1909.
NEW ZEALAND.

DEPARTMENT OF LANDS:

REPORT ON THE SAND DUNES OF NEW ZEALAND:

THE GEOLOGY AND BOTANY, WITH THEIR ECONOMIC BEARING.

By L. COCKAYNE, Ph.D.

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

INDEX TO CONTENTS.

SIR,— Department of Lands, Wellington, 1st June, 1909.

I have the honour to submit herewith a report on the sand dunes of New Zealand, written by Dr. Cockayne in accordance with your instructions.

The subject of dune reclamation, as is well known, has occupied the earnest attention of experts for a long period of time and in many parts of the world, notably in France, Germany, and the United States, but in New Zealand comparatively little has been done to control the sand-infested areas and render them productive. When it is realised that over 300,000 acres of land in this Dominion are covered with moving sand, the importance of the question of reclamation becomes apparent.

The present report deals mainly with the scientific side of the subject, it being clear that a sound knowledge of general principles, as well as of the local conditions, is a necessary preliminary to any attempt to cope practically with the sand-drift evil. It is hoped that a subsequent report will follow dealing with the more specially economic aspects of the question—viz., the methods of afforestation, the kind of trees, shrubs, &c., to be used, and other matters of a similar nature.

I have, &c.,

WILLIAM C. KENSINGTON,
Under Secretary.

The Right Hon. Sir J. G. Ward, P.C., K.C.M.G., Minister of Lands.

I. 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 especial 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 recognised 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.

The Hon. R. McNab, then Minister of Lands, thoroughly recognising 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 work being begun in the middle of November, 1908.

---

* In the MS. report of the Lands Department certain of the smaller areas are not mentioned, and I have increased the acreage slightly, but probably hardly enough.

A commencement was made with the dunes of western Wellington, an area of more than 90,000 acres extending for about 170 miles along the coast, my instructions being to pay special attention to the Crown lands. The work on these dunes was concluded on the 8th February, and till the 18th February the time was spent in investigating certain coastal tree-planting which had been undertaken in the South Island, including that by Dr. Truby King at Karitane, near Waikouaiti, Otago.

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.

Leaving out of the question the above private studies, the recent investigation has been devoted in the first place to the economic aspect, and in the second to the scientific, so far as one may divide two aspects which can hardly be distinguished, so much do they dovetail and depend on one another. The origin of dunes, cause of movement, relation to climate, and their special flora are certainly matters of pure science, but a knowledge of these is absolutely requisite before any intelligent scheme dealing with their reclamation can be elaborated or discussed. Furthermore, the dunes have been much altered by human occupation, new factors for change have entered in, and a knowledge of these changes and factors is essential. Finally, without going into further details, comes a study of the reclamation methods pursued elsewhere, and the consideration of such with regard to the special circumstances in New Zealand.

From the above it may easily be seen that a three months' investigation of one special dune region does not by any means entitle me to formulate a conclusive scheme as to dune reclamation in New Zealand as a whole. Dogmatic utterances at this stage of the inquiry would be not only useless but dangerous. The reclamation of the dunes on the coast of the Baltic and North Seas has occupied the highest scientific thought for more than a hundred years, and, although the general principles on which success has been there attained are doubtless applicable here also, local conditions and the very different climate must materially modify methods.

This portion of the report seeks rather, then, to explain the general principles on which dune reclamation depends by giving an account of the natural history of the dunes, so as to pave the way for those final conclusions which are only to be derived from a knowledge of the New Zealand dunes as a whole. The study of the Wellington dunes has opened up many questions which can only be solved by the examination of other areas, and, on the answers to such, important details of procedure depend.

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. 1). Others, again, are doing nothing; they recognise 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.

I must express my warmest thanks to those various runholders and others interested in dune reclamation who have rendered me welcome and valuable assistance, and especially to Dr. Truby King, Messrs. K. W. Dalrymple, A. W. Amon, D. L. Blyth, D. Simpson, and J. Handley. I am also highly indebted to Mr. W. H. Field, M.P., for some most excellent photographs of dunes and for assistance and advice; also to Mr. R. Speight, B.Sc., who has contributed the section on the origin and material of dune sand. For help from outside New Zealand my grateful thanks are due to Professor C. R. Barnes, Chicago University; Professor J. W. Harshberger, University of Pennsylvania; Professor L. Diels, University of Marburg; and Dr. B. T. Galloway, Chief Bureau of Plant Industry, United States Department of Agriculture. Finally, I must express my indebtedness to Mr. W. C. Kensington, Under-Secretary of Lands, who put at my disposal a MS. report prepared by his Department in 1903 on the sand-drift question, and which has been of considerable assistance.

(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 no 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. 2); 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 Mother-land 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. 3).

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. 4). Besides fertile soil, valuable flax swamps are filled and destroyed (see Photo. No. 5). Also, watercourses are choked or diverted, and the drainage of the neighbouring country is much impaired.

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. 6), 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, will be given in a succeeding part 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.

Afforestation of Dunes in Europe.

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 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 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 europeus*), 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 present time comparatively little has 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 (98), 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 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.

The following account is condensed from the unpublished report of the Department of Lands and Survey already mentioned, written in 1903. A few minor details are added by myself.

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

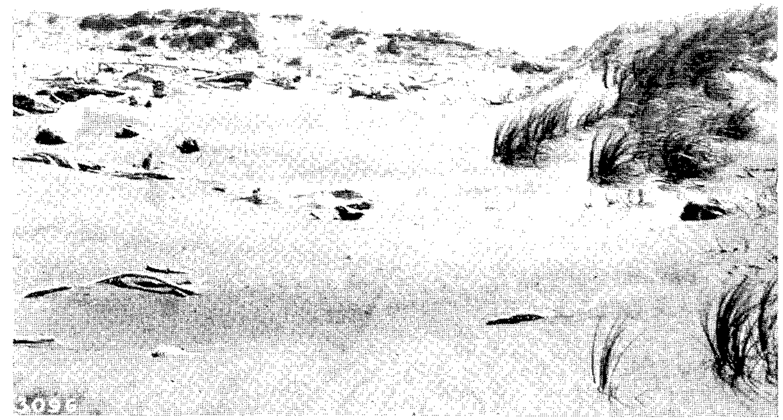
Commencing on the west at 3 miles south-east of Cape Maria Van Diemen, the dunes extend southwards for a distance of 1·7 miles, with an average width of 1·7 miles. Then the coast is rocky to Scott's Point, when a vast stretch of high sandhills forms a belt 47 miles long, with an average breadth of 3 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 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

* Almost every article hitherto written on New Zealand dunes merely gives an account of what was done in France.
† Usually sold under the name of *Pinus maritima* by nurserymen.

Face p. 4.]

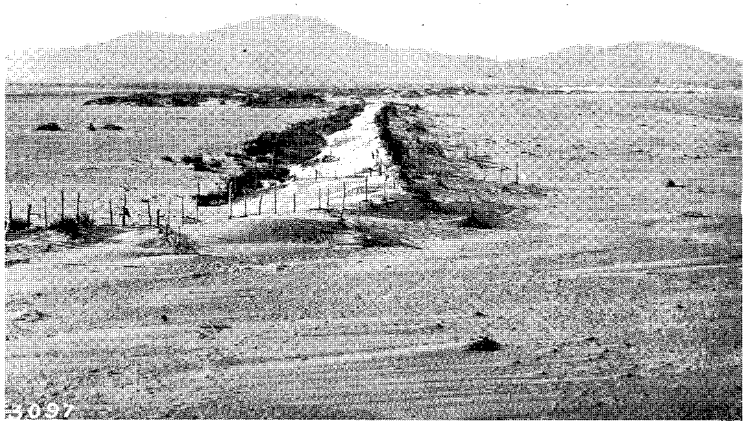
No. 1. Marram-grass planted in a wind-channel formed by two hills. Here growth impossible without protection.

[Photo W. H. Field.



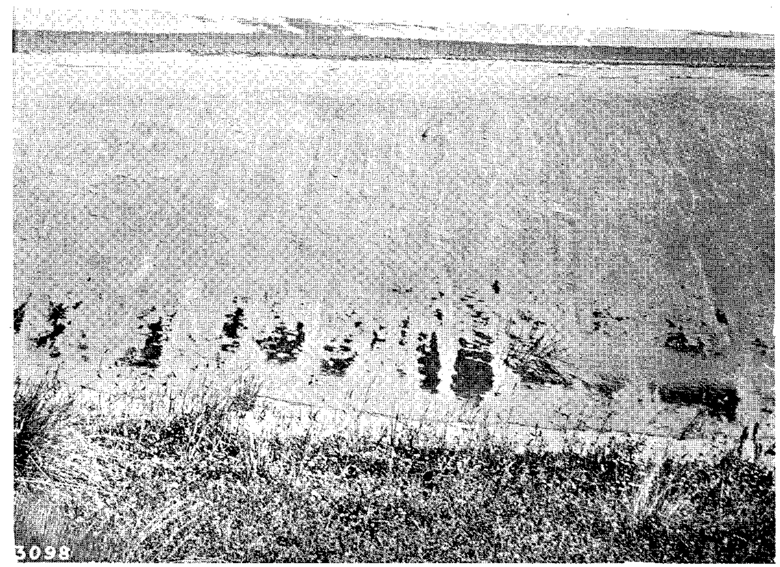
No. 2. Breach in foredune made by sea, north of Rangitikei River. Driftwood carried inland. On right the Pingao (*Scirpus frondosus*).

[Photo L. Cockayne.



No. 3. Sand-spit, Waikouaiti Bay. In centre artificial foredune; natural dunes beyond.

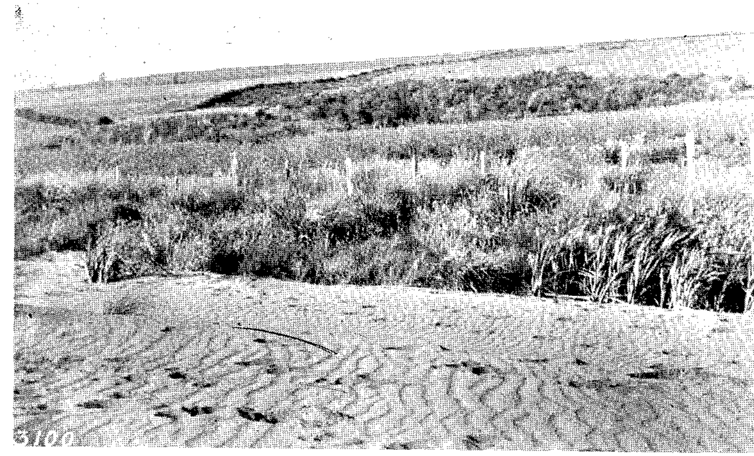
[Photo L. Cockayne.



