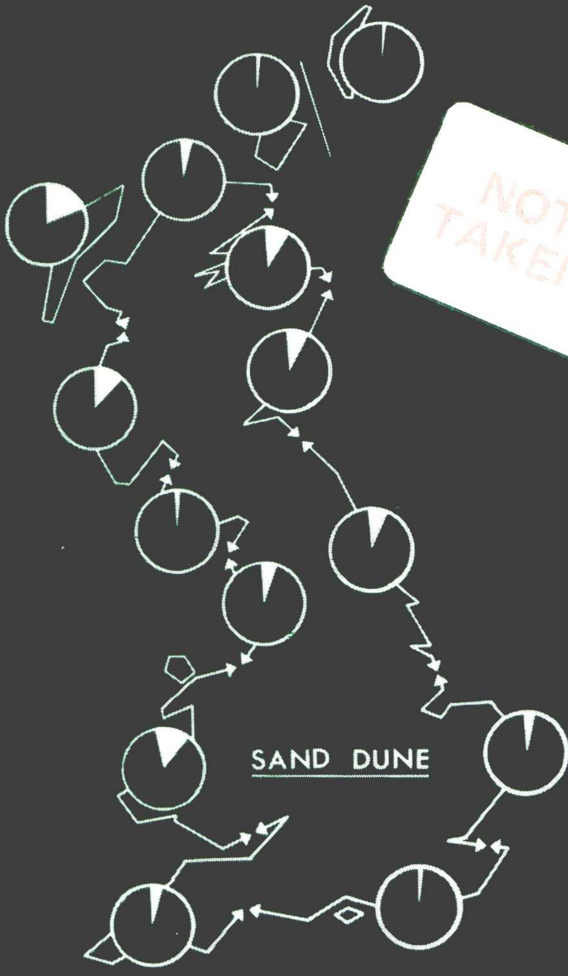
COAST DUNE MANAGEMENT GUIDE



INSTITUTE OF TERRESTRIAL ECOLOGY

NATURAL ENVIRONMENT RESEARCH COUNCIL

Coast dune management guide

Natural Environment Research Council

Institute of Terrestrial Ecology

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COVER ILLUSTRATION
The sector diagram shows the proportions of linear lengths of coastline occupied by sand dunes in Great Britain

The *Institute of Terrestrial Ecology (ITE)* was established in 1973, from the former Nature Conservancy's research stations and staff, joined later by the Institute of Tree Biology and the Culture Centre of Algae and Protozoa. ITE contributes to, and draws upon, the collective knowledge of the 14 sister institutes which make up the *Natural Environment Research Council,* spanning all the environmental sciences.

The Institute studies the factors determining the structure, composition and processes of land and freshwater systems, and of individual plant and animal species. It is developing a sounder scientific basis for predicting and modelling environmental trends arising from natural or man-made change. The results of this research are available to those responsible for the protection, management and wise use of our natural resources.

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ITE's expertise is widely used by international organizations in overseas projects and programmes of research.

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INTRODUCTION

Coast dunes are of value in coastal protection as reserve defences against encroachment by the sea. Unlike most desert dunes, they support (and are in fact usually built by) vegetation. Plants help not only to protect their surface from erosion, but also to encourage sand accretion, so improving their role as a bulk defence against the sea. Accretion is defined as vertical accumulation of sand. Conventional engineering solutions to coast erosion problems involving structures are increasingly costly to erect and maintain. For example, in the United States, a 4-fold increase in coastal defence expenditure has occurred in under 2 decades (Silvester 1974). Relatively inexpensive methods of assisting coast protection, involving the use of vegetation and artificial structures (eg fencing), are therefore of special interest in the present economic climate. There is particular need to explore the combined use of physical and biological approaches so that integrated solutions to problems can be employed where appropriate.

While sea walls are essential defences in heavily populated areas vulnerable to erosion, it is worth pointing out that dunes do have certain specific advantages over sea walls. Dunes offer a barrier against flooding and a reservoir of sand to replace beach losses. When waves attack sand dunes (or soft cliffs), the eroded sand helps to raise shore levels, thus reducing the height of waves generated over the shore, and their subsequent power to attack the dunes. Dunes absorb wave energy. Sea walls resist wave attack and, under storm or surge conditions, allow water levels to build up. If a breach does occur, this can result in a sudden release of high-level flood water to landward. Less resistant dunes do not allow such dangerously high water levels to build up. Following a breach, floods therefore occur more gradually and at a shallower level. Successive dune ridges provide a series of coast defences; sea walls normally provide only a single line of defence. Vegetated dunes have powers to regenerate and increase their height, sea walls do not.

It is estimated that there are in the order of 250 miles (402 km) of coast length with dunes in England and Wales, about 9% of the total coastline. On some 60 miles (97 km), dunes are the sole or partial sea defence (Cole 1960). The remaining 190 miles (306 km) have dunes which play at least some part in coast protection. These figures are orders of size only and are subject to revision.

Vegetation has been used traditionally for centuries to help build dunes for coast protection. Routine inspection patrols were organized in bad weather, stores of repair equipment were kept on site, and local inhabitants turned out to help in emergency. The natural dune systems were respected in the words of Webber (1956) as 'an elastic system of defence in depth' against the sea (Plate 1). Rising costs of labour have checked the local care and maintenance formerly carried out, just at a time when increased human activities at the coast are putting extra pressure on highly vulnerable dune vegetation. The 1953 tidal surge was a reminder that Britain lies in a storm wave zone by global standards, and that we can ill afford to neglect our coast protection and sea defence activities.

Plate 1. This aerial view of Balmedie Bay dunes, Aberdeenshire, Scotland, shows clearly the extent of the active dune system landward of the coastline. This is the zone required for the mobile dunes to become stable naturally. It does **not** represent a continuing, progressive, further landward invasion by sand inundation.
(Photograph RAF, Crown copyright)

Much of the coast protection work involving vegetation carried out on dune coasts in Britain has been 'ad hoc', and has remained undocumented. Where documented information exists, it is widely scattered in obscure journals, or in unpublished reports, and is not readily available to engineers and others concerned with coast protection. Also, the relatively new discipline of ecology, and recent advances in the study of physiography have led to new insights into the natural processes at work in dune systems. This information is also relevant, but needs to be communicated effectively to those directly concerned with the use of vegetation in coast protection. Coast protection engineers in the

Department of the Environment, in English and Welsh regional water authorities, and in local authorities, could benefit from guidance on what should be done with vegetation and how it should be done, in relation to coast protection activities. This report is designed to supply that guidance so far as dunes are concerned.

OBJECTIVES

The Department of the Environment commissioned the Institute of Terrestrial Ecology from 1 July 1980 for one year, under contract no. DGR/480/675, with the following specific objectives.

1. To produce a brief report on the adequacy of existing information on dune management for engineers.
2. To prepare a coastal dune management guide including:
   i. an account of the way biological phenomena modify coastal sand accumulations;
   ii. an assessment of the impacts of human uses of dune systems on coastal protection;
   iii. a summary of techniques using vegetation, likely to be of use in securing dune coast protection;
   iv. condensed practical examples of case histories;
   v. definition of principles of management relating to coast protection in dune land.
3. To prepare a bibliography of key literature for the use of coastal engineers.

