol.		Shore-buttercup	S.A.	N., C., S., Ch., Sub.	1	Sand-hollow	Herb, small, with creeping underground stems, rosette-form	Not particularly common on dunes.
DROSERACEAE.								
Drosera auriculata Backh.		Climbing-sundew	Aus.	N., C.	1	Heath	Liane, herbaceous, tuberous	Only in north.
ROSACEAE.								
**Acaena novae-zealandiae* T. Kirk		Red piripiri; red New Zealand burr	End.	N., C., S., Ch.	2	Semi-stable dune; shrub dune; heath	Subshrub, prostrate, spreading	Bitter considers this a subspecies of *A. Sanguisorbae*.
—— —— var. *pallida* T. Kirk			End.	C.	0	Semi-stable dune	Subshrub, prostrate, spreading	Dunes, Lyall Bay, Wellington.
—— (*microphylla* Hook. f.) ?			End.	S.	0	Grass dune; semi-stable dune	Subshrub, forming dense patches	Dunes of Southland.†
LEGUMINOSAE.								
Carmichaelia australis R. Br.	Whakaka	Red-seeded broom	End.	N., C.	2	Shrub dune	Shrub, medium, with flat assimilating stems	Only on northern dunes, where it is common.
—— (*subulata* T. Kirk) ?			End.	C., S.	0	Shrub dune	Shrub, medium, with terete assimilating stems	Dunes of Canterbury.
—— *flagelliformis* Col.		Slender New Zealand broom	End.	N., C., S.	2	Grass dunes; shrub dunes	Shrub, with leafless assimilating stem	Dunes of Wellington.
GERANIACEAE.								
Geranium sessiliflorum Cav.		Short-flowered cranesbill	Aus., S.A.	C., S.	3	Semi-stable dunes	Herb, small, of rosette-form	Dunes of Southland and Stewart Island.
OXALIDACEAE.								
Oxalis corniculata L. var. a.			End.	N., C.	0	Semi-stable dunes	Herb, small, procumbent.	
—— —— var. *ciliifera* (A. Cunn.) Hook. f.			Cos.	N., C., S.	0	Grass dunes	Herb, small, erect.	
*—— —— various other forms			?	Ker., N., C., S.	0	Grass dunes	Herb, small, creeping.	
LINACEAE.								
**Linum monogynum* Forst. f.	Rauhuia	White flax	End.	N., C., S., Ch.	1	Semi-stable dunes; shrub dunes	Subshrub, low, erect.	
EUPHORBIACEAE.								
***Euphorbia glauca** Forst. f.	Waiuatua	New Zealand spurge	Norf. I.	N., C., S., Ch.	0	Sand-grass dune	Herb, tall, sand-binder.	
CORIARIACEAE.								
**Coriaria ruscifolia* L.	Tutu; tupakihi	Common tute	S.A.	Ker., N., C., S., Ch.	3	Heath; grass dune	Shrub, or small tree, spreading habit.	
—— *thymifolia* Humb. & Bonpl.		Thyme-leaved tute	S.A.	C., S.	3	Semi-stable dune	Herb or subshrub, with creeping underground stem.	Only on Stewart Island dunes.
CORYNOCARPACEAE.								
Corynocarpus laevigata Forst.	Karaka; kopi (Chatham Island)		End.	Ker., N., C., Ch.	0	Ancient stable dune	Tree, low	Not a common dune-plant even in position indicated.
SAPINDACEAE.								
Dodonaea viscosa Jacq.	Akeake		Cos. trop.	N., C., S., Ch.	0	Shrub dune; heath; ancient stable dune	Tree, low	Frequently merely a shrub, or prostrate on dune. Not a common dune-plant.
RHAMNACEAE.								
Pomaderris phylicaefolia Lodd.	Tauhinu		Aus.	N., C.	2	Heath	Shrub, low, spreading.	
**Discaria toumatou* Raoul	Tumatukuru	Wild-irishman	End.	N., C., S., Ch.	3	Heath; sand-hollow	Shrub, divaricating, semi-deciduous	Not on northern dunes, except at Waikato Heads.
GUTTIFERAE.								
Hypericum gramineum Forst. f.			Aus., New Cal.	N., C., S.	1	Sand-hollow; grass dune	Subshrub, small, erect.	

† This plant varies much in leaf, especially in length of peduncle. A very distinct variety has quite sessile flowers hidden amongst the leaves. This form keeps, for years, its character under cultivation, both in my garden and in that of the late Mr. H. J. Matthews.

(b.) LIST OF THE INDIGENOUS SPERMOPHYTA AND PTERIDOPHYTA OF THE NEW ZEALAND DUNES—*continued.*

Species, Family, &c.	Maori Name.	English Name.	Distribution.			Plant Association of Dunes.	Growth-form.	Remarks.
			Beyond New Zealand, or Endemic.	Within New Zealand.	Altitude.			
VIOLACEAE.								
***Viola Cunninghamii* Hook. f.**	..	Common New Zealand violet	Aus. ..	C., S., Ch. ..	3	Fixed dune ..	Herb, small, open rosette-form	Dunes near Colac, Southland.
Melicytus ramiflorus Forst.	Mahoe	Whitewood; cowleaf	Pol., Norf. I.	Ker., N., C., S.	2	Ancient fixed dune	Tree, low	North Island dunes, but not common.
THYMELAEACEAE.								
***Pimelea arenaria** A. Cunn.	Aute-tauranga; toroheke	Sand-pimelea ..	End. ..	N., C., S., Ch.	0	Semi-stable dune; shrub dune	Shrub, low, dense ..	Not on Stewart Island or Southland dunes.
—— *laevigata* Gaertn.	..	Common pimelea ..	End. ..	N., C., S. ..	3	Dune-hollow; heath; grass dune	Shrub, small, procumbent.	
—— *Lyallii* Hook. f.	..	Lyall's pimelea ..	End. ..	C., S. ..	3	Semi-stable dune ..	Shrub, procumbent ..	Only on dunes of Southland and Stewart Island.
MYRTACEAE.								
**Leptospermum scoparium* Forst. ..	Kahikatoa; manuka	Red tea-tree ..	Aus. ..	N., C., S., Ch.	3	Ancient fixed dune; heath; sand-hollow	Shrub, tall.	
*—— *ericoides* A. Rich.	Kanuka; manuka	White tea-tree ..	End. ..	N., C., S. ..	2	Heath; sand-hollow; ancient fixed dune	Shrub or tree, tall ..	Always a shrub on the exposed dune.
—— *lineatum* (T. Kirk) Cockayne sp. nov. = L. *ericoides* var. *lineatum* T. Kirk in Students' Flora, p. 158	..	Narrow-leaved tea-tree	End. ..	N.	0	Heath; sand-hollow	Shrub, low or medium ..	This differs from *L. ericoides* in its being always a shrub, in its very narrow linear silky leaves and small flowers. It is constant over wide areas, and is recognized from *L. ericoides* at a glance.
Metrosideros lucida (Forst. f.) A. Rich. ..	Rata	Southern rata; ironwood	End. ..	N., C., S. Sub.	3	Dune forest ..	Tree, medium	Only on dunes (western) of Stewart Island, and formerly in some parts of Southland.
—— *tomentosa* A. Rich.	Pohutakawa ..	Christmas-tree ..	End. ..	N.	1	Fixed dune; semi-stable dune	Tree, medium	Very rare on dunes, and especially where not stable. Extends on west for short distance into central province.
ONAGRACEAE.								
**Epilobium Billardierianum* Ser.	..	Red-stemmed willow-herb	Aus. ..	N., C., S., Ch.	0	Sand-hollow, moist ..	Herb, erect, moderate.	
—— *junceum* Sol.	..	Narrow-leaved willow-herb	Aus. ..	N., C., S. ..	3	Sand-hollow ..	Herb, erect, moderate.	
—— *confertifolium* Hook. f.	..	..	End. ..	Sub. ..	1	Fixed dune ..	Herb, creeping	Dunes of Auckland Islands.
*—— *nerterioides* A. Cunn.	..	Wrinkled willowherb	End. ..	N., C., S., Ch., Sub.	2	Sand-hollow ..	Herb, creeping.	
HALORRHAGACEAE.								
Halorrhagis incana Walp.	..	..	End. ..	N.	0	Heath	Herb; semi-erect, low.	
—— *procumbens* Cheesem.	..	..	End. ..	N., C., S. ..	1	Heath	Herb, prostrate.	
**Myriophyllum Votschii* Schindler ..	..	..	End. ..	N., C., S. ..	1	Sand-hollow, moist ..	Herb, minute.	
***Gunnera arenaria** Cheesem. ..	..	Sand-gunnera ..	End. ..	N., C., S. ..	0	Sand-hollow, moist ..	Herb, creeping, forming patches.	Especially abundant in western Wellington.
ARALIACEAE.								
Stilbocarpa Lyallii J. B. Armstrong ..	..	Stewart Island stilbocarpa	End. ..	S.	0	Fixed dune ..	Herb, large, terete, far-spreading stolons	Only noted on dune at Stewart Island.
UMBELLIFERAE.								
Hydrocotyle americana L.	..	American marsh-pennywort	S.A., N. America	N., C., S. ..	1	Sand-hollow ..	Herb, small, creeping ..	Dunes of Southland occasionally.
—— *novae-zealandiae* D.C.	..	New Zealand marsh-pennywort	End. ..	N., C., S. ..	3	Sand-hollow ..	Herb, small, creeping ..	Var. *robusta* occurs in the north of Auckland and is a lowland plant.
*—— *asiatica* L.	..	Asiatic marsh-pennywort	Cos., Subtrop	N., C., S., Ch.	2	Sand-hollow ..	Herb, small, creeping.	
Apium prostratum Lab.	..	Wild celery ..	Aus., S.A., Tristan Da Cunha, S. Africa	Ker., N., C., S., Ch., Sub.	0	Sand-hollow; semi-stable dune	Herb, moderate, prostrate	Not particularly common as a dune plant.
—— *filiforme* (A. Rich.) Hook.	..	Slender celery ..	End. ..	N., C., S. ..	0	Sand-hollow ..	Herb, small, prostrate.	
**Crantzia lineata* Nutt	..	Common crantzia ..	Aus., S.A., N. America	N., C., S., Ch.	2	Sand-hollow, wet ..	Herb, small, creeping.	
Aciphylla squarrosa Forst.	Taramea; kurikuri	Speargrass ..	End. ..	C., S. ..	3	Fixed dune ..	Herb, of yucca-form ..	On some of the Southland dunes.
CORNACEAE.								
Griselinia littoralis Raoul	Kapuka; papaumu	Broadleaf	End. ..	N., C., S. ..	3	Fixed-dune forest ..	Tree, low	Stewart Island, Mason Bay.
EPACRIDACEAE.								
**Styphelia fasciculata* (Forst. f.)	Mingimingi ..	Tall bearded heath ..	End. ..	N., C., S. ..	3	Heath	Shrub, tall	Very frequently prostrate on the dunes. Absent on southern dunes.
Epacris pauciflora A. Rich.	Koputotara ..	..	End. ..	N., C. ..	1	Heath	Shrub, medium.	Only on northern dunes.
Dracophyllum Urvilleanum A. Rich. ..	..	..	End. ..	N., C. ..	0	Heath	Shrub, medium.	Only on northern dunes.
MYRSINACEAE.								
Rapanea Urvillei (A. D.C.) Mez. ..	Mapau; tipau ..	Red mapau, matipo, or maple	End. ..	N., C., S. ..	2	Ancient dune in forest	Tree, small.	
Suttonia chathamica (F. Muell.) Mez. ..	Matipo	Chatham Island matipo	End. ..	S., Ch. ..	0	Dune forest ..	Tree, small, or shrub ..	As dune-plant in Stewart Island on old dune, Old Neck.
PRIMULACEAE.								
Samolus repens (Forst.) Pers. var. *procumbens* R. Knuth	..	Southern water-pimpernel	Aus., S.A., Norf. I.	N., C., S., Ch., Sub.	0	Sand-hollow ..	Herb, creeping.	
GENTIANACEAE.								
Gentiana saxosa Forst. f.	..	Coastal gentian ..	End. ..	S.	0	Fixed dune ..	Herb, prostrate.	Only on dunes of Southland and Stewart Island.
CONVOLVULACEAE.								
**Ipomaea pes caprae* Roth.	..	..	Cos. trop. ..	Ker. ..	0	*Pes caprae* dune ..	Herb, prostrate.	
Calystegia Soldanella (L.) R. Br. ..	..	Shore-convolvulus ..	Cos. temp. ..	Ker., N., C., S., Ch.	1	Sand-grass dune ..	Herb, sand-binder.	
Dichondra repens Forst.	..	..	Cos. trop. and Subtrop.	N., C., S., Ch.	2	Grass dune ..	Herb, small, creeping.	
BORRAGINACEAE.								
Myosotis antarctica Hook. f. var. *Traillii* T. Kirk	..	Small-flowered forget-me-not	End. ..	S.	0	Semi-stable dune ..	Herb, small, prostrate ..	Only on some of the Southland and south-west dunes of South Island.

(*b.*) LIST OF THE INDIGENOUS SPERMOPHYTA AND PTERIDOPHYTA OF THE NEW ZEALAND DUNES—*continued.*

Species, Family, &c.	Maori Name.	English Name.	Distribution.			Growth-form.	Remarks.
			Beyond New Zealand, or Endemic.	Within New Zealand.	Altitude.	Plant Association of Dunes.	
LABIATAE.							
Mentha Cunninghamii Benth.	..	New Zealand mint ..	End. ..	N., C., S., Ch.	3	Grass dune ..	Herb, small, prostrate.
SOLANACEAE.							
Solanum nigrum L.	..	..	Cos. ..	Ker., N., C., S., Ch.	1	Sand-hollow ..	Herb, medium, erect.
SCROPHULARINACEAE.							
Mazus pumilio R. Br.	..	..	Aus. ..	N., C., S. ..	0	Sand-hollow, moist	Herb, small, with creeping underground stem
Glossostigma elatinoides Benth.	..	..	Aus. ..	N., C., S. ..	2	Sand-hollow, moist	Herb, minute, forming matted patches.
**Limosella tenuifolia* Nutt.	..	..	A u s., S.A., N. America, Europe	N., C., S. ..	2	Sand-hollow ..	Herb, minute, forming patches.
MYOPORACEAE.							
Myoporum laetum Forst. f.	Ngaio	..	End. ..	Ker., N., C., S., Ch.	0	Dune forest, semi-stable dune	Tree, small .. ..
PLANTAGINACEAE.							
Plantago Raoulii Deone.	Kopakopa ..	Raoul's plantain ..	End. ..	N., C., S. ..	3	Grassed dune ..	Herb, small, of rosette-form.
—— *triandra* Berggr.	..	..	End. ..	C., ? S. ..	3	Sand-hollow ..	Herb, small, of rosette-form
—— —— var. *Hamiltonii* T. Kirk ..	..	..	End. ..	S.	0	Sand-hollow ..	Herb, small, of rosette-form.
RUBIACEAE.							
***Coprosma acerosa** A. Cunn. ..	Patarahake ..	Dune-coprosma ..	End. ..	,N., C., S., Ch.	0	Shrub dune; sand-grass dune	Shrub, low, divaricating habit.
CAMPANULACEAE.							
Pratia angulata (Forst. f.) Hook. f. ..	Panakenaki ..	Creeping-pratia ..	End. ..	N., C., S. ..	3	Stable dune ..	Herb, small, creeping.
—— *arenaria* Hook. f.	..	Big-fruited pratia ..	End. ..	Ch., Sub. ..	0	Stable dune ..	Herb, small, creeping ..
**Lobelia anceps* L. f.	..	..	Aus., Norf. I.	Ker., N., C., S., Ch.	0	Sand-hollow ..	Herb, small, erect ..
Wahlenbergia saxicola (P. Br.) A. D.C. ..	..	New Zealand blue-bell	Aus. ..	C. S. ..	3	Semi-stable dune ..	Herb, small, creeping ..
—— *gracilis* (Forst. f.) A. D.C. ..	..	Slender blue-bell ..	Aus., Norf. I.	Ker., N., C., S., Ch.	3	Grass dune ..	Herb, medium, erect, annual or perennial.
GOODENIACEAE.							
**Selliera radicans* Cav.	..	Creeping-selliera ..	Aus., S.A. ..	N., C., S. ..	2	Sand-hollow ..	Herb, small, creeping.
COMPOSITAE.							
**Leucophora pumila* (Forst. f.) Cheesem. ..	Papataniwhaniwha	New Zealand daisy ..	End. ..	Ker., N., C., S., Ch., Sub.	2	Sand-hollow ..	Herb, small, creeping.
Olearia Solandri Hook. f.	..	..	End. ..	N., C. ..	0	Shrub dune ..	Shrub, medium.
—— *Traversii* (F. Muell.) Hook. f. ..	..	Chatham Island ake-ake	End. ..	Ch. ..	0	Dune forest ..	Tree, low.
Celmisia longifolia Cass.	..	Common celmisia ..	Aus. ..	N., C., S. ..	3	Grass dune ..	Herb, small, erect, rosette-form
**Gnaphalium luteo-album* L.	Pukatea ..	White cudweed ..	Cos. ..	Ker., N., C., S., Ch., Sub.	2	Sand-hollow; shrub dune	Herb, small, erect, annual.
Raoulia australis Hook. f.	..	Silvery raoulia ..	End. ..	C., S. ..	3	Sand-hollow; stable dune	Herb, small, forming raised mat
—— sp. aff. *R. Monroi* T. Kirk ..	..	..	End. ..	S.	0	Sand-hollow; stable dune	Herb, small, forming mat
—— *Monroi* Hook. f.	..	..	End. ..	C., S. ..	3	Grass dune ..	Herb, small, forming patches
Helichrysum bellidioides (Forst. f.) Willd. ..	..	Mountain-daisy ..	End. ..	C., S., Ch., Sub.	3	Grass dune ..	Herb, small, creeping ..
***Cassinia retorta** A. Cunn.	..	..	End. ..	N.	0	Shrub dune; heath	Shrub, medium.
—— *leptophylla* (Forst. f.) R. Br. ..	Tauhinu-korokio ..	Cottonwood ..	End. ..	C.	0	Shrub dune; heath	Shrub, medium.
—— *fulvida* Hook. f.	Tauhinu; taihinu	..	End. ..	C.S.	3	Shrub dune; heath	Shrub, medium.
Cotula coronopifolia L.	..	Swamp cotula ..	Cos. ..	N., C., S., Ch.	0	Sand-hollow, moist	Herb, small, semi-erect.
**—— dioica* Hook. f.	..	Salt-meadow cotula ..	End. ..	N., C., S., Sub.	3	Sand-hollow ..	Herb, small, creeping.
—— *pulchella* T. Kirk	..	..	End. ..	S.	0	Sand-hollow ..	Herb, small, creeping ..
Erechtites quadridentata (Labill.) D.C. ..	..	..	Aus. ..	N., C., S., Ch.	3	Sand-hollow ..	Herb, tall, erect.
Senecio lautus Forst. f. var. *s.*	..	..	Aus., Norf. I.	Ker., N., C., S., Ch.	0	Semi-stable dune ..	Herb, small, erect.
—— *rotundifolius* (Forst. f.) Hook. f. ..	Puheritaiko ..	Round-leaved shrubby groundsel	End. ..	S.	3	Sand-hollow ..	Shrub, tall .. ..
Sonchus littoralis (T. Kirk) Cockayne ..	..	Coastal sowthistle ..	End. ..	N., C., S. ..	0	Sand-grass dune ..	Herb, large .. ..
—— **grandifolius** T. Kirk	..	Chatham Island sow-thistle	End. ..	Ch. ..	0	Sand-grass dune ..	Herb, large.

Remarks.
Local in distribution, and rare in actual dune-areas.
Rarely occurs on the active dune.
Canterbury dunes occasionally.
South dunes in places.
Only on Auckland Island dunes.
Not on southern dunes.
A form which is probably var. *congesta* Cheesem., occurs on the semi-stable dune at Fortrose.
Have only noted this on ancient southern dunes.
Extends into northern province for a short distance.
Only on Southland dunes.
Dunes of Canterbury.
Southland dunes only, and rare.
Not on Southland or Stewart Island dunes.
Only Southland and Stewart Island dunes.
Stewart Island dunes.
Stewart Island dunes.
Now almost confined to sand on ledges of rock; probably eaten out by stock.

(c.) LIST OF NATURALIZED PLANTS OF THE NEW ZEALAND DUNE-AREAS, EXCLUDING TREES, SHRUBS, AND ORNAMENTAL PLANTS OF GARDENS, PLANTATIONS, ETC.

GRAMINEÆ.

Panicum sanguinale L. (finger-grass).
Crus-galli L. (cockspur-grass).
Stenotaphrum glabrum Trin. (buffalo-grass).
Phalaris canariensis L. (canary-grass).
Anthoxanthum odoratum L. (sweet vernal-grass).
Alopecurus pratensis L. (meadow-foxtail).
Polypogon monspeliensis Desf. (beard-grass).
Agrostis tenuis Sibth. (*A. vulgaris* With.), (red-top).
Agrostis alba L. (florin).
Ammophila arenaria Lk. (marram-grass).
Lagurus ovatus L. (harestail-grass).
Holcus lanatus L. (Yorkshire fog).
mollis L. (soft grass).
Aira caryophyllea L. (hair-grass).
Cynodon Dactylon Pers. (doab-grass).
Eragrostis Brownii Nees.
Briza minor L. (trembling-grass).
Dactylis glomerata L. (cocksfoot).
Cynosurus cristatus L. (dogstail).
Poa pratensis L. (meadow-grass).
Festuca Myuros L. (barren fescue-grass).
bromoides L.
Bromus sterilis L. (barren brome-grass).
hordeaceus L. (soft brome-grass).
racemosus L.
unioloides H. B. & K. (prairie-grass).
Elymus arenarius L. (lyme-grass).
Lolium perenne L. (rye-grass).
italicum A. Br. (Italian rye-grass).
Agropyron repens Beauv. (couch-grass).
Hordeum murinum L. (barley-grass).

CYPERACEÆ.

Kyllinga brevifolia Rottb.
Cyperus tenellus L. f.
vegetus Willd.

IRIDACEÆ.

Iris germanica L. (German iris).

POLYGONACEÆ.

Rumex obtusifolius L. (common dock).
pulcher L. (fiddle-dock).
crispus L. (curled dock).
sanguineus L (red-veined dock).
acetosella L. (sorrel).

CHENOPODIACEÆ.

Chenopodium album L. (fathen).
murale L.

PHYTOLACCACEÆ.

Phytolacca octandra L. (poke weed).

AIZOACEÆ.

Mesembrianthemum edule L. (Hottentot fig).

PORTULACACEÆ.

Portulaca oleracea L.

CARYOPHYLLACEÆ.

Silene anglica L. (*S. gallica* L. p. 1067 Cheeseman's Flora), (catchfly).
Lychnis coronaria Desr. (rose-campion).
Cerastium viscosum L. (*C. glomeratum* Thuill.), (mouse-ear).
vulgatum L. (*C. triviale* Link), (larger mouse-ear).
Stellaria media Cyr. (chickweed).
Minuartia serpyllifolia (L.) (*Arenaria serpyllifolia* L.), (sandwort).
Sagina procumbens L. (pearlwort).
apetala L. (pearlwort).
Spergula arvensis L. (spurrey).
rubra J. & C. Presl. (sand-spurrey).
Polycarpon tetraphyllum L. (four-leaved allseed).

RANUNCULACEÆ.

Ranunculus aquatilis L. (water-buttercup). Abundant in dune lakes of western Wellington.
Ranunculus sceleratus L. (cursed crowfoot).
repens L. (creeping buttercup).
sardous Crantz (hairy buttercup).

PAPAVERACEÆ.

Eschscholtzia californica Cham.

CRUCIFERÆ.

Radicula Nasturtium-aquaticum Brit. and Rend. (*Nasturtium officinale* R. Br.), (watercress).
Alyssum maritimum Lam. (sweet alyssum).
Sisymbrium officinale Scop. (hedge-mustard).
Capsella Bursa-pastoris Medic (shepherd's purse).
Coronopus didymus Sm. (wart-cress).
Lepidium ruderale L. (narrow-leaved cress).
Cakile maritima Scop. (sea-rocket).