No. 4. Dune-fall of wandering dune gradually filling up a fairly fertile hollow.

[Photo L. Cockayne.

No. 5. Sand-drift filling up Phormium swamp. Dunes of western Wellington.
[Photo L. Cockayne.



No. 6. Wheatfield threatened by a deep drift from a wandering dune, which has partially filled a swamp in front.
[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.*

No. 8. Coastal cliff north of Wanganui, near the Ototoka Stream.
[Photo L. Cockayne.

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 Rangaunu Bay, having a length of 17 miles, and varying from $\frac{1}{4}$ mile to 2 miles. 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 $\frac{1}{2}$ 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.

(*b.*) 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.

(*c.*) 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 $\frac{1}{4}$ mile; on the beach at Waimarama, 8 miles south of Cape Kidnapper; at the mouth of the Porangahau River; near Cape Turnagain.

(*d.*) 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 $2\frac{1}{2}$ miles and a greatest width of about 6 miles. There are also small areas on the shores of Wellington and Porirua Harbours, and at Lyell, Haughton, and Island Bays.

(*e.*) 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 $\frac{1}{2}$ mile (see Napier Bell, 62). There are also small areas at West Wanganui Inlet, Cape Farewell, Golden Bay, and Tasman Bay.

(*f.*) 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 $12\frac{1}{2}$ miles, having an average width of 7 chains. Another narrow belt extends from the mouth of the River Clarence for $3\frac{1}{2}$ miles to Waipapa Point.

(*g.*) 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.

(*h.*) 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 Cluthā 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.

(*i.*) 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), and from the Waiau River westwards.

(*j.*) 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.

(*k.*) 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.

(*l.*) 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, 84.)

(*m.*) 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.

II. GEOLOGY.

(A.) GENERAL REMARKS.

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 recognised, leading to a fixed goal, while at the same time a somewhat similar retrogression is in progress. Thus forms resembling one another may be fashioned by growth, or by decay.

Hand-in-hand with the building of dunes under natural conditions goes their occupation by plants, these assisting 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 the exception rather than the rule, a dune area 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. Moreover, man, with his introduced grazing animals, fires, and methods of cultivation, has further assisted to upset the equilibrium of the dunes, rendering them still more desert-like.

A general knowledge of the changes 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, B.Sc., F.G.S., Lecturer on Geology, Canterbury College.]

(a.) 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 these vaster *débris* masses locally called "shingle-slips." From these the fragments pour into our rivers. During their movement seawards breaking up goes on constantly, and fine materials are also added to the load of the river from the country through which it passes. From the waste of the land, materials of all grades of fineness are thus produced, from boulders of huge dimensions down to almost impalpable powder. The term "sand" is usually restricted to these grains, varying in diameter between $\frac{1}{100}$ in. and $\frac{1}{20}$ in. However, there is no real difference as far as origin is concerned between gravel and sand, the one passing into the other by insensible gradations. There is a difference, however, in composition. Gravel is 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. 8). 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 aestuarine 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 under those conditions capable of being moved by the waves is, then, very great, so that the supply available for dune-building is great also.

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. 10).

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 Lyell Bay, near Wellington; and far north of Auckland, where the mountain headlands from Cape Maria van Dieman to the North Cape are joined to the solid land near Mongonui by the best-developed sandspit and sand-dunes occurring in the Dominion.

(b.) 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 action 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 iron-sands of its 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 further 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.

In Bulletin No. 6 of the Geological Survey (page 119) it is stated, "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.

(c.) 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. Desert sands are always rounded for this reason. 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.

(*a.*) 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 watermarks, building up the lower shore, or the "sea-wall," as it is sometimes called. Other portions are deposited in the shallow water, forming sand-banks, 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 at best 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.

(*b.*) 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 over a river several miles in breadth. The air-borne particles, since they do not fall all at once in heaps, but are scattered over wide areas, play no primary part in dune-building, the rolling and hopping sands being alone of moment in that regard.

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.

(*c.*) 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 (5, 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 iron-sands, 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. 11), 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.

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 (15, p. 54).

(*d.*) 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 leeside 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 "sand-fall" 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 Photos. Nos. 28 and 30).

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.

(*e.*) Effect of Obstacles.

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.

(α.) *Solid Obstacles.*

These are very frequent, and may consist of a piece of drift-wood, 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 advancing sand cannot pile up against the obstacle, but forms a heap at some distance in front (see Photos. Nos. 16 and 22). 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. 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.

(β.) *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. 12).

(γ.) *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. 29).

(*f*.) 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 layers of sand differing in coarseness* 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.

(*g*.) 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 hours yearly during which rain falls 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, 85, 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 often at first 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.

Frost is not of much moment in New Zealand generally, but on certain South Island dunes it retards drifting.

(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 drift wood or a strand plant, it is 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 on captured by *Scirpus frondosus* in the southern floristic 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 (38, 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. 3). At New Brighton, Canterbury, is a much better example, which has quite checked the former very troublesome drift from the shore, and its further extension is a matter urgently needed by the borough.

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

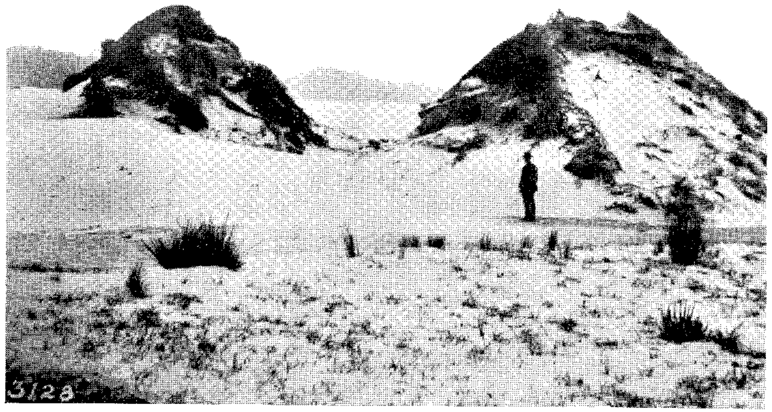
Where the supply of sand is small there may be only a foredune, and this of the smallest dimensions, but usually behind the foredune are numerous chains of sandhills of quite irregular form, which are generally divided in places by basin-like hollows of greater or less extent. Usually the ridges are 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 (*c*) 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" (10, p. 194), a term well suiting the case.

---

* Consequently of different water-holding power.

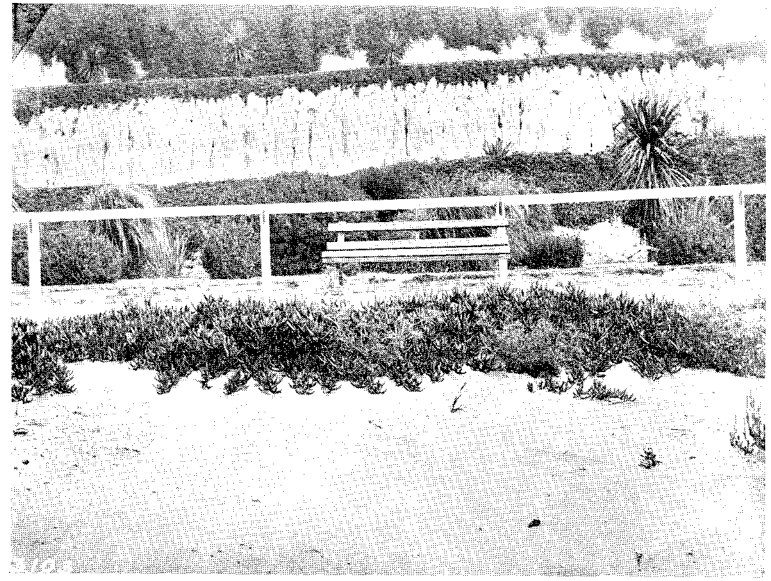
† Small masses of sand whose wet grains cohere will be blown along if loosened by some means, as by the hoof of an animal. Particles of this kind are frequently blown along a wet shore.

Face p. 10.]



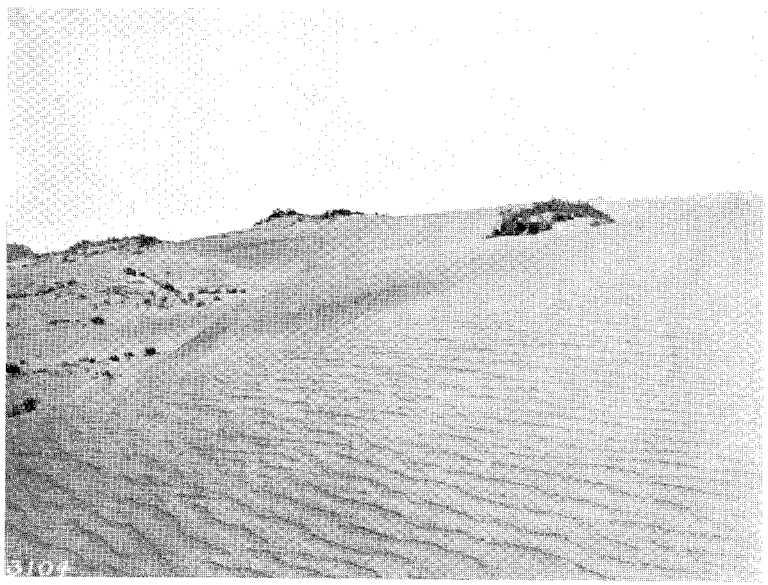
No. 9. Sand-plain in which drifting sand is being fixed by *Carex pumila*. Wind-channel and wrecked dunes in centre.

[*Photo W. H. Field.*



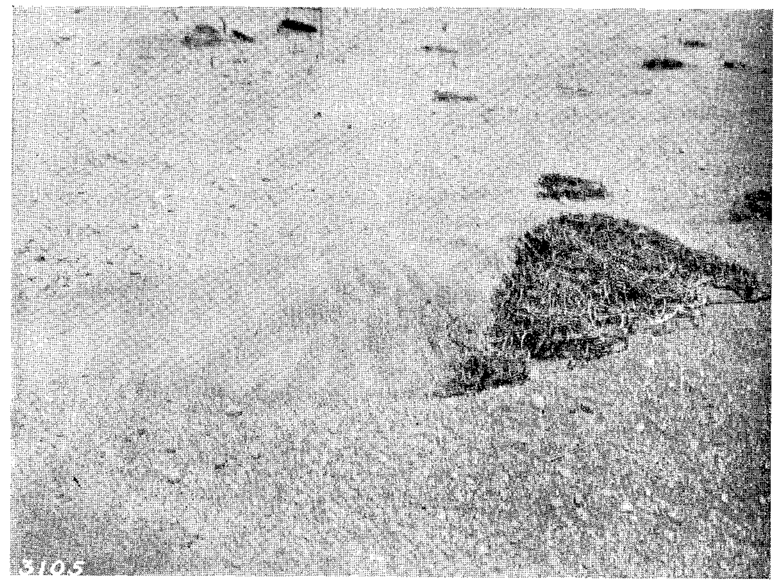
No. 10. Foreshore, Caroline Bay, Timaru, formerly gravelly, now covered with sand. Embryonic dune built by planting Mesembrianthemum.