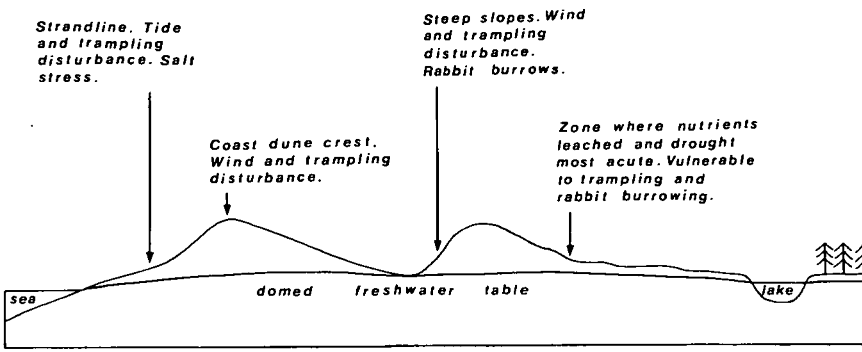
NOMENCLATURE

Plant names are in accordance with Clapham *et al.* (1952). Three important dune grasses have been renamed recently, and their synonyms are as follows:

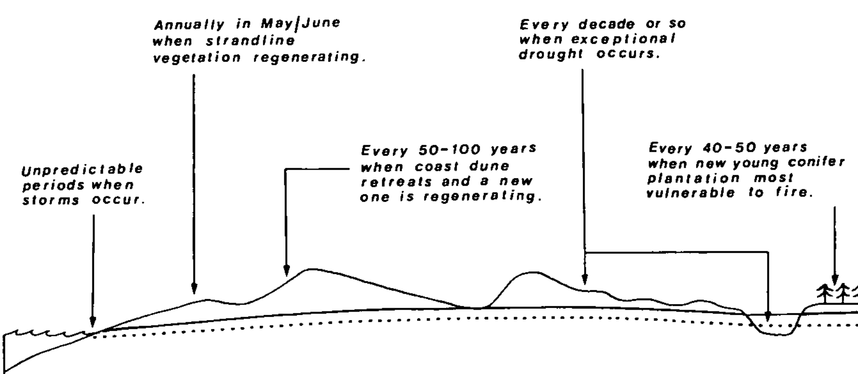
Old name	New name
Agropyron junceiforme (sand couch-grass)	*Elymus farctus*
Elymus arenarius (lyme-grass)	*Leymus arenarius*
x *Ammocalamagrostis baltica* (hybrid marram grass)	x *Calammophila baltica*

1 BIOLOGICAL AND PHYSIOGRAPHIC INFLUENCES ON COASTAL DUNES

This Section describes the elements of sand movement, and the growth and decay of dunes built with the aid of plants. There are vulnerable phases, both in time and in space, during the development of dune systems (Figure 1). For example, dunes are especially vulnerable to coast erosion at the time of coast dune retreat, and from trampling where leaching of nutrients downwards from the surface by rainfall counterbalances the rate at which they accumulate in maturing soil. Knowledge of these vulnerable times and locations is essential for the engineer so that medium- and long-term coast protection programmes can be planned effectively.



A.



B.

Figure 1. A, locations in space, and B, phases in time, when dunes are especially vulnerable to erosion

It should be made clear from the start that vegetation in itself can add little to the bulk strength of a dune attacked by powerful hydraulic forces during storms. However, it does have a capacity of self-repair after such damage, and a powerful ability to hold the dune surface in place against strong wind erosion forces.

1.1 LAND AND SEA LEVEL ADJUSTMENTS

Coastlines in temperate regions are subject to long-term adjustments of land and sea level, controlled by the extent of glaciation in neighbouring polar regions. The changing weight of ice, or water, deforms the earth's crust locally. Glacial melt-water raises sea level.

Much of our south and east coastline, over the past 100 years at least, has been affected by a net rise of sea level. This is a factor that can have a far-reaching influence on the width and slope of the intertidal zone, and in turn the supplies of dry sand at the top of the shore available to build dunes.

In connection with the report of the Royal Commission on Coast Erosion (RCCE), May (1979) comments: 'The RCCE reported in 1911 that 19 426 ha of land had been gained during the previous 30 years, but only 2687 ha lost. It also noted that 28 372 ha intertidal land was lost to the sea in contrast to 9322 ha gained. The intertidal zone was becoming steeper, but the implications were either ignored or overlooked. Without exception, writers since RCCE have emphasised the net gain of land, but have failed to recognise that a net volumetric loss of coastal sediment was taking place'.

Also, he notes that, in connection with the Ordnance Survey measurement of changes in the low water line, the Commissioners remarked: 'It is curious that in each country the loss of foreshore should be so much greater than the gain . . . as the loss of foreshore is general in the United Kingdom we can only suppose that the two tide lines, high water and low water, must be approaching one another, and that the gradient of the foreshore must be becoming steeper'.

1.2 SOURCE OF SAND

The pattern of sand round our shores is largely a legacy from the last glaciation which ended some 10 000 years ago. Sand is derived from 3 sources by a variety of agencies:

1. from the land via rivers;
2. from coasts via wave action, and wind erosion;
3. from the sea bed via currents, storms, and dredging for beach-feeding purposes.

The river source was important to start with; now it is of less significance as river beds have become graded. The coastal source has also diminished because many sections of coast are now protected by sea defence structures. The earliest extensive urban coast protection structures on the East Anglian coast were developed in the 1820s and 1830s, and occupied some 10% of the coastline

(Craig-Smith *et al.* 1975). It has been calculated that 60% of the East Anglian coast is now defended (Clayton 1980). The results of sand budget studies (Clayton *et al.* 1983) suggest that long sections of sandy beaches on the East Anglian coast are dependent on large natural feeds from eroding cliffs. It follows that we may well be in a position of diminishing sand supply for the maintenance of dunes on the East Anglian coast. Clayton (1976) estimates that 95% of material eroded from the coast is transported out to sea. How much is returned to the shore from the sea bed is not known. The sea can transport offshore deposits shoreward, from depths of 10 m or more (C E Vincent, pers. comm.). For that reason, the coastal engineer must be increasingly concerned about offshore sand and gravel extraction near to coasts he has to protect.

1.3 SHORE ZONES

The immediate source of sand for dune building is the shore. No matter how much sand is exposed between tide marks, it cannot be moved by the wind and contribute to dune growth, unless the surface dries out, at least temporarily, between tides. The lower shore is, however, an important feeder zone from which breaking waves in relatively calm periods can cast up sand to higher levels.

The foreshore is defined as the zone between mean low water and the mean high tide line. Most of the foreshore remains permanently wet, but higher levels dry out sufficiently to supply up to 10-20% of wind-blown sand for dune building.

The backshore is defined as the zone from the mean high tide line to the dunes. This zone supplies up to 80% of the sand for dune building as it is only submerged during storms, or exceptionally high tides, on 2 or 3 days a month at most (Krumbein & Slack 1956). The width, the length, and the height of this backshore zone are therefore of key importance to the continued growth of a dune system. Where the direction of the commonest sand-moving winds is oblique to the coastline, a long, narrow backshore may supply as much sand for dune building as a shorter, broader one.

A basic input to the effective planning of any shoreline protection scheme is, ideally, a reliable set of statistics which describe the environment against which such protection is necessary. Pugh and Faull (1983) review recent work on the characteristics and interactions of British tides, meteorologically induced surges and mean sea level.

1.4 SAND MOVEMENT

Formulae have been developed for calculating the annual amount of sand transported by wind along a beach (Kawamura 1951; Kadib 1964; Adriani & Terwindt 1974). They are of limited use to practising engineers because they require extensive detailed wind velocity and direction records, not generally available, and take no account of sand brought in by storm waves. Some idea of the magnitude of the amount of sand blown inland is given by Kadib (1964) who calculated that, for a 10 000 ft (3 km) length of west-facing beach in southern California, inland sand transport was equal to 10 690 cubic yards per year (8174 $m^3 yr^{-1}$). The difficulty in applying such a formula can be seen by the fact that transport on individual lengths of beach varied by a factor of 3000.