ROSACEÆ.

Rubus fruticosus L. (in its wide acceptation), (blackberry).
Acaena ovina A. Cunn.
Rosa rubiginosa L. (sweetbriar).
canina L. (in its wide sense), (dog-rose).

LEGUMINOSÆ.

Lupinus arboreus Sims (tree-lupin).
Ulex europæus L. (gorse).
Cytisus scoparius Link. (broom).
candicans Lam. (Cape broom).
Medicago lupulina L. (black medick).
maculata Willd. (spotted medick).
Melilotus Petitpierreana Hayne and Willd. (*M. arvensis* Wallr.), (field melilot).
Trifolium arvense L. (harefoot-clover).
scabrum L. (rough clover).
glomeratum L. (clustered clover).
repens L. (white clover).
resupinatum L. (reversed clover).
procumbens L. (hop-trefoil).
dubium Sibth. (yellow suckling).
Vicia sativa L. (common vetch).
hirsuta S. F. Gray (common tare).

GERANIACEÆ.

Geranium molle L. (soft cranesbill).
Erodium cicutarium L'Herit. (stork's bill).
moschatum L'Herit (musky stork's bill).

LINACEÆ.

Linum marginale A. Cunn.

MALVACEÆ.

Lavatera arborea L. (tree-mallow).
Malva rotundifolia L. (dwarf mallow).
parviflora L.
verticillata L.
Modiola multifida Moench.

LYTHRACEÆ.

Lythrum hyssopifolia L. (hyssop loosestrife).

ONAGRACEÆ.

Oenothera odorata Jacq. (evening primrose).

GENTIANACEÆ.

Centaurium umbellatum Gilib. (*Erythræa centaurium*), (centaury).

BORRAGINACEÆ.

Myosotis cæspitosa Schultz.

VERBENACEÆ.

Verbena officinalis L. (vervain).

LABIATÆ.

Mentha Pulegium L. (pennyroyal).
Prunella vulgaris L. (self-heal).
Marrubium vulgare L. (horehound).

SOLANACEÆ.

Solanum sodomoeum L. (Dead-sea apple).

SCROPHULARINACEÆ.

Verbascum Thapsus L. (mullein).
Veronica arvensis L. (wall speedwell).
Bartsia viscosa L. (marsh painted-cup).

OROBANCHACEÆ.

Orobanche minor Sutt. (broom-rape).

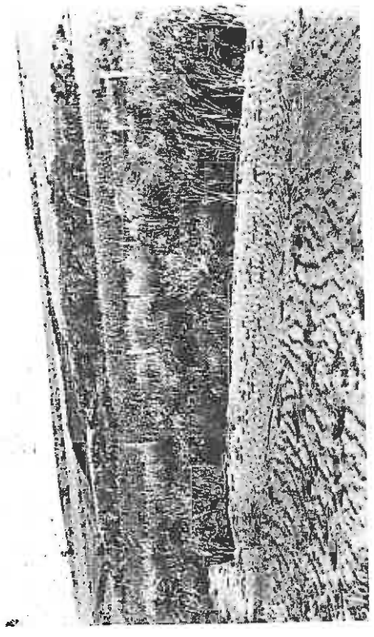
PLANTAGINACEÆ.

Plantago major L. (greater plantain).
lanceolata L. (rib-grass).
hirtella H. B. & K.

COMPOSITÆ.

Erigeron canadensis L. (Canadian fleabane).
Achillæa millefolium L. (yarrow).
Anthemis Cotula L. (stinking mayweed).
Senecio vulgaris L. (groundsel).
Cryptostemma calendulaceum R. Br. (Cape weed).
Cnicus lanceolatus Willd. (Scotch thistle).
Lapsana communis L. (nipplewort).
Crepis capillaris Wallr. (*C. virens* L.) (smooth hawk's-beard).
Hypochoeris radicata L. (catsear).
Sonchus arvensis L. (corn sowthistle).
asper.
Taraxacum officinale Wigg. (dandelion).

No. 43. TREE-LUPIN (*Lupinus arboreus*) GETTING BURIED AND KILLED BY A SMALL WANDERING DUNE. DUNES OF CANTERBURY. [*Photo L. Cockayne.*

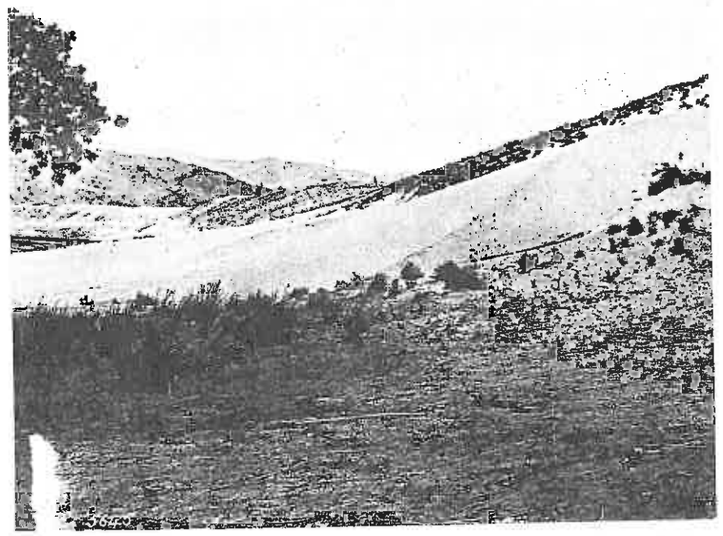


No. 42. WHEATFIELD THREATENED BY A DEEP DRIFT FROM A WANDERING DUNE, WHICH HAS PARTIALLY FILLED A SWAMP IN FRONT. [*Photo L. Cockayne.*

To face page 42.]

No. 44. GENERAL VIEW OF OCEAN BEACH DUNE NOW HELD BY TREE-LUPIN. [*Photo L. Cockayne.*

No. 45. Coarse Sand remaining, the fine having been blown away. Alexandra Dunes.
[*Photo L. Cockayne.*



No. 46. Source of the Cromwell Sand. Dunes below Terrace of River Clutha.
[*Photo L. Cockayne.*

PART II.—THE RECLAMATION OF THE DUNES.

I. INTRODUCTION.

(*a.*) GENERAL.

As seen from the preceding part of this report, the dunes of New Zealand are no longer in their virgin condition. Large areas which were firmly fixed by nature when the early settlers arrived are now in a state of great instability, and not only useless in themselves but daily encroach upon, and so render valueless, the neighbouring fertile ground (see Photo No. 42). The checking of such encroachment is obviously the first aim of dune-reclamation in this country. But the amelioration of the sand-areas goes much further than this, and *the final goal should be their improvement as a whole through their occupation by a continuous plant covering that shall be of commercial value.*

The methods in vogue for the artificial fixation of dunes are based altogether upon those which nature herself uses. Thus a clear grasp must be gained of the following fundamental principles which clearly follow from the geological and botanical data of Part I:—

1. The motion of the surface under the influence of frequent wind is the essential factor which has to be met in dune-cultivation.
2. No motion of the sand can occur if the surface be altogether covered by either a living or a dead covering.
3. When the surface of the sand is wet no movement is possible.
4. On drifting sand, only sand-binding plants can become permanently established.
5. A sand-binding plant is a perennial which has the power of growing above the sand as it is buried, and putting forth new roots from the rising stem.
6. Where there is no drift a close covering of almost any plants will hold the surface, but those of long life, such as trees, are the most efficacious.
7. Non-sand-binding plants such as tree-lupin and forest-trees will be buried by a drift, and a moving naked dune will result. It follows then that before trees be planted the drift should be stopped.
8. Two contiguous hills will lead to the presence of a wind-channel, in which the air is compressed and has special erosive power.
9. Any prominence rising above the general level of the surface is liable to damage by the wind.
10. Building of isolated mounds by the uneven planting of sand-binding plants may finally lead to their destruction in accordance with principles 8 and 9.
11. Dunes are always moist at a few inches below the surface, so there is little fear of death from drought by plants tolerant of dune conditions once they are established.
12. Plants which form an abundance of humus are of special value, since they not only increase the cohesion of the sand-grains but supply nutritive matter and a water-holding mulch.
13. Burning, grazing of animals, and indeed anything that can damage the plant covering or disturb the surface may lead to the movement of the sand.
14. Every blade of grass, unevenness of the surface, or obstacle of any kind helps to break the force of the wind.
15. Average sand-dunes without any manure whatsoever will support a remarkable number of species.*

The experience of considerably more than a hundred years in Europe, and the more recent attempts to cope with drifting sand (United States, Cape Colony, Australasia), have proved beyond a doubt that the most efficacious of sand-binding plants is marram-grass (*Ammophila arenaria*), a native of Europe, North Africa, and North America, and that when it is planted correctly drifting sand, even where the winds are exceptionally violent, can be fixed. There is therefore no need for the experimental planting of other sand-binders in the first instance, except under exceptional circumstances. Gerhardt in his most exhaustive treatise goes into the various methods of planting marram-grass at great length and with much detail. Although I have drawn upon his work freely, I have refrained from quoting his methods at length, since many details and excessive minutiæ would deter those for whom this report is intended from commencing the work of sand-planting, as being too technical and difficult. Some of the methods herein advocated may seem crude to the European planter, but, so far as I can judge, they have been efficacious in New Zealand, and possess the merit of simplicity and comparative cheapness.

Notwithstanding that certain methods of dune-reclamation are recommended by me, it must not be concluded that success depends upon any hard-and-fast rules. To be sure, the general principles detailed above must not be violated, but the local climate of any particular locality, a knowledge of the intensity of the wind and its average direction, the degree of coarseness of the sand, the selection of material for sand-fences, and so on—all these matters will be the concern of the local "sand-planter," while his experience and sound judgment will have an important bearing upon his success.

* In certain instances there are layers of more fertile soil within the dunes; in other cases the dunes overlie clay, loam, rock, &c. Thus a plant growing apparently in pure sand may have its ultimate rootlets in a much more nourishing soil.

Further, there are places where planting is much easier than in others, and success on these areas must not be taken as measures of what are suitable elsewhere. For instance, although buffalo-grass (*Stenotaphrum glabrum*) is used with great benefit on the dunes near Tewaharoa, and the so-called ice-plant (*Mesembrianthemum edule*) grows on the foredune near Ahipara, it is certain that both these plants would be useless in most parts of the dunes of western Wellington, eastern Canterbury, or the north Waikato Head. Even the great success of the tree-lupin at New Brighton, Canterbury, and at Ocean Beach, Dunedin, does not sanction that shrub for universal use.

The New Zealand climate allows a very much wider choice of plants than do the dunes of Europe generally or of eastern North America. The tree-lupin (*Lupinus arboreus*) is a case in point. It can be grown with the greatest ease on pure sand in virtually any part of New Zealand. It forms dense thickets, grows readily from seed, and allows no sand to move where it is established, thus seeming an ideal sand-plant. And in consequence it is planted most extensively and bracketed along with marram-grass as a plant *par excellence* for sand-planting. This opinion, though true enough in certain cases, is equally false in others. It therefore seems well, before dealing specifically with methods of sand-planting, to compare the relative values of marram-grass and tree-lupin, and to explain the correct application of each.

(b.) MARRAM-GRASS AND TREE-LUPIN AS PLANTS FOR DUNE-FIXING.

(i.) MARRAM-GRASS.

Marram-grass owes its efficiency to its being a true sand-binding plant. It possesses a far-creeping and branching, stout, rather rigid, underground stem which gives off, so closely together that tussocks are formed, erect leaf-bearing branches. It also, but somewhat irregularly, puts out other underground stems of great length, which, extending horizontally, can build colonies of plants at a considerable distance from the parent tussock. The leaves are of a greyish-green colour tinged with blue. Their texture is thick and somewhat hard. The blade is rolled into a narrow pipe, so that the upper surface is quite hidden; but on moist cloudy days it can unroll and become more or less flat.* The under-surface is turned outwards, and is alone exposed to the wind and blowing sand. There is a long leaf-sheath which protects the young bud. The tussocks are about 3 ft. tall, but may be much smaller. As the shoots become buried by the drifting sand new roots are put down from the nodes, and the plant grows upwards above the sand, provided the drift is not too severe and prolonged. If this should happen, the leaves may be altogether buried, in which case the plant will probably die. But this is the exception rather than the rule. The grass is thoroughly attuned to the drifting sand, *without which it cannot exist*, and if the sand-supply fails altogether it will turn yellow, and finally succumb. When planted at a suitable distance the grass-bunches become sufficiently close in a year's time to virtually stop all surface-movement, and at the same time they will arrest the flying sand, and the ground-surface will be gradually raised.

There are many other foreign sand-binding grasses or grass-like plants besides marram—*e.g.*, the lyme-grass (*Elymus arenarius*), the Baltic marram (*Ammophila baltica*), the sand-sedge (*Carex arenaria*), the Chilian *Distichlis thalassica*, the North American *Agropyron dasytachyum*. Further, there are the indigenous sand-binders cited in Part I. *Elymus arenarius* is the only one of the above which has been introduced into New Zealand, but although an admirable plant in many ways, it is hardly needed where marram is available.

(ii.) TREE-LUPIN (see Photo No. 67).

Tree-lupin (*Lupinus arboreus*), a native of California, where it grows on the dunes of the Pacific coast, is not a sand-binder at all. *It consequently cannot exist where exposed to moving sand* (see Photo No. 43), *and is therefore worthless as a plant for such circumstances. When this fact is generally appreciated in New Zealand much money, time, and annoyance will be saved for the sand-planter.* The tree-lupin is a much-branched shrub of dense growth 8 ft. tall. The older branches are stout and brittle, the youngest slender, straight, flexible, juicy, and little-branched. The bark is purplish and smooth on branches of medium age, but finally becomes furrowed, on young branches it is purple on the upper and green on the under part. The leaves are rather distant, and are frequently borne on very short lateral stems. They have long, slender, flexible stalks. The blade is digitately divided into seven or eight linear-lanceolate leaflets, which are slightly glaucous-green in colour, and pubescent on the under-surface. The sides of the leaflets are frquently more or less folded together. It is by no means long-lived. When a number of these shrubs are growing closely side by side they form a most efficacious covering to the sand (see Photo No. 70), and, moreover, their dead twigs and leaves give rise to a considerable amount of humus. Further, the nodules on their roots contain bacteria which add nitrogen to the soil. Thus far tree-lupin is much better than marram-grass as a sand-fixer, and plays exactly the same *rôle* as a covering of trees, which is the ideal sand-holder. But when a body of sand advances, or a rapid drift attacks the lupin thicket, the sand first of all piles up against and among the marginal plants which arrest its progress, and, rising higher and higher, by degrees buries them, the ultimate branchlets alone jutting out of the sand. Were these able to root in the moist sand the plant would have a fresh existence, and, rising with the drift, would check the advance; but they can do nothing of the kind. If the drift continues, the sand advancing will, in time, submerge the whole plantation, pouring over its lee as a naked and wandering dune.

* This statement, which I take from Abromeit (18, p. 207) is questioned by F. W. Oliver, who has only noted the rolling of the leaf after it is plucked (120A, p. 296).

Where there is no drift, as when there is a well-fixed marram-area to the windward, nothing can be better than tree-lupin as a sand-covering. The ease with which it can be raised from seed is a most valuable property; and, in addition, the rapidity of growth of the seedlings renders it, in countries where it is hardy, one of the most valuable instruments in the hands of the sand-planter. At Ocean Beach, Dunedin, the sand facing the sand-supply—*i.e.*, the shore—has been well fixed in the first place by marram-grass; and behind this protection the lupin thrives amazingly, forming, too, a perfect covering to the sand, until such time as it shall be replaced by forest (see Photo No. 44).

At New Brighton, Canterbury, tree-lupin is not an unmixed blessing. In some places many acres are well fixed through its aid; in others it is rapidly being transformed into moving dunes (see Photo No. 67). It was planted some years ago, before the establishment of the artificial foredune, in the front garden of a house facing the beach; and, in consequence, a moving sandhill was formed, which came so close to the windows that the house had to be raised on piles a considerable number of feet.

In some parts of New Zealand, especially in the neighbourhood of the River Rangitikei, the farmers possessing sandy land look askance at tree-lupin, and will not use it for their dunes, fearing that it will seize on their sandy well-grassed hollows. It undoubtedly will spread and occupy such land if it is allowed in the first instance to increase; but there is no need to permit it to gain a foothold, and, even if it does so, *it is easily cut down, and there is no danger of its again growing from the stump.* It certainly seems to me that a plant which can do the best of work and be established much more cheaply than any other plant, should not be discarded without some better reason for so doing.

II. THE PRESENT CONDITION OF THE DUNE-AREAS.

Without an intimate acquaintance extending over many years with any special dune-area, let alone the whole sand region of New Zealand, it would be impossible to make a statement of any moment regarding its present condition as compared with that of long ago, or as to whether the ground as a whole is more or less stable than formerly. It is certain, however, that in the days of early settlement the greater part of the wandering dunes and the drifting sands as they now exist were wanting, and that in their place were hills clothed with a carpet of grass, with scrub, with waving toetoe, stately flax and cabbage-trees, while the hollows contained food for stock in abundance. But even in those early days drifting sand was not unknown, as evidenced by the account of the dunes in the neighbourhood of Wanganui published in 1849 by Lieutenant C. H. Smith and Lieutenant C. Hutchinson, who speak of the sand blowing in their faces, and of the numerous sandhills along the coast, which were very deep and "being drifted by the heavy gales." ("Notes on New Zealand," No. 6, p. 18; 1850.)

But, although comparative statements are of little moment, something can be said as to the present conditions of the dunes. It will be remembered that the various areas differ considerably in their topography, the extreme cases being those with a perennial supply of sand from the shore and those on the summits of cliffs, which receive little or nothing from the above source at the present time. Considering the former first, the foredune, although sometimes in an admirable state of preservation (see Photo No. 13), is very frequently indeed much damaged, in certain cases being altogether absent for considerable distances, as to the south of Reef Point, north-western Auckland (see Photo No. 21). Behind the foredune comes the area I have called the "dune-complex," which consists of chains of hills, isolated hills, and sand-hollows of various kinds. This area, taking the dunes of New Zealand as a whole, is probably changing very little. Of course, it is far from stable; hills are being eroded and blown away; bare masses of sand are slowly moving forward; sand-hollows are being filled up. But with the destruction goes on probably an almost equivalent construction; nor is there, generally speaking, any marked advance of this area inland.

Between the dune-complex and the most ancient and usually highest dunes, where the dune-area reaches its maximum, as in western Wellington, lie extensive sand-plains, the site of farms. These, of course, are being encroached upon to some extent, and in some cases to a dangerous degree. As for the ancient chains of dunes which abut in many cases upon first-class farm-lands—and the same applies to the cliff-dunes—they were originally admirably fixed by nature. At the present time many are still perfectly stable, and afford excellent pasturage for sheep. Others, again, have been transformed into typical wandering dunes with a long, flat, windward slope, and a great sandfall on the lee 100 ft. to 200 ft. or more in depth (see Photo No. 14). They advance slowly but surely, and bury all before them—fertile meadow-lands, cornfields, plantations, flax swamps; also, their lower portions may be rapidly blown over the lands adjacent as a sand-drift, burying and killing the grass covering.

The above account has also its bright side. Dunes, which some time ago must have been formidable enough, are in process of fixation on their lee slopes by plants which have come naturally. Toetoe-grass (*Arundo conspicua*) is doing admirable work in this regard, particularly on many of the dunes of western Auckland. Nor with regard to dune-amelioration must it be forgotten that the settlers themselves have in many instances done a good deal through planting-methods; but this is dealt with below.

The inland dunes of the Clutha valley, notwithstanding the work which has been expended on them, are still more or less troublesome. Those of Cromwell actually invaded the town, and the sand had to be carted away at great expense. The drift at the approach to the Bannockburn Bridge is very troublesome, the deep cutting which leads to the bridge being constantly choked by fine sand, the removal of which is a costly matter. At present, with the exception of the Alexandra dunes, the sand-supply from the River Clutha seems to have much diminished, and in addition vast quantities of fine sand have been blown away on to the distant hills, &c., leaving chiefly in many places only the very coarse sand (see Photo No. 45). One drift at Tarras is altogether gone, and the present one seems

to be losing its power, while the dunes proper are confined to the lee slope of certain terraces, to the source of the sand at Sandy Point (see Photo No. 63), and to the vicinity of the old accommodation-house. No sand is said to come from Sandy Point at the present time, and the presence of certain plants, especially of *Epilobium melanocaulon*, strongly support that statement. At Alexandra the dunes are well developed, and more active than elsewhere in the district. Rather than as moving dunes, it is as flying sand and as rapid drift that the Central Otago sand is most troublesome. Roads are buried, crops are damaged, rich soil is cut into and then blown away, and houses are made almost uninhabitable when the sand-storm rages.

So far as dune-reclamation in New Zealand goes, a good deal has been done here and there, but the patches are generally isolated, while vast stretches exist where nothing has been attempted as yet. In Taranaki many cliff-dunes which drifted some years ago have been stopped. Here, according to Mr. James Mackenzie, the sand-drifts have passed through their most dangerous state, and, with one or two exceptions, have been overcome by the regular planting of marram-grass. In western Wellington the younger dune-complex is, in nearly all cases, altogether unplanted. Planting has been carried out on the private lands to the lee of the above dune-complex, and in some instances with marked success, especially in the case of Mr. McKelvie, who has planted some hundreds of acres (see Photo No. 62). Here and elsewhere where tree-lupin has been used it has been planted without a true knowledge of its effect. There has been some planting on the Auckland dunes as far as Whangape Harbour, but it is much scattered; further north all is in the wild state.

The South Island dunes, generally speaking, are of less moment than those of the North Island. Marram-grass has been planted in many localities, but only a few examples can be cited here. At New Brighton, where the effect of the east wind is much felt, a long foredune has been established by the Town Council on the shore in front of the town. Tree-lupin has also been used with good results in many places, and probably some hundreds of acres are thus covered. In some places it is, however, in process of burial. At Ocean Beach, Dunedin, there is to be seen the most complete and successful example of dune-planting in New Zealand. Marram and tree-lupin combined have been used, together with a small foredune of marram-grass (see Photo. No. 47). The work here does not nearly approach in difficulty many other places on the New Zealand coast, but this does not detract from the excellent manner in which it has been carried out by the Domain Board. The Invercargill Town Council has done some marram-planting on the reserve near the head of the New River. This, unfortunately, I was only able to see from a distance. A little marram and tree-lupin have been planted in Central Otago—at Alexandra, Cromwell, and Tarras. At Cromwell the common tussock of the neighbourhood has been used, and grows remarkably well, as it also does naturally at Alexandra, but it would not tolerate a strong drift. A little marram has been planted near the road between Waiouru and Lake Taupo, where it passes over the Rangipo desert. Here the grass grows well in the pumice and ash, far from the sea.

As for tree-planting, nothing has been done on the younger dune-complex. There is an extensive plantation at New Brighton, Canterbury, consisting of a good many kinds of trees. There has also been much private planting, chiefly of *Pinus insignis*, on the more landward dunes. Here comes my former experiment-garden, where a good many different species of trees and shrubs not used elsewhere in dune-planting are growing vigorously (see Photo No. 48). Trees are now being planted on the Dunedin dunes by the City Council under the direction of Mr. D. Tannoch, and there is every chance of great success. It is hoped ultimately to have a forest facing the beach for its entire length. Earlier planting by the Dunedin Reserves Improvement Society showed the capabilities of these dunes for afforestation.