[*Photo L. Cockayne.*



No. 11. Conversion of dune-complex into wandering dune, which is advancing burying hills and adding to its volume.

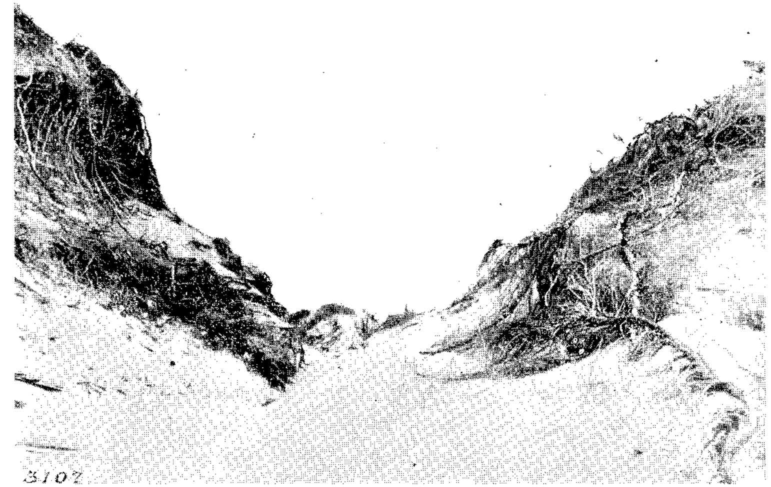
[*Photo L. Cockayne.*



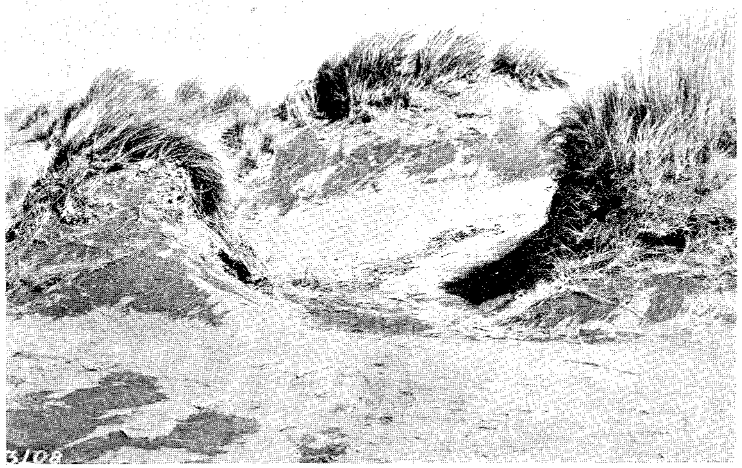
No. 12. Tongue of sand in lee of prostrate shrub (*Coprosma acerosa*) on stony desert, south of Wanganui.

[*Photo L. Cockayne.*

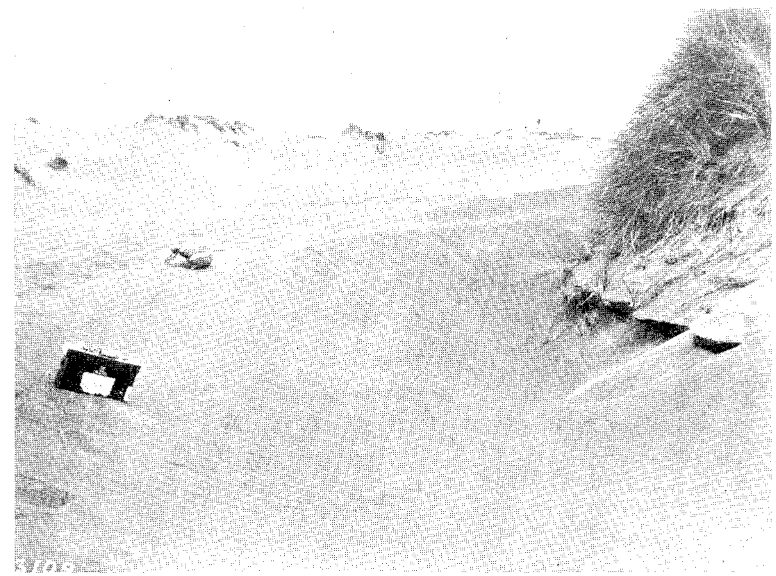
No. 13. Natural foredune near Waikanae held by the Silvery Sand-grass (*Spinifex hirsutus*), forming an excellent protection to the coast.
[*Photo W. H. Field.*



No. 14. Wind-channel between two hills, showing destructive effect of mounds raised by sand-binding plants.
[*Photo L. Cockayne.*



No. 15. Marram-grass planted to arrest drift has built hills which have led to wind-channels and fresh destruction in consequence.
[*Photo L. Cockayne.*



No. 16. Wind-trough caused by eddy from face of mound raised by planting Marram-grass.
[*Photo L. Cockayne.*

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 at all worthless by any means. There are 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. 19).

Generally speaking, the view from an eminence is that of a sea of sand, the ridges stationary billows, as indeed they are, the scanty vegetation showing only as small yellowish or dark patches on the general white or greyish groundwork.

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

(F.) MOVEMENTS OF DUNES AND DUNE SAND.

(*a.*) 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 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 (46). 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.

(*b.*) 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* (35, 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 to be discussed in a continuation 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, tussock, or shrub—favours erosion. Still more is the velocity of the wind increased by the proximity of two objects, as two adjacent mounds, making a channel (see Photos. Nos. 1, 14, and 15). 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. 1). Nor is it simply a direct wind-current which operates; 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, 29). 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. 15). 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, 15, pp. 343–44) with the caspian willow (*Salix caspica*), a plant which tolerates sea-spray, 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. 16). When a strong wind is blowing the eddy on the steep leeside 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 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 take 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 mark the position of former sandhills (see Photo. No. 20).

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.

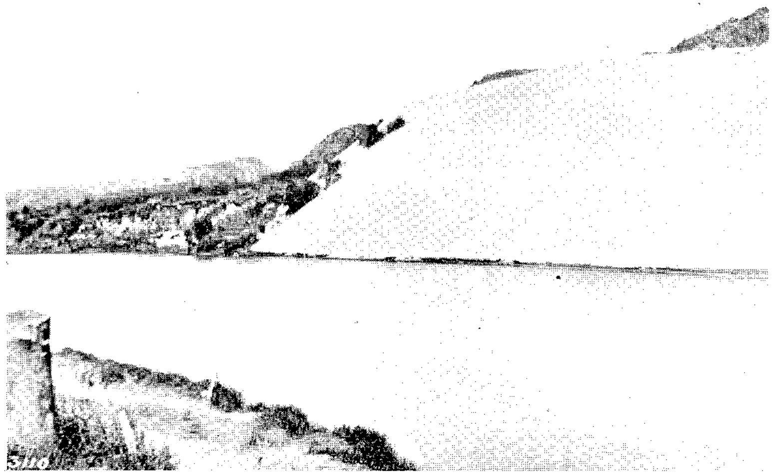
Sand-plains within the dune complex may remain for many years undisturbed, as evidenced by the age of their vegetation, and in places they become occupied by good pasture plants. But sooner or later there will be a sand invasion, and a new dune complex or dune chain occupy their site.

(c.) 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 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 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.

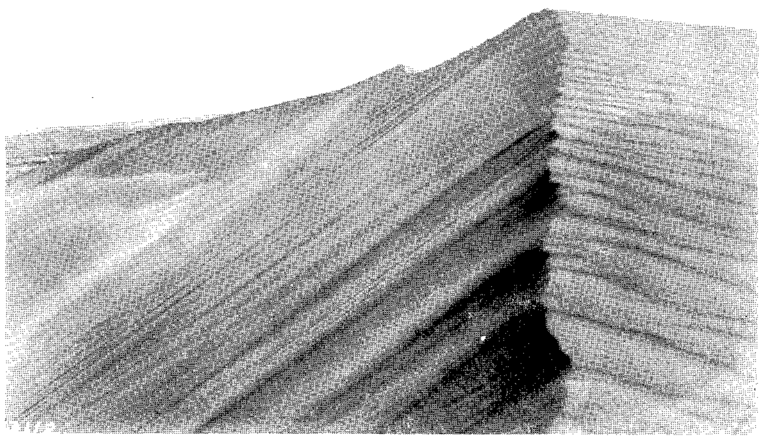
The rate of movement is governed by a number of factors. The shape and height of the dune is of great importance, a high dune, other things being equal, moving more slowly than a lower one. Climate, specific gravity of the sand, size and shape of sand-grains, velocity of wind, plant-covering of the dunes, 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. 17). 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 the 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.

Dune-wandering is especially dangerous since it is slow and insidious, but in its very slowness lies the security to those *who recognise the danger*, since it gives abundance of time for permanent reclamation work.

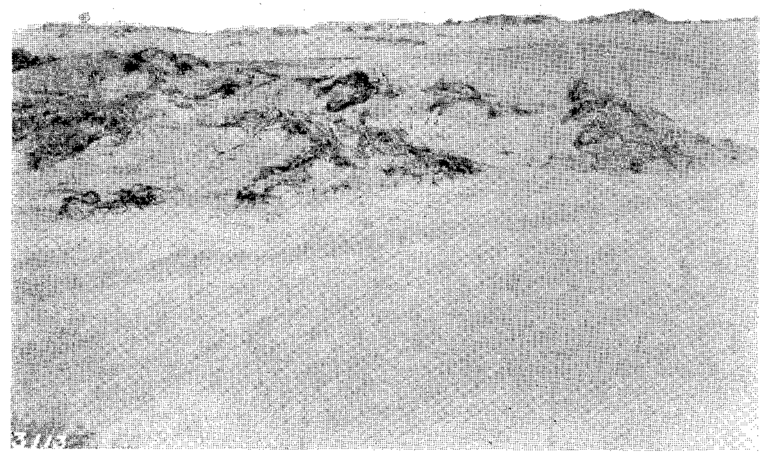


No. 17. Advance of wandering dune stopped by River Turakina. Well-fixed portion of dune above.

No. 18. Sand-drift from shore killing grass in dune-hollow. In centre and to right *Mariscus undulatus*.