Shore sand is not sterile, but subject to biological influences from microscopic animals and plants which affect its surface stability characteristics. Visually undetectable amounts of silt or clay as little as 1% of the total markedly increase its microbiological content and surface stability under wave action. Increased amounts of silt may so increase the stability that salt marsh plants can establish on a sandy shore formerly too unstable for such plant growth. Such a change may result from the training of a low water channel to one side of an estuary, as has happened in the Dee estuary, Cheshire, and also in the Burry estuary, Glamorgan. The natural downstream progression of estuarine sedimentation, for example at Port Meirion, Gwynedd, also results in a change from a sand to a silt shore.

1.4.1 Impact velocity

Even if the sand is dry, wind cannot move it until a certain threshold speed is reached capable of dislodging sand grains from the surface. For average-sized desert sand grains, this happens with winds of about 4 m s^{-1} (Bagnold 1941). Microbiological influences in shore sand resulting in grain aggregation can raise this threshold significantly. The surface roughness of the sand is a source of friction which keeps wind speeds low just above the sand surface.

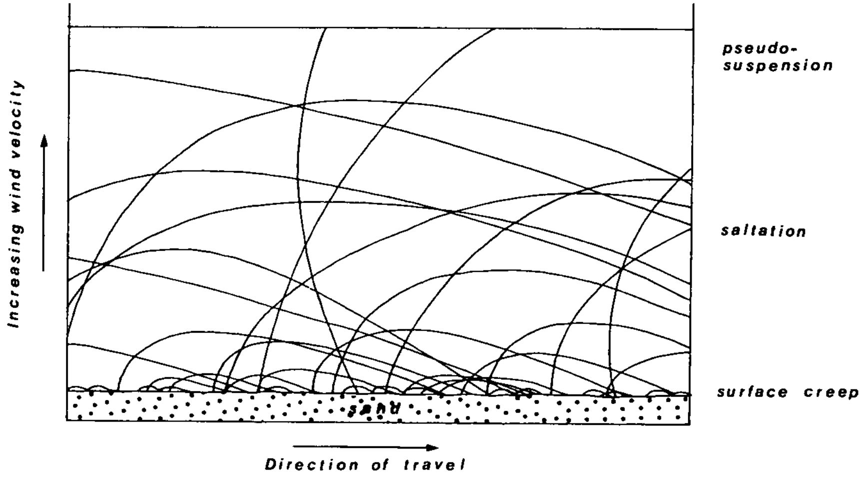


Figure 2. Movement of sand near the ground surface. Where the surface is pure sand, movement at low windspeeds is mainly close to the surface, by surface creep and saltation. Where the sand surface has scattered pebbles or windspeeds are higher, some sand grains are bounced or carried up by wind eddies into higher zones in a form of suspension (after Bagnold 1941)

1.4.2 Saltation

Once a sand grain has been raised from the surface into the airstream, the forward motion given by the wind to the grain is ultimately counteracted by its tendency to fall back to the surface under its own weight. In doing so, it strikes other grains at the surface and causes them to bounce up into the higher wind speed zones where grains can be carried further. This bouncing action of the sand grains is cumulative, and this process of sand movement is known as saltation (Figure 2). Above the impact velocity (4 m s^{-1}), rate of sand flow varies as the cube of the wind velocity. Consequently, really substantial sand movement is only accomplished by high wind velocities. At such velocities (eg 20 m s^{-1} or more), some sand may be carried at the height of a man or higher. Even then, most of the sand streams in a zone only 30 cm above the surface, where its movement is readily visible.

1.5 SAND DEPOSITION IN TIDAL LITTER

Sand streams over a level sand surface in the wind, but does not accumulate unless there is some obstacle to interrupt its flow. Tidal litter, plants, and sometimes pebbles provide obstacles on the backshore. They disturb airflow and slow up wind velocity, causing some of the sand load to be dropped among the obstacles (Hesp 1981). Most tidal litter on sandy shores consists of drift seaweed. The amount varies according to the proximity of intertidal and subtidal rock surfaces which support seaweed, and the incidence of storms which tear it off. Most litter is brought to the shore in autumn and winter storms, and it becomes piled up on the backshore by the high tides of the spring equinox, where it accumulates sand and becomes buried during the summer. Tidal litter is a vital ingredient in raising backshore levels and is a very important source of nutrients for the first colonizing plants.

1.6 STRANDLINE VEGETATION

The strandline is a band of varying width between dunes above high water mark and the regularly flooded intertidal foreshore. Once sand has accumulated over tidal litter on the backshore in early summer, the stage is set for a sequence of events that can, in favourable circumstances, lead ultimately to the formation of a coast dune up to 10 or 15 m high on British coasts. Storms can, of course, arrest this sequence at any time and throw the process back to an earlier stage. Equally, there is a chance that this sequence will proceed to a successful conclusion with, if needed, the aid of only relatively inexpensive materials and simple techniques, as described in Section 3.

The first plants to colonize the backshore are annuals such as sea rocket (*Cakile maritima*) and saltwort (*Salsola kali*). They reproduce from comparatively large, double- or single-seeded fruits which can float for at least a week (Ignaciuk & Lee 1980) and are tolerant of long periods of immersion in sea water. They germinate rather late (May), but grow rapidly to form plants up to 1 m in diameter and 0.5 m in height. They depend on buried tidal litter and sea water spray for nutrients. These plants trap wind-blown sand in hummocks, and sea rocket can raise sand level locally as much as 1 m in one growing season. Even in winter, their dead stems help to retain some sand. However, strandline annuals are not an essential precursor to dune formation and, providing levels are high enough, dune-forming grasses can colonize the backshore direct. Strandline vegetation is ephemeral in appearance, depending on propagules available in the soil, and the location and width of backshore zones suitable for colonization. The presence of buried rhizome fragments with green shoots provides a valuable indicator in winter of sites where sand fences and dune grass plantings are likely to survive. Absence of strandline vegetation may be the result of excess trampling, and does not necessarily mean that it cannot survive.

1.7 DUNE INITIATION

1.7.1 Dune-building grasses

The chief sand-accumulating plants on European coasts are grasses. Most people are familiar with marram grass (*Ammophila arenaria*), but many are unaware that dune growth is most frequently started by sand couch-grass (*Agropyron junceiforme*). This species and the more locally distributed lyme-grass (*Elymus arenarius*) are tolerant of salinities up to sea water strength (3.5% sodium chloride), providing tidal inundation lasts only a few hours. In contrast,

Plate 2. Plantings of lyme-grass (foreground) and marram grass (background) at Mellon Udrigle, Ross-shire, Scotland. Note lyme-grass has been severely reduced in height by grazing, while marram grass has apparently remained ungrazed.
(Photograph W T Band, Countryside Commission for Scotland copyright)

marram grass tolerates only 1% salinity (less than one third sea water strength), and is less successful at strandline level than sand couch-grass and lyme-grass. Hybrid marram grass (*xAmmocalamagrostis baltica*) is more tolerant of strandline conditions, but is a sterile grass of hybrid origin and can only spread vegetatively (J R Rihan, pers. comm.). Lyme-grass is near to the southern limit of its range in south England (Clarke 1965). Flowering shoots are sparse and it produces little seed on the East Anglian coast (Turner 1977), probably because it is very susceptible to rabbit grazing (Plate 2). American beach grass (*Ammophila breviligulata*) has been introduced to this country, for example at Newborough Warren, Anglesey, but has not proved superior to our native marram (R Griffith, pers. comm.), and is susceptible to fungal disease when transplanted outside its normal range in North Carolina. Distinguishing features of the British species of these dune grasses are given in Figure 3.