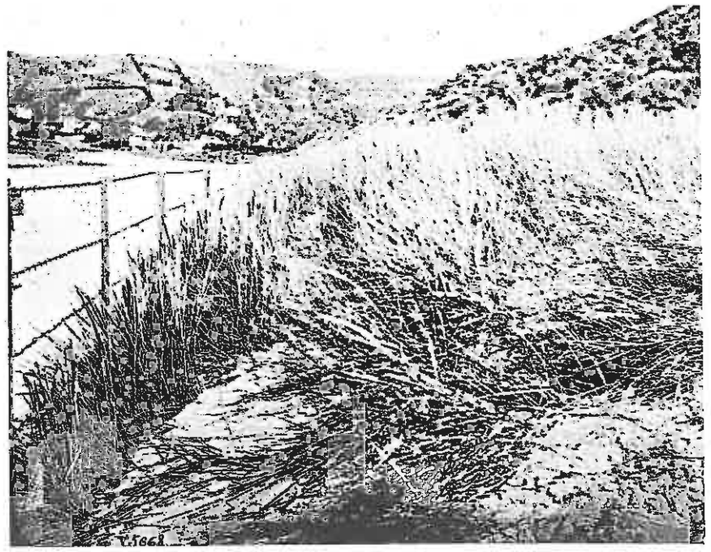
In the North Island there has been very little tree-planting on the dunes, and that mostly by private individuals. Near Foxton especially there are some fine plantations of *Pinus insignis*.

Generally speaking, there is not much to be learnt from the planting of New Zealand dunes. A great deal has been carried on in easy places. Other plantings are being blown away or buried. Some in difficult places appear to be successful, but they are mostly of no great age, and time alone will certify as to their efficacy. So far as the planting of tree-lupin is concerned, it has usually been quite futile, not because it did not grow, but because the planter did not know its correct application.

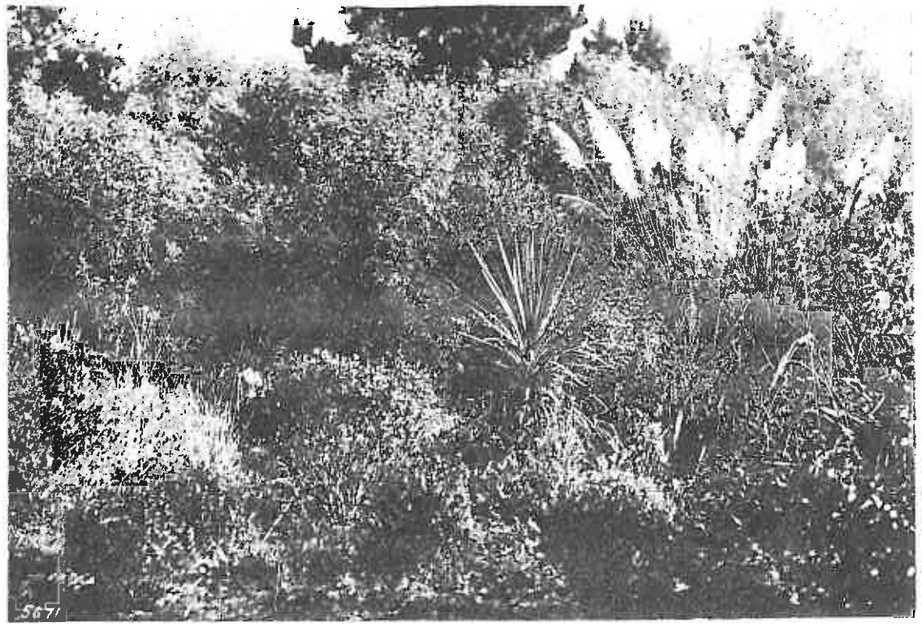
III. METHODS OF RECLAMATION.

(*a.*) GENERAL.

A great proportion of the dune-areas as they at present exist are, in the first place, a constant menace to the surrounding lands, and, in the second, are themselves valueless. Reclamation-methods seek to change this state of affairs, and to render them both harmless and profitable. This may be brought about by clothing them with a *continuous* plant covering, and the one which is most permanent and will yield the best income is undoubtedly forest. But in many places it is absolutely impossible to establish trees in the first instance, and in other places it would be, if not impossible, a work of the greatest difficulty, and altogether too costly to entertain. Other methods must then frequently precede afforestation. Further, as already pointed out, there are many acres of fertile land forming broad oases in the sandy wastes where there are valuable farms, and the protection of these is imperative. In Europe generally, whence come our methods of dune-reclamation, the protection of the coast-line and the treatment of the adjacent dune-area is the first need, just as it was at Ocean Beach, Dunedin; and European methods especially refer to such work. But in New Zealand the actual coast-line usually matters little at present. *The critical portions of the dune-areas are where the sand and farm-lands meet*, and those hollows in the dune-complex which are now grassed but liable



No. 47. Artificial Foredune, Ocean Beach, Dunedin.
[*Photo L. Cockayne.*



No. 48. Various Species of Australian Acacia. Experiment Garden of Author in March, 1903.
[*Photo A McIntyre.*

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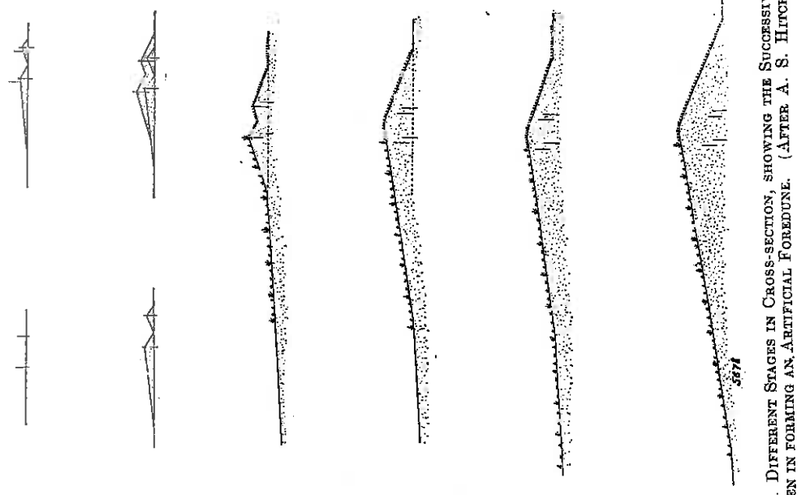
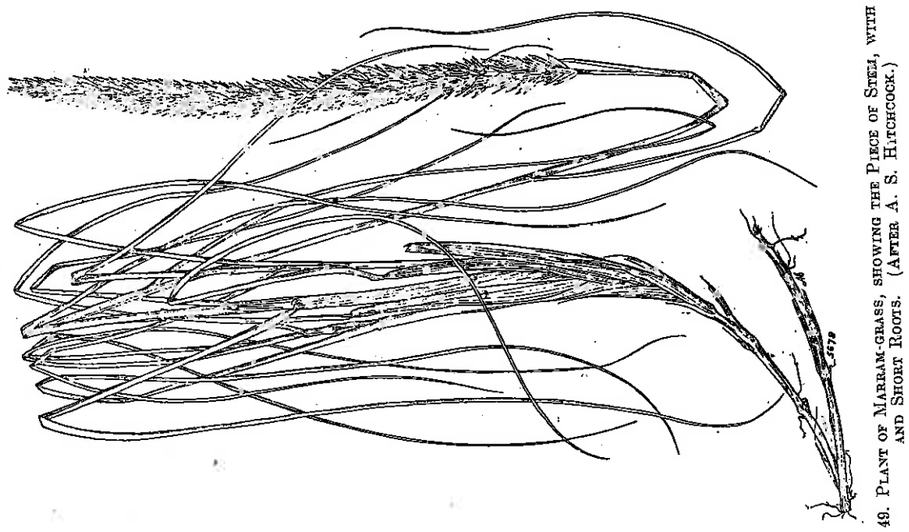


No. 50. Different Stages in Cross-section, showing the Successive Steps taken in forming an Artificial Foredune. (After A. S. Hitchcock.)



No. 49. Plant of Marram-grass, showing the Piece of Stem, with Nodes and Short Roots. (After A. S. Hitchcock.)

at any moment to a sand-invasion. *Methods for stopping drifting sand as quickly as possible are then the first requisite.* Next come the barren areas, much of them Crown land. In order to cope with these, operations on a much larger scale are demanded, so great indeed that *it is beyond the power of private individuals to deal with the question, and becomes one for the State.* Needless to say, if these areas are reclaimed the danger of sand-invasion would be enormously lessened, so that the work is one of no small value, even though the reclaimed areas should not be made specially reproductive.

It will be seen further on that irregular planting of marram-grass, &c., is considered worthless from the theoretical standpoint, since it leads to the formation of mounds followed by erosion, by wind-channels, and by ultimate destruction of the grass, and a revival of drifting sand. In point of fact, it seems to me that such planting is better than nothing. Shrub and grass dunes, as they now exist, arose from irregular planting by nature; and although a primitive dune-area was not exactly stable, it was sufficiently quiescent to have allowed the formation of hollows full of vegetation, and those soil-covered and well-grassed hills which attracted the farmer and, through his operations, have reverted to their primitive condition. *The chief objection to irregular and ill-conducted planting is that its results are but transitory. It is, in fact, money thrown away, when the same expenditure could produce permanent results* which would encourage the planter and others to continue their operations.

(*b.*) The Planting of Marram-grass.

(i.) Time of Planting.

Marram-grass planting must be carried on during autumn, winter, and early spring. Local conditions must determine the actual date of commencing, and this will be regulated, too, by the wetness or dryness of the particular year. It is evident that some seasons will be much more favourable than others, as so much depends upon the frequency of violent winds.

(ii.) Preparing the Plants.

If the planter has already the grass growing on his property, the supply for planting can be taken without damage from the most luxuriantly growing clumps. It can be easily pulled up by hand from the clumps, or taken up with a spade or mattock. Should there be no marram on the property, it should be procured from the nearest source. It is now grown more or less extensively on nearly all the New Zealand dunes, excepting those of the far north of Auckland, and can usually be easily procured. But it is best when collected near at hand, for it must be as full of vigour as possible when planted. Therefore it is well to plant preliminary patches on any piece of sand a year or two before extensive operations are undertaken. Also, by this means the expense of carting the grass for any considerable distance will be avoided.

After the grass is taken from the ground it should be pulled into pieces suitable for planting, or the pieces may be pulled directly from the growing bunch. Each plant must consist of a piece of the stem with the leaves attached, and the stem must have at its base one or, preferably, two nodes (see Photo No. 49). Without these latter there can be no growth, since from these the roots arise. *Young plants should be selected; those two years of age are the best.* The preparation for planting should be done on the spot, so as to combat the danger of the plants becoming dry, for the roots are extremely sensitive to the drying effect of wind and sun. The individual plants must be tied with a piece of flax (*Phormium tenax*) into bundles, each bundle being of such a size as to conveniently go under the arm. *No bundle must be left lying upon the surface, but all must be heeled into the moist sand near the scene of operations.* Before planting, many New Zealand planters by means of a sharp spade cut off the leaves, reducing the plants to about 1¼ ft. in length. The object of this is to protect the plant from being blown about by the wind before it is rooted. Transpiration is also greatly reduced during a critical period for the plant. Also, the reduced weight of the grass-bundles makes carting somewhat cheaper, as Mr. Dalrymple has explained in a valuable letter he wrote, at my request, regarding his methods of planting. This procedure is contrary to European or American practice, but I have certainly seen it followed by most excellent results.

(iii.) Methods of Planting.

(*a.*) *Spade Planting.*

Planting in New Zealand is carried out by means of spade, long-handled shovel, or plough. In any case two or more people are needed to best carry out the work, though one can do so, but much more slowly.

With regard to spade planting, the procedure is as follows: One man uses the spade, and makes a hole by thrusting the blade into the ground, and working the handle backwards and forwards until a V-shaped hole is made. The other worker (a boy may be employed), who carries the bundle of plants, inserts about six in the hole—but the actual number does not much matter—and flattens out the bunch. The first man inserts the spade in the ground just behind the hole, and pushes the sand tightly against the grass, gives a press with his foot (or the foot alone may be used for closing the hole), and the exceedingly simple operation is concluded. Sand for this method must be sufficiently moist, or the sides of the hole may fall in.

(*β.*) *Long-handled Shovel Planting.*

The long-handled shovel method as practised at New Brighton will suit any class of sand. There are again two workers. The one with the shovel takes out a shovelful of sand for the first hole. The planter places in position the small bundle of plants. The first man then digs a second hole, and fills the first hole with the sand from his shovel, and so on, the sand from one hole being used to fill the preceding. In each case the second worker presses the new ground tightly with his foot.

(γ.) *Plough Planting* (see Photos Nos. 58 and 66).

The plough method can only be used where there is sufficient room and the slope not too abrupt. Most of Mr. Herrold's excellent planting has been done in this manner, and certainly no fault can be found with his results. I cannot do better than describe Mr. Herrold's procedure in his own words :—

"The method of preparing plants is to pull out sufficient to make a bundle that can be comfortably carried under one arm. Lay all the roots evenly one way, then with a sharp spade the tops are cut off at a distance of from 12 in. to 15 in. from the top of the roots. The bundle is then tied up with flax and placed in the sand, until the number of bundles to do, roughly, a week's work at planting are secured. Planting with the plough is done by the ordinary plough making furrows 1 yard or 2 yards, as required, apart. The planters then come along, and, with the bundle of grass under one arm, pull out plants with the disengaged hand and drop them into the furrow a yard apart, at the same time pushing some sand over the roots with one foot. Usually within a week the wind completes the work of filling in the furrows. The depth of the furrow I generally try to make is not less than 6 in., and, as the plant is always lying down to a certain extent, as the sides of the furrow slope, about 6 in. to 9 in. would be left above ground. I find it better to be on the deep side with planting. In windy weather I generally pull plants, and in wet weather plant them."

The chief objection to the plough method, as pointed out to me by Mr. K. W. Dalrymple, is that the grass is planted obliquely, and so is in greater danger of burial and destruction by an excessive drift. Oblique planting was at one time advocated amongst European methods, in the expectation that more roots would be rapidly developed than by vertical planting; but this is said not to be the case, and the plan is now rarely adopted. The chief objection that I see in the plough method is that the loose covering of sand is liable to blow away and leave the plants bare, with consequently an excessive percentage of failures. Spade planting, on the contrary, leads to the plants being placed as firmly as possible in the sand. All things considered, then, in very windy positions spade planting or dibbling, described lower down, is to be preferred to any other method.

(δ.) *German Methods of Planting.*

The Germans, who have reduced marram-grass planting to almost mathematical accuracy, distinguish between "*bunch planting*" and "*line planting*." Bunch planting is divided into "*round bunch*" and "*flat bunch*" planting, according as the plants are inserted bunched up together in a round hole made with a special dibble, or a V-shaped hole made also with a special spade. The number of plants used per hole varies in different parts of their dunes from three to ten plants, and the holes vary in distance from about 1 ft. to 1 ft. 7 in. The dibble employed for round-bunch planting is about 3 ft. long, $3\frac{1}{5}$ in. in diameter, shod with iron for a distance of $2\frac{1}{4}$ ft., has a rounded apex, and is furnished with a cross-handle about $1\frac{3}{4}$ ft. long. The holes for planting are 1·4 ft. deep.

Line planting is thus described by Gerhardt: "By means of moving the spade not only backwards and forwards, but also to some extent right and left, the holes will become broader than the spade itself. A spade 16 cm. (6·4 in.) broad makes a hole about 20 cm. (8 in.) broad. On an average six plants can be apportioned to this breadth. These plants will then stand about 5 cm. (2 in.) from one another. If a space of about 10 cm. (4 in.) is left between each hole—*i.e.*, a distance of about 30 cm. (12 in.) from the centre of one hole to that of another—the stems and leaves of the plants will so spread out that a continuous line is formed. The rows are planted at right angles to the prevailing wind, against which they offer a greater resistance than do plants in holes separated from one another." It would be quite easy to plant in lines by the New Zealand plough method (see Photo No. 55).

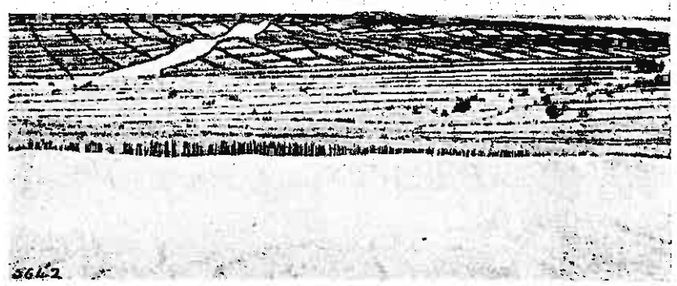
A still more efficacious method of combating excessive wind, especially when it comes from several quarters, is that called by Gerhardt "network planting." In this method the grass is planted in squares like a chess-board, the squares arranged at right angles and not obliquely to the prevailing wind. The squares are 2 m. (6 ft. 8 in.) broad, and within them a variable number of grass-bunches are planted. The number of bunches to be planted on the sides of each square, and the number inside, are varied according to the force of the wind they have to encounter.

(ε.) *Distance apart of the Bunches.*

The distance apart of the bunches in the usual bunch-planting as practised in New Zealand should differ according to the amount of sand likely to be brought by the wind. If the sand-supply is very abundant and the plants are set too closely they will grow so vigorously that they will choke one another out. At a distance of 3 ft. apart the bunches will touch in two to three years, according to circumstances. The foredune-planting at New Brighton is carried on at 1 ft. 6 in. apart. Probably a good distance is 2 ft.; but, of course, the closer the more expensive, and much more distant planting has been efficacious on many New Zealand dunes. The bunches should not be set one behind another, but alternately in adjacent rows. *Rows parallel to the prevailing wind should be avoided, for they lead to wind-channels.*

(c.) MANAGEMENT OF MARRAM-AREAS.

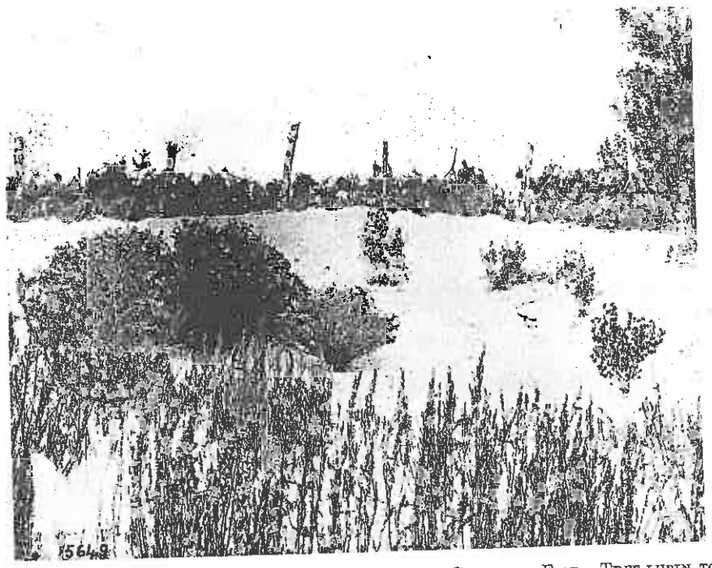
It is undoubtedly best if the area is fenced from stock. Still, this procedure is not absolutely necessary, and as it so much increases the expense it may generally be omitted. In Central Otago rabbits eat the grass to some extent, and should it be necessary to fence with rabbit-proof netting the expense of planting is very much increased. Where failures have occurred the blanks should be filled up later in the season if possible, and, if not, then during the succeeding year. *Lack of attention to a marram-planting is frequently the cause of its ultimate non-success.* Burning the tussocks should never be permitted. Certainly, they may grow again, unless overwhelmed before the new shoots appear; but, in any case, the shelter they afford—one of the reasons why marram is so valuable—is removed.



No. 51. Reed Wind-fences. (From Gerhardt.)

No. 52. Catching-fences. (From Gerhardt.)

To face page 48.]



No. 53. Catching-fence, 15 ft. tall, nearly buried. Cromwell Flat. Tree-lupin to left. Fat Hen in foreground. [*Photo L. Cockayne.*

No. 54. Catching-fence buried. Cromwell Flat. [*Photo L. Cockayne.*

Marram is not planted as a fodder plant. Dunes cannot be turned into pasture through marram alone. Although stock will feed on it when hungry, the nourishment they get is probably slight. *Marram is planted in the first place simply and solely to fix the unstable surface; and to do anything that can injure the grass is to build with one hand and pull down with the other.*

(*d.*) COST OF MARRAM-GRASS PLANTING.

Particulars as to cost are not easy to get. Mr. James Mackenzie in his manuscript report to the Lands Department cites £1 2s. 6d. to £1 10s. per acre as the price in Taranaki; but he says nothing as to the distance apart of the bunches or the rows. Mr. J. H. Herrold, of Waipipi, Auckland, tells me he gets his dunes planted by contract by Maori labour, by the plough method, at 15s. per acre—the bunches 3 ft. apart, and the rows 6 ft. For spade planting by hand, the bunches 3 ft. apart, he pays 17s. 6d. per acre. Planting at New Brighton, at 1½ ft. apart in all directions, costs at the rate of £8 per acre; but this is day-labour, for areas of a quarter of an acre or less. By contract on a larger scale it would be done for considerably less. Mr. K. W. Dalrymple informs me that in the Rangitikei district spade planting, with the plants 3 ft. apart, costs about £1 per acre if "the area to be planted is fairly compact, and the plants are handy—say, within a mile; if the plants have to be carted much more the cost would be a little more." Payment by the week Mr. Dalrymple considers more satisfactory than contract-work; but a reliable man must be in charge. The cost will be, in this case, £1 per acre. The wages are about £1 12s. 6d. and not found, or £1 2s. 6d. to £1 5s. and found, and the grass is carted to the ground. Boys and young men only are employed.

The cost of planting marram-grass upon the wandering dunes of the Kurische Nehrung is, according to Gerhardt, from about £3 8s. to £4 8s. per acre, but this includes collecting, delivering, and planting; but details are no stated as to methods or closeness of planting.

(*e.*) ESTABLISHING THE TREE-LUPIN.

Establishing seedling plants is a method not to be commended. The cheapest and most easy plan is to sow the seed. *This is best done by laying branches of lupin upon the bare sand as soon as the seed is ripe, or, better, just before it is going to be shed.* The lupin-branches cover the naked sand and prevent it moving, the seedlings germinate and grow rapidly, and before a year is past cover the ground with a close growth. Of course, this method can only be applied where the planter has an abundance of lupin on his ground. He must, then, make a preliminary plantation by sowing the seed on some sheltered part of his dunes, so as to have a future supply. Simply scattering the seed upon the ground may also be resorted to, and good results have been gained in this manner; but the wind buries and unburies the seed, the seedlings have no protection from sand-laden gales, and failure by this plan is not uncommon.

I can give no particulars as to cost of sowing tree-lupin per acre, but it cannot be great if the branches are to be got close at hand, and it should in that case be easily the cheapest method of dune-fixing. *But it must not be forgotten that it is but a quite temporary method if there be exposure to a drift.*

(*f.*) SAND-FENCES AND GROUND-COVERINGS.

(i.) General.

There are critical points in the dunes where it is extremely difficult to get even marram-grass to grow. There are also times when it is expedient temporarily to stop a moving dune, or to raise a sand-ridge. For these purposes obstacles that will break the force of the wind, or fix or catch the sand, are required.

To simply fix the sand for a time, anything that can cover the sand closely and will not blow away will suffice. In Europe heather is used for the purpose, as it grows naturally on the dunes. In New Zealand manuka, or "tea-tree," as it is often called, which is frequently abundant on many dune-areas, at once suggests itself. Or any of the dune-shrubs whose branches are heavy enough may be used. Pieces of manuka (*Leptospermum scoparium*), if laid closely upon the sand, will keep it altogether from drifting until such time as the twigs and leaves fall off and decay or drifting sand from the windward covers it. Broom, gorse, tree-lupin, *Cupressus macrocarpa*, and *Pinus insignis*, all of which are frequently available, at once suggest themselves as material for dune-fixing, through laying branches or portions of branches flat upon the sand. If the pieces are small they may be made to overlap one another, and a small amount of sand be placed on them to hold them in position.

For quite small areas nothing is better than covering the surface entirely with soil, having first by some means or another made the surface level. This method has been for a long time in operation at New Brighton, clay being used as the covering material. The whole surface of the town proper, formerly a badly drifting dune-complex, is now altogether stable, and but for the adjacent unreclaimed dunes no one could suspect the original character of the ground. The shelter of houses and fences has also helped in bringing about the above state of affairs.