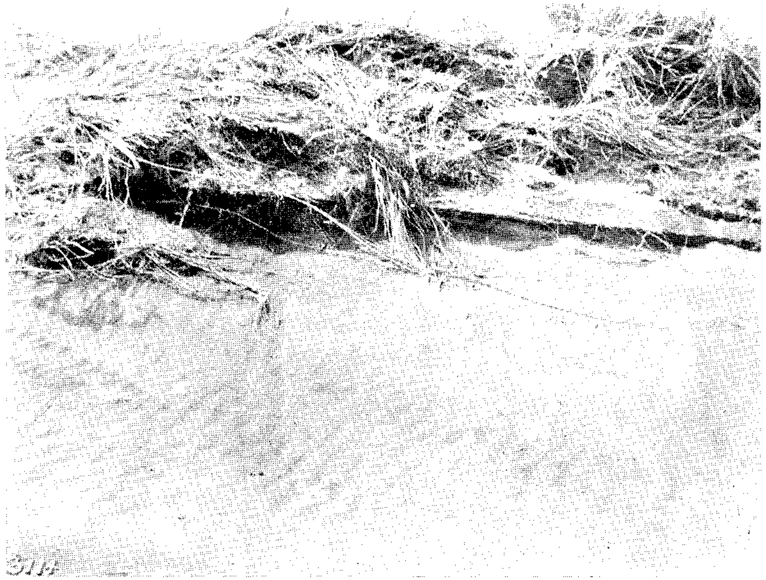


No. 19. General view of wandering dune, formerly good grazing-land, showing ridge at summit of sand-fall.



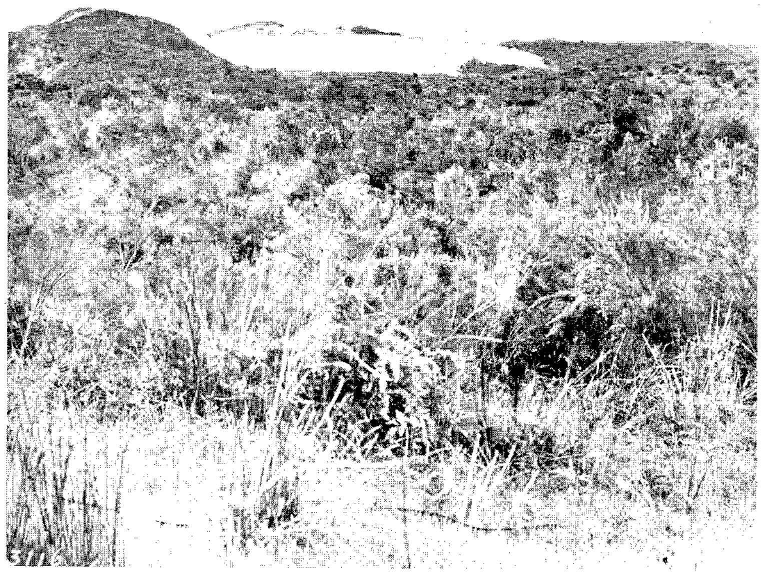
No. 20. Wandering dune in process of formation. In centre wrecks of *Scirpus frondosus* dunes.

[Photos L. Cockayne.

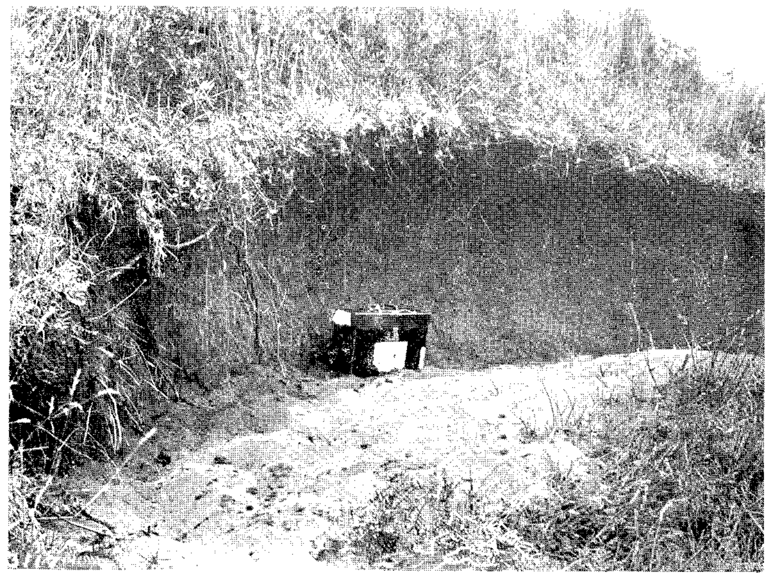


No. 21. A planting of Marram-grass which had succeeded well being now undermined on its windward side.

No. 22. Base of coastal cliff, Patea. Portion of under-cliff dune on right, and ascent of sand by gully to summit of cliff.



No. 23. Dune naturally fixed reverting to the active stage at summit. Shrubs in front chiefly *Cassinia leptophylla*.



No. 24. First stage in history of a wandering dune: hole made by sheep. 5 by 4 camera-case for scale.

[*Photos L. Cockayne.*

(*d*.) 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, especially from hollows where the wind has full power (see Photo. No. 18). 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 such which are nearly always shown as examples of how to control dunes in general—a quite misleading object-lesson.

(G.) LAND FORMS OF THE DUNE AREA.

(*a*.) Dunes.

(1.) *Dune Ridges.*

The foredune is a typical example of a dune ridge, and has already been described. Partly sheltered by the foredune are 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 but semi-stable, the plant-covering usually only occupying half their surface, and in many places are so bare as to be a transition to the wandering dunes.

Fixed Ridges. (See Photo. No. 33.)

Ridges absolutely fixed by nature are to be found only at the inland termination of a dune area. 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 further inland.

(2.) *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.

(3.) *Wandering Dunes.* (See Photo. No. 19.)

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 "sand-fall," 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, 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 sand-fall is often a sharp ridge, the result of the eddy (see Photo. No. 19). 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. 20). 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. 21) causes an accumulation of loose sand, thus giving material for burial of plants and filling up of hollows. According to Jentzsch (15, p. 81), it takes 100 dune chains, each 6 m. high, to build a wandering dune 60 m. 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, 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 in so much 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.

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.

(4.) *Cliff Dunes.*

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 (see Photo. No. 22). Dunes similar in origin are formed in front of high sandhills, or even on dunes themselves. These "cliff dunes," to give them a name, the "*Stufendünen*" of Jentzsch (15, p. 72), are of two kinds—the under cliff, as just described, and the upper cliff dune.

The Upper Cliff Dune.

Where a 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.

Between Wanganui and Cape Egmont there is, except in a few places, a long line of coastal cliffs (see Photo. No. 9) on which are dunes, some extending inland, and "wandering."

Possibly these dunes have a twofold origin. Thus they may be the remnant of what occupied the site of the cliff-surface now weathered away,* or they may be in part upper cliff dunes such as described above. Personally, I had no opportunity of witnessing the effect of a high wind on the foreshore at their base. Where there are gullies in the cliff, even though very steep, the sand ascends by their aid to the summit (see Photo. No. 22), and such a drift may be considered a combination of upper and under cliff dunes.†

(5.) *Juvenile Dunes.*

Dunes are encountered in every stage of building. Certain plants—*e.g.*, *Carex pumila*—raise quite low mounds, only a few inches tall, which never attain any noticeable height, but do not drift to any extent. On sand-plains, fed by a rich supply of material, mound after mound, all touching, may be formed by the silvery sand grass (*Spinifex hirsutus*), and present a remarkable spectacle. Embryonic dunes are built by certain shrubs on their leeside or interior, or they finally bury the plant; in both these cases the form is but transitory, the wind rapidly removing the sand-heap.

(6.) *Sandspits* (see Photo. No. 3).

Sandspits are of great economic importance, in so much 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.

(7.) *Sand-plains.*

These have been already dealt with, and need no further comment.

(8.) *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 the dune area, but generally it is nearer the landward than the sea boundary.

---

* Pharazyn, who first called attention to these dunes, considered there had been such a weathering, and he calls attention to remains of trees and lignite, especially near Kai Iwi, buried beneath the sand (107).

† The dunes referred to here were quite active in 1849 according to Lieutenant C. H. Smith and Lieutenant C. Hutchinson. ("Notes on New Zealand," No. 6, p. 18, March, 1850.)

(9.) *Lakes.*

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.

Before the advent of man there can be little doubt that the dunes were much more stable than they are at present. The opinion, however, expressed by many that their present instability and 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.

Notwithstanding what is stated above, there can be no doubt the virgin dunes were, as a whole, much more stable than at the present time. Even now the dune complex near the sea does not move to any great extent, and certain hills are completely shrub-clad and actually stable, and will remain so until such time as the advancing sand shall bury the plants.

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 keep back any moving sand of moment. Doubtless, too, in certain cases, there has been a rising coast-line, and certain of the inland dunes are very ancient. In Stewart Island, for example, dunes extend virtually across the island from the head of Paterson Inlet to Mason Bay, marking the presence of a former strait.* A line of ancient dunes also forms the "backbone" of the great sandspit between Mongonui and the North Cape.† Ancient dunes covered with loam should be much less liable to drift when disturbed than would the youngest but furthest inland dunes of an area in progress of formation.

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 native grasses, shrubs, and bracken fern, and beneath a layer of loamy sand. Burning the shrubs, &c., here did no harm, but rather good at first, preparing the way for various useful grasses. 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. 23).

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. 24) 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 power. Such gully wounds are most difficult to heal (see Photo. No. 1), 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. 25), 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 so 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

---

* See Cockayne, 79. † Cheeseman, 70; Mackay, 98. ‡ *Leptocarpus simplex* and *Scirpus nodosus.*

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, 56, 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.

III. 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 generalisations 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 (see Photo. No. 26).

The dune flora 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, 90).

(B.) CONDITIONS FOR PLANT LIFE.

(*a.*) 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 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.‡

(*b.*) CLIMATIC FACTORS.

(α.) *Wind.*

Wind is by far the most important of the climatic factors. According to the position of the sea-shore with regard to the prevailing wind, so is the average intensity very different.

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 life, 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.

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.
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.

---

* Recently the United States Government sent one of its botanists over to Europe to study foreign methods of dune-culture for the benefit of the above district and elsewhere (see Hitchcock, 21).

† 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.

‡ This fact has generally been quite overlooked by New Zealand writers on dune reclamation.

7. Transpiration is much accelerated, thus leading to desiccation, and strong xerophytic structure is thereby demanded, or plants may be wholly or in part killed.*

(β.) *Heat (taken in conjunction with the Soil).*

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 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 dune plants are "making soil" is to some extent unwarranted. Generally speaking, there is but little frost on the dune areas. Those of eastern Canterbury are the coldest, owing to the cold air from the Southern Alps sinking to a low level; but they rarely, if ever, experience more than 15° of frost, and that for but a few hours.