1.7.2 Natural propagation of dune-building grasses

The pioneer dune grasses propagate both by seed and by rhizome fragments in the strandline. Seedling roots of sand couch-grass can reach down 7 cm to more or less permanently moist sand within 10 days. Subsequent growth of short and then long horizontal rhizomes (underground stems) with production of tufts of shoots at intervals enables the plant to retain its hold and trap a low sand mound. Even though top growth is ripped off by storm tides, the base of the plant may persist and regenerate. This ability appears to be due to the imposition of dormancy on subordinate rhizome buds, which has the effect of keeping in reserve buds and nutrients against the threat of repeated mechanical disturbance (Harris & Davy 1986). In addition to horizontal growth, rhizomes and shoots are capable of vertical elongation in response to sand burial. It is these special characteristics which make these dune grasses so valuable in raising sand levels at the coastline. Where net sand accumulation is 25 cm or less in a year, sand couch-grass can keep pace with it. Where it is from 25 cm to 50 cm, vertical rhizomes extend upwards and carry new shoots to the superior surface level in the following year. Where sand accumulation significantly exceeds 60 cm per year, neither lyme-grass nor sand couch-grass can survive. Marram grass is the only species with virtually unlimited capacity for both horizontal and vertical rhizome growth. It is these qualities which make it so valuable in building high-level coastal dunes and, exceptionally, it can survive in zones where annual sand accretion up to 1 m per year occurs. Although marram can produce abundant seed, and natural seeding densities of 150–200 m^{-2} occur in sheltered situations, Huiskes (1977) records very high seedling mortality from erosion and desiccation.

1.7.3 Responses to burial

Seasonal variations in the weather provide variable amounts of sand, which may or may not allow time for dune grasses to keep pace with the intermittent

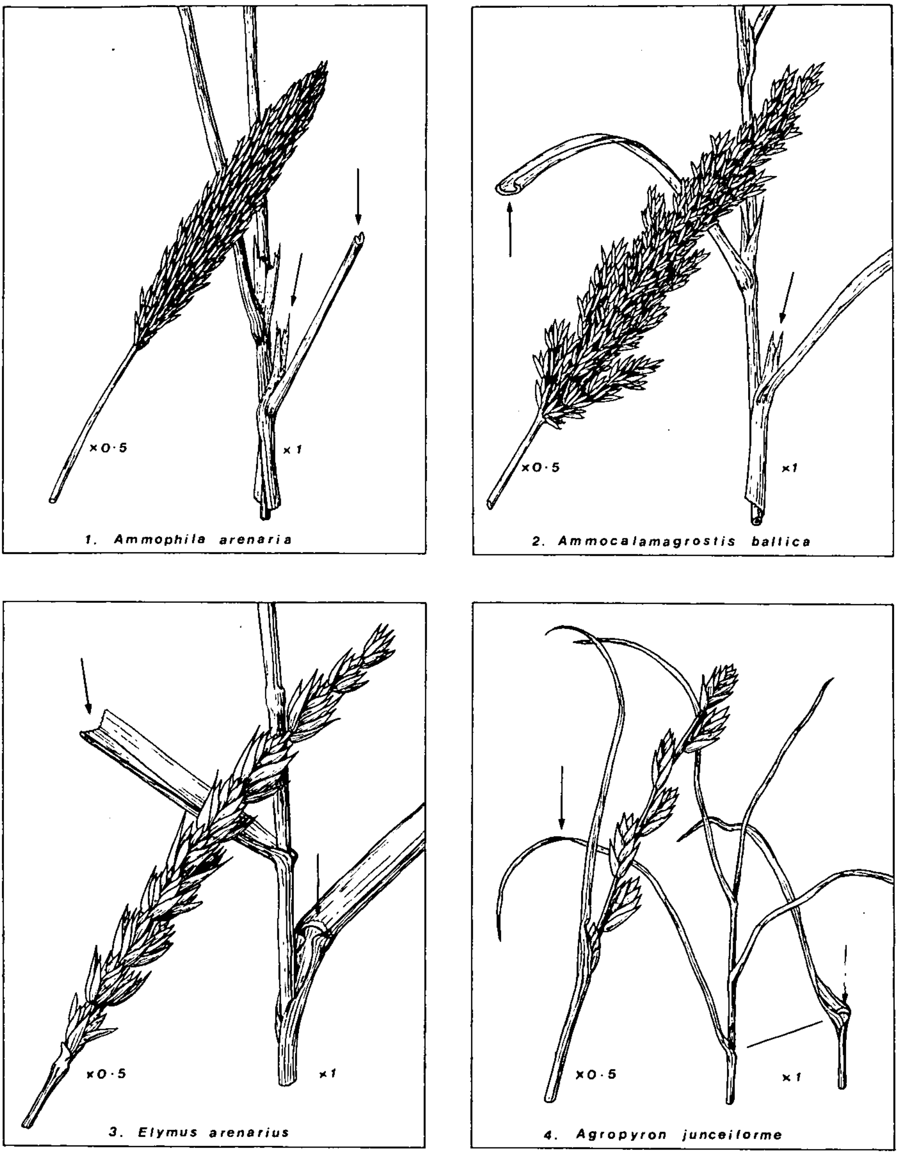


Figure 3. Characteristics of the 4 dune-building grasses. Note differences in leaf widths and leaf rolling, and in the size of the ligule at leaf bases, are useful aids to identification when the grasses are not in flower

sand supply. It is not unusual for a single gale on exposed coasts to deposit 30 cm or more of sand on to marram growing on the lee slope of a coastal dune. Where its leaves are almost buried, further accretion, before the shoots or rhizomes have had time to elongate, will kill it. However, the system is self-regulatory to some extent, because sand accumulation tends to cease once vegetation is 'filled up' with sand.

1.8 DUNE BUILDING

1.8.1 Dune morphology

The natural shape of an isolated bare sand mound in the desert (barchan dune) is one with a shallow windward slope. Sand is pared off the windward surface to stream over the crest forming a steeper leeward slope at about 36° from the horizontal, the critical angle of rest of loose dry sand. A vegetated coastal dune has a cross-sectional shape which is just the reverse: like an aerofoil, it has a relatively steep windward slope and a long shallow leeward slope. The important point to bear in mind here is that the presence of vegetation transforms the natural tendency towards barchan form into an inherently unstable shape. So, unless the dune is completely covered with vegetation, wind will all the time tend to convert the steep windward face to a shallower profile. Side by side with the tendency to accretion in the vegetated parts is the tendency for erosion in the bare parts. As the dune builds in height, the wind velocity over its summit steadily increases and erosion tends to counterbalance accretion. As a result, there is a natural height restriction on the growth of dunes which varies according to sand supply, climate, and exposure related to local topography.

1.8.2 Height of dunes

European dunes may rise to the spectacular height of 90 m, on the Coto Doñana in Spain for example. At this site, there is an ample supply of sand, and warmth and humidity favour an extended growing season. On cooler and stormier British coasts, dunes rarely reach more than 30 m in height and are frequently not much more than 15 m high. The average annual vertical increment of sand accretion on an actively growing dune at Newborough Warren, Anglesey, was about 20 cm. It follows that a dune at this site may take at least 75 years to reach full height. In other words, it may take about a human lifetime to build a typical coastal dune to full maturity on our shores. For anyone concerned with the management of a dune system, it is of the utmost importance to keep this timescale in mind, because it puts all maintenance work and costs into right perspective.