Sand-fences are of the following two kinds: (1) Catching-fences, which are designed for holding the sand and building a dune; (2) wind-fences, which are used to break the force of the wind and hold the sand.

(ii.) Catching-fences.

Catching-fences can be made from the branches of manuka, pine-trees, *Cupressus macrocarpa*, or the like. Fairly straight branches are cut into pieces varying from 2 ft. to 3 ft. in length, according to requirements. The ends, if necessary, are sharpened, or this may be done by cutting off the piece obliquely. The side twigs are cut off roughly. The pieces are thrust into the sand, so that about 1 ft. is buried, side by side, in a row at right angles to the prevailing wind, and a space is left between each equalling its diameter. Much more elaborate and expensive sand-fences, constructed of stout posts, wire, and brushwood, sometimes 12 ft. or more high, have been occasionally used in New Zealand, but such great erections are quite needless and extremely expensive. Similar fences—just an odd fence here and there—have been used on the wandering dune, but are worse than useless, as they merely get buried and are of no value as shelter-fences (see Photo No. 68). In Central Otago where no sand covers the ground it will be necessary to erect post-and-wire fences, but they do not need to be more than 3 ft. or 4 ft. in height.

(iii.) Wind-fences.

Wind-fences are constructed out of similar material to catching-fences, but it must not be so stout. Any straight pieces of stick will serve, and the stalks of flax (*Phormium tenax*) or toetoe (*Arundo conspicua*) might be used. The pieces (rods) are set at twice the distance of those in the catching-fence—*i.e.*, at twice the diameter of the rods—or, where the wind is less powerful, at a greater distance still. The height above the ground should be about 1 ft., and about 6 in. beneath. Wind-fences are arranged in chess-board squares (see Photo No. 52), the size of which depends upon the capacity of the sand to drift, and may vary from 9 ft. to 12 ft. The squares should lie at right angles to the prevailing wind.

Wind-fences are chiefly used in Europe in afforesting the dunes. They have not been employed as yet in New Zealand, but there are certain places and conditions where their use might be very advantageous indeed.

Wind-breaks, but of less efficacy, could be made by thrusting quite short pieces of manuka, &c., into the ground in rows or squares, or by laying pieces of the same or other scrub in squares, and holding them in position with a little sand. (The above is taken in part from Gerhardt (18).

(*g.*) CHECKING SAND-MOVEMENTS.

(i.) Protection-belts.

The first need on the sand-areas, as already explained, is the protection of the fertile lands against sand-drifts, wandering dunes, and the frequent combination of both. Railway-lines, roads, and at times houses, demand similarly rapid protection.

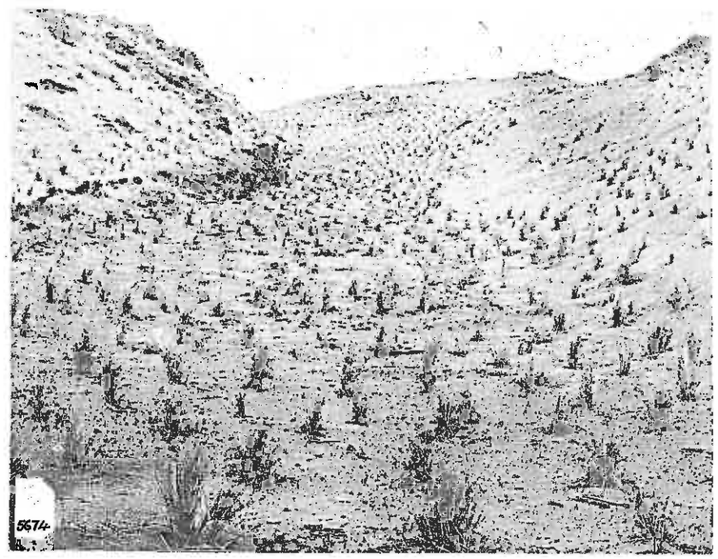
Where the need is very urgent, as when a town is threatened—*e.g.*, in the case of Cromwell, Central Otago—catching-fences should be erected across the line of sand-movement, so as to hold the sand by forming an even dune-line, which should be planted eventually with marram-grass as already explained, the bunches being from 1½ ft. to 3 ft. apart, according to circumstances. The Cromwell dunes have not been planted as yet except in a few scattered patches, and if the sand-supply is sufficient they will overtop the barriers and advance towards the town (see Photo No. 53). But probably this will not be the case, as the sand-supply is certainly diminishing, and many areas on the flat are now either quite bare or the sand is fixed by the indigenous tussock-grass. For advancing dunes of that kind tree-lupin is useless. Where a house is threatened, as is the case with such as stand directly on the dunes, planting a belt of marram a few yards broad will raise a hill to the windward of the house, the sand which has accumulated near the house will blow away, and the house will be secure both from the troublesome flying sand, which penetrates every crevice, and the danger of burial.

With regard to the invasion of fertile hollows amongst the dunes themselves, and to farm-lands just outside the actual dune-areas, the mischief has generally been allowed to increase to an alarming extent before any steps have been taken or much thought given to the matter. *The drift is, in nine cases out of ten, the result of some trivial damage by stock, or through burning, which, had it been attended to at once, would have cost but a few shillings. The early planting of all bare sand-patches which occur on the ancient well-grassed dunes would mean the saving of thousands of pounds* by preventing movements of the sand, which in a much shorter time than is generally supposed would become both very expensive and difficult to arrest. Above all things, it must be urged on the farmer to permit no bare patch of sand on his fertile land to remain untreated. These small bare patches may be covered with scrub, in which case, probably without any further care, the grass will return of its own accord. Or, to make sure, some grass-seed may be sown upon the patch and the sand then covered with scrub. Should the patch be larger it should be planted closely with marram-grass, with tree-lupin or annual lupin, as the case may require, and if it is likely to be damaged by stock a light barbed-wire fence should be put round it. Some farmers, very wisely indeed, attend to trivial sand-wounds at present, but the majority look upon these wounds as such a very small matter that they do nothing at all.

The sand-advance is of a twofold character. It may come slowly—a few yards or so yearly—as the lee face of a high wandering dune, or the advancing sand may be quite shallow and have blown for a long distance during some specially heavy gale. *In order to make the work permanent it is necessary to plant the whole of the bare sand* (see Photo No. 62). This may seem so large an order that the sand-owner might well shrink from undertaking it all at once, and not wrongly consider the cure worse than the disease. Therefore he must have recourse to *protection-belts*—by which I mean comparatively

No. 55. Marram-grass put in by the Plough by Mr. Herrold. Dunes South of Manukau Harbour.

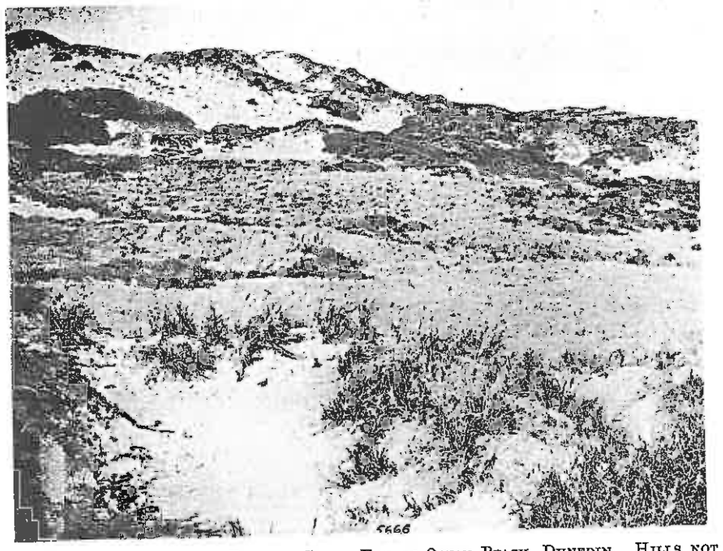
[*Photo L. Cockayne.*



No. 56. Successful Planting of Marram-grass in a Wind-channel. Plants rather too far apart. Cliff-dunes, South of Manukau Harbour.

[*Photo L. Cockayne.*

To face page 59.]



No. 57. Partly Reclaimed Dune at South End of Ocean Beach, Dunedin. Hills not planted.

[*Photo L. Cockayne.*

No. 58. Three-year-old Marram-grass planted by Plough by Mr. Herrold. Dunes South of Manukau Harbour.

[*Photo L. Cockayne.*

narrow bands of marram at the junction of the advancing sand and the invaded ground. It must not be forgotten that even where such belts grow and form a grass-covered ridge or series of ridges there will be a most abundant sand-supply from the naked sand to the windward; in fact, a protection-belt of this kind is in a better position for a large sand-supply than is even the foredune. Therefore there is no absolute safety until the whole of the sand to the windward is planted.

Planting, then, properly speaking, should commence at the source of the sand-supply. Where the latter is the shore an artificial foredune should be raised if the natural one is not sufficient, but where there is no communication with the shore, and where the area to be treated yields its own sand-supply, planting for permanency should begin at its windward boundary.

A protection-belt, however, may serve for many years, and it can always be repaired when damaged. Generally in New Zealand they are made too narrow, for the sake of cheapness. Experience alone will tell the best width under different circumstances of wind, rainfall, and weight of sand-grains. Possibly a chain might suffice in many cases. The area covered could be made much greater by the addition of tree-lupin, without adding much to the expense. In this case a dune at right angles to the wind should be formed by planting a belt of marram-grass, say, 12 yards wide; another such belt, but narrower, could be planted several chains to the lee of the last one, and other belts similarly. Between these belts tree-lupin could be sown by laying the seed-bearing branches upon the sand, as already directed. Possibly in many cases there would be no need for the secondary belts of marram-grass.

Where a wandering dune is slowly covering fertile land there is generally a considerable amount of sand at its base just beneath the dune-fall. This and the steep dune-fall (lee face) can be easily planted by spade. Planting the lee face is not alone sufficient, but the work must be extended beyond the ridge for a chain or more on the windward slope of the dune. In Germany, except very occasionally, wandering dunes are not planted with marram-grass, but are covered with a network of wind-fences, trees being planted in the squares (see Photo No. 51).

(ii.) The Foredune.

(α.) *General.*

The shore being the source of all the coastal sand, and a perpetual supply being brought daily by the sea, it is plain that in any comprehensive scheme dealing with the whole of a dune-area, such as would be the case if afforestation of a portion of the dunes were to be attempted by the Government, the sand blowing from the dry foreshore must be arrested and held. This is done at the present time to some extent by the existing first line of dunes, called in this report the "foredune." Further, where towns are built on the dunes, or have such in their vicinity that can damage public reserves, or where there are harbours or navigable water liable to be choked by drifting sand, attention to the foredune is imperative. On the other hand, generally speaking, such work is not the affair of a private individual.

In some parts the foredune is all that can be desired (see Photo No. 13), in other places it is badly in need of repair, while in others again it is wanting, or, if present, too far from the loose sand of the foreshore. It is therefore necessary in many cases to construct an artificial foredune. The position of this dune must be on the upper shore at some slight distance beyond the reach of the highest tide. The line of the dune must not conform to every indentation of the present dune-line, but must conform to the shore-line as a whole, and be as little arched as possible. Certain parts of the artificial foredune of Gascony extend for miles in a virtually straight line. The summit of the foredune must be as even as possible; there must be no mounds and depressions, and still less peaks rising above the general even level. A well-constructed foredune should possess a wide base, a low summit, and flat outer and inner slopes. Its function is to fix the unstable sand of the upper shore, to resist the action of the waves, to prevent sand passing inland, and to shelter the planting in its lee. As it is subject to a constant sand-drift, it is evident that it can be fixed only by sand-binding plants.

(β.) *Method of Construction.*

The most approved method of building a foredune is to erect a catching-fence such as already described, 2½ ft. in height, along the line the dune is to follow, and at a distance of 6 ft. 8 in. behind this to erect an exactly similar fence. In time, according to the sand-supply and the number of windy days, the sand will reach the top of the fences (see Photo No. 50), since they are sufficiently open to permit the wind to pass through, but, its velocity being decreased, the sand is dropped within and on both sides. A second pair of fences similar to the first are now fixed in the new dune a little to the seaward side of the first, and when they are buried the planting of marram-grass will take place. Such planting is done in Germany in squares 2 m. (6 ft. 8 in.) broad on the outer side, and on the inner side and crown in rows which are best at right angles to the direction of the dune. The grass, catching the sand, gives a fairly permanent shape to the dune, with a long gentle slope to the windward and a steep slope on the lee. (See Gerhardt, 18, pp. 368–400.)

The natural foredune can be made to serve in some cases. If so, the hills rising above the general level must be lowered by removing any vegetation and allowing the summit to blow away. Hollows must be filled up by the employment of short catching-fences.

According to A. S. Hitchcock (27), who visited many of the dune-areas of Europe on behalf of the Government of the United States, a foredune is not made either in Holland or in Denmark. The British Vice-Consul at Flushing, however, writes thus: "The coastal dunes form the main protection of the whole sea-coast; the coast-line is receding, and during heavy storms it very often happens that

the waves undermine the steep cliff-like slope and cause sand-slips, so that the front of the dunes is washed away. The barren sand-slopes are planted as soon as possible with sea marram-grass (*Ammophila arenaria*). The main object of all sand-binding work is, in consequence, to keep the sea-front of the dunes ('zeereep' it is called) as much intact as possible, and to protect the beach against the sometimes heavy surf a great number of piers are made perpendicular on the coast-line." In France and Germany the establishment of a foredune is considered the very root of dune-improvement.

(γ.) *Artificial Foredunes in New Zealand.*

Artificial foredunes have been formed in certain parts of the New Zealand coast—*e.g.*, at New Brighton, where, though not so exactly proportioned a structure as those of Europe, it has done excellent service for more than ten years. Formerly one of the chief duties of the Town Council was to remove the sand from the front of the garden-fences and the streets. This is so no longer, nor does any sand from the shore invade the private properties to the lee of the barrier. This dune has been formed in part by merely planting bunches of marram upon the sloping upper shore, and in part by raising a dune in the first instance by laying boughs of tree-lupin on the shore 3 ft. to 4 ft. in depth; on these the sand rapidly accumulated, and was then planted with marram-grass. It is hard to tell at the present time the method of formation of any special part of this foredune from its appearance. It has been the haunt of hundreds of bathers yearly, and notwithstanding this it keeps its form remarkably well. The lee side is not planted. One objection to simply planting the marram on the shore is the slowness with which the dune is built, and the consequent loss of its protection for several years, so that tree-planting in its rear is delayed. A secondary result of the New Brighton dune appears to have been an actual raising of the foreshore.

The foredune at Ocean Beach, constructed under the direction of Mr. Hancock, Chairman of the Domain Board, was first built by using a catching-fence made of a wire fence interwoven with manuka-scrub. This caught the sand, on which marram was finally planted. This foredune has been a conspicuous success (see Photo No. 47).

(*b.*) Preserving Dune-areas as Farm-lands.

(i.) General.

Were it not that within the dune-areas many ancient sand-plains clothed with excellent grasses exist, and that there are also well-grassed cliff-dunes and ancient sandhills far from the sea, I, for one, should never dream of advocating farming on the dunes. But the farms are there already. Even the dune-complex, barren as most of it is, is used for grazing-runs, some of which are private property. It must not be forgotten that in the early days of settlement these dune-areas contained an abundance of feed, and seemed stable enough. Their plant covering, too, was altogether the work of nature. Now, what nature has accomplished, man should be able to do again, and that more quickly. There is, however, this material difference: *Nature performed the work in the absence of grazing-animals and burning, but the farmer wishes to carry on his work in the presence of these two destructive agencies.* This, if not altogether a vain hope, renders the task vastly more difficult than if stock were absent, since it was stock, together with fire, that set most of the hills moving. Turning stock again on to dunes which are artificially fixed and lack the covering of a humus soil that nature gave, may very probably undo the good which has accrued from this artificial fixing. Turning sandhills into pasture is certainly a very risky procedure, which I do not think is even hinted at by any foreign writers on dune-reclamation. Nevertheless, I believe, under certain circumstances regrassing a dune may be a legitimate practice.

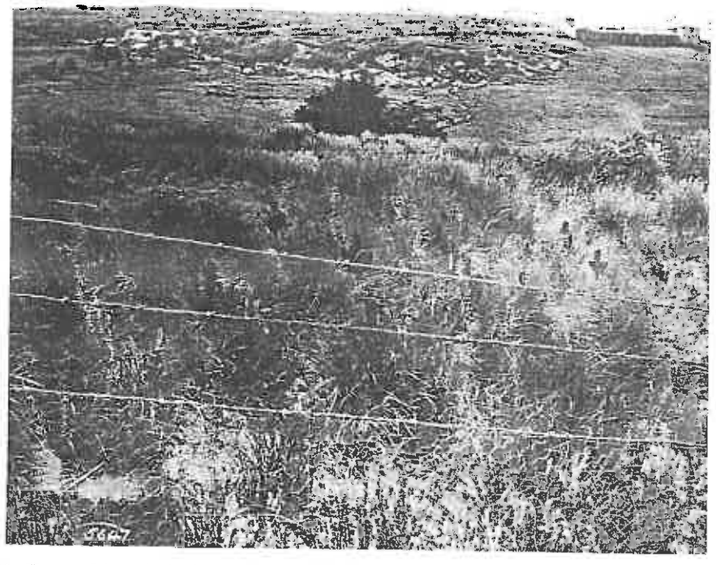
(ii.) Burning.

Whatever may be said in favour of turning stock loose over regrassed or primitive dunes, nothing can defend the too common practice of burning. Leaving the moist hollows out of the question, there is no plant elsewhere that is not playing a useful part, unless it be one which, having built a mound, is inviting wind erosion. But fire cannot discriminate between the good and the bad. In dry weather it will sweep over a wide area, laying the sand bare and exposing it suddenly to the action of the wind. The indigenous sand-binding plants, the shrubs which have gained a footing after many difficulties, all are swept away, and for nothing! The mistaken idea is that they are agriculturally worthless, taking up the place of grasses. The farmer is always expecting he will get some valuable fodder plant that will grow on the unstable dunes—*a hope that is biologically impossible*, for it is just the qualities that make plants suitable to the sand that make them unsuitable for fodder plants. The only ground that can grow nutritious grasses, &c., are the moist hollows and perhaps the ancient dunes. To attempt clothing the exposed hills in the dune-complex with a carpet of grasses fit for stock is to court disaster. All that can be done in that part of the dunes is to fix the hills so that they will not advance on the moist hollows. Where fire is suggested for eliminating something worthless in the plant covering, such as bracken-fern, then recourse should be had rather to overstocking. This is not good either, because it may lead to blow-outs; but, at any rate, it does not destroy the humus portion of the soil.

(iii.) Treatment of the Dune-complex.

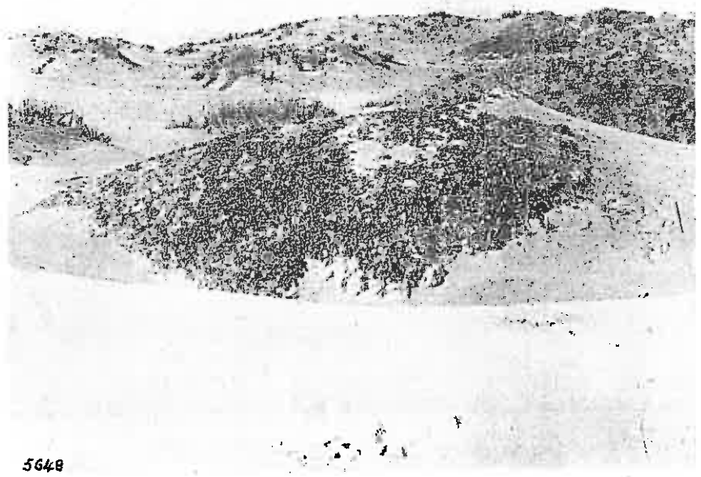
Theoretically, in order to fix the dune-complex with its hills and hollows, the tops of the hills should be denuded of plants, so that they could blow away and help to bring about a fairly level surface, where there should be no contiguous hills and no consequent wind-channels. But the dune-complex

No. 59. Trees growing on Sand at Ocean Beach. *Picea Douglasii* in Centre.
[*Photo L. Cockayne.*



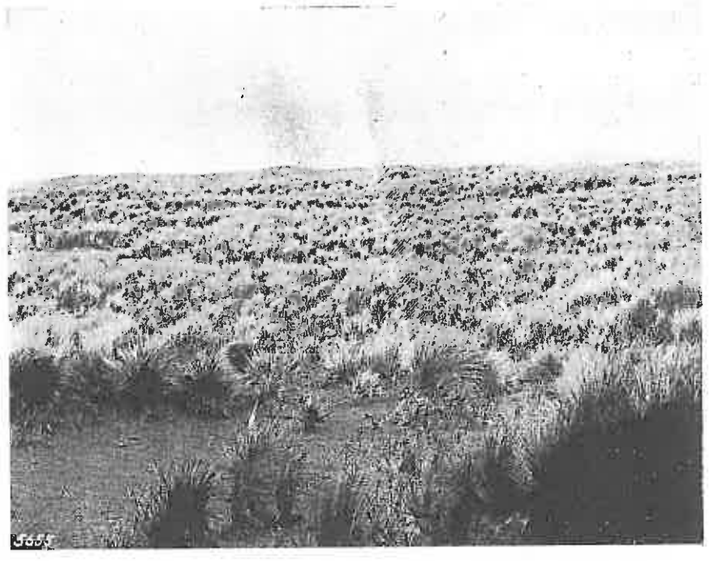
No. 60. Young *Pinus insignis* planted by Mr. Tannoch amongst Marram-grass, Ocean Beach.
[*Photo L. Cockayne.*

To face page 52.]



No. 61. *Calystegia soldanella.* Dune persisting notwithstanding Strong Sand-movement.

[*Photo L. Cockayne.*



No. 62. Successful Planting of Marram-grass by Mr. McKelvie. Dunes near Mouth of the Rangitikei.

[*Photo L. Cockayne.*

is frequently fairly stable under existing circumstances, and has been so for dozens of years, and there are shrub dunes virtually stable; so it seems to me that, theory notwithstanding, a much greater stability still could be brought about by judicious planting (see Photo No. 66). Nor is the method here suggested very different from that of Holland and Denmark, where hills and hollows are planted, and where the summits of the hills are let alone. The unstable and semi-stable hills themselves are of no value for grassing operations; it is the sand-hollows and sand-plains which alone serve in that regard. These will require protection from the drifting sand; their protection is the first demand. To bring this about, the hollows near the bases of the hills should be planted with marram-grass. The hill-tops must be let alone (see Photo No. 57). Only the hills which are discharging sand into the hollows should be planted in the first place; and in cases of that kind, where the drift is bad or where there is a semi-wandering dune, a fair breadth of marram must be planted in the adjacent hollow. Tree-lupin might be used in conjunction with marram-grass in many places, as already described; but, of course, *a protection-belt of marram must be arranged on the windward side of the tree-lupin.* In difficult places the marram is far more likely to grow evenly if planted in squares, as already directed, with a few plants in the inside of the square. Belts of trees would be invaluable; but they would have to be in the lee of the marram protection-belts. The question of the kinds of trees, &c., is dealt with further on under another head. Planting hills and hollows with marram and tree-lupin has succeeded admirably at Ocean Beach, Dunedin; but, it must be remembered, the conditions there are not severe. Photos Nos. 55 and 56 also show how marram-grass will grow even when planted in a wind-channel and on steep slopes exposed to violent winds, but it must not be forgotten that such planting is unorthodox.

(iv.) Grassing Operations.

(*a.*) *General.*

At the first thought it might be considered that the formation of pasture should be the ultimate aim of dune-fixation. This, even now, is the opinion of some who have given no thought as to the methods by which pasture is established, or the relationship of a barren, dry, unstable, humus-free soil to a plant covering. Needless, thus far in this report, to further explain that such an idea is both *erroneous* and *dangerous* in nearly every phase of sand-reclamation. *Moving masses of sand must be regarded not as potential pasture-lands, but as serious and immediate menaces to the valuable farm-lands adjacent.* Were this not so, the dunes of this Dominion, extensive though they are, could well be left in abeyance until such time as an increased population, coupled with a scarcity of land, rendered their utilization imperative.