(γ.) *Rain.*

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 more than 100 in. yearly, has a dune vegetation no richer than the sandhills of eastern Canterbury, with their rainfall of some 25 in. An extreme number of rainy days combined with cloudy skies, however, does bring a change, as seen in the low mixed forest on the leeside 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, 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 (15, p. 103) that in all probability there is an internal formation of dew, and this theory seems quite feasible. The dry layer of surface-sand assists strongly in checking evaporation, playing the part of what gardeners call a "dry mulch." At the base of the dunes is abundant water, and this can be utilised by deep-rooting plants. The powerful surface-dew must also play an important part.

(b.) 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 wet, 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, the sand remaining moist for a longer period. Humus is frequently altogether absent, except on the surface of the ancient fixed dunes. 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.‡

The chemical composition, theoretically of much moment, is actually of little account, though a pure quartz sand, according to Warming (55, 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 uniformity of vegetation occurs on all the New Zealand dunes, those of the Auckland Islands excepted.

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, 24). 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*

* The "salt-gales" of the coast of part of Wellington and Taranaki, which occur every few years, make their effect felt even at twelve miles inland, damaging deciduous trees, eucalypti, and some conifers, while certain species—*e.g.*, Norfolk Island pine and African boxthorn—are undamaged.

† Forests of the Chatham Island akeake (*Olearia Traversii*) were formerly common on the dunes of Chatham Island, but many have been buried since the introduction of sheep and cattle.

‡ That of the New Brighton dunes makes an excellent soil for experiments in pure cultures of plants, as it contains no seeds of any kind.

§ I have noted an incrustation of salt on the leaves of *Scirpus frondosus* at Haughton Bay, Cook Strait. Salt is also carried for some miles inland by the Taranaki "salt-gales."

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*.

(*c*.) The Plant-covering.

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.† 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 hordaceus*,‡ *Trifolium arvense*, *Hypocharis radicata*, &c.

C. THE MOST CHARACTERISTIC PLANTS, THEIR LIFE-FORMS AND ADAPTATIONS.

(*a*.) 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 to no small degree by 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 specialised 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 life-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 arisen 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 principle of mutation or natural selection.

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 up of many wiry or flexible branches; or they may simply arrest the sand, as do certain plants of the tussock form.

Finally, there are the plants of moist hollows, which have no special dune "adaptations," though one (*Gunnera arenaria*) is found nowhere else, 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 life-forms, &c., have evidently nothing to do with dune conditions, and so receive no treatment here.

In what follows a brief account is given of each species, there being altogether too few to allow of generalisations as to life-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—possess life-forms and "adaptations" similar to those of dune plants elsewhere.§

The following are the most important species of the moving dunes and dune hollows, the ones peculiar to the dune areas being marked with an asterisk:—

(*b*.) List of Leading Dune Plants.

(*a*.) *Sand-binders.*

(1.) *Major.*

**Spinifex hirsutus* (Gramineae).
**Scirpus frondosus* (Cyperaceae).
**Euphorbia glauca* (Euphorbiaceae).

(2.) *Minor.*

**Carex pumila* (Cyperaceae).
**Calystegia Soldanella* (Convolvulaceae).

(*β*.) *Sand-collectors.*

(1.) *Major.*

**Coprosma acerosa* (Rubiaceae).
**Pimelea arenaria* (Thymelaeaceae).
Cassinia leptophylla (Compositae).
,, *fulvida* (Compositae).
,, *retorta* (Compositae).

† This must not be overestimated, for reasons given before.
‡ Generally known as *Bromus mollis*.
§ These are detailed by Warming (51, p. 251, and 55, p. 264 and pp. 266–268).

(2.) *Minor.*

**Festuca littoralis* (Gramineae).
**Calamagrostis Billardieri* (Gramineae).
Scirpus nodosus (Cyperaceae).

(γ.) *Wet-ground Plants.*

Leptocarpus simplex (Restionaceae).
**Gunnera arenaria* (Halorrhagaceae).

(*c*.) 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, bind 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 $\frac{4}{10}$ 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 frequently as to 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 $\frac{1}{3}$ 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 a foot 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. 14.)

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-brancing, 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 $\frac{5}{8}$ 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, lightly bound together at the base by their sheaths, the diameter there being about $\frac{7}{8}$ 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 $\frac{1}{4}$ 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 under surface, 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; Waiuatua*).

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. It is terete, brittle, brownish, and much-branching. The *stems* are prostrate and trailing,* variable 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. 27) 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 band of this colour down 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.) 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. 28) 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, $\frac{3}{10}$ 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.

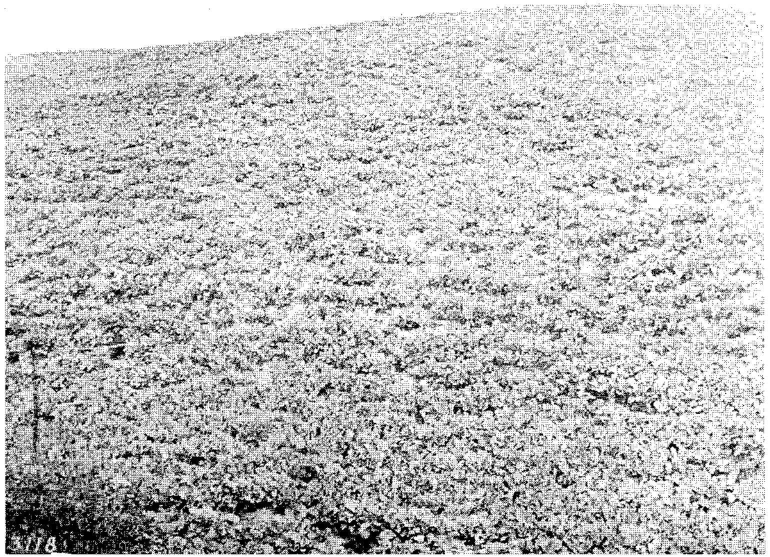
---

* Where growing amongst shrubs, &c., the stems not unusually twine, the plant then becoming a liane.

† This is *Coprosma acerosa* A. Cunn., var. *arenaria* T. Kirk. The var. *brunnea* T. Kirk I consider a good species, which would then be called *C. brunnea*, while the var. *arenaria* will be identical with *C. acerosa* A. Cunn., and is so considered in this report.

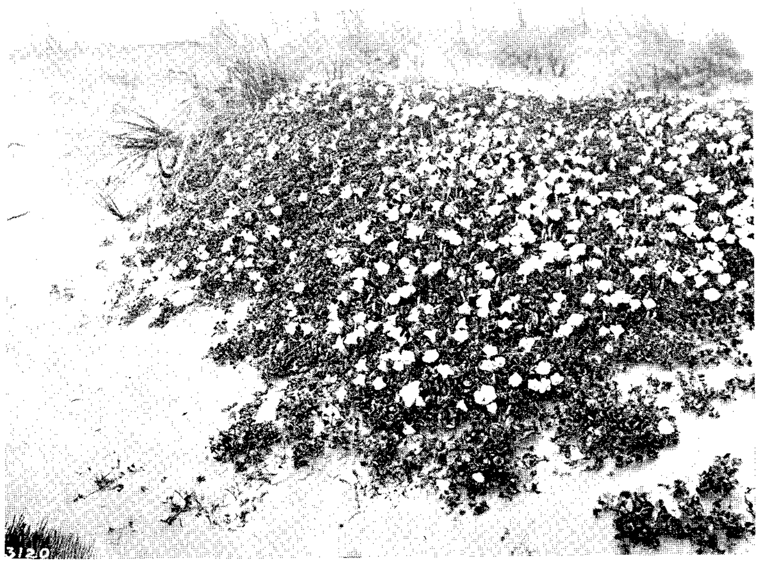
‡ Where shaded they are much more open.

Face p. 20.]

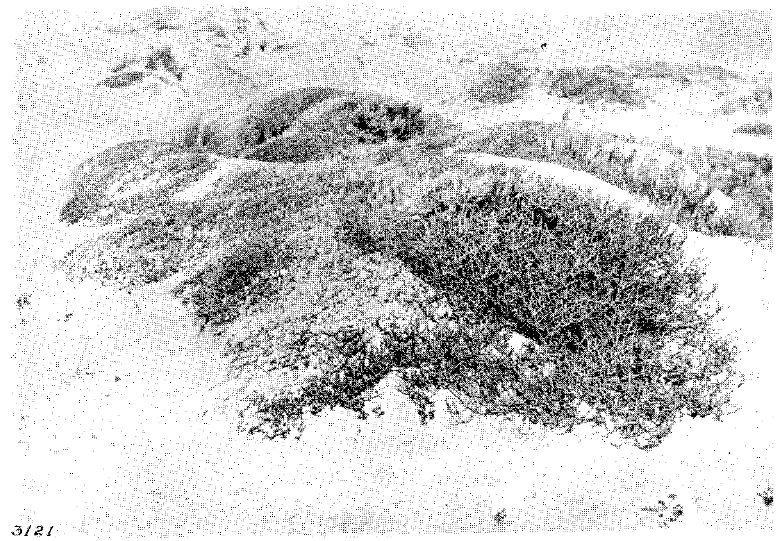


No. 25. Crop of Rape on ancient fixed dune. Dunes of western Wellington.
[Photo L. Cockayne.

No. 26. Tree-lupin (*Lupinus arboreus*) getting buried and killed by a small wandering dune. Dunes of Canterbury.
[Photo L. Cockayne.



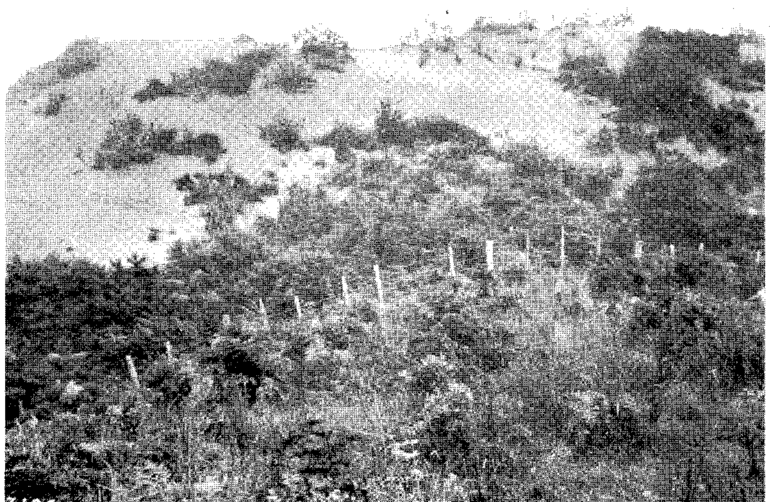
No. 27. The Shore-convolvulus (*Calystegia Soldanella*) in bloom and showing close habit of growth.
[Photo A. H. Cockayne.



