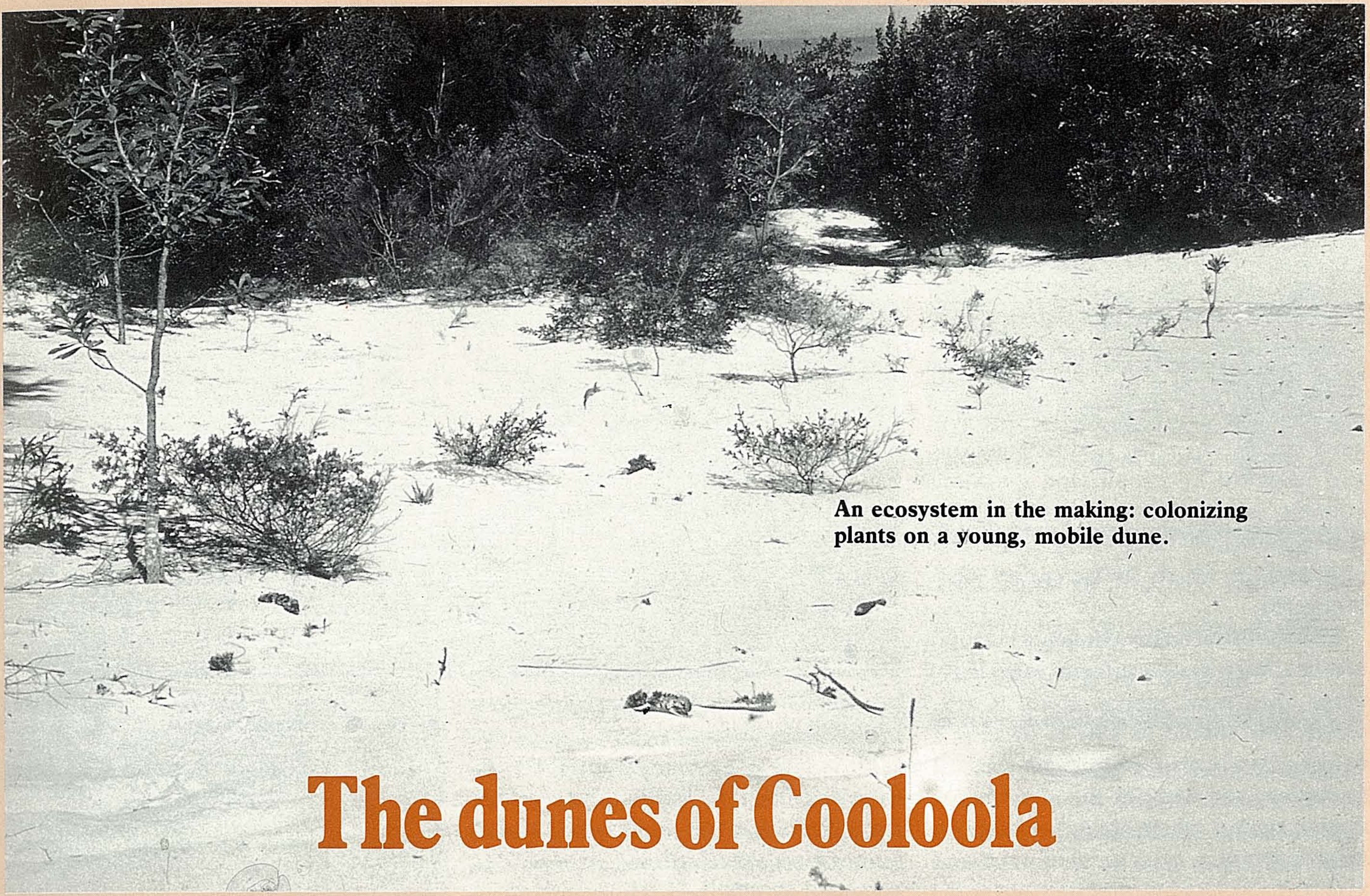


An ecosystem in the making: colonizing plants on a young, mobile dune.

The dunes of Cooloola

Tourists stepping out of their buses to admire the coloured sands of Rainbow Beach, 175 km north of Brisbane, probably do not realize that they are looking at the edge of one of the most scientifically interesting — and thoroughly studied — dune systems in the world.

Rainbow Beach lies near the northern tip of the Cooloola sand mass, a huge mound of overlapping dunes that have been heaped and shaped by sea, wind, and rain for many thousands of years. The oldest dunes were formed perhaps 400 000 years ago.

Because the dunes belong to several different age-groups, and because some are so old, Cooloola offers excellent opportunities for studying the development of landscapes, soil, and entire ecosystems. In 1974, scientists at the Brisbane laboratories of the CSIRO Division of Soils began a 7-year research project on the sandhills.

The program initially grew out of the Division's concern at the increasing rate of degradation of Australian soils and landscapes, but the web of questions demanding attention expanded until a multidisciplinary team had formed, including members of four CSIRO Divisions, three universities, and a State museum. The field and laboratory work of these 19 scientists is now bearing fruit in a series of about 40 research papers that, among other things, will:

- interpret the sand mass as a series of dune systems formed during eight distinct periods
- cause ecologists to rethink the concept of climax vegetation
- quantify the contribution of airborne chemicals to the nutrition of coastal trees and shrubs
- explain the previously mysterious phenomenon of 'black' and 'white' waters
- supply a formula for predicting the erosion of vegetated dunes by rain
- increase our understanding of the natural processes occurring on a coastline coming under increasing human pressure; this understanding will be essential for sound management

The oldest dunes were formed perhaps 400 000 years ago.

The sand mass

The Cooloola sand mass stretches 60 km along the Queensland coast, extends up to 10 km inland, and covers about 24 000 ha. Its tallest dunes rise more than 240 m above sea level. Cooloola belongs to a family of large sand deposits whose other main Queensland members are on Fraser, Moreton, and Stradbroke Islands and around Shoalwater Bay.