1.9 DUNE EROSION

1.9.1 Wave erosion

The most powerful agent of coastal dune erosion is wave action at the coast. It is quite normal for a mature coast dune to become undercut by wave action at the toe in winter, and for the damage to be made good by renewed sand accretion in summer. Where shore sand supplies become depleted, deeper water inshore allows more powerful waves to develop and attack the dune coast. Exceptional storm surges like that of 1953 on the east coast of England can cut back horizontally into dune systems as much as 18 m in a matter of hours. Once the sea regularly attacks a coast dune, waves gouge out the base, and the upper parts become undercut and slump, leaving a near vertical face. This face is too unstable for plants to colonize and will remain a continuously eroding surface under wind action. Non-vegetated slopes fail as an uncohesive granular solid almost immediately after undercutting. Vegetated slopes are up to 50 times stronger and behave as a cohesive mass failing intermittently in a series of small rotational slips (Carter 1980a). Providing the coast dune was originally well vegetated, many viable fragments of marram grass will fall to the shore and may help to regenerate dune growth in gaps after a storm. Thus, the system has an inbuilt self-healing capacity.

1.9.2 Rain erosion

Very heavy rainfall at Newborough Warren, Anglesey, carved channels with unstable vertical walls up to 1 m in height through low-lying bare sand. These channels were later obliterated by wind-blown sand movements. Such events seem to be rare in British climatic conditions. In general, rain has a stabilizing effect on the dune sand surface, as wet sand cannot itself be moved by wind

Plate 3. Large-scale sand movement overwhelmed settlements on many parts of the European coast in medieval times. It can still be a problem locally, as at Gwithian, Cornwall, England.
(Photograph Nature Conservancy Council copyright)

(even by high wind velocities). Surface changes did not correlate with rainfall incidence in a study carried out at Noordwijkerhout (Netherlands), perhaps because wet sand is dried out rapidly by strong winds (Jungerius *et al.* 1981).

1.9.3 Wind erosion

Wind is the primary agent of dune erosion and, as we have seen, the bare sand surface is readily disturbed even by winds of quite low velocity. It follows that any factor which destroys the protective vegetation cover, like plant disease, over-grazing, cropping, trampling, or fire, allows higher velocity winds to reach the sand surface and erode the sand (Plate 3).

Right from the very onset of dune formation, accretion and erosion occur side by side, but, while the dune is building, vigorous plant growth encourages more sand accumulation than is lost by erosion. As winds become stronger at higher elevations, the critical height to which the dune can grow is reached; desiccation and mechanical damage reduce capacity for plant growth, and hence the power to trap sand. Erosion increases as accretion diminishes, and eventually counterbalances it. Bare sand areas expand at the crest of the mature dune and lead to expanded eroding zones. Where a small section of dune begins to erode in this way, it may develop into a U-shaped or parabolic dune with a crescentic, bare, windward face and lower-lying partially vegetated 'arms'. Such dunes may travel inland independently from the parent ridge for distances of several kilometres. This process, coupled with sea erosion at the dune base, leads to extensive bare seaward faces in the mature coast dune, especially where prevailing and dominant winds are onshore. This is a perfectly natural process on exposed coasts with onshore winds dominant and can occur independently of damage from people or grazing animals. Ultimately, the whole coast ridge may start to move inland (Plate 4). Such dunes can travel at rates up to 6 m a year in Britain, and, on the Atlantic coast of Europe, rates up to 30 m a year have been recorded (Garcia Novo 1979).

1.10 DUNE ENVIRONMENT

Dune sand appears to be a very inhospitable medium for plant growth at first sight, and indeed it does have a low moisture-holding capacity and is generally poor in mineral nutrients essential for plant growth.

1.10.1 Water table

It is sometimes assumed that, if you dig down in a sand dune, you will come to a permanent water table not far below the surface. In fact, this is not so, and soil moisture, after increasing to a depth of about 60 cm, diminishes or remains constant below that depth until the permanent water table near the base of the dune is reached (Figure 1). The moisture requirements of dune grasses are maintained entirely by that part of the rainfall which can be held by the sandy soil (pendular water) and dew. Dew is vital in maintaining water supplies at and near the surface in prolonged periods of drought (Salisbury 1952). The permanent water table near the base of the dune is of no significance to those dune grasses whose roots lie many metres above it. The maximum depth of root penetration of most dune grasses and herbs is not more than 2 m.

A big dune system behaves as an isolated catchment for rain, and it has been shown that the water table is dome-shaped, ie highest near the middle of the system and lowest at the periphery (Figure 1). It is for this reason that there is often a lake, or lakes, at the landward side of a big dune system where water from the dunes meets that draining coastwards from the land. Because there is also a positive seaward flow of fresh water from the dune system to sea, sea water is normally unable to penetrate landward through the main coast dune into hollows in the dune system, so these are under the influence of fresh water once they are insulated from direct tidal flooding by the growth of the coast dune. Such hollows are known as dune slacks or dune valleys, and they carry a marsh plant flora quite different from that of the dunes (Ranwell 1960; Laan 1979). Slacks may be simply parts of the shore incorporated in the dune system as it grows seawards, or they can be derived from the residual plains left when parabolic dunes erode down to permanently damp levels as they move inland under wind erosion. Most of the big dune systems contain a mosaic of dunes and slacks.

1.10.2 Soil nutrients

Sand dune soils vary widely in their lime content, mainly derived from broken marine shells. They are poor in organic matter and plant nutrients, including nitrogen, phosphate and potassium. In the course of time, rain tends to leach soluble lime and other nutrients downwards, but increased cover of plants with increasing stability adds organic matter to the soil, and improves its moisture- and nutrient-holding capacity. Thus, the soil always tends to become more acid with time in dunes. Dunes which start with about 3% of calcium carbonate become lime-deficient at the surface in about 200 years in the British climate, but, where the initial carbonate level is 10% or more, acid soils may not develop for many centuries. All the soluble nutrients leached downwards by rain in a dune system enrich the water table, so, while the dunes become depleted of nutrient, the slacks become richer. It is for this reason that one often finds heath on higher ground on the more acid soils of dunes, and plant communities of base-rich soils on lower ground where lime has accumulated in the ground water.

1.10.3 Animal influences

The most significant animal influences on dunes of concern to the coastal engineer arise from stock grazing and rabbit burrowing. As both are associated with people, these influences are dealt with in Section 2 – Human uses and impacts.

1.11 TYPES OF DUNE SYSTEMS

There are 5 main types of dune system (Figure 4). They differ from one another in quite fundamental ways, according to the topography and weather conditions where they are formed. It is important for the dune manager to know how any particular dune system fits into the series if it is to be understood and managed effectively. Some dune systems have characteristics of more than one type and some are intermediate between types, but it should not be difficult to