No. 28. The sand-collecting shrub *Coprosma acerosa* building a small dune. On left almost buried.
[Photo L. Cockayne.

No. 29. A close growth of Marram-grass in process of destruction by a very active sand-drift.

No. 30. Sand-shrub dune with small portion of sand-plain in front. Dunes of western Wellington.



No. 31. Fixed dune, which had become active through damage by sheep, getting naturally reclothed by plants.

No. 32. Face of active dune getting naturally clothed by *Phormium tenax*, *Arundo conspicua*, and *Cassinia leptophylla*.

[*Photos L. Cockayne.*

(η.) Pimelea arenaria (*the Sand Pimelea; Aute-taranga, Toroheke*).

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 $\frac{3}{8}$ 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.

(θ.) Cassinia leptophylla (*the Cottonwood; Tauhinu*).

Found only in New Zealand in the central floristic province. The two closely related plants, *C. retorta* and *C. fulvida*, are found, the former in the northern and the latter in the southern province, on the dunes. *C. Vauvilliersii* occurs in Stewart Island, but it is not a dune plant, though quite well adapted for such a situation.

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 $\frac{1}{8}$ 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 under surface 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.

(ι.) 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.

(κ.) 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 $3\frac{3}{4}$ in. long by $\frac{3}{10}$ 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.

(λ.) Scirpus nodosus.

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.

(μ.) 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.

(ν.) Gunnera arenaria (*the Sand Gunnera*).

Found only in New Zealand, extending along the coast, but confined to dune hollows, 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 altogether by vegetative means, which amply suffices under favourable conditions to cover the ground.

(D.) THE DUNE PLANT ASSOCIATIONS OF WESTERN WELLINGTON.

General.*

The comparative simplicity in the progress of dune development, its rapidity, and the ease with which it can be observed, as stated already in Section II, 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 associations in the midst of dunes originally unstable, so too can afforestation be carried on artificially, 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 dunes under consideration may be taken as typical of those of the central floristic province of New Zealand — that is, from latitude 38° S. to latitude 42° S. — although, of course, local

* By no means full details as to the species present in the associations are given, as I propose to give a list of dune plants indigenous and introduced in the continuation of this report, which also will contain a full account of foreign trees, shrubs, &c., suitable for dune-planting.

differences occur. 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. Where the dunes abut on river mouths and estuaries are salt meadows and marshes, but these are here excluded.

(*b*.) Dune Associations Proper.

(*a*.) "*Sand-grass*" *Dunes*.*

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 westerly winds. At first they are clothed with the pingao (*Scirpus frondosus*) and the silvery sand-grass (*Spinifex hirsutus*), one or both; but by degrees shrubs enter in, which finally becoming dominant, the next stage of dune development, the shrub-dune, is installed.

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 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. Generally one or other of the above species are 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 generally 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 retrogressing fixed dunes at the landward boundary of the area.

Calystegia Soldanella, *Euphorbia glauca*, *Festuca littoralis*, 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*, 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 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 of western Wellington, but when it is present it forms colonies of considerable size, the pale-green colour of the leaves and erect habit rendering it conspicuous.

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 plant 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, catching the windward drift, which is finally arrested by the leaf-branches, each 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 destruction of the dunes, as already explained in Section II. 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 frequently destroyed (see Photo. No. 9).†

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 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*.) *Shrub Dunes*.

(1.) *Sand-shrub Dunes* (see Photo. No. 30).§

Sand-shrub dunes are the second stage of progressive dune evolution. They are occupied only by those shrubs which tolerate drifting sand (*e.g.*, *Coprosma acerosa*, *Cassinia leptophylla*,

---

* The shifting or white sand-dunes of Warming (55, pp. 263–264).

† Artificial plantings in many positions are much benefited by the use of suitable expedients to prevent the sand-drift. An account of these, including the various kinds of sand-fences successfully used abroad, will be given in the sequel to this report.

‡ Thus a knowledge of the vegetation of the area to be reclaimed is an important preliminary.

§ The stationary or grey sand-dune of Warming (55, pp. 265–268).

Pimelea arenaria). On the Wellington dunes under consideration the sand coprosma (*Coprosma acerosa*) and the tauhinu (*Cassinia leptophylla*) are the dominant plants, the sand pimelea (*Pimelea arenaria*) being much less abundant.

Where the sand-grasses have become well established 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. 30), the sand accumulating in their interior, but eventually, if the drift continues, burying them altogether. The tauhinu (*Cassinia leptophylla*) is a much taller and more erect plant than the two preceding. Its 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. *Cassinia leptophylla* at all stages of burial and disinterment is 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, 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. There will be usually more or less introduced plants which are able to tolerate a dry station if there be sufficient shelter, *Trifolium arvense*, *Hypochaeris radicata*, *Sonchus asper*, *Bromus hordaceus* being especially common.

As for the stability of these *Cassinia-Coprosma* dunes, all depends upon their position 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.*

(2.) *Heath Dunes.*

The heath dunes are the third stage towards the evolution of the fixed sandhill, 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. It is the presence of manuka (*Leptospermum scoparium*) which 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, a point plainly brought out in my report just published by the Lands Department on Stewart Island Botany (90). On a dune area it is clear that *the presence of the manuka is altogether dependant 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 dominant plant, manuka, a considerable variety of species may make up the association. The great tussocks of the toetoe (*Arundo conspicua*) and the New Zealand flax (*Phormium tenax*) will be present. 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. 31, 32). 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.

Occasionally certain trees appear along with the manuka—*e.g.*, the cabbage-tree (*Cordyline australis*), the ngaio (*Myoporum lactum*), the mahoe (*Melicytus ramiflorus*), the mapau (*Rapanea Urvillei*), and others.

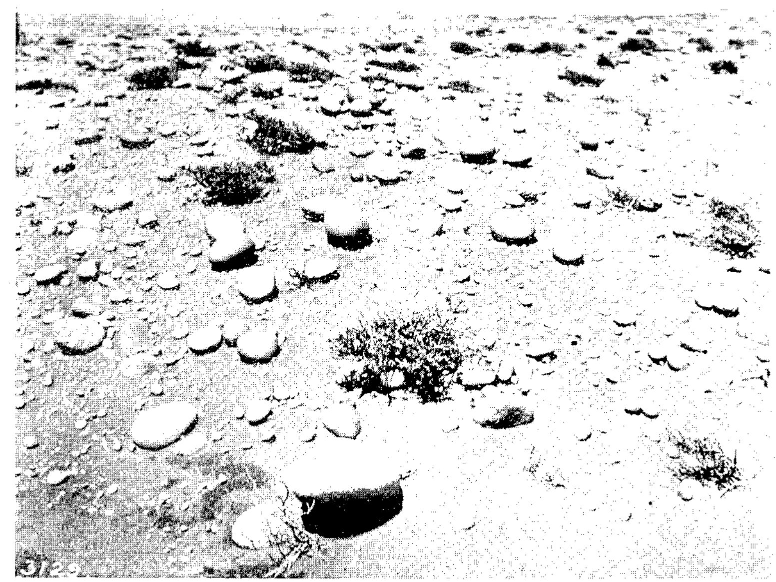
---

* Such disturbance is bound to come sooner or later on dune areas used for grazing purposes.

† The converse of this also holds. Eliminate, by artificial means, the sand-drift, and a considerable choice of plants suitable for dune culture is available.

No. 33. Crop of Oats growing on naturally fixed dune ridge. Dune-area of Western Wellington.

No. 34. Manuka heath of sand-plain. In front are bushes of the Wild Irishman (*Discaria toumatou*).



No. 35. Stony desert near Nukumaru, south of River Waitotara. The shrub is *Coprosma acerosa*.

[Photos L. Cockayne.

(γ.) *The Fixed Dune.*

Even now, short as is the time since the first settlement of western Wellington, it is not easy to say what was the typical vegetation of a fixed inland dune. 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, while probably even yet all the original native species remain, though in a much different percentage from what they were in the primeval vegetation.

In all probability there would be a manuka heath in many localities*; in others the bracken fern (*Pteridium esculentum*) would dominate. The following would be common plants: The tutu (*Coriaria ruscifolia*), *Styphelia Fraseri*, *Cordyline australis*, *Phormium tenax*, *Carmichaelia flagelliformis*, *Scirpus nodosus*, *Müehlenbeckia complexa*, *Coprosma acerosa*, *Olearia Solandri*, *Cassinia leptophylla*, *Arundo conspicua*, *Danthonia semiannularis*, *D. pilosa* var. *racemosa*, *Discaria toumatou*, *Acaena Sanguisorbae*, *Mariscus ustulatus*, *Carex lucida*, *Oxalis corniculata*.

In sheltered gullies there were small woods containing the following species of trees and shrubs: *Cordyline australis*, *Macropiper excelsum*, *Sophora microphylla*, *Melicytus ramiflorus*, *Rapanea Urvillei*, *Myoporum laetum*, *Pittosporum tenuifolium*, *Muehlenbekia australis*,† *Clematis Colensoi*,† *Corynocarpus laevigata*, *Dysoxylum spectabile*, &c.

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, interspersed with a varying quantity of the indigenous plants mentioned above, and others.

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. 33).

But, notwithstanding such a use as the above, 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.

(c.) Hollows and Sand-plains.

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 long stage of stability, in which case an evolutionary series of associations will succeed one another, culminating in a climax association; but this final stage may be reached by different paths.

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

The damp sand is early on 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. Colonies of the umbelliferous *Crantzia lineata* are common, the small, green, rush-like leaves bent to the ground. *Lobelia anceps* and *Carex pumila* are also frequent. In places water lies during winter, but these are frequently quite dry in summer, and have at times a surface temperature of 100° Fahr., and probably more, notwithstanding which certain moisture-loving plants grow—*e.g.*, *Epilobium Billardierianum*, *E. nerterioides*, *Cotula coronopifolia*, *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 much rounded and smaller leaves than the typical form. The small brownish-coloured *Elaeocharis novo-zelandica* is common in places, catching a certain amount of sand.

---

* Captain Smith, R.A., pointed out what excellent pasturage was afforded by parts of the dune area in the year 1849, between the rivers Rangitikei and Turakina. He also noted the great extent of bracken fern. ("Report on Cook's Strait," Notes on New Zealand, No. 6, 1850.)

† These are lianes.

‡ Thus afforestation of hollows, easy as it might be, would be a precarious piece of business without fixation of the neighbouring shrub or sand-grass dunes.

Where the ground is a little drier, and *Leptocarpus* does not occupy all the space, there will be a more or less continuous turf, which, even in close proximity to the sea as near the mouth of the Turakina River, will contain a number of fodder plants, especially white-clover (*Trifolium repens*), yellow suckling (*T. dubium*), some cocksfoot (*Dactylis glomerata*), Yorkshire fog (*Holcus lanatus*), meadow poa (*Poa pratensis*). The greater part of the introduced plants are, however, of little or no value—*e.g.*, the melilot (*Melilotus arvensis**), the yellow rattle (*Bartsia viscosa*), the toothed medic (*Medicago denticulata*), the sorrel (*Rumex Acetosella*), the soft brome grass (*Bromus hordaceus*), the hares'-tail grass (*Lagurus ovatus*), the silver hair-grass (*Airacaryophyllea*).