But, apart from the worst sand, there are various parts of most dune-lands that will grow grass permanently, provided they can be kept or made stable or protected from being overwhelmed. *Sand-plains, dune-hollows, ancient dunes* which have reverted to moving sand, and *wounds* in fixed pasture-clad dunes at once suggest themselves as stations for grassing and regrassing operations.

Unfortunately, very little can be learnt from other lands, where using dunes for farming is not generally recognized; while in New Zealand, except in some cases to be dealt with, nothing has been done, and fire has been usually the sole method of reclaiming a dune-hollow. Therefore the methods advocated further on must be looked upon in some cases rather as experimental than as definite directions how to gain the object desired. As I attempt to show at the conclusion of this report, *experiment is urgently demanded so far as details as to sand-reclamation go in New Zealand.*

(*β.*) *Pasture and its Relation to Drifting Sand.*

In dealing with the formation of sand-pastures, the factors involved and the objects to be aimed at are altogether different from those where afforestation is concerned. In this latter the whole object is to keep the sand in check until the trees are well established, at which time, if close enough, they will form a perfect shelter to the easily blown sand. In this case *wind*, the sole cause of the drifting sand, is completely eliminated so far as the *soil-surface* is concerned, and of that no movement can take place. The wind, of course, may have a very prejudicial effect on the subsequent growth of the trees, but that is quite another matter. With a sand-pasture the condition of affairs is quite different, for *the wind blowing over the surface will always be a factor of prime importance* in opposing the formation of a thick turf; and *in permanent pastures, until a thick turf is formed, the danger of the sand drifting will be ever present.*

The cohesion of dry sand-particles, as already pointed out, is exceedingly feeble, otherwise the sand would not move nearly so readily. Therefore *the great object to be attained in attempting the grassing of sand-areas is to increase the cohesion of the upper layer of sand*, so that its power for resisting wind movement will be correspondingly increased. The best method of getting this increase is by increasing the humus-content. Dune-sand is notoriously deficient in humus. Were it possible all at once to remedy this deficiency in some cheap manner, the task of forming pasture on sand would be immensely reduced. In closely settled districts where farming is carried out on sandy soils this increasing the humus-content is always given special prominence to, either by using large quantities of stable manure or by the frequent employment of cover-crops for the purpose of green-manuring. This system will probably come into operation in New Zealand, when, with the increase of population, special crops, such as certain vegetables, will be largely grown on our at present sandy wastes. This is indeed the case near Foxton, Wellington, at the present time, and at New Brighton, Canterbury. Generally, however, stable manure must be ruled out of the question in pasture-making, and the humus-content will have to be supplied by the plants that are sown. *In the earlier stages of pasture-making on sand special attention must be given to using those plants that are likely to thrive and produce the maximum amount of humus. Their value as feed will be a point of minor consideration.*

When once the humus-layer is sufficiently developed—*i.e.*, when a layer of *black* sand not easily moved by the wind is formed—the best methods of increasing the feeding-value of the pasture will have to be considered. Even if a good sward is finally developed, a very little bad management is liable to cause the destruction of the pasture, for it must be remembered that *the wind factor will be ever present* ready to attack a weak spot and to undo in a few hours what it may have taken years to accomplish.

The milestones on the journey towards pasture-completion stand out clearly enough, but to successfully pass them is another matter. The first is the stopping of sand sweeping over its surface within and without the area to be grassed; the second is the increasing of the humus and the formation of a black sand-layer; while the third is the use of those pasture plants that can best resist the action of the wind and form a *thick* and *permanent* turf; finally comes the mending and regrassing of any breaks that may occur in the continuity of the sward.

The farmer may probably exclaim at this point, "I don't want to know anything of all this; I want a mixture that I can sow upon my sand, and which in a season or two will produce a good sward." Such a demand, with the plants available in the world at the present time, it is impossible to meet. A desert cannot, without an unremunerative expenditure, be turned offhand into a grazing-ground, but a certain succession of plant associations may be developed by degrees, which might finally culminate in a permanent and fairly stable pasture. The botanical part of this report has shown how nature has acted in this regard. *The farmer must follow the principles which nature has clearly laid down.*

(γ.) *Grasses, Clovers, and other Fodder Plants for Sand-pastures.*

(a.) General.

The following account of grasses and clovers for dune-planting deals only with those which are to be used when the main drifts have been stopped by sand-binders, &c., as already explained. Leaving the consideration of badly drifting sands out of the question, it is hoped that the information here supplied may be of value for those dealing with sandy soil, especially for those having the better-class farms in the dune-areas.

(b.) The Annual Lupins, and their Employment.

The annual lupins are not to be confounded with the tree-lupin (*Lupinus arboreus*), invariably spoken of as "lupin" in New Zealand dune-reclamation. The term "lupin" is, in fact, generic in its use, and applied to the 170 or so species found in temperate America, Asia, and Europe, and occasionally on tropical mountains.

The annual lupins—yellow lupin (*Lupinus luteus*), blue lupin (*L. angustifolius*), white lupin (*L. albus*), all natives of the Mediterranean region—will probably prove of considerable value in the attempt to form pasture on sand. They will be utilized chiefly in the early stages of the work. Their main function will be to completely cover the ground on which they are sown, and so stop all sand-movement. *They will be of no use to arrest rapidly drifting areas, as they are not sand-binders*; but where any threatening drifts have been stopped by these latter, and where there is danger of local drifts starting (as in Photo No. 58), they can be employed as a temporary covering, to be replaced later on by grasses. In afforestation-work the annual lupins will also be of value as true nurses—*i.e.*, as the trees grow, the lupins will be wiped out, but not before they have discharged the dual functions of nurses and drift-preventers. Also, they will have greatly enriched the soil by forming a layer of humus, and increasing the nitrogen-content. Finally, during summer they will act as a fire-break.

Annual lupins will also be of moment in dealing with sandy fields and sand-plains which are not too moist in winter, *as a crop to be ploughed in* and so increase the humus-content and prepare the soil where required for certain annual crops, such as oats and rape. After the crop is taken off annual lupin can be again grown, and either fed off or ploughed in so as to benefit any succeeding crop. Annual lupin, as shown further on, will play an important part in repairing sand-breaks that occur in permanent pasture through the effects of grazing animals or fires.

As fodder plants the annual lupins are not first-class, although they contain a larger amount of digestible albuminoids than any other crop; but their herbage, owing to the presence of an alkaloid, is rather bitter, and so not palatable to cattle and horses. Sheep, however, soon get over their distaste and will feed well upon it.

Again, under certain little-known conditions *the green leaves, and also the hay made from annual lupins, may contain a poisonous principle*, known as lupinotoxine, and in such case are a dangerous feed. Experiments in this regard will have to be undertaken; and if in certain localities this poisonous property is developed, annual lupins should not be allowed to be grazed on. They will, however, be still valuable as sand-fixers and humus-producers. Where poisonous and used for the above, cattle alone will have to be grazed in their vicinity, and changed from time to time. They will not eat the lupin if there is anything else to be procured. Probaby, however, little danger is to be anticipated from lupin poisoning.

The yellow lupin (*L. luteus*) is the species most commonly cultivated as a field crop. It is an annual with yellow flowers and erect hairy stem 1 ft. to 3 ft. tall. The seeds are about the size of those of the field-pea, kidney-shaped, whitish in colour and flecked with black spots and small streaks. Sowing may be broadcast or by drill. Probably about a bushel per acre would suffice.

The blue lupin (*L. angustifolius*) is taller than the yellow, more woody, and hence not so suitable for fodder. The seeds are rough, and about the size of a small bean-seed.

The white lupin (*L. albus*) will probably be the most valuable of all the lupins for sand-culture. Seed does not ripen in England, and so is difficult to procure. In Portugal, under the name "pramoso," it is used to suppress sorrel.

The price of annual-lupin seed varies from season to season, but is generally about 18s. per bushel. If the value of these lupins becomes established in the Dominion the farmer will easily be able to save sufficient seed for his own requirements.

(c.) Grasses.

Yorkshire Fog (*Holcus lanatus*).—This is a grass almost universally despised, except by sand-farmers, who are well aware of its value; probably, however, it is one of the most valuable pasture plants for sand-culture. It grows freely upon pure sand, and seeds well, coming spontaneously on to bare sand so soon as a little shelter is provided. It should certainly be one of the first grasses to sow after the sand is fixed, and probably its place will be eventually taken by *Poa pratensis*, *Danthonia pilosa*, and *Microlæna stipoides*. It is *one of the best grasses for the all-essential formation of humus*. The seed is generally very cheap, say about 4d. a pound. That known as "shelled fog," a by-product of cocksfoot-cleaning, should be used.

Indian Doab-grass (*Cynodon Dactylon*).—A very important grass for sand, especially on the more northern dunes. Once established it makes a dense mat and a sward not likely to be injured by either wind or grazing animals. Its creeping roots hold the sand together even where its herbage is scanty. The seed costs about 2s. a pound, as the demand is small.

Paspalum dilatatum.—How far this grass is suitable for sand-culture I cannot say. Certainly I have seen it growing on pure sand on the Auckland dunes, where it had been planted. Its habit of spreading out from the main crown and clothing the ground well, fits it eminently for sand-work. It is a native of Brazil, and can tolerate very little frost indeed. The seed costs about 1s. per pound, and is frequently very bad, the germination being very often less than 10 per cent., so that the price is no criterion of the cost of sowing. Should the grass take kindly to sand it will be one of the most important for the northern dunes.

Schrader's Brome-grass; Prairie-grass (*Bromus unioloides*).—This is generally known in New Zealand as "prairie-grass." It is a most valuable grass, the cultivation of which has been much neglected in the Dominion. Had it been exploited in the same way as *Paspalum dilatatum* and canary-grass it would probably be now one of the most widely grown grasses for winter feed. As it is a common wayside grass, however, its good qualities have been much underestimated, and its great failing, inability to endure continuous stocking—an inability it shares with red clover, cowgrass, English trefoil, and timothy—is continually urged against it. As a sand-grass *Bromus unioloides* must always have a prominent place. It grows freely in pure sand, and continues its growth throughout the months of winter, and, *if not stocked heavily, will seed naturally*. It is a perennial with rather harsh broad leaves, and forms tufts up to 3 ft. in height. *It is not a sand-binder*. Its main use will be in sheltered hollows. It could be used with advantage, after annual lupin in sandy fields, as a special winter feed to be cut for cattle. It would not occupy any important place in the vegetation of stable grassed dunes, for there its liability to be eaten out would come into play. The dead leaves help towards the formation of humus. The seed is generally about 3d. a pound. New-Zealand-saved seed is of excellent quality. In the Argentine the grass is looked upon with great favour, and occupies much the same position as Italian rye in New Zealand. The seed from sandy soils is rather small, but of a good colour; and, as there is a good export demand for seed, many sheltered dune-hollows and sand-plains might be very much worse occupied than by the growing of prairie-grass for seed.

Rhodes-grass (*Chloris virgata*, *C. Gayana*).—These two grasses, the one a native of tropical America and the other of tropical Africa, should be given a good trial on the northern dunes. They spread rapidly by creeping stems lying prostrate on the ground, and leafy shoots are developed near the nodes, as in the case of such grasses as fiorin. The leaves are long, and palatable to stock. In favourable localities the grass grows 4 ft. in height. These grasses will probably prove valuable both in sheltered hollows and also as constituents of stable grassed dunes, for they are not liable to be eaten out. In the Transvaal *C. virgata* is largely used for hay, which commands a good price in Johannesburg and Pretoria (1, p. 160). The seed is generally expensive, being not less than 3s. per pound.

Danthonia (*D. semiannularis* + *D. pilosa*).—Without doubt, danthonia is the most valuable grass that can be grown on permanent sand-pastures—*i.e.*, always provided that permanent sand-pastures are a biological possibility. In my opinion *the ultimate aim of sand-pasture-establishing is the production of a danthonia sward*. *Danthonia semiannularis* and *D. pilosa* are both suitable; but the latter in its various forms should be favoured, as it gives a greater yield of herbage. *D. pilosa* can now be supplied true to name by many of the northern seed-merchants, it having at last become more or less generally known as a superior grass to the small-seeded *D. semiannularis*. Danthonia should be sown after the sand has been treated previously by annual lupin, followed probably by a mixture of Yorkshire fog and other humus-formers. In sand-pasture-making the logical procedure is by producing a succession of distinct plant coverings, culminating in danthonia, the poas, &c. Danthonia-seed is generally about 11d. to 1s. 1d. per pound. *D. pilosa* is dearer, as there are fewer seeds to the pound. The numbers are, approximately, *D. semiannularis* 950,000 per pound, and *D. pilosa* 500,000.

Ratstail (*Sporobolus indicus*).—This is another grass with a bad name which, on the worse sand, is a most important constituent of pasture. In fact, where the wind is not too strong, *Sporobolus* pasture might be formed without any preliminary. The leaves are very harsh, and wear away the teeth of grazing animals; but this will always occur in sand-pastures, owing to the grains of sand getting taken up with the food, so the above is not really a serious objection. The price of the seed is about 1s. 3d. per pound. The seed is very small. Shelled seed and unhusked are about equal in ordinary samples.

Rice-grass (*Microlaena stipoides*).—This indigenous grass will be used much as danthonia. It will be specially valuable where the rainfall is highest. The seed is about 1s. 3d. per pound.

Meadow-grasses (Species of *Poa*).—*Poa pratensis* is extremely valuable for fixed dunes as a final component of the turf in conjunction with danthonia, &c. The seed is said to germinate badly, but this opinion may arise from the primitive methods used to test this grass in New Zealand. Be this as it may, a good deal of seed is sown annually, and where used this grass soon becomes a most important constituent of any pasture. The seed costs about 8d. per pound, and the number of seeds render this grass one of the cheapest, provided a fair percentage germinates. *Poa pratensis* forms a thick and close turf, but it does not mix well with other grasses, but occurs in patches. Canadian blue-grass (*Poa compressa*), the seed of which can be imported, might be valuable. It is plentiful already in northern New Zealand, where it is confused with *P. pratensis*. Texas blue-grass (*P. arachnifera*) should also be tried.

Couch-grass (*Agropyron repens*).—Weed though this may be on ordinary farm-lands, it is far from being so on a sand-area. Its far-creeping and powerful stems, which ramify to a great depth beneath the surface of the ground, are just what are wanted in a loose soil the play of every passing breeze. As a grass it yields a large amount of nutritious herbage. White clover grows with it very well indeed—in fact, according to observations made in my garden at New Brighton, it seemed that in sandy soil white clover would gradually replace the couch-grass. Its use is specially suggested for the more difficult sand, and especially for areas within the dune-complex itself.

(d.) Clovers or Clover-like Plants.

Sand-clover (*Anthyllis vulneraria*).—A variety of this grows naturally on the dunes of northern Europe. It is a deeply-rooting perennial, and would probably be a very useful pasture plant. Its nutritive properties approach those of red clover.

Egyptian Clover (*Trifolium alexandrinum*).—This, the famous Bersin clover of Egypt, where it gives three green crops in the season, each 2 ft. tall, would probably be a good clover for sand-hollows in the north that are fairly moist. It is not so likely to be eaten out as red clover. On the pure sand it would be useless.

Suckling-clover (*Trifolium dubium*).—This should be included in all mixtures for sand-pastures. It is an annual, but reproduces itself regularly from seed. The seed is cheap—about 4d. per pound—and is a by-product in the cleaning of white clover (*T. repens*). One of the great advantages of the yellow suckling is that it grows well with other grasses, and will fill up the bare patches where grasses are apt to grow too tufted.

White Clover (*Trifolium repens*).—This is one of the most important fodder plants for dune-culture. It thrives best on sand-plains and sheltered hollows. It is also amongst the first plants to appear spontaneously amongst marram-grass. On the exposed stable hills it is probably little better than the yellow suckling. The seed costs from 10d. to over 1s. per pound: It need not be too well dressed; its chief impurities other than sorrel and yellow suckling are not likely to spread on sandy land. Californian thistle (*Cnicus arvensis*) is, however, occasionally found.

Burr-clover (*Medicago denticulata*).—This plant has, as I am well aware, the reputation of being valueless; in fact, it is also considered dangerous, as its hooked burr-like seed-pods become entangled in wool. Nevertheless, *M. denticulata* is an important fodder plant in Argentina and Chile, where there are extensive areas of sand. There cattle and sheep thrive upon it; but it requires yearly sowing to keep established. It has prostrate branches which enable it to extend over a considerable area. Overstocking is fatal to its spreading, as it does not then produce sufficient seed. The seed is not often met with commercially, but it may be bought as "Buenos Ayres lucerne." The allied spotted burr-clover (*Medicago maculata*) is never eaten by stock, so it is valueless, although producing a large quantity of herbage, but it would be useful for green-manuring in orchards growing on sandy soil. It also grows in autumn and winter just when clover-crops are required for an orchard. Both these medicks might be useful on the sides of sandy roads, and here too the useless melilots—*Melilotus officinalis*, *M. arvensis*, and *M. albus*—might play a part.*

Birdsfoot-trefoil (*Lotus corniculatus*).—This might be valuable for stable pastures on dry slopes. The seed is dear, often 2s. to 2s. 6d. per pound. It frequently contains a good deal of *L. uliginosus* (the "*L. major*" of Auckland farmers), but this latter is of no value for sand-culture, unless near lakes or swamps. *L. angustissimus* may also be used.

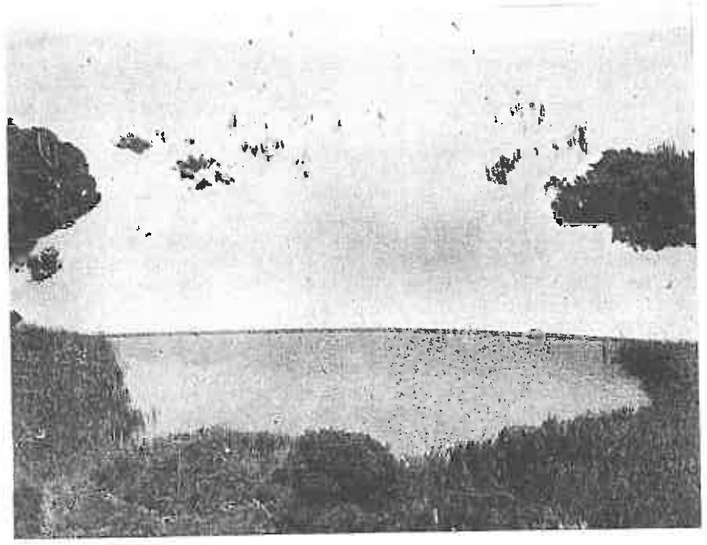
Strawberry-clover (*Trifolium fragiferum*).—This might be used in the hollows where the salt-meadow species occur.

(δ.) *The Type of Seed to be sown.*

In ordinary farming it is good policy to sow only the highest-grade, well-cleaned seed, but on the dunes the cleanness of the sample is not nearly of so much account as its capacity for germination. The weed impurities are in all probability such as will not thrive on sand, while others—*e.g.*, sorrel—will be a positive good. To give one instance, the following impurities will probably be present

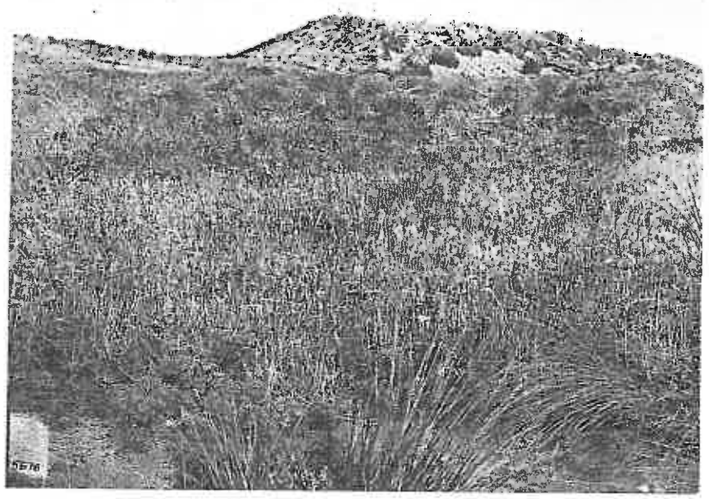
* The King Island melilot (*Melilotus parviflora*), so much advertised as a dune fodder-plant, is, according to Ewart (13A, p. 23), "perhaps of some use as a humus-former on poor soils and for green manuring, is not a good grazing-plant, and is an unmitigated weed on good land."

No. 63. Sandy Point. Source of Tarras Drift.
[*Photo L. Cockayne.*



No. 64. Gully with Stream in Bottom, blocked by Sand, and Small Lake formed by River also getting filled. Reef Point, North-west Auckland.
[*Photo L. Cockayne.*

To face page 56.]



No. 65. Marram-grass getting naturally replaced by Yorkshire Fog (*Holcus lanatus*), etc. Dunes South of Manukau Harbour.

[*Photo L. Cockayne.*

No. 66. Moving Sand of Cliff-dune held by Marram-grass which had been put in by Plough. Dunes South of Manukau Harbour.

[*Photo L. Cockayne.*

in white-clover seed imperfectly cleaned: sorrel, chickweed, *Anthemis Cotula*, *Anthemis arvensis*, fathen, *Silene* sps., suckling-clover, alsike, *Spergula arvensis*, and *Plantago lanceolata*. None of the above will be harmful, and several will be of value.

(c.) *The Grassing.*

(a.) General.

The areas to be grassed will vary greatly in their adaptability for such treatment, according to their position within the dune-area and to their drifting capacity. Where the drifting is excessive marram-grass must be the primary covering, or a shelter-belt of this to the windward and then tree-lupin or annual lupins, according to the rate of movement, these latter only being suitable where the movement is comparatively slight. In any case, after sowing the annual-lupin seeds the ground must be covered with brushwood. Tree-lupin should be sown as already directed (see p. 49).

(b.) Grassing after Marram (see Photo No. 65).

Grassing after marram depends upon the principle that this grass dies out by degrees when the sand-supply stops, and that its dead parts add a good deal of vegetable matter to the sand. The death of the individual plants occurs at different times, so that, although the bare patches will increase yearly, there will for a time be plenty of plants remaining to break the force of the wind.

The dunes most suitable for regrassing in this manner are the cliff-dunes or ancient stable sandhills which have been set in motion by stock, &c., and receive no sand-supply except what comes from the bare patch itself. Such an area of moving sand leaves the ground quite bare to the windward, and may advance forward either as a rapid drift over the pasture-land in front or move slowly on to this latter as a sandfall. In any case *the whole* of the moving sand should be covered with marram-grass. Planting should commence at the windward limit, but of course, if needful, a protection-belt may be first of all planted at the landward margin. Probably the work of planting the marram may occupy more than one season.

When the ground is quite covered, even with one-year-old plants, or less, the force of the wind will be so greatly reduced that, except during gales, there will be little motion of the sand. Very soon other plants will spontaneously make their appearance. Amongst the first-comers there will very likely be the following: Yorkshire fog (*Holcus lanatus*), sowthistle (*Sonchus asper*), catsear (*Hypochoeris radicata*), and haresfoot-trefoil (*Trifolium arvense*). The indigenous wood-sorrel (*Oxalis corniculata*), bracken-fern (*Pteridium esculentum*), and the indigenous *Muehlenbeckia complexa* will appear early on, the two latter having probably arisen from plants buried by the drift.

As soon as the marram commences to die out sowing may commence. The principle advocated is to encourage the formation of humus in the first place, using for this purpose humus-forming grasses, &c., especially Yorkshire fog and clovers, while later on these are to be gradually replaced by the shorter and more compact turf-formers—*e.g.*, species of *Danthonia*, *Poa*, &c. The dying marram itself will do a great deal towards the formation of humus. Annual lupin can be used at quite an early stage. Seed-mixture E (see further on) may be sown in the autumn when there is a fair amount of bare ground, and further sowings can be made from time to time. Should a repetition of the drift be feared, ratstail could be freely used in the north, and in the south couch-grass (*Agropyron repens*) together with white clover, these two going well together for a time, as already explained. Should any symptoms of drifting occur while the grassing is in progress, if slight it may be checked by laying scrub on the ground, sowing annual or tree lupin, &c., but perhaps the safest plan would be to plant marram as quickly as climatic conditions allow.