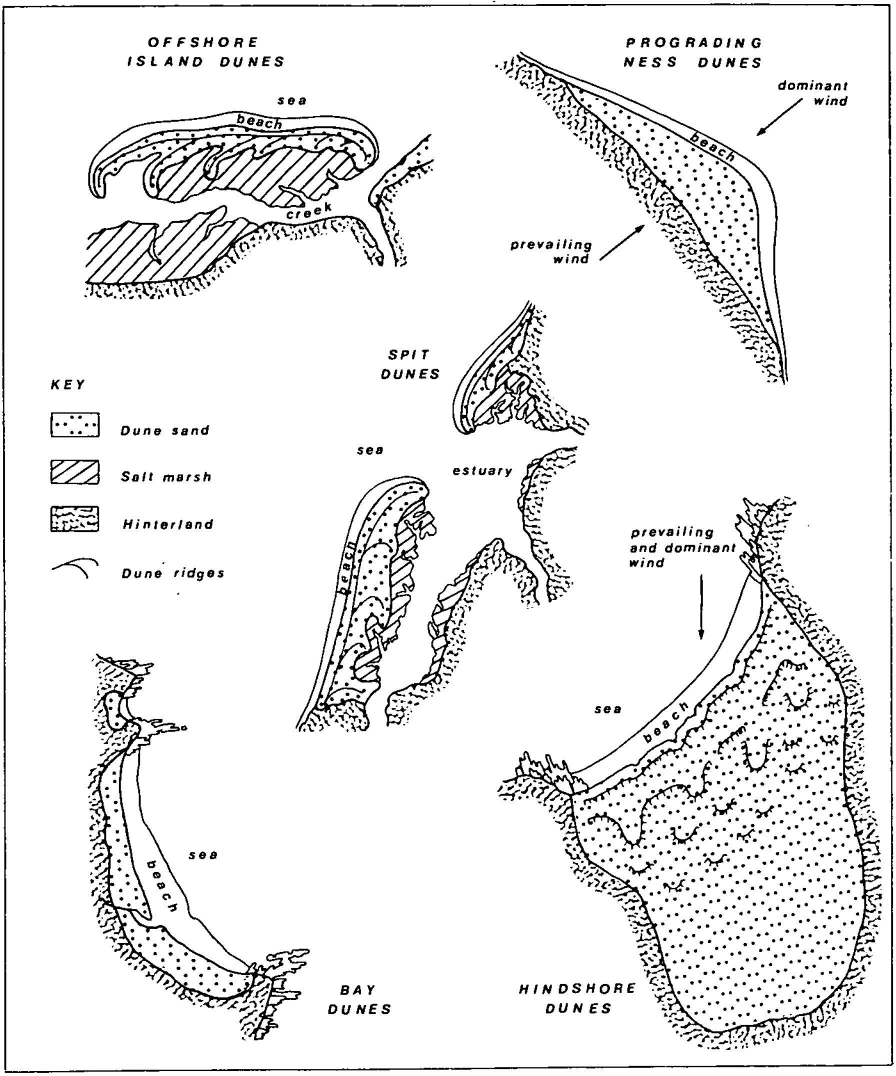


Figure 4. Types of dune systems

recognize where any particular system stands in relation to the following 5 classes.

1.11.1 Offshore island dune systems

The most maritime dunes of all are those associated with offshore or barrier islands, like the Friesian islands off the Danish, German, and Dutch coasts, or the island dune systems off the Norfolk coast. They rarely develop high dunes in such exposed situations. They often rest on coarse, freely draining deposits of sand or shingle, formed under high wave energy conditions. The smaller of these systems rarely develop fresh water slacks, but hollows may have some tidally controlled brackish water influences where the dunes rest on highly permeable shingle. These offshore dunes provide sufficient shelter for mudflats and marshland to form on their landward side. There is usually a tendency for such island systems to extend in the dominant direction of longshore drift. As a result, they may be narrow in width and form an age series extending in one direction along the coast, as at Blakeney, Norfolk. These narrow dune systems are subject to tidal overwash from time to time, like the much more extensive barrier islands off the east coast of North America. Steers (1964) has made historical studies of this type of system on the Norfolk coast.

1.11.2 Prograding dune systems, nesses and cuspate forelands

Dune systems may build out, or prograde, from an open coast where there is an abundant supply of sand for dune formation, either from a very broad high-level shore to seaward, or at an accumulation point (ness) receiving sand by longshore drift from 2 directions at once. These conditions are more usually found on the eastern shores of Great Britain where the prevailing wind blows offshore and is in opposition to the dominant wind from another direction. On such shores, tidal litter may chance to rest on a beach berm well seaward of the existing limit of dune vegetation, leaving a shallow brackish hollow between, which ultimately becomes fresh when dune growth cuts off access from the sea. In this way, an alternating series of low and relatively narrow dune ridges and intervening slacks develop (eg Morrich More, Ross and Tentsmuir, Fife in Scotland). The seaward progression of such systems can be so rapid that dunes do not have time to grow very high before their sand supply from the shore is captured by the next new dune ridge to seaward. The successive dunes and slacks become stabilized *in situ*, forming an age series normal to the coast.

Winterton Ness in Norfolk lies at a point of inflexion of the coastline; the coastline to the south runs north-north-west, while that to the north of the ness runs due north-west. Longshore drift of sand under the influence of wind-induced wave action brings sand to the ness from the 2 directions where it accumulates as apposition ridges.

Cuspate foreland dune systems (like that at Magilligan in Antrim, Northern Ireland, or Killinallan dunes at Islay, Argyll) form a link between nesses and the

Plate 4. Ample sand supply and onshore prevailing winds enable marram grass to build high coast dunes. As the dune increases in height, marram grass can no longer retain sand, and crest erosion expands until the whole of the seaward face of the coast dune becomes bare. Not until the dune moves landward (right) is there room for embryo dunes (centre) to start the dune-building process once again. Morfa Dyffran, Gwynedd, Wales. (Photograph D S Ranwell)

Plate 5. On high-energy shores, strong winds and tidal overwash may prevent a coast dune establishing. Permanent vegetation in the form of turf eventually stabilizes sand blown to landward, as at Sandwood Bay, Sutherland, Scotland. (Photograph S S Anderson)

Plate 6. Erosion scars up to 8 m deep can be initiated by rabbit burrowing on exposed, steep, turf slopes at Oldshore Beg, Sutherland, Scotland. Note figure bottom left for scale. (Photograph S S Anderson)

Plate 7. Moderate rabbit grazing maintains diversity of plant species in the dune flora. The Scottish primrose and many other attractive flowering plants in dune turf would be shaded out in the absence of grazing. Note scale given by rabbit droppings.
(Photograph D Cheyne)

next type of system, spits formed at the mouths of estuaries. These cuspate systems form at the mouth of large shallow sandy-floored lochs where again the sand supply is from 2 directions, the outer coast shore and the inner loch shore. Rae (1972) gives an account of the prograding system at Morrich More, Easter Ross, and Carter (1979) describes the cuspate foreland system at Magilligan, Northern Ireland.

1.11.3 Spit dune systems

Spits are one of the commonest types of sand dune system. They form as sandy promontories at the mouths of estuaries (eg North Haven Peninsula, Poole Harbour, Dorset, and Whiteford Burrows, Glamorgan). Usually one of the 2 estuary mouth spits is larger than the other, depending on sand supplies and the dominant direction of longshore drift. They often form a fan-like series of dune ridges and intervening slacks, with the handle of the fan tied to the mainland. However, they are highly varied in shape and size. From the dune manager's point of view, they have one important feature: access to them (other than by boat) is at one end, and is therefore more readily controlled than in systems more broadly tied to the land like bay dunes. Carr (1971) has brought together information on South Haven Peninsula.

1.11.4 Bay dunes

Bay dunes are much the most frequent of all dune systems. Stable bay beaches approximate the half-moon shape. Comparison of beach areas either side of a perpendicular from the chord of a bay indicates the direction in which the beach is tending to build up or 'rotate' (Ritchie & Mather 1969). Sand trapped within the relative shelter of embracing headlands is often limited in supply and insufficient to form more than a single narrow band of coastal dune. The disposition of sand within a bay system is controlled by the shelter effect of the local topography in relation to dominant winds. These bay dune systems are frequently associated with a moderately indented rocky coastline like that of south Wales, and the north-east coasts of England and Scotland. Tidal litter from nearby rocky shores in the form of seaweed is not only often abundant, but tends to accumulate in the shelter of bays, favouring strandline vegetation growth. Mather and Ritchie (1977) have made major contributions to our knowledge of bay dune systems in Scotland in a series of reports published by the Countryside Commission for Scotland.