(β.) *Manuka Heath or Swamp.*

Further from the sea, with the increase in stability as well as greater age of the sand-plain, it is occupied by a manuka heath (see Photo. No. 34), or manuka swamp, according to the absence or presence of standing water upon the ground. 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*, *Eleocharis Cunninghamii*, *Ranunculus macropus*, *Potentilla anserina* var. *anserioides*, *Scirpus inundatus*, *Carex secta*, *Carex ternaria*, *Olearia Solandri*, *Mazus pumilio*, *Coprosma propinqua*.

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.

(γ.) *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.

The lakes contain various aquatic plants—*e.g.*, *Potamogeton Cheesemannii*, *P. ochreatus*, *Myriophyllum elatinoides*, *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 do not affect to any great extent the dune economics.‡

(δ.) *Dry Hollows* (see Photo. No. 9).

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 on occupied by the sand sedge (*Carex pumila*), 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 recognised 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."

(ε.) *Rapid Drift on to Sand-plain.*

Where there is a rapid increase of blown sand *Carex pumila* will be buried, but generally the native "sand-grasses" appear, and dune-building commences, the further progress of the hollow towards heath or meadow ceasing. *Spinifex hirsutus* in some places 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, will be *Calamagrostis Billardieri* and frequently *Mariscus ustulatus* and *Scirpus nodosus*. Finally, the drift continuing, the hollow ceases to be, and a dune chain occupies its site.

(ζ.) *Stony Plain* (see Photo. No. 35).

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 closely-related *M. officinalis* has been widely advertised as a valuable sand plant, but it is of no use whatever for growing on moving dunes, and is *not* relished by stock.

† So in my notes, but I have no specimen for certain identification.

‡ Of course, it is a great loss when a valuable *Phormium* swamp is filled by drifting sand, though in this case at first a good deal of the "flax" survives through its power of growing upwards with a drift.

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 betweeen 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 south of the River Waitotara, from near the cliffs to the dunes some half-mile or more distant.

The vegetation reminds one more of the desert near Mount Ruapehu than of that of the dunes. Everywhere are dotted about the shrubs *Pimelea laevigata** and *Coprosma acerosa* 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 long tongue of sand (see Photo. No. 12). 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 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* is almost prostrate.

IV. LIST OF WORKS CONSULTED.†

(A.) GENERAL LITERATURE.

1. Beck, G. von: "Die Vegetationsverhältnisse der Illyrischen Länder"; 1901.
2. Chrysler, M. A.: "Anatomical Notes on certain Strand Plants"; Bot. Gaz., vol. 37, p. 461; 1904.
3. Clements, F. E.: "Research Methods in Ecology"; 1905.

3A. ——— "Plant Physiology and Ecology," London; 1907.

4. Cole, G. A. G.: "Aids to Practical Geology"; 1902.
5. Cornish, V.: "On the Formation of Sand Dunes"; Geog. Journ., vol. ix, p. 278; 1897.
6. ——— "On Desert Sand Dunes bordering the Nile Delta"; Geog. Journ., vol. xv, p. 1; 1900.
7. ——— "On Sand-waves in Tidal Currents"; Geog. Journ., vol. xviii, p. 170; 1901.
8. ——— "On Snow-waves and Snow-drifts in Canada"; Geog. Journ., vol. xx, p. 137; 1902.
9. Coulter, S.: "A Catalogue of the Flowering-plants indigenous to Indiana"; 1900.
10. Cowles, H. C.: "The Ecological Relations of the Vegetation of the Sand Dunes of Lake Michigan"; Bot. Gaz., vol. xxvi, Nos. 2–5; 1899.
11. Diels, L.: "Die Pflanzenwelt von West Australien südlich des Wendekreises"; 1906.
12. Fippin, E. O., and Rice, T. D.: "Soil Survey of Allegan County, Michigan"; Field Operations of Bur. of Soils, 3rd Rep., p. 93; 1902.
13. Forsyth, T. D.: "On the Buried Cities in the Shifting Sands of the Great Desert of Gobi"; Proc. R. Geog. Soc., p. 27; 1876.
14. Ganong, W. F.: "The Nascent Forest of the Miscou Beach Plain"; Bot. Gaz., vol. xlii, p. 81; 1906.
15. Gerhardt, P.: "Handbuch des deutschen Dünenbaues"; 1900. The geology by A. Jentzsch, the botany by J. Abromeit, and the forestry by P. Bock.
16. Hall, A. D.: "The Soil"; 1904.
17. Harshberger, J. W.: "An Ecological Study of the New Jersey Strand Flora"; Proc. Acad. Nat. Sci. Phil., pt. iii, p. 623; 1901.
18. ——— "Additional Observations on the Strand Flora of New Jersey"; Proc. Acad. Nat. Sci. Phil., vol. liv, p. 642; 1903.
19. ——— "The Reclamation and Cultivation of Salt Marshes and Deserts"; Bull. Geol. Soc. Phil.; July, 1907.
20. ——— "The Comparative Leaf-structure of the Sand-dune plants of Bermuda"; Proc. Am. Phil. Soc., vol. xlvii, p. 97; 1908.
21. Hitchcock, A. S.: "Methods used in Controlling and Reclaiming Sand Dunes"; U.S. Dept. Agric., Bur. Pl. Ind., Bull. No. 57; 1904.
22. Kearney, T. H.: "The Plant Covering of Ocracoke Island"; Contrib. U.S. Nat. Herb., vol. v, No. 6; 1900.
23. ——— "Report on a Botanical Survey of the Dismal Swamp Region"; Contrib. U.S. Nat. Herb., vol. v, No. 6; 1901.
24. ——— "Are plants of Sea-beaches and Dunes true Halophytes"; Bot. Gaz., vol. xxxvii, p. 424; 1904.
25. ——— "Agriculture without Irrigation in the Sahara Desert"; U.S. Dept. Agric., Bur. Pl. Ind., Bull. No. 86; 1905.

* A common plant in the Ruapehu desert.

† A bibliography of 260 works, &c., is given by Gerhardt, but, of course, the greater part are in no New Zealand library.

26. Kearney, T. H., and Harter, L. L.: "The Comparative Tolerance of Various Plants for the Salts Common in Alkali Soils"; U.S. Dept. Agric., Bur. Pl. Ind., Bull. No. 113; 1907.
27. Keilhack, K.: "Lehrbuch der Practischen Geologie"; p. 327; 1908.
28. Lamson-Scribner, F.: "Grasses as Soil and Sand-binders"; Year-book U.S. Dept. Agric., p. 421; 1895.
29. ——— "Sand-binding Grasses"; Year-book U.S. Dept. Agric., p. 403; 1898.
30. Langley, S. P.: "The Internal Work of the Wind"; Am. Journ. Sc., vol. xlvii, p. 41; 1894.
31. Lesage, P.: "Influence du bord de la mer sur la Structure des Feuilles"; 1890.
32. Maiden, J. H.: "The Sand-drift Problem in New South Wales"; Journ. and Proced. R. Soc., N.S.W., vol. xxxvii., p. 82; 1903.
33. Massart, J.: "La Biologie de la Végétation sur le littoral Belge"; Mém. Soc. R. Bot. Belg., vol. xxxii, p. 7; 1893.
34. Nansen, F.: "Oscillations of Shore-lines"; Geog. Journ., vol. xxvi, p. 605; 1905.
35. Olsson-Seffer, P.: "Relation of Wind to Topography of Coastal Drift Sands"; Journ of Geol., vol. xvi, p. 549; 1908.
36. ——— "Relation of Soil and Vegetation on Sandy Sea-shores"; Bot. Gaz., vol. xlvii, p. 85; 1909.
37. ——— "Hydrodynamic Factors influencing Plant Life on Sandy Sea-shores"; New Phytol.' vol. viii, p. 39; 1909.
38. Owens, J. S., and Case, G. O.: "Coast Erosion and Foreshore Protection"; 1908.
39. Petrie, W. M. F.: "Wind Action in Egypt"; Proc. R. Geog. Soc., vol. xi, p. 646; 1889.
40. Porsild, M. P.: "Bidtrag til en Skildring af Vegetationen paa oen Disco"; saetr. af "Meddel. om Gronland," vol. xxv, p. 93; 1902.
41. Réclus, E.: "The Ocean," p. 187; 1874.
42. Reiche, K.: "Grundzüge der Pflanzenverbreitung in Chile"; 1907.
43. Reid, C.: "Coast Erosion"; Geog. Journ., vol. xxviii, p. 487; 1906.
44. Schimper, A. F. W.: "Plant Geography upon a Physiological Basis" (English Translation); 1903.
45. Schlich, W.: "Manual of Forestry"; 1897.
46. Shaler, N. S.: "Phenomena of Beach and Dune Sands"; Bull. Geol. Soc. of Am., vol. v, p. 207; 1894.
47. Smith, R. and W. G.: "Botanical Survey of Scotland, iii and iv—Forfar and Fife"; Scotch Geog. Mag., vols. xx, xxi; 1904–5.
48. Snow, L. M.: "Some Notes on the Ecology of the Delaware Coast"; Bot. Gaz., vol. xxxiv, p. 284; 1902.
49. Vischer, H.: "A Journey from Tripoli across the Sahara to L. Chad"; Geog. Journ., vol. xxiii, p. 241; 1909.
50. Warming, E.: "Halofyt-Studier"; Mem. Acad. R. d. sc. et d. Let. d. Danemark, Copenhague, 6me sér., sect. d. sc., t. viii, No. 4; 1897.
51. ——— "Lehrbuch der Ökologischen Pflanzengeographie"; 1902.
52. ——— "Ekskursionen til Fano og Blaavand"; Saer. af Bot. Tid., bd. xxv, H. 1; 1902.
53. ——— "Der Wind als pflanzengeographischer Factor"; Eng. Bot. Jahrb., bd. xxxi, H. $\frac{4}{5}$, p. 556; 1902.
54. ——— "Die Windfrage"; Eng. Bot. Jahrb., bd. xxxii, p. 25; 1903.
55. ——— "Oecology of Plants"; Oxford; 1909.
56. Webster, A. D.: "Trees and Shrubs best adapted for Planting as Shelter in the Islands of Scotland"; Trans. High. and Agric. Soc. of Scot., p. 78; 1890.
57. Westgate, J. M.: "Reclamation of Cape Cod Sand Dunes"; U.S. Dept. of Agric., Bur. Pl. Ind., Bull. No. 65; 1904.
58. Wilkie, T.: "The Varieties of Trees best adapted for Shelter in the Highlands of Scotland"; Trans. High. and Agric. Soc. of Scot., vol. v, p. 88; 1889.