(c.) Treatment of Surface-wounds, Blow-outs, etc.

It has already been emphasized how important it is to attend at once to any bare sand-patches that may arise on a well-grassed hillside. If the wound be very trivial—*i.e.*, a few square yards or so in area—covering with a little brushwood may be all that is required, the natural pasture plants returning of their own accord. Or, to make certain of a cure, some Yorkshire fog, ratstail-grass, finger-grass (*Panicum sanguinale*), or yellow suckling may be sown. Should the damage be greater through longer neglect, and the trampling of cattle have brought up the pure sand, so that the more cohesive layer of black sand is buried, then the wind can exercise its power. The sand will drift beyond the edges of the wound, killing out the grass as this is covered. There is an abundant sand-supply, the the hill is burrowed into and falls in, the supply of easily blown sand gets greater and greater, and, if neglected, we have here a wandering dune in the making.

In a case like the above, if the wind is not excessive and the drift comparatively slow, sow annual lupin, covering the ground completely with scrub, which had better extend beyond the bare patch. Should the wind be more powerful, then use tree-lupin, sowing it by laying its own branches on the ground, if at the season the seed is ripe. To make still more sure, a shelter-belt of marram to the windward of the lupin will be required. When the blow-out is very extensive and in the track of the full sea wind, then the whole surface may need planting with marram. Many at the present time use marram for even the most trivial wounds, but this comparatively expensive treatment is in such cases quite unnecessary.

As the annual lupins are eaten off, the ground may be sown with a grass-mixture in the autumn. Should the sowing turn out a failure—and this will be known in the spring—the ground may be again sown with annual lupin, and another attempt made at regrassing in the autumn.

Where tree-lupin has been used the procession of events will be slower, and several years will have elapsed before patches of bare ground appear amongst the tree-lupin. Here prairie-grass may be

sown. This will attract the cattle, which, in eager quest of the grass, will break down the lupin and make space for grass-seed mixture on the surface, now temporarily held by the accumulation of humus from the decay of the lupin leaves and stems.

Sowing marram-patches has been already dealt with, and the procedure is the same whether these be large or small.

Fencing in some cases may be necessary, in which quite a light temporary fence of barbed wire should be used.

(d.) Treatment of Sand-plains and Hollows.

(1.) *General.*

Sand-plains and hollows amongst the stable and semi-stable hills are really the only legitimate areas for grassing operations. Generally they are left quite in their wild condition, except that they have been overstocked and ravaged by fire for years. Sand-plains frequently contain a sufficiently cohesive sand, and their water-content is abundant enough—indeed, it is often too great. The indigenous plant covering gives some clue to the treatment demanded. Where salt-meadow plants predominate (see botanical section) various foreign salt-meadow or even salt-swamp fodder plants might with advantage be introduced. Such are strawberry-clover (*Trifolium fragiferum*), *Atropis distans*, *Leersia oryzoides*, *Glyceria fluitans*, and fiorin (*Agrostis alba*). Amongst indigenous plants *Crantzia lineata* (already present) and *Pratia arenaria* are considered by Chatham Island sheep-farmers most valuable pasture plants. The sand-sedge of the dry hollows (*Carex pumila*) is also an important fodder plant, and its spread should be encouraged. This is often not the case, and sandy hollows where it forms a close covering are frequently planted with marram-grass, a quite mistaken and useless proceeding, unless a strong sand-drift requires checking.

(2.) *Treatment of Sandy Fields.*

The treatment of sandy fields near homesteads is a matter of special importance. Of course the first requisite is to protect them from sand-encroachment by planting protection-belts if necessary. Belts of trees on the windward side would also be very valuable, willows, poplars, and alders being suitable trees for the purpose (see section on tree-planting and list of useful plants).

These sandy fields can be put to a variety of uses. The object need not of necessity be permanent pasture, but a rotation of crops. Annual lupin may be ploughed in, followed by a crop of prairie-grass (*Bromus unioloides*), fed lightly in the winter and to be cut for seed the following year. The seed-stalks should be cut as high as possible, and then the plants turned in. Follow this with a crop of rape, or, where the ground is fairly stable, with an early crop of potatoes. Near New Brighton I have had excellent results in a wet year by growing potatoes on a high sandhill and manuring with superphosphate. Potatoes are objectionable, however, since they leave the ground bare during the late summer. After rape, put in a green crop of, say, Cape barley or vetches. Feed off lightly, and turn in, or put in annual lupin again *if it has been found that the sheep thrive on it.* A root-crop, such as mangels, can then be grown if there is a supply of stable manure that can be spread over the field before the green crop is turned in. Prairie-grass can again follow, or the field can be laid down in grass for some years and then a crop of oats taken off.

The chief feature in dealing with these areas will be the abundant use of cover-crops for green manure. As they will form good ground for wintering dairy cows, a mixture of *Phalaris bulbosa* and prairie-grass might often be found most useful, the sod being turned in in the spring, and another crop substituted.

Sand-fields or sand-plains could, of course, be turned into horse-paddocks, in which case the object would be to produce a good sod of mixed herbage, having *Poa pratensis* and white clover as the dominant plants. Perhaps the addition of couch-grass (*Agropyron repens*) might be made with great advantage (see before, p. 56, regarding the uses of this grass).

(3.) *Sandy Hollows without Humus.*

Sandy hollows without humus in the top layer are frequent in the dune-areas. Their origin has been discussed in the botanical section, as well as their natural destiny. In attempting to cultivate these the drifting sand must be stopped. This done, their surface will be either pure sand quite flat and without plant-life, or there will be hillocks covered with *Scirpus frondosus* or *Spinifex hirsutus*. If so, so much the better. The sequence of artificial vegetation I would suggest is—annual lupin for perhaps three years; then sow with a mixture of Yorkshire fog and prairie-grass. As the humus-content improves, clovers and perhaps cocksfoot may be used.

(4.) *Scrubby Hollows.*

Hollows full of scrub (the "heath" of the botanical section) should not be burnt. Amongst the tea-tree, &c., on the flat ground the aim should be to develop a sward of *Poa pratensis* and white clover, or, where more sandy, of *Danthonia pilosa* and suckling-clover. If it is necessary to get rid of the scrub then cut it down, *always leaving sufficient for shelter purposes on the windward side.* Good use can be made of the cut tea-tree in covering any neighbouring drifting sand—much better use than burning it—and sowing some or other of the sand-covering grasses—*e.g.*, *Panicum sanguinale*, *Agropyron repens*, or *Sporobolus indicus*—amongst it.

As for the actual hills of the dune-complex, I have already given various reasons why, so far as preparing them for grazing goes, nothing should be done; and if tree-planting operations are not in view they should be let alone, or, if active, planted with marram-grass.

(e.) Seed-mixtures.

[By A. H. Cockayne, Government Biologist.]

(1.) *General.*

It is impossible to lay down any hard-and-fast formulae for seed-mixtures. Very little attention has hitherto been given to the relative percentages in point of number of plants that may be produced of each of the varieties in a mixture. In consequence *too much* or *too little* of the seed is often used. *In order to secure a well-balanced mixture the number of seeds per pound and the average germination should be known.* The following table has been designed in order to supply this important information:—

(2.) *Table showing Number of Seeds per Pound, and Average Germination capacity, and Price of Ordinary Commercial Samples of Fair Average Quality.*

Scientific and Common Name of Species.	Number of Seeds per Pound.	Average Germination.	Average Price.
		Per Cent.	s. d.
Anthyllis vulneraria (sand-clover)	180,000	90	1 0
Bromus unioloides (prairie-grass)	55,000	88	0 3
Chloris Gayana (Rhodes grass)	2,000,000	75	3 0
—— *virgata* (Rhodes grass)	1,400,000	70	3 0
Cynodon Dactylon (doab-grass)	1,200,000	85	2 0
Danthonia pilosa	500,000	65	0 11
—— *semiannularis*	950,000	60	0 11
Dactylis glomerata (cocksfoot)	550,000	70	0 6
Holcus lanatus shelled (Yorkshire fog)	1,100,000	70	0 4
Lotus angustissimus (hairy birdsfoot-trefoil)	1,000,000	92	2 0
—— *corniculatus* (birdsfoot-trefoil)	490,000	92	2 0
Microlaena stipoides	220,000	75	1 0
Medicago lupulina	330,000	88	0 7
—— *denticulata* (burr-clover)	91,000	94	*
Paspalum dilatatum	400,000	0 to 75	1 0
Phalaris bulbosa	300,000	90	3 6
Poa arachnifera (Texas blue-grass)	2,100,000	45	*
—— *compressa* (Canadian blue-grass)	1,600,000	60	*
—— *pratensis* (rough-stalked meadow-grass)	1,600,000	†	0 8
Sporobolus indicus (rat-tail)	2,000,000	80	1 3
Trifolium alexandrinum (Bersin clover)	250,000	92	1/3 to 1/6
—— *fragiferum*, shelled (strawberry-clover)	300,000	85	1 6
—— *dubium* (suckling)	90,000	94	0 4
—— *procumbens* (hop-trefoil)	1,800,000	92	‡
—— *repens* (white clover)	800,000	90	0 10
—— *subterraneum*	300,000	92	*

* Seed not usually quoted. † Germination always higher than tests: allow 20 per cent. ‡ Not quoted.

(3.) *Method of calculating Amount of Seed required.*

Mixtures for pastures should be so calculated as to give not less than 5,000,000 plants per acre. The method of using the above table is to multiply the number of seeds by the germination-percentage and divide by 100: this will give the number of living seeds per pound. In sand-work an allowance of 50 per cent. of the seed not developing into plants should be made. Thus the following formula should be applied to each of the seeds: $\frac{\text{Number of seeds per pound} \times \text{germination-capacity}}{200}$; and from this will be got the approximate number of seeds per pound that will germinate when surface-sown under favourable conditions. Thus, in Yorkshire fog, using the above table, we should have $\frac{1{,}100{,}000 \times 70}{200} = 385{,}000$ seeds per pound. In this way a properly balanced formula can be easily secured, and can be altered with accuracy when any special percentage of any grass, &c., is required. Thus a mixture of 10 per cent. of white clover, 10 per cent. suckling-clover, 35 per cent. Yorkshire fog, 10 per cent. *Danthonia semiannularis*, 10 per cent. *D. pilosa*, 15 per cent. *Poa pratensis*, 5 per cent. rice-grass, and 5 per cent. birdsfoot-trefoil worked out on a 5,000,000 basis would be—

Name of Plant.	Seeds required.	Seeds per Pound after applying Formula.	Weight.
			Lb. oz.
White clover	500,000	360,000	1 6
Suckling-clover	500,000	423,000	1 3
Yorkshire fog	1,750,000	385,000	4 9
Danthonia semiannularis	500,000	285,000	1 12
Danthonia pilosa	500,000	162,500	3 10
Poa pratensis	750,000	240,000	3 2
Birdsfoot-trefoil	250,000	225,400	1 2
Rice-grass	250,000	82,500	3 0

As regards prairie-grass, which is a rapid grower and forms large tufts, the percentage of seed used need not be great: about 2 per cent., or 4 lb., will be ample in most cases. When sown pure in sand-hollows, sand-fields, &c., 2 bushels of seed should be used, 40 lb. per acre, together with 2 lb. of suckling-clover to make a little bottom growth and so keep the ground covered.

I would strongly urge the calculating of seed-mixtures somewhat after the method I have outlined, in preference to the ordinary guesswork formulae of the present day.

In many cases a general mixture will not be used, but some special seed will be sown to increase the value of the pasture in some way, either with reference to feeding-value or to the formation of humus.

(4.) *Mixtures for Special Purposes.*

The following tentative mixtures are suggested :—

(*A.*) For sandy fields : Prairie-grass, 40 lb. ; suckling-clover, 2 lb. To be *lightly* fed off, and afterwards cut for seed.

(*B.*) For moist hollows with standing water in winter : *Trifolium fragiferum*, 30 per cent. ; *Trifolium alexandrinum*, 10 per cent. ; *Medicago lupulina*, 12 per cent. ; Yorkshire fog, 35 per cent. ; prairie-grass, 2 per cent. ; white clover, 5 per cent. ; *Anthyllis vulneraria*, 5 per cent.

(*C.*) For hollows dry and liable to blow in summer : Yorkshire fog, 40 per cent. ; prairie-grass, 3 per cent. ; suckling-clover, 10 per cent. ; anthyllis, 10 per cent. ; *Phalaris bulbosa*, 10 per cent. ; white clover, 10 per cent. ; Rhodes grass, 10 per cent. paspalum, 9 per cent. (if used).

(*D.*) General mixture for permanent pasture on stable hills : Yorkshire fog, 15 per cent. ; *Poa pratensis*, 10 per cent. ; *Danthonia semiannularis*, 20 per cent. ; *Danthonia pilosa*, 20 per cent. ; rice-grass, 10 per cent. ; suckling-clover, 10 per cent. ; ratstail, 10 per cent. ; anthyllis, 5 per cent. *Cynodon Dactylon*, Rhodes grass, *Agropyron repens*, lotus, &c., may prove useful, but require experimenting with ; and so, too, with *Paspalum dilatatum* for frostless districts.

(*E.*) For sowing amongst marram : Yorkshire fog, 35 per cent. ; prairie-grass, 2 per cent. ; suckling-clover, 10 per cent. ; cocksfoot, 10 per cent. ; white clover, 10 per cent. ; *Medicago lupulina*, 5 per cent. ; annual lupin, 20 per cent. ; *Lotus angustissimus*, 8 per cent.

Finally, it must here be insisted on that it is impossible to give really satisfactory formulae until all the grasses that are likely to succeed on *sand* have been carefully tested.

(*i.*) AFFORESTATION OF DUNES.

(i.) General.

It is recognized by all authorities on dune-reclamation that a close covering of trees gives the most permanent stability to the sand ; its establishment is the final goal. Forests have been established for many years on various dune-areas in Europe. In Germany, generally speaking, marram-grass is used only for the foredune, while immediately in its lee the planting of trees takes place without any preliminary fixing by sand-binding plants ; but the sand is first fixed by a network of sand-fences. So, too, in France extensive forest-areas, gained not by planting but by sowing seeds, extend from just behind the foredune inland.

So far as New Zealand is concerned, *no tree-planting of moment has been carried out under difficult conditions*. It is true that in many parts plantations have been successfully formed on the older dunes and hollows at some distance from the sea, as in the neighbourhood of Foxton, New Brighton, and elsewhere. At Ocean Beach, Dunedin, too, trees are growing very well indeed in fairly close proximity to the shore (see Photo No. 59). But in the absence of definite examples of the more difficult planting of trees upon the New Zealand dunes, it must be understood that what follows regarding dune-afforestation is to be considered suggestive rather than definite. Before any extensive planting is attempted by either the Government or private enterprise experiments as to methods, and in some cases as to trees, will be required.

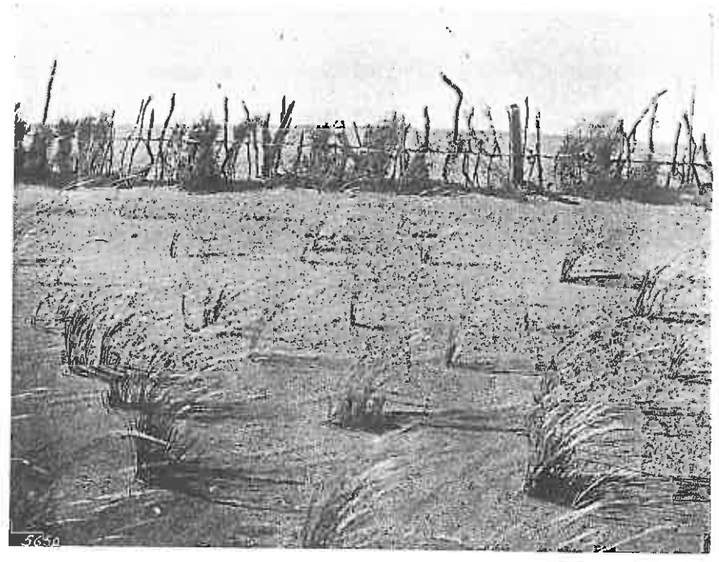
So far as dune-afforestation in general goes, apart altogether from the trouble with moving sand, the climatic difficulties are usually very considerable, and these increase as the shore is neared. *Successes at a distance of a mile or more from the sea are no measure of what can be accomplished in the intervening space.* Nor can the experience of a fairly sheltered shore or a specially moist climate guide the would-be planter of an average New Zealand dune-area. The fear so commonly expressed that dunes provide too poor a soil for trees may be dismissed at once (see Photo No. 71). Reduce the force of the wind, arrest the moving sand, and a surprising number of trees and shrubs can be grown with ease. Even the present experience of New Zealand, notwithstanding the small amount of dune-planting, supports this assertion. Pine-trees of many kinds, hardy Australian acacias, eucalypti, various willows and poplars, together with many other arborescent plants detailed further on, are growing excellently on apparently pure sand in various parts of the Dominion.

A most important distinction to be drawn in arranging for sand-planting is between those species which can tolerate sea-spray and those which cannot do so. The former are obviously suited for planting close to the shore behind the shelter of the foredune, and also in positions specially exposed to violent salt gales, such as those of Taranaki. *Spray-resisting trees, in short, are especially important as shelter-belts, behind which will come the ordinary sand-tolerating trees.*

That which has been already stated regarding the danger of disturbing the plant covering of the dunes applies also to artificial dune forest. For this reason some authorities look upon dune forest as a protecting but not commercial forest. It seems to me that this may be quite true, so far as New Zealand is concerned, with regard to forest close to the shore, but when it comes to our wide dune-

No. 67. In Front Wandering Dune formed by Sand covering Tree-lupin, filling up Flat, Small Well covered by Tree-lupin. Plantation on Dunes in Distance. East Canterbury.

[*Photo L. Cockayne.*

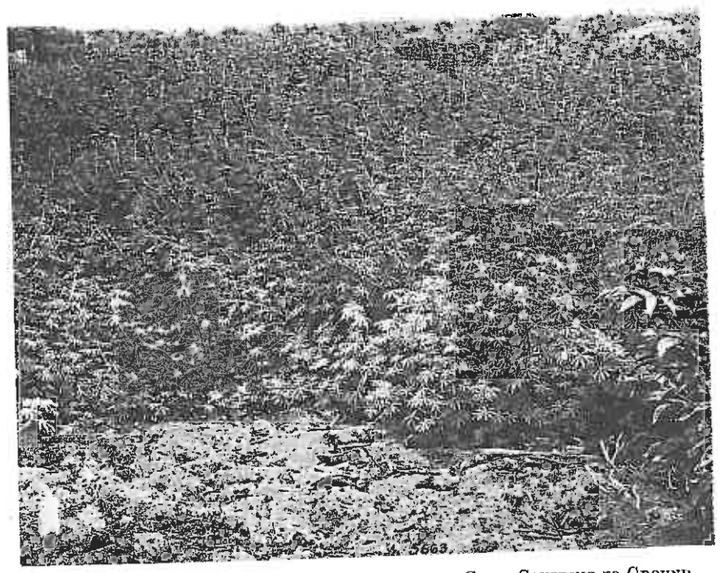


No. 68. Isolated Catching-fence serving no Useful Purpose, and almost buried.

[*Photo L. Cockayne.*

To face page 60.]

No. 69. Osier Willow (*Salix viminalis*) forming a Mound. Dunes of East Canterbury.
[*Photo L. Cockayne.*



No. 70. Tree-lupin, Six Months old, showing its Close Covering to Ground. Dunes of East Canterbury.
[*Photo L. Cockayne.*

areas extending for some miles inland I can see no reason, unless the difficulties of establishing are too great and costly, why the commercial should not be the main aspect. Leaving this aside for the present, the demand for dune-plantations near towns, &c., and on the public reserves will increase, and a knowledge of the suitable trees to plant and methods of planting is distinctly a desideratum.

(ii.) The More Important Trees and Shrubs for Dune-afforestation.

Further on is given a list of plants specially suited for dunes, and short accompanying notes. Here certain trees and shrubs are cited which experience has shown to be of primary importance for purposes of dune-afforestation.

(a.) *Spray-resisting Species.*

(a.) *Olearia Traversii* (the Chatham Island Akeake).—This is the most important tree at the disposal of the New Zealand sand-planter for resisting sea-spray and salt gales, and its value can hardly be overestimated. Plants put in at Ocean Beach by Mr. D. Tannoch have overtopped all others; they have thriven during an abnormally dry season, and are the picture of health (see Photo No. 10). *Olearia Traversii* is found only in the Chatham Islands. There it grows naturally in most diverse stations—viz., dunes, swamps, forest, and *rocks fully exposed to the sea-spray*. As a dune-tree in the Chathams it is from 15 ft. to 20 ft. tall, but in favourable positions it grows considerably taller. When adult it has a naked trunk 1 ft. or 2 ft. in diameter, clothed with rough bark and possessing a rather dense crown. The leaves are opposite, about 2 in. long, more or less, oblong to ovate in shape, thick but soft, bright shining green on the upper surface, but the under-surface is clothed with an extremely dense white mat of silky hairs, as are also the short leaf-stalks, young branches, and branches of the inflorescence. Young specimens are of an erect, fastigiate habit of growth, and are branched and leafy from the base.. Therefore, when planted in lines they make an effective wind-screen. The tree can be raised from seed, but it grows very readily from cuttings put in in the autumn, and this is the best method of propagation. The timber, according to T. Kirk, is "dense, heavy, firm, and compact, with a satiny lustre when worked up. In old trees the outer portion is more or less mottled. . . . The late Mr. Seuffert, cabinetmaker, of Auckland, received small parcels at various times, and valued it highly for inlaying and special work" (114a, p. 47).

(b.) *Pinus pinaster* (also known as *P. maritima*), (the Cluster-pine).—*P. pinaster* is a native of the Mediterranean region. It is especially celebrated as being the tree so successfully cultivated upon the dunes of Gascony, in France. It grows excellently on sandhills in New Zealand, even where fully exposed. Under favourable conditions it will attain a height of 60 ft. to 80 ft. The wood is soft and contains abundance of resin, but rather than as a timber-tree is it grown for its turpentine, a mature tree yielding 12 lb. to 16 lb. of turpentine per annum, and the tree may be tapped without injury for many years.

Pinus halepensis (the Aleppo pine), a native of the eastern Mediterranean region, where it grows at times on exposed coastal cliffs, has not been used in New Zealand as yet for dune-planting, but should be a tree of great value. It yields valuable timber, and also turpentine and tar.

(c.) *Araucaria excelsa* (the Norfolk Island Pine).—How far this beautiful tree will thrive on pure sand I do not know. It is, however, of importance as a coastal tree wherever it is hardy, since it is quite undamaged by the most violent salt gales.

(d.) *Cupressus macrocarpa* (the Monterey Cypress).—This tree, so common in cultivation with us as to need no description, is in the wild state one of the rarest trees in the world, being "limited to two localities on the ocean-shore at the mouth of the Carmel River, near Monterey. The Cypress Point grove extends along the cliffs and low bluffs from Pescadero Point to Cypress Point, a distance of two miles, reaching inland about an eighth of a mile. The Point Lobos grove is much smaller. The trees are scattered over the summits of two headlands, and cling to the edges of the cliffs, where, on account of the erosive action of the ocean, they are occasionally undermined and fall into the sea." —W. L. Jepson (28, p. 119). Economically the wood of *C. macrocarpa* is considered of little value in New Zealand, but according to C. S. Sargent (Report on the Forests of North America, 1884, p. 179) its wood is "very beautiful and of undoubted value as a cabinet wood." But for sand-planting it is of importance in any case, its wind-resisting and drought-resisting power being so great, and fitting it for shelter-screens; and, morever, it can be procured very cheaply from the nurserymen.