The oldest record of local settlement dates from 1877, when man's predominant economic interest in Cooloola was native timber. Mature rainforest and eucalypt forest on the spine of the sand mass were eventually incorporated in a State forest, and Cooloola remained hardly known to the general public until 1963, when a mineral company applied for a sand-mining lease on the low ridges north of Rainbow Beach.

Other companies then sought heavy minerals in the high dunes, where mining was opposed by conservationists. After several years' dispute, culminating in an appeal to the Privy Council, much of the sand mass around the present State forest became a national park.

The dunes now seem unlikely to be mined, but Cooloola, like so many dune systems, faces increasing threats from other human activities, especially tourism and recreation.

The Brisbane scientists, led by Dr Alan Moore, were looking for a place to study the processes that shape landscapes and the flow of water and other materials through them. They chose Cooloola for several reasons.

Man had caused little disturbance; being part of a State forest and, more recently, a national park, many areas had been largely protected against bushfires and invasion by people and domestic animals; and sand-dune soils offer excellent opportunities for studying the natural processes in which the scientists were interested.

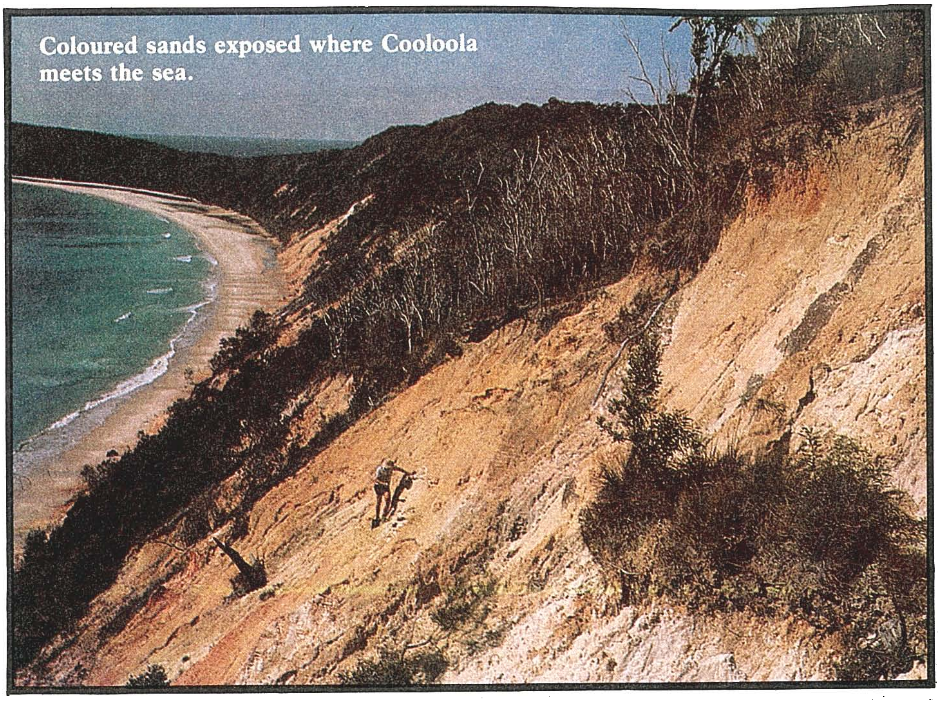
Because of the relative simplicity of sand systems, fewer factors influence this landscape than most others. Here, if anywhere, one should be able to develop a model of landscape development and soil formation, and compile 'baseline' information against which changes caused by man or Nature may be measured and assessed.

Shaping the dunes

The Cooloola dunes consist almost entirely of quartz grains. For hundreds of thousands of years the rocks of eastern Australia, mainly the granites and sandstones of northern New South Wales and southern Queensland, have been eroding into particles about one-fifth of a millimetre in diameter, which have been flushed down rivers to the sea and then gradually borne northwards by coastal currents.

Waves and wind have deposited this sand along the shore. Sometimes it accumulated faster than plants could invade it, and whenever winds exceeded about 20 km per hour they whipped the bare sand into dunes, which advanced inland before being colonized by vegetation. In subtropical Queensland these winds blew mainly from the south-east.

The Cooloola sand patch: a mobile dune belonging to system 1.



Coloured sands exposed where Cooloola meets the sea.

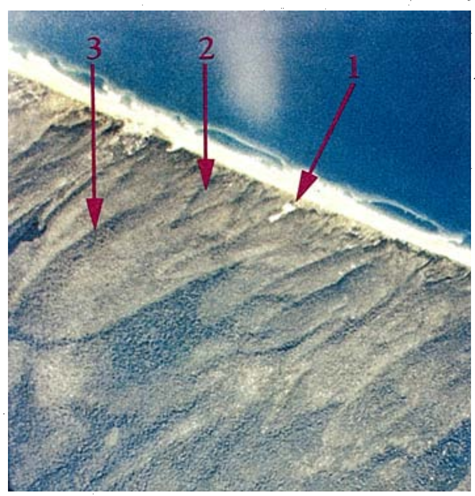
Wind and water continually move the bare sands near the sea, but the researchers believe that the large dune systems formed most actively during eight periods, separated by relatively stable times.

Rain and colonizing plants gradually convert the sand into a soil with well-defined bands.

The vegetation on older dunes caused younger dunes to develop a characteristic shape. The process began when the wind found a weak point in the shore-line dunes and dislodged some sand, forming a 'blow-out'. As the blow-out sand invaded vegetated dunes, its margins were caught by plants to become the 'trailing arms' of a dune with a characteristic shape, roughly like a U or V when seen from the air.

Stabilized by vegetation, the sand suffered gradual erosion by rain, just like a typical inland landscape, and the oldest dunes at Cooloola have long since lost their original form and become broad, low 'whale-back' sandhills.

The CSIRO scientists think that the three youngest dune systems formed within the last 10 000 years, after the most recent glaciation. The older systems extend back to at least the last interglacial, which ended about 140 000 years ago. Together, the dunes constitute far and away the longest continuous series found anywhere in the world.