1.11.5 Hindshore dune systems

The most majestic of all dune systems are found on extensive sandy coasts where the prevailing wind is also the dominant one. Vast masses of sand are driven landward in huge arcs or massive ridges which continue to erode until they are literally flattened by the wind several miles inland from the shore. The Culbin sands in Scotland; Newborough Warren in Wales; Braunton Burrows in

England; the Coto Doñana in Spain; and, biggest of all, the great dune system of Les Landes on the Gascony coast of France are all of this type. There are many historical records of such dunes overwhelming whole villages in the past (Quinn 1970). Such dune activity in medieval times stimulated legislation to conserve marram grass and encourage its planting and to promote afforestation as a means of stabilization (Plate 3).

As each coastal dune develops to maturity within a century or so, it moves back under the influence of wind erosion and continues to move either as a single, huge eroding ridge or as an irregular chain of parabola-shaped dunes budded off from ridges. The damp dune slack level forms a basal surface over which successive waves of dunes pass to their final point of stabilization. In these circumstances, the age series becomes obscured by the turnover of sand and the whole dune landscape may become a complex web of dunes and slacks as the structure is broken up by varying winds from different quarters.

Extreme forms of hindshore dune system called 'machair' (ie plain) are found locally in western Scotland. They are formed as a result of exceptionally strong winds which limit severely vertical sand dune growth (Plate 5). Strong winds drive sand landward to form a blanket over the rock and peat bogs (characteristic of this part of the world), sometimes carrying the sand to elevations of 100 m or more. These systems are often strongly affected by the grazing of sheep and rabbits (Plates 6 & 7).

Willis *et al.* (1959) and Ranwell (1958, 1959, 1960) have studied hindshore systems at Braunton Burrows, Devon, and at Newborough Warren, Anglesey, and there are 3 recent reports on machair (Ranwell 1974, 1977, 1981).

To conclude, it must be emphasized that erosion is a normal phenomenon in all dune systems and the problem for coast engineers is to contain it within acceptable limits – not necessarily to stop it altogether. Periods of high vulnerability (Figure 1) are relatively short-lived and it is hoped that, armed with the background information on processes at work in dune systems given here, this report will enable the engineer to work with the system, rather than against it, wherever possible to maintain effective coast protection.

2 HUMAN USES AND IMPACTS RELATING TO COAST PROTECTION

Dune systems are useful as a source of aggregate, a source of ground water, and as a bulk defence in coast protection. They are of interest to a growing number of people for the diversity of wildlife (plants and animals) they support, and their sandy shores are of outstanding value for recreation. They can be cultivated, grazed, or afforested, and have, in the past, been much in demand for military training use. Dune systems have provided sites for aerodromes, railways and roads, domestic housing, and industry, and they are increasingly subject to influences from energy-related developments at the coast, where abundant supplies of cooling water are available, for power stations for example. Often a single dune system is affected by several of these activities simultaneously. All have a legacy of historical human influences which go a long way to explain differences of the vegetation between one system and another.

This Section assesses the impacts of these human uses of dune systems on coastal protection.

2.1 SAND EXTRACTION

2.1.1 Mining

Sand is dug from dune systems for building purposes (eg Shetland); it is dug from the shore for glass making (eg Southport); and shell sand is removed to improve the fertility of poor agricultural soils (eg in the Hebrides). Also, sand contains heavy metal residues which are mined extensively on Australian and South African beaches, but which are not of industrial interest in Britain. Heathershaw *et al.* (1978) conclude that erosion on the east side of Swansea Bay has been brought about largely by sand extraction from the foreshore. Foreshore extraction has lowered intertidal beach surfaces by 0.25 m, and this seems to be a permanent effect as onshore/offshore sediment exchanges are minimal.

In most parts of Britain, these onshore sand-mining activities are now of comparatively minor significance, following awareness of the sensitivity of dune landscapes to erosion, and the increased vigilance of regional and local planning authorities.

Removal of sand from the shore may reduce supplies to the backshore so that it can no longer feed dune growth (Mather *et al.* 1972). This practice could be especially serious in areas where coal mining has resulted in subsidence to below sea level in the hinterland, as at Druridge Bay, Northumberland. Removal of sand from the coast dune (eg at Laggan Bay, Islay) creates a continuously eroding seaward face and destroys dune grasses vital for dune regeneration. Removal from back dunes may mobilize them and result in the overwhelming of adjacent property by sand inundation. Lowering of dune levels by mining may (depending on the local topography) enlarge the consequences of a chance breach in the coast dune and result in a much wider sea incursion than would otherwise have occurred. However, local needs for building materials in remote sites may necessitate some sand extraction from 'safe' landward sites.

Historical evidence of the mis-management of dune coasts suggests that memories are short. So, even though the onshore sand-mining activities round our shores may have diminished in recent years, new use of sand-derived materials may arise and be argued powerfully in the national interest. It pays therefore for the engineer to be fully aware of the possible consequences of sand mining, for whatever purpose it is carried out.

2.1.2 Dredging

The very high export value of sand and gravel aggregate has led to a great increase in dredging of these materials, under licence, in the offshore zone round our coasts. Concern that this dredging could affect coast protection interests has led to a study by the Hydraulic Research Station, and the recommendation that shingle dredging (in general) should not take place in water less than 18 m below low water level (Joliffe 1973). Applications are no longer automatically notified to regional water authority, or local authority engineers, and this lack of notification may give cause for concern, especially if regulations are not strictly observed. Most offshore dredging for gravel is controlled by Crown Estate Commissioners who keep operators away from nearshore banks, but navigational dredging is free of these restrictions. Up to 250 000 m^3 yr^{-1} has been dredged from the Harwich Channel (Clayton 1980).

2.2 WATER EXTRACTION

Excessive ground water extraction for domestic housing or industrial use in the neighbourhood of coastal dune systems has 3 adverse effects. It not only destroys wetland vegetation, but lowers the existing water table, and therefore the depth to which wind erosion can lower the surface. It can also result in saline incursions into the ground water (eg at Southwold, Suffolk). As the vegetation of dune hollows landward of the coast dune is dependent on fresh water, it could be damaged at least temporarily by salt penetration. Such problems have arisen in the Netherlands where the water table in the principal dune catchment areas has been lowered well over 5 m (Maarel 1979). Attempts to rectify the situation at Zandvoort (the dune catchment for Amsterdam), by infiltration with polluted Rhine water, have adversely affected wildlife. Variety and rare species have been replaced by uniformity and common weed species (Londo 1966, 1975). Such considerations are likely to impose constraints on purely engineering solutions to water management in the future.

2.3 COAST PROTECTION AND SEA DEFENCE

The Coast Protection Act 1949, which is concerned with erosion and encroachment by the sea, was administered by the Department of the Environment until 1 April 1985. Then, under a Transfer of Functions order (Statutory Instrument no. 442, 1985), this responsibility was transferred to the

Ministry of Agriculture, Fisheries and Food. The Ministry was already concerned with the protection of low-lying land against flooding by the sea, under the Land Drainage Act 1976, and thus the 2 functions became the responsibility of a single Department.

Purely engineering solutions to the problems of coast erosion, involving the use of rigid structures, though essential where life and substantial amounts of property are at stake, inevitably diminish one of the biggest sources of sediment for coast protection – the coast itself. It needs to be kept in mind that 90% of a large coastal dune system is behind the coast and temporarily out of circulation so far as its coast protection function is concerned. Providing such a system is backed by rising land and it has been kept free of permanent buildings, it represents a valuable bank from which sediment supplies can be drawn by the sea, but only if there is no rigid barrier isolating the dunes from the sea. Clayton (1976) has drawn attention to the fact that, while cliff sections of the East Anglian coast have retreated at a rate of 1 km per 1000 years locally, elsewhere on this coast marshlands and dunes have been created. In area terms, gains have more than balanced losses, though he gives reasons to suggest that this favourable balance may not persist. Carter (1980 b) points out that instability is inherent in vegetated dunes. The position of high water mark is not permanent, but varies according to the state of growth of a coast dune. Coast protection, however, aims to fix permanently the position of high water mark, though this may be in conflict with natural cycles of shore and dune development.