(e.) *Pinus insignis* (correctly called *P. radiata*), (the Monterey Pine).—This is also a tree with an extremely restricted habitat locally, and yet is now the best-known and most widely cultivated of all the Californian pines. It grows naturally on dry, rocky, and sandy hills near the sea, and is confined to a few limited localities on the Californian mainland and to some small islands off the coast. *I unhesitatingly consider it the most important of all trees for dune-afforestation.* Its cheapness of production, the perfect certainty of its growth with the minimum trouble in planting, its extremely rapid growth, its tolerance of high winds and drought, and its great value as a most quickly produced timber, if only of the second class, mark it out as a sand-tree of prime excellence. Regarding its value for timber purposes, much more is now known than was the case some years ago, when it was the fashion to speak of it slightingly. In Canterbury it was planted very largely by many of the earlier settlers, rather for shelter and ornament than for timber. But of late years many of these plantations have been converted into timber, and the wood is daily gaining a reputation for use where not exposed to the weather, and for the rougher farm-buildings. The trees which are being used, it must be remembered, were not planted closely on forestry lines, and contain very many more knots in the wood than would otherwise have been the case. Mr. T. W. Adams's dictum *re* the timber of

P. insignis (and I can quote no one whose words could carry greater weight) should be well considered: "In thinking of a future timber-supply, one naturally asks what are likely to be the needs of the future; and if we go to older and better-developed manufacturing countries we find that there is a great demand for soft woods for packing-cases, wood-pulp for making paper, &c., and for these purposes some tree or trees are required that will grow quickly and produce cheap wood. In Europe and America the greater portion of the supply of soft woods is from the different spruces, a lesser supply coming from poplars and willows. All these different trees from Europe and America have been introduced into New Zealand, but I venture to say that *Pinus insignis* will produce twice as much timber per annum as any one of them; consequently, *Pinus insignis* is to be preferred for planting for the production of wood of this class; and I speak from the experience of the growth of twenty species of European and American spruces, besides several Asiatic ones." (Kensington, W. C., 106A, p. 113.)

(f.) *Pinus muricata* (the Bishop Pine).—This pine is a native of California, and grows naturally on low swampy hills, swampy flats, or rocky hills, and always near the ocean-beach or within a few miles of it. In New Zealand it is preferred by many as a sand-tree to *Pinus insignis*, especially in the neighbourhood of Wanganui. The wood is "very resinous, light, hard, and rather coarse-grained. It is sometimes used for piling, as the light-brown heartwood is very durable." (Jepson, *op. cit.*, p. 74.) It is somewhat more hardy than *P. insignis*, and therefore to be preferred for shelter-belts on the sand-drift areas of Central Otago. On some soils it is very apt to be blown over during gales.

(g.) *Tamarix gallica* (the Tamarisk).—The tamarisk grows very well indeed upon dunes close to the sea. At New Brighton it is one of the few plants that are never damaged by the salt winds. Though not the equal of *Olearia Traversii* for shelter purposes, it is a valuable low tree nevertheless. It is propagated very readily by means of cuttings. Other species of *Tamarix* are also suitable for dune-cultivation.

(h.) *Lupinus arboreus* (Tree-lupin).—This, and its uses, &c., have been already dealt with.

(β.) *Trees, &c., not usually tolerating Sea-spray, but growing well in Sand.*

(a.) Various Species of Eucalyptus.

The species which can be grown will depend altogether upon the winter climate. Where there is at times 12° of frost, only the following can be relied upon: *Eucalyptus globulus* (blue-gum), *E. Gunnii* (cider-gum), *E. Muelleri*, *E. coriacea*, *E. viminalis*, *E. Stuartiana*, *E. urnigera*, and *E. coccifera*. Where there is less frost the following may be grown: *E. amygdalina*, *E. obliqua*, *E. numerosa*, *E. regnans*, and *E. pilularis*. There are probably many species which could be grown in northern Auckland, but their hardiness has not been tested as yet to any extent so far as I know.

(b.) Various Species of Acacia.

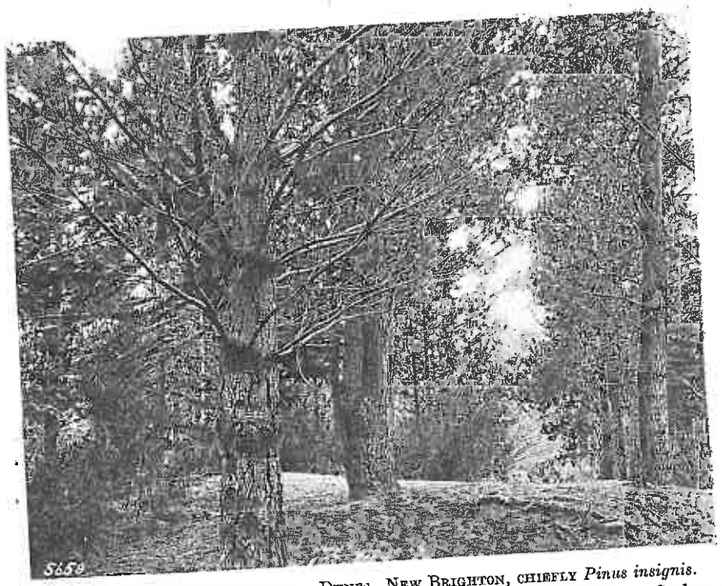
(1.) *Acacia melanoxylon* (Lightwood; Blackwood).—This tree grows excellently and fairly rapidly upon pure sand. *It is certainly one of the most valuable trees for dune-afforestation.* It forms eventually a moderate-sized tree, and should be available for timber in thirty years. The wood is specially useful for ornamental purposes, such as the interior of railway-carriages, &c., ornamental work in houses, and furniture. It is hardy in any part of the North and South Island dunes. It and all the species of Acacia are raised easily and rapidly from seed; but this statement only applies to seed just freshly gathered, which I have known to germinate in seven days. Old seed, on the contrary, germinates with extreme slowness, and may take a year or more. Such seed requires soaking in nearly boiling water for some hours just before sowing.

(2.) *The various Australian Wattles.*—All the wattles grow well and with extreme rapidity on sand. They are a splendid instrument in the hands of the dune-cultivator. *Acacia decurrens* (black wattle) is especially valuable on account of the bark for tanning purposes. *A. dealbata* (silver wattle) grows at an astonishing rate. It gives off an abundance of suckers from the roots, so that thickets may arise in this manner covering many square yards. Damaging the roots leads also to suckers. Drifting sand can thus be covered very rapidly with a close growth; but if the space be at any time required for any other purpose the eradication of the wattle would be very costly. Its use, then, must be regulated by circumstances. *A. pycnantha* (golden wattle) is not so hardy as the two preceding species. Its bark is richer in tannin than is that of *A. decurrens*, but the yield of bark is considerably less. It never grows very tall, and is of a shrubby habit of growth.

(3.) *Other Species of Acacia.*—There are a number of species of Acacia (*A. longifolia*, *A. lunata*, *A. salicina*, *A. sophorae*, *A. penninervis*, and others) which grow with the greatest rapidity on pure sand, forming a very close growth (see Photo No. 48). They are very ornamental, especially when covered with multitudes of soft yellow blossom. The only drawback is that the older branches are liable to be broken by the wind, but such damage usually does no harm to the tree.

(c.) Willows (see Photo No. 69).

A considerable number of willows grow excellently on sand, while some are actually true sand-binding plants. A number are dune-plants of the Northern Hemisphere. A selection of the species



No. 71. Interior of Plantation on Dunes, New Brighton, chiefly *Pinus insignis*. [*Photo L. Cockayne.*

No. 72. Another View of New Brighton Plantation. Trees on Summit of Dune. [*Photo L. Cockayne.*

To face page 62.]

considered specially suitable is to be found in the "List of Plants for Cultivation." The Caspian willow (*Salix caspica*) will tolerate sea-spray. It is objected to in Europe because it is liable to form mounds, and the same would apply to other shrubby willows. All the same, it and other sand-binding willows might with advantage be naturalized on our dunes. Although growing excellently from cuttings, such should not be used *in situ*, but should be struck in advance under favourable conditions; poplar-cuttings should be treated in a similar manner.

(d.) Poplars.

Several kinds of poplar grow well on sand. *Populus deltoides* (cottonwood), (also known as *P. monilifera*, *P. carolinensis*, and *P. angulata*), a dune-plant in North America, though much more frequently growing in moist soil, is perhaps the most important poplar for dune forestry. The wood is light, soft, close-grained, but not strong. It is used for paper-pulp, light packing-cases, &c. *P. balsamifera* (Balsam poplar) and the Lombardy poplar (*P. fastigiata*) are also good sand-plants.

(e.) Various Kinds of Pine-trees.

A large number of pine-trees, besides those noted above, grow very well indeed upon sand, though none are quite so easy to establish as those conifers already mentioned. For timber purposes *Pinus laricio* (Corsican pine) is the most esteemed of all. It has hardly been grown as yet on dunes in New Zealand, but it should certainly be tried, especially as it is used for dunes in Holland and elsewhere in Europe. The following valuable species grow quite well on dunes in New Zealand: *Pinus pinea* (stone-pine), *P. Coulteri* (big-cone pine), *P. austriaca* (Austrian pine), *P. strobus* (Weymouth pine).

(f.) Common Alder (*Alnus glutinosa*).

The alder is an important tree for the moist hollows, but it will also grow upon the hills themselves. It tolerates the sea wind to a very considerable degree, and if damaged will quickly put forth new shoots. It is thus valuable as a shelter plant. The timber is esteemed for its durability under water.

(iii.) Methods of establishing the Trees.

(*a.*) *General.*

Between the planting of trees and marram-grass there is the great difference that the latter can hold any moderate amount of flying and drifting sand, but the former cannot do so, and may be buried or uprooted. At the same time it must be borne in mind that a sandy surface planted closely with trees will, under ordinary circumstances, not move to any great extent, and consequently, if the wind of the locality is not powerful, tree-planting can take place without the providing of special shelter. Planting of this kind can be carried on in the case of dunes which are virtually stable, such as occur frequently at some distance inland. But, in general, such a simple method will not suffice, and as a preliminary the sand must be fixed with either marram-grass or some inert covering. Even when a sand-hollow has to be planted, any drifting sand from the windward must be stopped as a preliminary. The plantation may be established either by planting young trees or sowing seed. This latter method has hardly been tried in New Zealand, except with tree-lupin, but is the common mode in France. For planting, very small trees one to two years old must be used. Where the plantation is for ornament a variety of trees should be employed, but where for profit, then large stands of one species will be the rule. *But it is never advisable to plant any area with one species alone, since a disease peculiar to that species might easily destroy the entire plantation.*

(*b.*) *Establishing Plantations from Seed.*

(a.) General.

The chief advantage of sowing would be its cheapness. The chief disadvantages are uncertainty of germination, patchy results, and the difficulty of procuring absolutely reliable seed. *Only those species can be raised in this manner whose seeds germinate very rapidly, and whose seedlings are also of rapid growth and can withstand the drifting grains of sand.* Pines of good germinating-capacity, Eucalypti, *Cupressus macrocarpa*, oaks, acacias, and varieties of broom suggest themselves as suitable for the sowing method.

(b.) Method of Procedure.

The seeds may be sown either broadcast by means of a drill, or by scraping a very shallow hole in the sand with some light instrument, or even making a slight depression with the foot, dropping in the seed in the two latter cases, and pushing a little sand over it. The drill method will be the most successful for sowing on a large scale, but it can only be employed where the sand is bare and where the surface is not too steep. In all cases, if a covering of marram-grass does not clothe the ground, the sand after sowing must be fixed by laying closely over it pieces of brushwood, as already directed, using whatever material is most easy to procure. Should the seed germinate well and there be a good crop of seedlings, in due course the young plants must be thinned out, but it is well to leave them in

any case much closer than is intended for the final trees. Nature in such a station will do a great deal of thinning out. Broadcast sowing can also take place either where marram-grass has been newly planted or where it is dying out owing to a failing sand-supply. In France, gorse, broom, and marram-grass seed is mixed with that of the *Pinus pinaster* in order to supply nurse plants. Probably annual lupin would better serve the same purpose in New Zealand procedure, since both gorse and broom grow with astonishing vigour on sand, and soon attain a remarkable size.

(γ.) *Tree-planting.*

(a.) General.

The young trees may be either planted without any special preparation or they may be *mossed*. In early planting on New Zealand dunes, and even yet where only a few trees are to be planted, good soil was placed in the holes. *Such a method is quite out of the question for wholesale planting*, since the expense of procuring soil is too great, but otherwise it possesses certain advantages, as shown further on. Mossing consists in wrapping fresh sphagnum moss round the roots of the plant, fastening it on with a strip of flax, and moistening the moss before planting. This method is best for trees difficult to transplant—*e.g.*, species of *Acacia, Hakea, Eucalyptus, Ozothamnus rosmarinifolius, Pinus laricio*, &c. Mossing, of course, adds to the expense. If the young trees are mossed for some time previous to planting and then heeled into moist ground for a time, new roots will develop, and the chance of their growing be much increased.

More expensive still is raising plants in pots. This is done by sowing a seed or two in soil in a thumb-pot or one rather larger, and removing eventually all the seedlings except one. Or the plants can be raised in a seed-bed and afterwards potted. When almost pot-bound, the plant, earth and all, easily comes away from the pot, and should be planted at once. Very few failures result from this method, *provided the soil round the plant is wet at the time of planting*. Pot-plants are too cumbersome, and the method probably too expensive, for planting on a large scale, but it may be used with great advantage for minor plantings and for sandhill gardening, &c.

(b.) The Planting.

Planting may be conducted in a similar manner to that of marram-grass, using either a shovel, spade, or dibble, one person making the holes and the other planting. If the dibble is used one person will suffice, if necessary. A time when the sand is moist should be chosen. Quite small plants are the best. One-year-old *Pinus insignis*, for instance, are growing quite well at Ocean Beach (see Photo No. 60). The right age of trees for planting differs according to the species, but in many cases one-year or at most two-year-old trees are suitable. *Pinus laricio* does not transplant very readily, and perhaps should be mossed; but generally, so far as pines are concerned, plants which have been transplanted in the nursery and have plenty of fibrous roots will be suitable. The roots should on no account be exposed to sun or wind before planting. *Close planting is an essential both for the production of economic forests and for holding the sand.* The minimum might be 2 ft. apart, and the maximum distance 3½ ft. Close planting, of course, increases the expense. Before planting, if the ground is not already planted with marram-grass, the sand must be closely covered with brushwood. The German method of sand-fences in squares is doubtless a most excellent method of protection and sand-fixing, but can hardly be recommended for this country, except under very special circumstances, on account of the great expense it entails.

(c.) The Nature of the Ground to be planted.

The ground should be as even as possible. According to the German practice the dune-complex is flattened, the vegetation being removed from the tops of the hills, and the wind allowed free play until an even surface is secured. Such a practice, according to Gerhardt (18, pp. 330–331), is indispensable. On the other hand, so far as my examination of the New Zealand dunes goes, I have seen marram-grass undamaged on hills and in wind-channels (see Photos Nos. 55 and 56), and I have seen clumps of trees which have been for years on unlevelled sandhills. At the same time, no one can have been more struck than myself by the destructive effect of contiguous mounds, of peaks rising above the general level, and of the irregular planting of sand-binding plants and shrubs. But, as said before, many dune-complexes as a whole are not changing, construction and destruction going on slowly and simultaneously. It seems to me, then, that with the aid of shelter-strips of marram-grass in such an area the hollows, the lower hills, and the already flattened portions could be safely planted with trees. The dune-plantations at New Brighton may be considered secure, and they are a case in point, though hardly a crucial one. At any rate, any dune-area which is to be planted must be considered on its own merits.

The wandering dunes and the semi-wandering dunes, on the contrary, have an even surface, and could be planted with trees. Many flat areas exist in the dune-complex where the hills have been levelled by the wind, and here, too, all is ready for orthodox afforestation.

The hollows, so long as they are not in danger of invasion, will grow trees well and easily unless the water-content is too great. In that case the alder would be the best tree to use, and perhaps certain of the willows. Hollows where *Carex pumila* is dominant would generally be very suitable, and those still more so which are occupied by embryonic dunes of *Scirpus nodosus* or *Spinifex hirsutus*.

(d.) Use of Manures.

The question of supplying the sand with some of the nutritive salts in which it is so deficient, in order that the growth of the young trees at their early critical stage might be assisted, is of importance. So far as German procedure goes, fine loam, either alone or mixed with peat, is added to the sand before winter in the exact spot where the tree is to be planted, the frost further breaking up and mixing the soils. Hard lumps of clay or loam are worse than useless. Not only does the soil supply salts, but it retains the moisture better than the sand alone. The objection to a manuring with loam is the great cost of getting a sufficient supply to the dune-area, as well as the extra work its use entails. On the other hand, there are various artificial manures which would be easy of application as the trees were being planted, but any hints I could give as to which to use would be worthless. The recent work of Dr. Rackman with potash manures on some of the Prussian dunes is very suggestive in this connection. The empirical method of finding out which is best by a series of tests would, however, in time show their value, and manurial experiments, amongst many others, are demanded with regard to our dune-investigations.

IV. DUNE-RECLAMATION FROM THE NATIONAL STANDPOINT.

That we possess an area of more than 300,000 acres of sand, the greater part of which is not only worthless but a constant menace to the surrounding fertile land, is a fact of no small national importance. That, judging from foreign experience and to some extent from lessons to be learnt here, this great tract can be both rendered harmless and in large measure improved should at least cause some thought to be given as to ways and means. The dune-areas are in part Crown, in part Native, and in part private lands. Thus there is in many localities a conflicting ownership. Reclamation methods practised by one owner may be nullified by those owning the land adjacent. To meet this case the Sand-drift Act was framed. But as yet it has not been put into force, nor do I see that in the present state of affairs it could well be otherwise. The average owner of dune land knows nothing of reclamation methods; and even in the light of this report (whatever that may be worth), or with the experiences of others, he is not convinced that his land would be amenable to treatment. Nothing but ocular demonstration, or the stimulus of a general movement towards dune-reclamation, would make him take action. And in some respects this attitude is not unreasonable. Much of the dune-planting in New Zealand is unconvincing, much that has been successful concerns the easier areas, while as a rule the dune-complex—*i.e.*, the crucial point of the whole undertaking—has not been dealt with at all. As for foreign successes, it might be said, "They are a long distance away, while the conditions may not be identical with ours."

Dune-reclamation, the world over, has been considered rather the work of the State than of the individual. The labour involved is too vast, and the interests too diverse, for it to be undertaken by private individuals. The most such can attempt is to make their holdings secure for the time being.

Now, in a matter such as this, it seems to me the Government should proceed with great caution. Too little is known regarding the capabilities of our dune-areas for improvement to predicate an easy success, while still less is known as to the cost of such an undertaking. Could this barren land be turned into forest, even were the cost greater than that of afforestation generally, the work would cry aloud for its accomplishment. But even a profound knowledge of ordinary afforestation methods, and their expense, is of no moment with regard to planning work on the dunes. Before afforestation can be begun, experiments as to its feasibility should be carefully carried out, and, along with such, other experiments showing various methods of dune-reclamation and their cost. These would serve as an object-lesson for those who live on the dune-areas. Experiments such as these are of equal importance with any that can be designed on the experiment farms, and they have the merit of being eminently practical. If they should show the best and cheapest methods of stopping sand-drift and checking wandering dunes they would pay handsomely. And if they should show, further, that the present Crown lands, wastes of sand as they are, can be turned into forest, which will not only be pecuniarily remunerative but will break the sea wind for miles along the shore, then would the cost be returned a hundredfold.

Regarding the site for such experiments, I have carefully considered the question, and with a knowledge of most of the dune-areas. My opinion is that the dunes in the neighbourhood of Levin, Wellington, are specially suitable, since they could be easily visited by those interested, present sufficient difficulties, and are typical of wide areas. If experiments were contemplated elsewhere, under a different climate, I would suggest the dunes in the neighbourhood of Woodhill, Auckland. Both these areas are, I believe, Native land.

The present Crown lands include much of the worst sand-areas. They are at present let as grazing-runs. The question of resting some of these for a time was considered by me, but it would be quite impracticable. All that can be done is to see that the lessee does as little damage as possible. I would recommend that burning be prohibited. Planting of marram-grass, but not of tree-lupin, should be encouraged, and the rule *re* fencing-in any planted area might be relaxed in most cases. Trees, on the other hand, if planted, should be fenced in; but there is no use in planting isolated groups of trees. As for the marram-planting, it should be in wide belts, as already directed, and in places where it can do some good.

Native lands are in many instances a great source of danger. Usually nothing is being done upon them. In any national scheme of dune-reclamation the State would probably have to take over the Native dune-areas, most of which are at present worth less than nothing.

(V.) LIST OF PLANTS SUITABLE FOR DUNE-CULTIVATION IN NEW ZEALAND.[1]

* = Hardy only in the North Island and northern part of South Island. † = Hardy only in the north of Auckland.