From the air we can see a mobile dune (system 1), a V-shaped dune of system 2, and a system 3 'parabolic' dune whose apex is about 2 km inland.

The key to Cooloola is the historical sequence. Mr Cliff Thompson of the Division of Soils established this sequence from four kinds of evidence.

One is stratigraphy: on inspection, the dunes clearly lie in overlapping layers. A second clue comes from geomorphology: the size, shape, and orientation of the dunes, which show up particularly well in aerial photographs, tell us much about their origins. Thirdly, older dunes have suffered greater erosion. And fourthly, time has worked changes beneath the surface.

On all four counts, the researchers have concluded that the Cooloola dunes form a series of eight systems, six of which appear to have remained exposed in places at the surface since they were first formed.

The first stage in soil formation: plants growing in the sand of a young (system 1) dune. The scale is in centimetres.

A later stage: brown iron compounds have been leached from the pale A_2 horizon into the deeper B horizon. This young podzol belongs to dune system 2.

They deduce from the dunes' shapes that they have carried plant cover continuously since well before the last glaciation.

For much of this time the sea remained well below its present level, and water tables must have dropped correspondingly. It seems, therefore, that throughout this period sufficient rain fell to sustain vegetation.

Soil horizons

A newly formed dune consists of yellow-brown sand in a relatively homogeneous heap. Rain and colonizing plants gradually convert this sand into a soil with well-defined bands, known as 'horizons'.

On the sand's surface a litter of leaves, twigs, and bark gathers and is decomposed by micro-organisms. The resulting humus darkens the dune near the surface, creating the A_1 horizon.

Rain seeping through the sand picks up organic compounds and fine particles and, through a series of little-known chemical processes, deposits them deeper in the dune. The water also robs sand grains near the surface of their coatings of mineral compounds, particularly iron and aluminium oxides, depositing these with the organic matter. Left behind is a bleached layer, called the A_2 horizon, below the A_1 layer.

The humus and minerals leached from above accumulate in a deeper layer, the B horizon. This presents a striking appearance, being darkened by organic matter and stained a bright yellowish brown by iron compounds.

A soil formed in this way is classified as a podzol, from a Russian word describing the ashy appearance of a soil when a plough brings the A_2 horizon to the surface. The age range of Cooloola's dunes, and their undisturbed state, make them magnificent natural laboratories for studying podzol development.

Mr Thompson has found that on the newest dunes (the youngest ones within system 1) only the preliminary step has occurred: organic material has enriched the top few centimetres. In system 2 dunes, a bleached A_2 horizon has formed over a distinct B horizon, which begins about 40 cm below the surface.

In sands of systems 3 and 4, the A_1 horizon grows progressively thicker. Because the organic matter and oxides of the B horizon have gradually been remobilized and deposited yet deeper in the profile, the bleached A_2 horizon is also thicker.

In system 3, the B horizon begins about 1 m below the surface, and in system 4 it lies at about 5 m or deeper.

This remobilization and deeper deposition of the B horizon has clearly continued throughout Cooloola's history. In places on the oldest dunes, the scientists have drilled more than 20 m, most of the way through bleached A_2 sand, before reaching the B horizon.

The A_1 horizon mirrors the vegetation above it; the greater the biomass (quantity of plant matter) growing in the soil, the thicker the A_1 horizon will be. It reaches its greatest size in the dunes of system 4.

And on these system 4 dunes the vegetation reaches its climax — but not in the conventional ecological sense of a final,

Rainforest flourishes in the 'valleys' of system 4.

The sight of mature rainforest flourishing on coastal dunes can come as a surprise.

stable community (see the box on page 11). After achieving its greatest development on the dunes of system 4, where eucalypts grow up to 50 m tall, the vegetation declines into shrubby woodland on the oldest sands, where the tallest plants are only 2–3 m high.

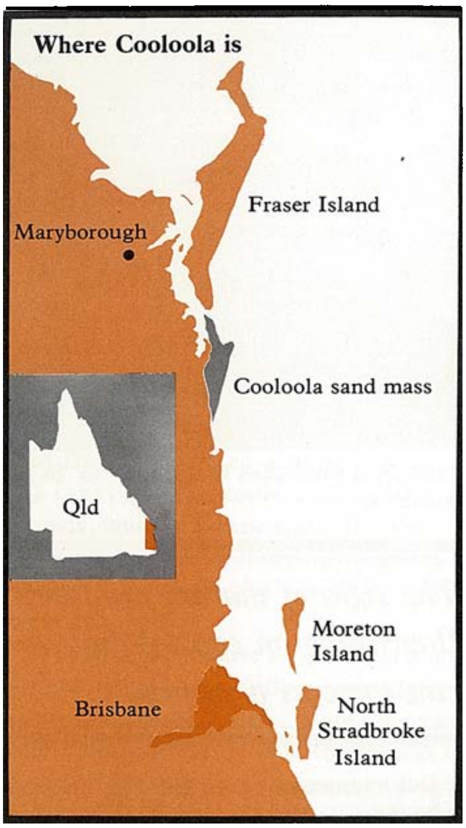
The older dunes of systems 5 and 6 support progressively poorer vegetation and have progressively thinner A_1 horizons. To understand why, we must examine the supplies of nutrients available to the plants.

From sky and sand

Plants growing on the dunes can obtain their nutrients (other than nitrogen) from only two sources: the rain and the sand. The researchers have carried out a series of experiments to ascertain the importance of each of these sources.

Near any coast, the atmosphere and the rain contain elements from sea spray. Mr Ron Reeve, Mr Ian Fergus, and Mr Jan Skjemstad, of the Division of Soils, set up funnels at seven sites on the dunes to collect samples of these elements both during and between periods of rain. They put the funnels on top of towers up to 12 m high, to stand above the canopy of local vegetation. In addition, they collected samples of 'throughfall' — also known as 'canopy drip' — that is, the liquid falling from leaves, especially after rain.