(B.) LITERATURE RELATING TO THE NEW ZEALAND DUNES.

58A. Aherne, R.: "Utilisation of Sandhills Reserve"; N.Z. Country Journal, vol. vi, p. 405; 1882.
59. Andrews, E. W.: "Pebbles and Drifting Sand"; Trans. N.Z. Inst., vol. xxvi, p. 397; 1894.
59A. Anonymous: "Note on *Psamma arenaria*"; N.Z. Country Journal, vol. xvii, p. 448; 1893.
60. Armstrong, J. B.: "A short Sketch of the Flora of the Province of Canterbury"; Trans. N.Z. Inst., vol. xii, p. 325; 1880.
61. Armstrong, J. F.: "On the Vegetation of the Neighbourhood of Christchurch, including Riccarton, Dry Bush, &c."; Trans. N.Z. Inst., vol. ii, p. 119; 1870.
62. Bell, C. N.: "Drift-material of New Zealand Beaches"; Rep. A.A.A.S., p. 479; 1891.
63. Bell, J. M., Webb, J. H., and Clarke, E. de C.: "The Geology of the Parapara Subdivision, Karamea, Nelson"; N.Z. Geol. Surv., Bull. No. 3, n.s.; 1907.
64. Buchanan, J.: "Sketch of the Botany of Otago"; Trans. N.Z. Inst., vol i, pt. iii, p. 22; 1869.
65. ——— "List of Plants found on Miramar Peninsula, Wellington Harbour"; Trans. N.Z. Inst., vol. v, p. 349; 1873.
66. Buchanan, J., and Kirk, T.: "List of Plants found in the Northern District of the Province of Auckland"; Trans. N.Z. Inst., vol. ii, p. 239; 1870.
67. Campbell, W. D.: "On Beach Protection"; Trans. N.Z. Inst., vol. xi., p. 147; 1879.
68. Carruthers, J.: "On the Formation of Detached Shingle Beaches"; Trans. N.Z. Inst., vol. x, p. 475; 1878.
69. Carse, H.: "On the Flora of the Mauku District"; Trans. N.Z. Inst., vol. xxxiv, p. 362; 1902.
70. Cheeseman, T. F.: "On the Flora of the North Cape District"; Trans. N.Z. Inst., vol. xxix, p. 333; 1897.

70A. ——— "Manual of the New Zealand Flora"; 1906.
71. Cockayne, A. H.: "Report on the Flaxbourne Estate"; 13th Rep. Dept. Agric. of N.Z., p. 400; 1905.
72. Cockayne, L.: "A Sketch of the Plant Geography of the Waimakariri River Basin considered chiefly from an Oecological Point of View"; Trans. N.Z. Inst., vol. xxxii, p. 83; 1900.
73. ——— "A Short Account of the Plant Covering of Chatham Island"; Trans. N.Z. Inst., vol. xxxiv, p. 243; 1902.
74. ——— "A Botanical Excursion during Midwinter to the Southern Islands of New Zealand"; Trans. N.Z. Inst., vol. xxxvi, p. 225; 1904.
75. ——— "Report on a Botanical Survey of Kapiti Island"; 1907.
76. ——— "Some Observations on the Coastal Vegetation of the South Island of New Zealand"; Trans. N.Z. Inst., vol. xxxix, p. 317; 1907.
77. ——— "Report on a Botanical Survey of the Tongariro National Park"; 1908.
78. ——— "Report on a Botanical Survey of the Waipoua Kauri Forest"; 1908.
79. ——— "Report on a Botanical Survey of Stewart Island"; 1909.
80. Colenso, W.: "Essay on the Botany, Geographic and Oeconomic, of the North Island of the New Zealand Group"; Trans. N.Z. Inst., vol. i; 1869.
81. Crawford, J. C.: "Directions for Raising and Spreading *Ammophila arundinacea* and *Elymus arenarius*"; Trans. N.Z. Inst., vol. v., p. 111; 1873.
81A. ——— "Notes on the Fixing of Sandhills" (with letter from W. Keene); Trans. N.Z. Inst., vol. vi, p. 376; 1874.
82. ——— "On Wind-formed Lakes"; Trans. N.Z. Inst., vol. xii, p. 415; 1880.
83. ——— "Remarks on Mr. Travers's Paper on Sand-fixing"; Trans. N.Z. Inst., vol. xv, p. 528; 1883.
83A. ——— "On Fixing Blowing Sands by means of Planted Grasses"; Trans. and Proc. Bot. Soc. Ed., p. 351; 1883.
84. Diels, L.: "Vegetations-Biologie von Neuseeland"; Eng. Bot. Jahr., b. xxii, H. 2, p. 202; 1896.
85. Haast, Sir. J. von: "Introductory Remarks on the Distribution of Plants in the Province of Canterbury"; Trans. N.Z. Inst., vol. ii, p. 118; 1870.
85A. Handley, J.: "Ammophila" (a genus of grasses closely allied to the reeds); no date.
86. Hooker, J. D.: "Handbook of the New Zealand Flora"; 1867.
87. Hutchinson, F.: "On Maori Middens at Wainui, Poverty Bay"; Trans. N.Z. Inst., vol. xxx, p. 533; 1898.
88. ——— "Notes on the Napier–Greenmeadows Road"; Trans. N.Z. Inst., vol. xxxiv, p. 409; 1902.
89. Hutton, F. W., and Kirk, T.: "Description of Arid Island, Hauraki Gulf"; Trans. N.Z. Inst., vol. i, p. 163; 1869.
90. Kirk, T.: "On the Botany of the Great Barrier Island"; Trans. N.Z. Inst., vol. i, p. 144; 1869.
91. ——— "On the Botany of the Thames Goldfield"; Trans. N.Z. Inst., vol. ii, p. 89; 1870.
92. ——— "Notes on the Botany of Certain Places in the Waikato District"; Trans. N.Z. Inst., vol. iii, p. 142; 1871.
93. ——— "On the Occurrence of Littoral Plants in the Waikato District"; Trans. N.Z. Inst., vol. iii, p. 147; 1871.
94. ——— "On the Flora of the Isthmus of Auckland and the Takapuna District"; Trans. N.Z. Inst., vol. iv, p. 228; 1872.
95. ——— "On the Botany and Conchology of Great Omaha"; Trans. N.Z. Inst., vol. v, p. 363; 1873.
95A. ——— "Notes on the Plants best adapted for the Reclamation of Sand Wastes"; Trans. N.Z. Inst., vol. vi, p. 45; 1874.
96. ——— "A Catalogue of Trees and Shrubs suitable for planting in New Zealand; Trees and Shrubs for Seaside Planting"; Pamphlet on Arbor Day, Dept. Agric. of N.Z.; 1894.
97. Kirk, T. W.: "Sand-binding Grasses"; 15th Rep. N.Z. Dept. of Agric., p. 180; 1907.
98. McKay, A.: "On the Geology of the Northern Part of Westland"; Rep. Geol. Surv. for 1892–93, p. 11; 1894.
99. ——— "On the Geology of Hokianga and Monganui Counties, Northern Auckland"; Rep. Geol. Surv. for 1892–93, p. 70; 1894.
100. Matthews, H. J.: "Tree-culture in New Zealand"; 1905. (Includes article by Dr. Truby King.)
101. Maxwell, C. F.: "On Alterations in the Coast-line of the North Island of New Zealand"; Trans. N.Z. Inst., vol. xxix, p. 564; 1897.
102. Morgan, P. G.: "The Geology of the Mikonui Subdivision, North Westland"; Bull. N.Z. Geol. Surv., No. 6, n.s.; 1908.
102A. Morgan, W.: "Grasses for Drifting Sands"; N.Z. Country Journal, vol. vi, p. 109; 1882.
102B. ——— "Grasses for Drifting Sands"; Ibid., vol. xiv, p. 6; 1890.
102C. ——— "Sand-binding Grasses"; Ibid., vol. xxi, p. 12; 1897 (containing an extract from leaflet by J. Handley).
102D. Murphy, M.: "The Possibilities of New Brighton"; Ibid., vol. xv, p. 143; 1891 (containing paper by F. Cotton *re* Dunes of Gascony *ex* Journ. R. Agric. Soc., vol. xi; 1875).
103. Park, J.: "On the Secular Movements of the New Zealand Coast-line"; Trans. N.Z. Inst., vol. xxxiv, p. 440; 1902.
104. ——— "The Geology of the Cromwell Subdivision, Western Otago Division"; Bull. N.Z. Geol. Surv., No. 5, n.s.; 1908.
105. Petrie, D.: "A Visit to Stewart Island, with Notes on its Flora"; Trans. N.Z. Inst., vol. xiii, p. 323; 1881.

106. ——— "List of the Flowering-plants indigenous to Otago, with Indications of their Distribution and Range in Altitude"; Trans. N.Z. Inst., vol. xxviii, p. 540; 1896.
107. Pharazyn, R.: "Remarks on the Coast-line between Kai Iwi and Waitotara, on the West Coast of the Province of Wellington"; Trans. N.Z. Inst., vol. ii, p. 158; 1870.
107A. Stewart, J.: "On the Reclamation of Sand Wastes on the Coast, and the Prevention of their Inland Advance"; Trans. N.Z. Inst., vol. vi, p. 42; 1874.
108. Stowe, E.: "The Effect of Wind-driven Sand as a Cutting Agent"; Trans. N.Z. Inst., vol. v, p. 105; 1873.
109. Thomson, P.: "On the Sand Hills or Dunes in the Neighbourhood of Dunedin"; Trans. N.Z. Inst., vol. iii, p. 263; 1871.
110. Travers, W. T. L.: "On the Sand-worn Stones of Evans Bay"; Trans. N.Z. Inst., vol. ii, p. 247; 1870.
111. ——— "Remarks on the Sand Dunes of the West Coast of the Provincial District of Wellington"; Trans. N.Z. Inst., vol. xiv, p. 89; 1882.
112. Townson, W.: "On the Vegetation of the Westport District"; Trans. N.Z. Inst., vol. xxxix, p. 380; 1907.
112A. Wells, B.: "The Reclamation of Lands Devastated by Shifting Sands"; N.Z. Country Journal, vol. ii, p. 146; 1878.
113. Whitcombe, C. D.: "On the Reclamation of Land devastated by the Encroachment of Sand" Trans. N.Z. Inst., vol. v, p. 108; 1873.

Approximate Cost of Paper.—Preparation, not given; printing (1,750 copies), including illustrations, £53 6s.

By Authority: John Mackay, Government Printer, Wellington.—1909.

Price 1s. 6d.]