Scientific Name.	Common Name.	Habitat.	Growth-form.	Remarks.
Acacia armata	Kangaroo acacia	Australia	Shrub, evergreen	Hedge plant.
—— dealbata	Silver wattle	Australia	Tree, evergreen	Eventually a tall tree. Produces many suckers; makes excellent firewood.
—— decurrens	Black wattle	Australia	Tree, evergreen	Bark used for tanning; makes excellent firewood.
—— longifolia		Australia	Shrub, evergreen	Dense habit of growth; makes rapid shelter; highly ornamental.
—— lunata		Australia	Shrub, evergreen	As for above.
—— melanoxylon	Blackwood; lightwood	Australia	Tree, evergreen	Valuable for timber. A very important tree for dune-afforestation.
—— pycnantha*	Golden wattle	Australia	Tree, evergreen	Bark excellent for tanning, but yield not great.
—— salicina		Australia	Small tree, evergreen	Dense habit of growth; makes rapid shelter; very ornamental.
				Besides the above species of Australian acacias there are many others probably equally hardy and suitable.
Agave americana	American century-plant	Tropical America	Perennial herb	Ornamental for sand-gardens; will grow on sea-shore. Produces many offsets.
Agropyron repens	Couch-grass	Europe	Grass, perennial	Valuable fodder plant for dunes, though elsewhere a terrible weed.
Agrostis alba	Fiorin	Europe, Asia	Perennial grass	*Also the var. *stolonifera*. Both are useful meadow-grasses; grow chiefly in sand-hollows.
—— vulgaris	Red-top	North temperate region generally	Perennial grass	As for above.
Alnus glutinosa	Common alder	Europe, N. Asia	Tree, deciduous	Suitable for sand-hollows. A very important tree for dune-afforestation.
—— incana	Hoary alder	Europe, Asia, N. America	Tree, deciduous	At best a small tree, frequently only a shrub.
Ammophila arenaria	Marram-grass	Europe, N. America	Grass, perennial	The most important sand-binding grass.
—— baltica	Baltic marram	Europe	Grass, perennial	Important sand-binder. Considered a hybrid between *A. arenaria* and *Elymus arenarius*.
Anthyllis vulneraria	Kidney-vetch	N. Europe	Herb, perennial	There is also a variety, *maritima*, which grows on the Baltic dunes.
Araucaria Bidwillii	Norfolk Island pine	Norfolk Island	Tree, evergreen	Resists the most violent salt gales. I cannot speak as to its capacity for growing on pure sand.
Arundo conspicua	Toetoe (often incorrectly written "toi")	New Zealand	Grass, perennial	Valuable for growing on lee slopes of wandering dune. Frequently comes spontaneously.
Astragalus arenarius		N. Europe	Herb, perennial	Has a creeping underground stem, and spreads more or less upon the surface of the sand with its branches 1 ft. in length. Not yet in New Zealand, but possibly of some importance as a fodder plant.
Atriplex nummularium†	Saltbush	Australia		Probably a good many varieties of the saltbush would be hardy on the dunes of northern Auckland; if so, they would make an important addition to the fodder-supply. All are readily raised from seed, which could easily be procured from Australia by the Agricultural Department.
—— semibaccatum				
—— halimoides†				
—— spongiosum				
—— vesicarium†				
—— Halimus	Tree purslane	Mediterranean region	Shrub, semi-deciduous	Used in California for hedges near the sea. Is a low spreading shrub.
Baccharis halmifolia	Groundsel-tree	N. America	Shrub, deciduous	Grows naturally near tidal rivers and in salt marshes.
Betula alba	Common birch	Europe, N. Asia	Tree, deciduous	Will not tolerate wind to the same extent as the alder.
—— papirifera	Canoe birch	N. America	Tree, deciduous	Probably grows better on pure sand than *B. alba*.
—— populifolia	White birch	N. America	Tree, deciduous	As above.
—— verrucosa		Europe	Tree, deciduous	Closely related to the common birch, and by some considered a variety.
Bromus unioloides	Schrader's brome-grass	N. and S. America	Grass, perennial	Called "prairie-grass" in New Zealand. Grows well on pure sand; spreads rapidly from seed. Much relished by stock, who eat it out; could be grown in hollows for winter feed.
Buchloe dactyloides	Buffalo-grass	N. America	Grass, perennial	Probably would grow on dunes; if so, would be a most valuable fodder plant. Not yet in New Zealand.
Buddleia globosa		S. America	Shrub, evergreen	Valuable for shelter; also hedge plant. Good for fire-screen.
Calamagrostis longifolia	Long-leaved reed-grass	N. America	Grass, perennial	Sand-binder.
—— epigeios		Europe, Asia	Grass, perennial	Sand-binder.
Carex arenaria	Sand-sedge	Europe, N. Asia	Sedge, perennial	Sand-binder; extends its creeping stem many yards beneath the sand. Not yet in New Zealand.
Casuarina quadrivalvis*	Coast-sheoak	Australia	Tree, evergreen	The branches can be lopped off and used for feed, according to Mueller.
Chenopodium auricomum†	Blue-bush	Australia	Herb, perennial	Might be hardy in the north of Auckland; and, if so, would be a useful fodder plant.
Cordyline australis	Cabbage-tree	New Zealand	Tree, evergreen	For ornamental planting.
Cornus stolonifera	Red-osier dogwood	N. America	Shrub, deciduous	A sand-binding plant.
Cupressus Lawsoniana (now generally put into the genus *Chamaecyparis*)	Lawson cypress	California	Tree, evergreen	Grows naturally on sandy ridges. The timber is durable, works easily, and is valuable for cabinet-work.
Cynodon Dactylon	Bermuda grass	Cosmopolitan	Grass, perennial	Valuable for fodder.
Cytisus canariensis*		Canary Isles	Shrub, evergreen	Shelter and ornament.
—— candicans	Cape broom	Mediterranean region	Shrub, evergreen	As above, also hedge plant.
—— scoparius	Common broom	Europe, N. Asia, &c.	Shrub, evergreen	An important plant for covering dunes rapidly; also excellent for laying on sand as brushwood. Rarely springs again from stump after being cut down, so does not become a nuisance like gorse.
Dactylis glomerata	Cocksfoot	Europe, N. Asia	Grass, perennial	Might be sown in the most favourable hollows and on ancient soil-covered dunes.
Danthonia semiannularis	Danthonia	New Zealand, Australia	Grass, perennial	One of the most valuable grasses for dunes.
—— pilosa	Danthonia	New Zealand, Australia	Grass, perennial	As above. These two species of *Danthonia* and their varieties constitute the "danthonia" of the New Zealand seed-merchant.
—— pectinata		Australia	Grass, perennial	Probably a useful fodder grass.
Distichlis spicata	Marsh spike-grass	N. America	Grass, perennial	Suitable for hollows. Grows naturally in salt meadows.
—— thalassica		S. America	Grass, perennial	Builds dunes in Chile. Not yet in New Zealand.
Elymus arenarius	Sea lyme-grass	Europe, Asia, N. America	Grass, perennial	Almost as important as marram as a sand-binder.
—— canadensis	Nodding wild rye	N. America	Grass, perennial	Sand-binder.
—— condensatus	Bunch-grass	California, &c.	Grass, perennial	Sand-binder.
Eryngium maritimum	Sea-holly	Europe, Asia, &c.	Herb, perennial	Ornamental and sand-binding.
Eucalyptus amygdalina	White peppermint gum	Australia	Tree, evergreen.	
—— botryoides*	Bastard mahogany	Australia	Tree, evergreen.	
—— capitellata*	Coast stringybark	Australia	Tree, evergreen.	
—— coccifera		Australia	Tree, evergreen	Only a quite small tree.
—— coriacea		Australia	Tree, evergreen.	
—— crebra†	Narrow-leaved ironbark	Australia	Tree, evergreen	An important timber-tree.
—— diversicolor†	Karri	W. Australia	Tree, evergreen	If hardy, a most important tree to introduce.
—— eugenioides†	White stringybark	Australia	Tree, evergreen.	
—— globulus	Blue-gum	Australia	Tree, evergreen.	
—— gomphocephala†	Tooart	W. Australia	Tree, evergreen	A very important tree if hardy.
—— goniocalyx†		Australia	Tree, evergreen	Intermediate in character between a box and a stringybark.
—— Gunnii	Cider-gum	Australia	Tree, evergreen.	
—— haemastoma*	White-gum	Australia	Tree, evergreen.	
—— haemiphloia*	Grey-box	Australia	Tree, evergreen	Considered a very excellent timber-tree.
—— leucoxylon*	Victorian ironbark	Australia	Tree, evergreen	Very useful timber.
—— macorrhyncа*	Victorian stringybark	Australia	Tree, evergreen.	
—— maculata*	Spotted-gum	Australia	Tree, evergreen.	
—— marginata†	Jarrah	W. Australia	Tree, evergreen	Should certainly be tried in the far north of Auckland.
—— obliqua*	Victorian messmate	Australia	Tree, evergreen.	
—— paniculata†	Grey ironbark	Australia	Tree, evergreen	Important timber-tree.
—— polyanthemos†	Red-box	Australia	Tree, evergreen.	
—— resinifera	Red-mahogany	Australia	Tree, evergreen	Excellent timber.
—— rostrata	Murray red-gum	Australia	Tree, evergreen.	

[1] A few plants are given which, although of little or no use for economic dune-work, are of value as ornamental plants for such as wish to form gardens on sand without the aid of soil or other manures. Many more plants suitable for such a purpose could have been cited.

(V.) LIST OF PLANTS SUITABLE FOR DUNE-CULTIVATION IN NEW ZEALAND—*continued.*

Scientific Name.	Common Name.	Habitat.	Growth-form.	Remarks.
Eucalyptus Sieberiana†	Mountain ash	Australia	Tree, evergreen.	
—— Stuartiana	Apple-scented gum	Australia	Tree, evergreen.	
—— urnigera		Australia	Tree, evergreen.	
—— viminalis	Manna-gum	Australia	Tree, evergreen.	
Genista monosperma		Mediterranean	Shrub, deciduous	All the genistas here mentioned will grow on pure sand, and are also ornamental.
—— tinctoria	Dyer's greenweed	Europe	Shrub, deciduous.	
—— aetnensis	Mount Etna broom	Europe	Shrub, deciduous.	
—— radiata		Europe	Shrub, deciduous.	
Glaucium luteum	Horn poppy	Europe	Herb, perennial	Handsome for sand-garden.
Helianthus tuberosus	Jerusalem artichoke	N. America	Herb, perennial	Useful in some cases for providing rapid shelter.
Helichrysum diosmaefolium (formerly known as Ozothamnus rosmarinifolius)		Australia	Shrub, evergreen	Grows excellently and rapidly on pure sand. Can be raised easily from seeds and cuttings. Both a splendid shelter plant and highly ornamental when in flower.
Holcus lanatus	Yorkshire fog	Europe	Grass, perennial	One of the best grasses for pure sand.
—— mollis		Europe	Grass, perennial.	
Ilex vomitaria	Cassena	N. America	Shrub or low tree.	
Hakea saligna		Australia	Shrub or low tree	Both ornamental and useful on sand.
—— acicularis		Australia	Shrub or low tree	Proclaimed a noxious weed, but certainly not so on sand.
—— rostrata		Australia	Shrub, evergreen.	
Juniperus communis	Common juniper	Europe, Asia, N. America	Shrub, evergreen.	
—— sabina		Europe, Asia	Shrub, evergreen.	
—— bermudiana	Bermuda cedar	Bermuda	Tree, evergreen	Wood used for pencils.
—— virginica		N. America	Tree, evergreen.	
Lathyrus maritimus	Shore-pea	Europe	Herb, perennial	Probably useful as a fodder plant. Sand-binder.
—— sylvestris		Europe	Herb, perennial	Fodder plant.
Lavatera arborea	Tree-mallow	Mediterranean region	Subshrub, biennial	Useful for rapid shelter.
Leptospermum laevigatum	Sandstay	Australia	Small tree or shrub	Close relation to the New Zealand manuka.
—— scoparium	Tea-tree; manuka	New Zealand, Australia	Small tree or shrub	If not present should be introduced into every dune-area.
Linaria vulgaris	Toad-flax	Europe	Herb, perennial	Probably a useful minor sand-binder. Many other species of *Linaria* grow well on sand, and the annual species of gardens will grow very well indeed without much water.
Lolium perenne	Perennial rye-grass	Europe	Grass, perennial	May be sown in the hollows.
Lupinus albus	White lupin	S. Europe	Herb, annual	Fodder plant.
—— angustifolius	Blue lupin	Mediterranean region	Herb, annual	Fodder plant.
—— arboreus	Tree-lupin	California	Shrub, evergreen	Next to marram-grass the most important plant for dune-reclamation.
—— luteus	Yellow lupin	Mediterranean region	Herb, annual	Fodder plant. Other species of lupin might with advantage be used on the dunes.
Lycium afrum	African boxthorn	Mediterranean region, S. Africa	Shrub, evergreen	Tolerates salt gales admirably.
—— chinense		China	Shrub, deciduous.	
Malva moschata	Mallow	Europe	Herb, perennial.	
Medicago lupulina	Black medick	Europe	Herb, annual or biennial	Valuable for pasture.
—— sativa	Lucerne	Europe, Asia	Herb, perennial	Might be grown in hollows.
Melaleuca ericifolia		Australia	Shrub, perennial.	
Melilotus officinalis	Melilot	Europe	Herb, perennial	Eaten by stock to some small extent.
Mesembrianthemum aequilaterale		Australia, New Zealand	Herb, perennial	Covers sand if the drift is not too strong, but generally of little use on the New Zealand coast.
—— edule	Hottentot fig	S. Africa	Herb, perennial	As for above. Many other species of *Mesembrianthemum* grow excellently on sand, and are very ornamental.
Myoporum laetum	Ngaio	New Zealand	Tree, evergreen	Tolerates sea-spray, but does not grow particularly well on sand.

Myrica caroliniensis	Bay-berry	North America	Shrub, evergreen	Used on the Cape Cod dunes, U.S.A., as first shelter before planting trees.
Oenothera biennis	Evening primrose	N. America	Herb, biennial	Ornamental.
—— Lamarckiana	Lamarck's evening primrose	N. America	Herb, biennial	As above.
Olearia avicenniaefolia	Akeake	New Zealand	Shrub, evergreen	Good for shelter.
—— Forsteri	Forster's daisy-tree	New Zealand	Shrub, evergreen	Makes splendid hedges; will bear close clipping. In some places takes a gall badly, and then is no use for planting.
—— odorata		New Zealand	Shrub, evergreen.	Many of the other species of New Zealand Olearias grow fairly well on sand, but they will not tolerate the dryest stations, and are of little moment for the North Island dunes.
—— stellulata		Australia	Shrub, evergreen	Formerly known as *O. Gunniana*.
—— virgata		New Zealand	Shrub, evergreen.	
Panicum amarum		N. America	Grass, perennial	Forms tussocks 3 ft. tall.
—— sanguinale	Finger-grass	Cosmopolitan	Grass, perennial	Useful for covering feebly drifting sand.
Paspalum dilatatum	Paspalum	S. America	Grass, perennial	Grows on sand, but its capacity for spreading and maintaining itself is not yet known. If it succeeds it would be a magnificient addition to the sand-pastures.
Picea Douglasii	Oregon spruce	N. America	Tree, evergreen	Probably this important timber-tree will only grow in the hollows or where it is well sheltered.
—— excelsa	Norway spruce	Europe	Tree, evergreen	As for above.
—— sitchensis	Tideland spruce; silka spruce	California	Tree, evergreen	Grows naturally sometimes on sandhills.
Pinus austriaca	Austrian pine	Europe	Tree, evergreen	Will grow on bare sand if sheltered.
—— contorta	Beach pine	California	Tree, evergreen	Grows naturally on sea-bluffs and dunes.
—— Murrayana	Tamrac pine	California	Tree, evergreen	Much as *P. contorta*, but taller.
—— Coulteri	Big-cone pine	California	Tree, evergreen	Grows well on pure sand.
—— halepensis	Aleppo pine	Mediterranean region	Tree, evergreen	An excellent pine for pure sand.
—— insignis	Monterey pine	California	Tree, evergreen	The most valuable of all trees for dune-afforestation.
—— laricio	Corsican pine	Corsica	Tree, evergreen	A most important timber-tree.
—— montana	Alpine pine	Europe	Tree, evergreen	The pine almost exclusively used by the Germans on the Baltic dunes. Not wanted for New Zealand dune-reclamation when there are available so many better timbers and rapidly growing trees.
—— muricata	Bishop pine	California	Tree, evergreen	Grows admirably and rapidly on pure sand exposed to sea wind.
—— pinaster	Cluster pine	Mediterranean region	Tree, evergreen	Probably the best pine for planting close to the sea.
—— palustris	Georgia pine	N. America	Tree, evergreen.	
—— pinea	Stone pine	Mediterranean region	Tree, evergreen	Grows well on pure sand.
—— pondorosa	Yellow pine	California	Tree, evergreen.	
—— rigida	Pitch pine	N. America	Tree, evergreen	One of the dune-pines of eastern North America.
—— strobus	Weymouth pine	N. America	Tree, evergreen	As above.
—— virginiana	Scrub pine	N. America	Tree, evergreen	Another dune-pine of eastern North America.
Poa caespitosa	Silver-tussock	New Zealand, Australia	Grass, perennial	Acts to some extent as a sand-binder.
—— pratensis	Meadow-grass	Europe, N. America	Grass, perennial	One of the best grasses for dune-culture.
Populus alba	White poplar	Europe	Tree, deciduous.	
—— balsanifera	Balsam poplar	N. America	Tree, deciduous.	
—— canadensis	Cottonwood	N. America	Tree, deciduous	Grows well on pure sand. A dune-plant of eastern North America.
—— fastigiata	Lombardy poplar	Spain	Tree, deciduous.	
Portulaca grandiflora		S. America	Herb, annual	Grows well on sand; good for sand-gardens.
Prunus maritima	Beach-plum	N. America	Shrub, deciduous	Grows naturally on beaches and dunes; 1 ft. to 7 ft. tall. Fruit edible.
—— pumila	Sand-cherry	N. America	Shrub, deciduous	More or less prostrate.
—— serotina	Wild black cherry	N. America	Tree, deciduous	Wood valuable for cabinetmaking.
—— virginiana	Choke-cherry	N. America	Shrub or small tree, deciduous.	

(V.) LIST OF PLANTS SUITABLE FOR DUNE-CULTIVATION IN NEW ZEALAND—*continued.*

Scientific Name.	Common Name.	Habitat.	Growth-form.	Remarks.
Quercus alba	White oak	N. America	Tree, deciduous	Wood valuable. With regard to oaks in general they are not to be specially recommended, on account of the difficulty of procuring good seed and the usual slowness of growth. However, in ornamental planting, as in domains, &c., some of these American oaks would be very acceptable.
— coccinea	Scarlet oak	N. America	Tree, deciduous	Wood hard, strong, coarse-grained.
— Ilex	Evergreen oak (the "Ilex" of non-scientific writers)	Mediterranean region ..	Tree, evergreen	Makes shelter.
— minor (syn. *Q. stellata*)	Post or iron oak ..	N. America	Tree, deciduous	Wood very durable.
— virginiana (syn. *Q. virens*)	Live-oak	N. America	Tree, evergreen	Wood very hard, tough, close-grained, and dense.
Rhagodia Billardieri*	.. ..	Australia	Shrub, evergreen	Of spreading habit. A fodder plant.
Robinia pseudacacia	Locust-tree	N. America	Tree, deciduous	Grows on bare sand. Wood extremely durable.
Salix alba	Huntingdon willow ..	N. Africa, Asia ..	Tree, deciduous	Wood valuable for many purposes.
— adenophylla	Furry willow	N. America	Shrub, deciduous	Grows naturally on dunes. Most of the willows are true sand-binders. Many more than here enumerated could be used.
— caprea	Goat or palm willow ..	Europe, Asia	Tree, deciduous	Grows naturally on dunes in Europe.
— cespica	Caspian willow	Asia	Shrub, deciduous	A powerful sand-binder.
— daphnoides	.. ..	Europe, Asia	Tree, deciduous.	
— glaucophylla	Broad-leaved willow ..	N. America	Shrub, deciduous.	
— pentandra (syn. S. laurifolia)	Laurel-leaved willow ..	Europe, Asia	Tree, deciduous	
— rosmarinifolia	Rosemary-leaved willow ..	.. ..	Low tree or shrub, deciduous.	An extremely handsome low tree with glossy leaves.
— viminalis	Osier-willow	Europe, Asia	Low tree or shrub	Excellent sand-binder.
Saponaria officinalis	Soapwort	Europe, Asia	Herb, perennial	Makes dense covering to the ground.
Sophora tetraptera	Kowhai	New Zealand	Tree, semi-deciduous	Valuable for fencing-posts. The name is used with its wide meaning.
Spartium junceum	Spanish broom	Mediterranean	Shrub, evergreen	A very handsome shrub.
Sporobolus indicus	Rat's-tail-grass	Cosmopolitan	Grass, perennial	Grows freely on sand. Said to damage teeth of grazing animals. Will grow where hardly any other fodder plant can exist.
Stenotaphrum glabrum† ..	Buffalo-grass	Cosmopolitan	Grass, perennial	Will bind minor sand-drifts. No value as fodder plant.
Tamarix gallica	Tamarisk	Mediterranean region, Asia	Tree, deciduous	Tolerates sea-spray. Other species of *Tamarix* may also be used.
Tilia americana	Basswood	N. America	Tree, deciduous	Wood serves for many purposes.
Trifolium agrarium	Perennial yellow-clover	Europe, Asia	Herb, perennial	Fodder plant.
— alexandrinum	Bersin clover	Asia Minor, Egypt ..	Herb, annual	Should be tried as fodder plant.
— fragiferum	Strawberry-clover ..	Europe, Asia, N. Africa	Herb, perennial	As above.
— dubium	Yellow-suckling ..	Europe, N. Africa ..	Herb, perennial	Valuable pasture clover.
— repens	White clover	North temperate region	Herb, perennial	Grows fairly well on pure sand, and excellently where there is a little humus, as on ancient dunes. The most important fodder plant for dune-culture.
— resupinatum	Annual strawberry-clover	Europe, Asia, N. Africa	Herb, annual	Fodder plant.
Ulex europæus	Gorse	Europe	Shrub, evergreen	Apt to become a nuisance, but all the same, is doing excellent work in New Zealand in fixing sands and river-beds, in which cases it should be exempt from the Noxious Weeds Act.
Uniola paniculata	Sea-oats	N. America	Grass, perennial	Sand-binding grass, 3 ft. to 8 ft. tall.
Veronica elliptica	Coastal veronica ..	New Zealand	Shrub, evergreen	Can be used for hedges close to or on the shore. A good many other New Zealand species of the genus will grow on sand, but they are valuable solely as ornamental plants.
Vicia sativa	Common vetch	Europe, Asia	Herb, annual or biennial	Probably a fodder plant of importance for sand-hollows, &c.
— tetrasperma	Lentil-tare	Europe, Asia, N. Africa	Herb ..	Fodder plant.
Yucca filamentosa	Adam's needle	N. America	Herb, evergreen	Grows on pure sand. Also ornamental plant.

APPENDIX.

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II. THE SAND-DRIFT ACT, 1908, No. 169.

AN ACT to consolidate certain Enactments of the General Assembly relating to the Encroachment of Sand-drift on Land.

BE IT ENACTED by the General Assembly of New Zealand in Parliament assembled, and by the authority of the same, as follows:—

Short Title.

1. (1.) The Short Title of this Act is the Sand-drift Act, 1908.

Enactments consolidated.

(2.) This Act is a consolidation of the enactments mentioned in the Schedule hereto, and with respect to those enactments the following provisions shall apply:—

Savings.

(*a*.) All Proclamations, orders, schemes, and generally all acts of authority which originated under the said enactments, and are subsisting or in force on the coming into operation of this Act, shall enure for the purposes of this Act as fully and effectually as if they had originated under the corresponding provisions of this Act, and accordingly shall, where necessary, be deemed to have so originated.

(*b*.) All matters and proceedings commenced under the said enactments, and pending or in progress on the coming into operation of this Act, may be continued, completed, and enforced under this Act.

Interpretation.

2. In this Act, if not inconsistent with the context,—

"Local authority" includes Maori Council:

"Owner" means the owner of land in fee-simple; and, in the case of Crown lands of which there is no occupier within the meaning of the Rating Act, 1908, or occupied as pastoral runs or small grazing-runs, means the Crown; and, in the case of other Crown lands, means the lessee or licensee; and, in the case of land owned by Maoris, means the owner or owners.

Sand-drift areas may be proclaimed.

3. (1.) The Governor may, on the petition of any local authority or of any two or more persons interested, from time to time by Proclamation declare that the provisions of this Act shall, on a day named in the Proclamation, come into force within any specified area in New Zealand (hereinafter referred to as "the proclaimed area"), and may in like manner declare that any such area or part thereof shall no longer be subject to such provisions.

(2.) In every case, where practicable, the proclaimed area shall be bounded by a road, river, or other feature.

(3.) Such Proclamation shall be publicly notified at least once a week for one month prior to the day fixed for the Act coming into force within the proclaimed area.

(4.) Where the proclaimed area includes any land owned by Maoris such public notice shall be made in the Maori as well as in the English language.

Minister of Lands to file scheme of operations and assessment.

4. Not later than six months after the issue of any such Proclamation the Minister of Lands shall file in the Magistrate's Court in or nearest to the proclaimed area a scheme for controlling the sand-drift and preventing its further encroachment, and apportioning the cost of and incidental to the operations proposed by the scheme among the owners of land within the proclaimed area, including in such cost the expenses incurred by the Minister in giving effect to this section.

Notice of scheme to be served.

5. Notice of the filing of such scheme shall be served on all owners of land within the proclaimed area:

Provided that where the Minister has obtained the consent in writing of any such owner, service of the notice on him may be dispensed with:

Provided also that in the case of an owner who is not in New Zealand, or whose address in New Zealand is not known to the Minister, a notification in the *Gazette* that the scheme has been filed in the Magistrate's Court as aforesaid shall be deemed to be a sufficient service of the notice.

Appeal.

6. (1.) At any time within two months of the service on him of such notice any owner may appeal to the Magistrate against the exclusion of any lands from the proclaimed area, the inclusion of any lands within the same, or the apportionment of the said cost as proposed by the scheme.

(2.) Such appeal shall be by summons addressed to the Minister, calling on him to show cause why such area or apportionment should not be varied; and the matter of such appeal shall be heard and determined by the Magistrate and two assessors, one to be appointed by the Crown and the other by the local authority.

(3.) The Magistrate, with the concurrence of at least one of such assessors, may—

(*a*.) Cite any additional parties to be parties to the appeal:

(*b*.) Vary the proclaimed area by striking out any lands not likely to be benefited by the scheme, or adding others likely to be affected by drifting sand:

(*c*.) Confirm or vary the apportionment.

Scheme to bind all owners of land.

7. Subject to any order of the Magistrate, every such scheme shall be binding on all owners of land within the proclaimed area.

Delegation to local authority.

8. The Minister may delegate to any local authority power to carry out the operations authorized by the scheme as filed by him or varied by the Magistrate, and to recover from the owners of land within the proclaimed area, according to the apportionment fixed by such scheme, the expenses of and incidental to such operations, in the manner provided by the Rating Act, 1908, with respect to rates; or he may himself carry out such operations, and recover such expenses in the manner aforesaid:

Provided that in recovering such expenses the Minister or the local authority, as the case may be, shall be limited to the proceeds of the sale or letting of the land included in the proclaimed area.

SCHEDULE.

Enactments consolidated.

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