Individual measurements of the coastal 'spray' have been made before, but this study was the first involving a transect of so many sites at such short distances (300 m to 25 km) from the sea.



If you analyse the samples collected in these funnels, what do you find? Very close to the sea, fall-out from the atmosphere contributes quite high concentrations of such elements as calcium, potassium, and magnesium, but as you travel inland you find that the concentrations rapidly fall. Only 500 m from the sea, the levels of these elements have already declined by more than half. Farther inland, the concentrations continue to drop, but less rapidly.

In other words, the supply of these nutrients by 'atmospheric accession' is richest for dune system 1, and much poorer for the other systems. Yet dune system 1 carries only shrubs and low trees; the most prolific vegetation grows on system 4, about 6 km inland. Clearly, the plants of system 4 cannot depend entirely on atmospheric accession for their nutrient supply.

One airborne nutrient gave anomalous results: the concentration of phosphorus, although very low, was much the same at all the sampling sites. The scientists cannot yet explain this; one suggestion attributes the phosphorus largely to pollen landing in the funnels.

Food grains

Sand is traditionally regarded as an infertile medium, and the sight of mature rainforest flourishing on coastal dunes can come as a surprise.

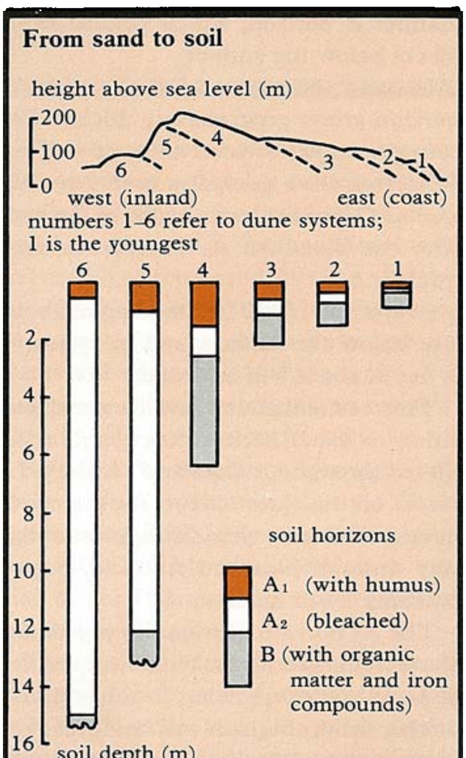
The sand grains themselves consist of little more than silica, and owe their yellowish colouring to coatings of iron and aluminium oxides around the quartz grains. Electron-probe analyses by Dr Keith Norrish of the Division of Soils in Adelaide showed that these coatings hold several elements necessary for plant growth.

> *To the root of a tree, the sand grains are like tiny gobstoppers.*

To the root of a tree, these sand grains are therefore like tiny gobstoppers. Their oxide coatings trap such nutrients as calcium, magnesium, potassium, phosphorus, and sulfur. Some trace elements, such as zinc and molybdenum, are probably caught in the coatings too.

However, these nutrients are held in chemical complexes from which roots cannot readily extract them. Plant physiologists have, for example, regarded the phosphorus attached to sand grains as largely unavailable to plants. Mr Walter Jehne of the Division has shown that plants colonizing mobile dunes do make use of the nutrients around sand grains — thanks to fungi.

Ramifying through the sand beneath the dune vegetation are enormous numbers of fine fungal threads called hyphae.



Above: **diagram of the overlapping dune systems.** ***Below:*** **soil profiles showing the development of deep podzols.**

They particularly abound in rainforest, but even bare sand near the sea contains fungal spores, and hyphae grow around the roots of plants colonizing the youngest dunes.

These fungi form mycorrhizas — intimate associations between roots and fungal hyphae in which the fungi make nutrients available to the higher plant, which in turn probably supplies various organic compounds that the fungus, having no chlorophyll, cannot synthesize for itself.

Such symbioses are familiar to growers of orchids and pine trees. Some hyphae even invade cells of the plant's roots, forming endomycorrhizas.

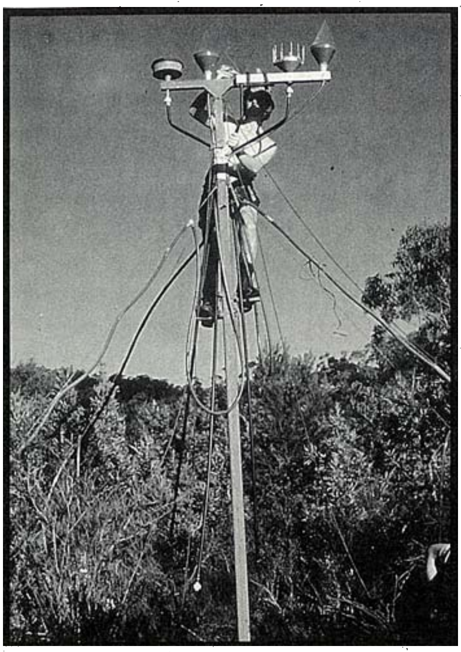
The CSIRO scientists found that all the colonizing plants on young dunes either formed mycorrhizas or possessed proteoid roots — the roots found in members of the family Proteaceae, such as *Banksia* and *Grevillea*, that are particularly efficient at extracting phosphorus from soil.

Hyphae abound on certain parts of the dunes. Between 2 and 20 cm below the surface, each millilitre of sand near a colonizing plant holds up to 4 m of fungal hyphae extending out from the plants' roots and clinging strongly to sand grains. Although the threads themselves are microscopic, you can often see long strings of grains, revealing the presence of the hyphae.

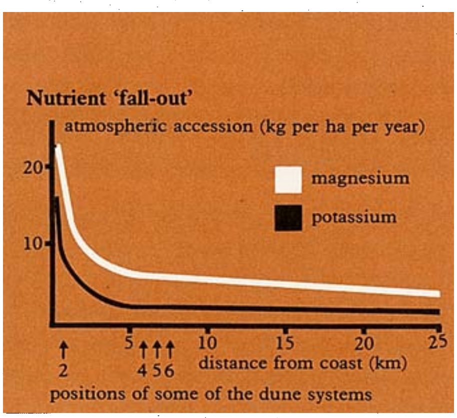
By clumping grains in this way, fungi help to stabilize bare sand. X-ray fluorescence analysis by Mr John Drinnan of the Division has shown that the grains next to hyphae are poorer in nutrient elements than other grains, and it seems certain that the hyphae have extracted these nutrients and transported them to the roots of plants. The fungi probably boost the supply of water to their associated plants, too.

A fuller understanding of the role of mycorrhizal fungi in helping higher plants become established on bare ground could be of value in projects to revegetate dunes and other areas disturbed by various forms

Bird's-nest fern in the rainforest.



Funnels above the tree canopy collect atmospheric samples, later analysed for nutrients.



Near the shore, the air contains nutrients from sea spray. Moving inland, the concentrations decline rapidly.

of mining throughout Australia. The Australian Mineral Industries Research Association Ltd has made a 3-year grant to the Division to extend these studies.

Because of the apparent importance of soil fungi in the native ecosystems, the CSIRO scientists called on Dr Jack Aberdeen, a mycologist now retired from the University of Queensland, to join them in a survey of the distribution of higher fungi at Cooloola. This survey has already shown that some species are characteristic of particular soil–vegetation classes.

Nutrient losses

Most of the minerals that the plants extract from the sand — and, to a lesser extent, from the air — eventually return to the surface of the sand as litter. Some are leached from leaves still on the trees; Mr Reeve and Mr Fergus found much more potassium and sodium in 'canopy drip' than in rain.

However, not all are subsequently absorbed by other plants. Nutrients continually 'leak' out of the ecosystem, washed over the soil surface into streams, for example, or leached out of the upper sand to the B horizon, from which some nutrients are always escaping into deep underground water stores and, ultimately, the sea.

Over thousands of years, the depth to the B horizon gradually increases, and the researchers conclude that this explains the decline in vegetation on the dunes inland from system 4. Eventually the B horizon descends beyond the root zone of most species, and the only remaining supply of nutrients — atmospheric accession — is inadequate to sustain the more productive ecosystems.

Dr Joe Walker of the Division of Land Use Research has calculated an index of vegetation biomass for each dune system by multiplying the crown cover by the height of the vegetation.

The biomass index calculated in this way is between 2 and 550 on system 1 dunes, but rises rapidly to a peak of 2300 in system 4 forests. Farther inland, the index declines again, falling to a mere 105 on the oldest system 6 dunes.

In a study of the Cooloola vegetation, Dr Arthur Harrold, a local botanist, has collected more than 750 species, of which 236 were found on the 54 well-drained sites used in the analysis of soil–vegetation relations. The scientists intend to continue this study and compile maps at a scale of 1:50 000 showing the distribution of the soil–vegetation units.

These maps should prove valuable aids in land use management. Similar maps will also be compiled for the dune systems of Shoalwater Bay, about 90 km north of Rockhampton.

Erosion

Although wind forms the dunes, it plays a minor role in moving sand once vegetation has become established. Dr Bryan Bridge and Mr Peter Ross, of the Division of Soils, found that water, on the other hand, shifted considerable quantities of sand even in the seemingly stable mature forests.

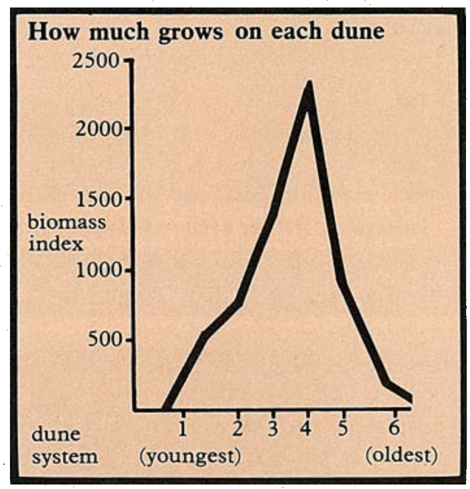
Nutrients in the soil

dune system	nutrient concentration (parts per million in top 3 m of soil): calcium	magnesium	potassium
2	230	280	1300
3	55	80	450
4	30	55	10
5	10	<50	5
6	20	50	5

Over many thousands of years, nutrients disappear from the root zone, absorbed by plants or leached to deeper soil levels.

To quantify this erosion and discover which factors influenced it, the scientists designed simple sand traps, like trays with gauze bases, that retained sand grains but let water through. They selected six study sites, and there laid the traps on the ground and installed rain-measuring equipment.

Every month for 3 years the scientists recorded the collected sand and total rain, and automatic recorders designed by Mr Ross enabled them to calculate the rain's intensity (number of millimetres falling per hour).



The biggest forests grow on the middle-aged dunes; later, nutrients run out. The biomass index is calculated from plant height and cover.

Every 3 months they took photographs of the ground cover, and they also measured several other factors, including physical properties of the sand and the rate at which water percolated through it.

The researchers found that water moves sand by two processes: 'splash' and 'wash'. Raindrops, when they hit the ground, splash sand in all directions, but generally more moves downslope than up. Surface wash occurs on certain sands: the rain runs over the surface much as it does on a bitumen road.

Surface wash may come as a surprise, for we generally think of sand as highly porous. When a wave retreats on a beach we can see water rapidly sinking into the sand.

Soil scientists describe beach sand as 'wetting'; it can accept as much as 600 mm of rain in an hour. Some sands, including those of certain dune systems at Cooloola, behave quite differently — they repel water, which therefore flows over the surface for perhaps a few metres before soak-

The rise and fall of Cooloola's vegetation

The vegetation on Cooloola's dunes largely reflects the availability of nutrients. Walking inland from the cliffs standing about 70 m above the sea, we come first to scattered pioneer plants colonizing the bare sand of young mobile dunes, interspersed with young, fully vegetated dunes supporting low, dense, shrubby woodland on embryonic podzols less than 1 m deep. All these dunes comprise system 1.

Beyond lie the dunes of system 2, rising about 100 m above sea level. Here we find low grassy forest, characterized by *Eucalyptus signata*. The dunes show signs of slight erosion, and the B horizon lies about 60 cm beneath the surface.

The system 3 dunes stand 120–150 m above the sea and have suffered greater erosion. On podzols from 2 to 6 m deep a taller grassy forest has developed, in which the main eucalypt is *E. intermedia*.

Inland again, the system 4 dunes show yet further erosion and deeper soil development. We have come to the crest of Cooloola; the dunes rise as high as 240 m and the forests grow taller here than elsewhere. On the well-drained soils grows a eucalypt forest dominated by *E. pilularis* and *E. intermedia*; in the lower corridors, better supplied with water and nutrients, rainforest flourishes.

On our walk so far, the vegetation has reflected increasingly good supplies of nutrients. The number of tree species and the total number of plants growing in each system have increased as we have travelled inland.

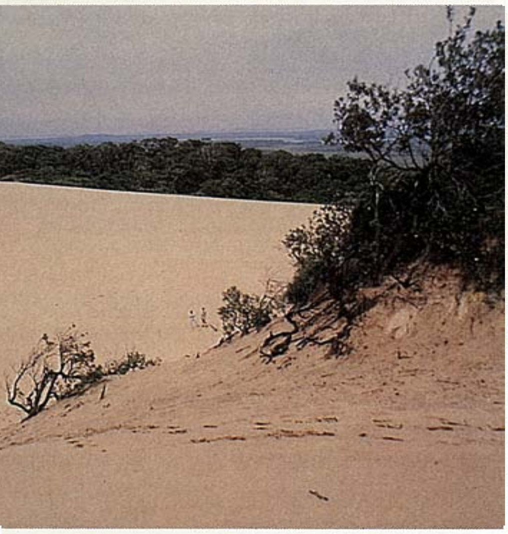
The system 4 forests represent the pinnacle of botanical achievement on these dunes. From here on, nutrients are lost to plants faster than they can be won.

The system 5 dunes support tall but shrubby woodland. *E. signata* reappears. This vegetation consists of plants that can exist on the 'stored capital' of nutrients remaining in the ecosystem, together with the meagre supply blowing on the wind.

The B horizon has now descended from 10 to more than 15 m below the surface.

Finally, we reach the ancient dunes of system 6, whale-back sandhills rising only 40–80 m above sea level. The two main plants of system 5, *E. signata* and *Banksia aemula*, grow here in a shrubby woodland on podzols 12–20 m deep, and on the deepest soils these plants may be less than 2 m tall.

Along our journey, we have seen the vegetation rise and fall; we have also probably walked through the best part of half a million years of botanical history.



Wind moves mobile dunes and scours sand from around plant roots.

ing into a more wettable part of the dune surface.

What makes these sands 'non-wetting'? Once again, fungi are inconspicuously having a profound effect on the dunes. When sands dry out, the countless fungal hyphae threading around the grains die, leaving a water-repellent coating of organic material over the sand.

At Cooloola, non-wetting sands mainly occur on the young dunes of systems 1 and 2 and in rainforest. Enough water washes over their surfaces to cause significant erosion, leading to the gullies and fans so characteristic of eroded clay soils.

Water shifted considerable quantities of sand, even in mature forests.

From their field measurement, the scientists derived equations relating the amount of sand moved to various factors. These mathematical models should prove valuable in predicting future sand erosion, and particularly the consequences of disturbing the dunes.

The researchers have found that wetting and non-wetting sands differ in their sensitivity to erosive forces. On non-wetting sands, water collects and causes surface wash. Rainfall intensity therefore matters: the harder it rains, the more likely are non-wetting sands to erode. The completeness of the forest canopy has much less influence.

Wetting sands, on the other hand, are shifted mainly by rain-splash. Their erosion therefore depends largely on how far they are protected: the more ground cover there is to intercept raindrops, the less a site erodes. Clearly, any human interference that removes ground cover — clearing, burning, or vehicle traffic, for example — could considerably increase erosion.

How much splash occurs also depends enormously on the canopy — particularly its extent and height. Much of the sand in open, shrubby woodlands is exposed directly to the rain, and heavier storms, with larger drops, therefore mean more splash erosion.

A closed canopy of low height shields the ground from the full force of falling raindrops. Sand beneath such a canopy, further sheltered by ground cover and leaf litter, will suffer little splash erosion.

By contrast, a tall canopy, like that of rainforest, can contribute to erosion. Rainwater gathers on tree leaves and then falls from the leaf tips in relatively large drops.

On vegetated dunes most erosion is caused by water. Here a tree root has been exposed.

In tall forest, these drops strike the ground at almost the velocity of unimpeded rain — and, being big, they are particularly erosive.

The scientists found that in these forests variations in the rain's intensity had little effect.

Because surface wash shifts more soil than splash does, non-wetting sands may erode markedly faster than wetting sands. To take one example from the field, during a period when wetting sand in eucalypt forest moved at the rate of 1·5 kg per metre of trap width per month, non-wetting sand in rainforest eroded at about three times this rate: 4·6 kg.

Water in the dunes

The Cooloola sand mass, like the offshore sand islands nearby, holds a large reserve of fresh water. Engineers planning future water supplies for the growing population of south-eastern Queensland have had their eye on similar sand-mass reserves since 1902.

'White' water.

A 'black'-water creek.

Soil animals on the dunes

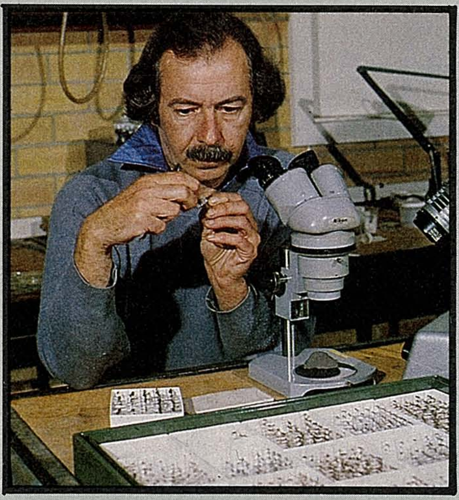
A variety of soil animals live on the dunes, and many of those so far studied have turned out to be more or less restricted to ecological communities occurring on only one or a few of the dune systems.

Dr John Greenslade of the CSIRO Division of Soils in Adelaide has found at Cooloola about 300 ant species, belonging to about 55 genera. Relatively few species live on the rather bare young dunes, exposed to prolonged hot sunshine in summer; the species diversity rises along the sequence of dune systems 1 to 4, but falls abruptly in deeply shaded rainforest.

The chief factors affecting ant distribution seem to be temperature, food supply, shade, and drainage.

Until 1976, only two species of earthworm had been recorded in the coastal dunes of south-eastern Queensland. When the CSIRO soil scientists dug their exploratory pits at Cooloola, they soon realized that earthworms played a significant role in the ecosystems of the dunes, and they called on Mr Geoff Dyne of the University of Queensland (now at the Queensland Institute of Technology) to investigate.

So far Mr Dyne has found 18 species, two of which apparently belong to a genus new to science. Some of the worms occur in only one ecosystem; others have a wider range.



Dr Greenslade has found about 300 ant species at Cooloola.

Both ants and earthworms can contribute dramatically to soil development. Just 100 years ago Charles Darwin published the first figures on soil movement by earthworms; since then the rate at which worms form casts has been assessed at from 530 to more than 9000 g per sq m a year in western Europe, and at more than 10 000 g in West African forests.

Mr Geoffrey Humphreys of Macquarie University recently found that worms living in sandy loam near Sydney shifted a modest 133 g per sq m in one year. In the same study, Mr Humphreys showed that funnel ants deposited 841 g of soil material per sq m on the surface in a year; this almost equals the highest figure published for ants anywhere in the world, although little work of this kind appears to have been done.

Termites also attracted the Cooloola group's attention. The scientists postulated that these animals, because they feed on wood, might turn up in all ecosystems on the dunes.

Mr Leigh Miller of the CSIRO Division of Forest Research is surveying this insect group; so far he has found about 20 species, of which two appear to be new to science. The distributions of most of these species support the original hypothesis, but a few seem to be restricted to particular ecosystems.

Ms Penelope Greenslade of the South Australian Museum has conducted a preliminary survey of the Collembola (springtails), finding 57 species, of which five have apparently never previously been collected. Ms Greenslade found the greatest species diversity in grassy forests; different plant communities seemed to support distinct communities of springtails, but a more intensive study needs to be made to check this conclusion.

Other active members of the dune communities include burrowing bees, snails, and, in certain places, fresh-water crayfish, but these have not been studied in detail at Cooloola.

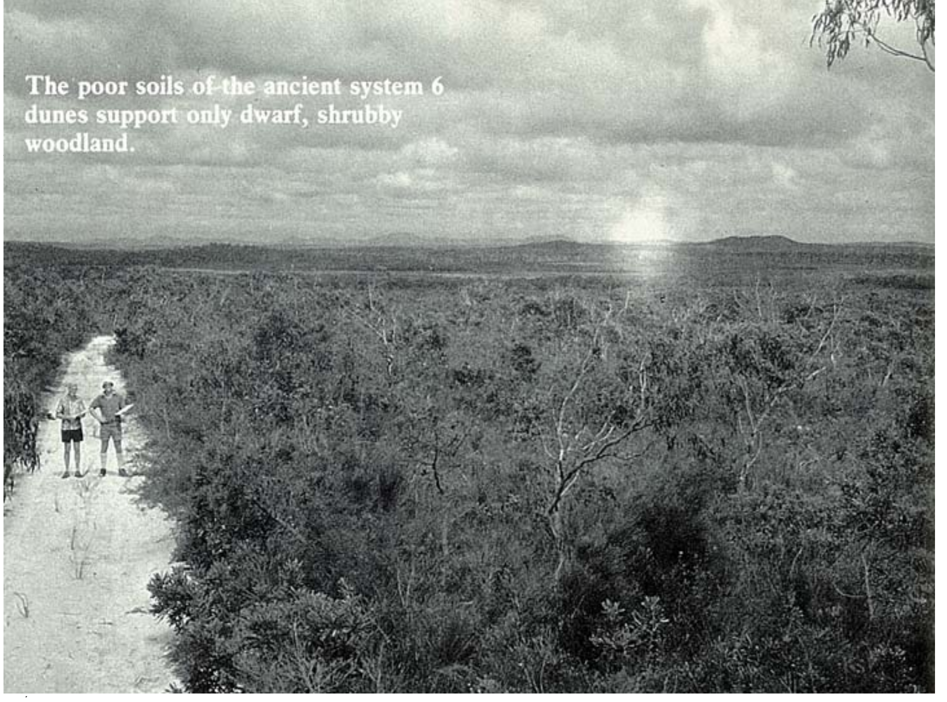
With the collaboration of Mr John Forth of Griffith University (now with the Engineering and Water Supply Department of South Australia), the scientists set up a network of rain gauges and stream gauges to measure the water entering and leaving the sand mass. Their equipment for measuring 'atmospheric accession' supplied information on incoming nutrients, and specially drilled wells gave an indication of the extent of the underground reservoir.

The scientists also measured the levels of naturally occurring tritium, a radioactive isotope of hydrogen, to obtain estimates of the size of the reservoir and of the rates at which water was moving through the sand mass.

These measurements, made over several years, showed that, on average, 550 mm of water infiltrates into the sand mass in a year. This means that an average 360 000 cu m of water per day enters the sand mass; and, to maintain the balance, the same amount leaves — through seeps, springs, and streams. The researchers estimated the volume of water in the reservoir at 9000 million cu m.

Although a dry salt spray from the sea falls over the dunes, the water's quality is good. Mr Reeve found that near the coast the level of 'total dissolved solids', to use the hydrologists' phrase, was a very acceptable 120 parts per million (p.p.m.); away from the sea the level dropped to only 35 p.p.m.

Cooloola's water resources could conceivably support a population of 150 000 people; this renewable resource is likely to be the sand dunes' main value to future generations.



The poor soils of the ancient system 6 dunes support only dwarf, shrubby woodland.

Cooloola's water resources could conceivably support 150 000 people.

Black and white

A visitor to Cooloola is struck by an intriguing sight: the water in some lakes and streams looks dark brown, but elsewhere it is clear and sparkling. The two kinds of water occur on other sand masses too; North Stradbroke Island has its Blue Lake and Brown Lake.

'Black' and 'white' waters, as they are commonly called, may occur close together and even merge into a single stream.

The phenomenon has been observed in other parts of the world — black water gave Brazil's Rio Negro its name — but without being satisfactorily explained. Scientists have usually suggested that the two waters have passed through different types of soil, but Cooloola has only one parent material: quartz sand.

The Cooloola researchers believe that black and white waters are derived from different parts of the podzol profile. The black water gets its strong colour from organic compounds. It has apparently seeped through the A horizon then escaped 'sideways' through a spring or seep without entering the B horizon. White water, it seems, has passed through the B horizon into the yellow-brown sands of the C horizon, unloading its coloured cargo of organic compounds on the way.

To test this idea, the scientists ran black water through yellow-brown unweathered sand in the laboratory. The iron and aluminium oxides coating the sand grains removed the organic matter from the water, which emerged clear and white.

Whether the world's other black and white waters can be explained in the same way remains to be seen.

Every year many tourists travel from Noosa and Rainbow Beach to see the coloured sands of the coastal cliffs. How do these sands fit into the sequence of dune systems worked out by the Division of Soils?

Unfortunately, despite several theories about where the sands came from and how they acquired their colours, the answer remains unknown. The researchers can say that definitely four, and perhaps five,

Measuring sand movement: erosion is particularly marked on the downslope side of trees. Mr Roy Prebble of the Division of Soils has found this is because the tree interferes with sand splash.

New thoughts on the climax concept

Research at Cooloola has issued a challenge to a long-standing ecological concept: that of a self-perpetuating 'climax' community of plants and animals.

Historically, the concept arose from studies of the types of vegetation that succeed one another in a changing environment such as the margin of a lake that is gradually filling in, or an abandoned field being invaded by plants.

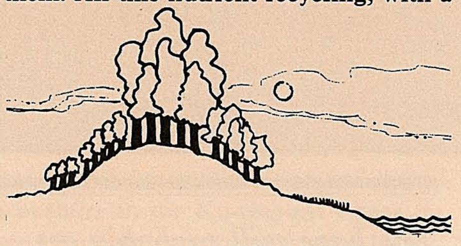
Ecologists noticed that, after some relatively rapid changes, the vegetation developed into an apparently permanent community, which perpetuated itself if it was left undisturbed. It seemed that a particular climax vegetation existed for every site in the world. Just what form that climax took depended upon a number of factors, such as soil type, the lie of the land, and the local climate.

A change in one of these factors could push the vegetation towards a different climax (big fluctuations in Australia's climate have seen some inland areas support forest and desert at different times) but most such changes are extremely slow, taking many millions of years. Over shorter periods — a few tens of thousands of years, say — the climax community has seemed to be the ultimate botanical state in a given place.

By giving us such a long historical perspective, Cooloola has scotched that idea. The sequence of events brought to light on the dunes shows that a climax is only a passing phase: eventually most ecosystems must decay. The researchers have identified the supply of nutrients as the key to the whole process.

A virgin dune holds a large store of nutrients. Fungi mobilize them, then higher plants use them to help build increasingly rich woodland, then forest.

For a long time — thousands of years — the forest appears to be satisfactorily sustaining itself. When leaves and bark fall, decomposer organisms recycle the elements and eventually higher plants use them again. Some nutrients soak down to the soil's B horizon, but roots absorb them. All this nutrient recycling, with a small trickle of elements contributed by sea spray, supports the community.



But all the time nutrients are escaping in various ways: through the soil into the underground water store, for example, or draining into creeks, or even being lost in fires.

Nutrients are being lost from the Cooloola forests faster than they are becoming available. The forest lives on borrowed, albeit extended, time.

Eventually the total quantity of nutrients in the community shrinks to the point at which it cannot support a forest, but only dwarf woodland. On the very permeable sands of Cooloola, the forest's difficulties are exacerbated by the gradual leaching of B horizon nutrients to depths that the roots of most species cannot reach.

The climax concept grew out of observations made on relatively fertile soils in the Northern Hemisphere, generally in landscapes that have developed only since the last ice age. The Cooloola researchers regard the northern 'climax' communities as simply too young yet to have started on the decline that must — barring major environmental change — eventually overtake them.

of Cooloola's dune systems lie above the coloured sands, which must therefore be old.

It seems likely that the colours, which come from iron compounds, developed after the sands settled in their present position.

Man upsets the fragile dune ecosystems: vehicle tracks cause a variety of damage, from changing the distribution of an ant species to increasing erosion.

The Cooloola study has underlined the fragility of dune ecosystems. The sandhills' rich scenic diversity and thriving plant and animal communities owe their existence to a delicate balance between the supply and loss of water and nutrients.

If man intensifies his use of the dunes, he must take great care not to upset this balance. South-eastern Queensland's coastal sands face growing pressures. Wise management of the sand masses demands knowledge and understanding of these natural resources and of the processes occurring within them — knowledge and understanding that can come only from detailed studies like those conducted at Cooloola.

John Seymour

More about the topic

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