2.4 WILDLIFE PROTECTION

The varied topography, and the conjunction of many habitat gradients (eg mobile to non-mobile, saline to non-saline, wet to dry, etc) result in an exceptional richness of flora and fauna on dunes of particular concern to those interested in wildlife. For example, half the total number of flowering plants in the British Isles can be found on dune systems round our coastline. For centuries, dunes have acted as a refuge, not only for many species pushed out of lowlands by intensive agriculture, but also for many immigrant species that have reached our shores since Britain was finally severed from the Continent by the rising sea level some 7000 years ago. In addition, dunes are of particular educational interest for the graphic way they illustrate dynamic coastal processes associated with the interaction of wind, sand, and plant growth.

For such reasons, many dune sites, or parts of dune sites, have received protection as National Nature Reserves or Sites of Special Scientific Interest from the Nature Conservancy Council, local authorities, and voluntary bodies such as County Naturalists' Trusts and the Royal Society for the Protection of Birds.

Such concern is advantageous for coast protection as it brings vigilant and knowledgeable people into association with the site, who are effective in helping to reduce damage to the vegetation and who can supply information relating to its regeneration. However, such interests may impose some restraints on coastal protection activities. They may require access routes to be restricted, to avoid damage to localized plant communities and disturbance during spring to breeding birds.

Dune sites were among the first to be colonized by our ancestors seeking areas clear of forest for agriculture, and shoreline food and bait (Crawford & Switzur 1977). Consequently, they are rich in archaeological sites which can be damaged irreversibly by uncontrolled movements of heavy vehicles. The Welsh Water Authority has considered both archaeological and wildlife factors in planning proposals relating to the line of a sewage pipe at Merthyr Mawr dunes (Glamorgan).

While emergency coast protection repair must always take precedence over these ancillary interests, there is obviously a case for close co-operation, wherever possible, for example in mapping the location of areas of particular wildlife interest, so that unnecessary damage can be avoided when coast protection activities are being planned.

2.5 RECREATION

The main recreational activities on dune coasts in order of diminishing impact on dune vegetation include: car driving, motor-cycling, horse riding, walking and golfing. These activities, directly or indirectly, affect dune grasslands.

2.5.1 Vehicle damage

Vehicle tyres and trampling reduce the height and density of the vegetation and increase soil compaction, which in turn reduces oxygen for respiration around plant roots (Liddle 1973). Decreased surface roughness allows winds of higher velocity closer to ground level. Shorter vegetation, in turn, attracts more activity both from people and from grazing animals, and patches of bare ground appear as the pressure intensifies. Even centuries-old dune soil accumulates little more than 10 cm depth of humus as most of it gets oxidized in summer each year during hot, dry spells in these open-textured soils. Once the vegetation has gone, it takes little more disturbance to break through these thin humus layers and expose sand which is easily and rapidly eroded by the wind. Erosion not only widens the damaged area, but, by spreading blown sand on to adjoining vegetation, reduces its surface density and therefore capacity to hold further sand. So, the processes leading to erosion, and the expansion of erosion, are cumulative, and therefore of serious concern. Path density on an air photograph can give a useful, instant impression of the intensity of recreational use at a site. Changes in path density using this method have been recorded by Brown (1973), Liddle (1975a) and Boorman and Fuller (1977) (Figure 7).

Car and motor-cycle tyre wear results in the most rapidly produced damage, but dune topography limits the influence of cars to the more level and accessible areas. Liddle (1973) measured the influences of car tyre wear on different types of dune turf at Aberffraw (Anglesey). He found that the passage of 200 vehicles in summer reduced dune grassland plant cover by 50%, and more in winter. Liddle also found that bulk density and soil penetration resistance were linearly related to the log of the number of passages of a car up to 256 passages, and of walkers up to 1024 passages (Liddle & Greig-Smith 1975b).

The recovery of vegetation on the St Ouens Bay dune plain (Jersey, Channel Islands) still showed the persistence of car tyre influences 5 years after cars were banned from the area (Plate 8).

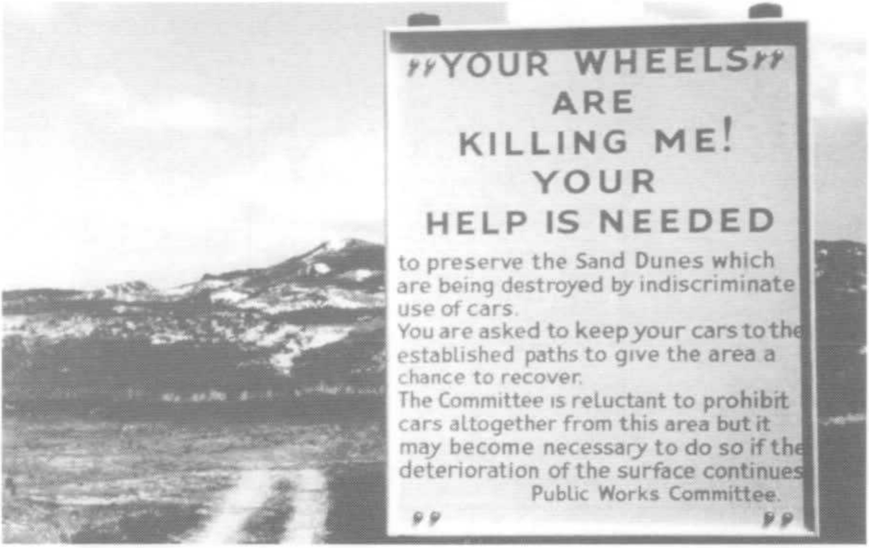


Plate 8. Well-designed notices enlisting the help of the public (or informing them of restoration activities) are an essential adjunct to effective management of dune systems. In fact, cars were eventually banned from this dune system at St Ouen's Bay, Jersey, Channel Islands. The notice served a useful purpose in alerting people to the damage, and reducing opposition to this change in recreational use of the system.
(Photograph D S Ranwell)

Studies in the United States at Cape Cod have shown that maximum damage to strandline vegetation is caused during the first few vehicle passes – 10 passes caused as much damage as 100 passes. On an 8° slope, some 2000 m^3 of sand can be displaced downwards by a single vehicle approaching perpendicular to the slope – less than 1000 m^3 where the approach is nearest parallel to the slope (Leatherman & Godfrey 1979). Frequent vehicle use of dune tracks can lower devegetated tracks by 0.6 m annually. Recovery of vegetation on beach areas takes at least 4 years; recovery in back dune areas is even more protracted, 4–8 years (Leatherman 1979b). Recommendations for control of off-road vehicles (ORVs) are given in Appendix 2.

2.5.2 Horse riding

Horse riding exerts similarly high levels of damage to dune vegetation, and especially when horses are trotting and the weight is distributed over minimum hoof area with close to maximum frequency of hoof impact. There are few places in a dune system inaccessible to a horse rider, but overall density is generally low, and use is often channelled to some extent by topography or bridle paths.

2.5.3 Spectator sports

Sand ski-ing is concentrated on steep eroding slopes, where it can be exceptionally damaging. In contrast, sand yachting is confined to the foreshore where it causes no damage to the dune system. However, both can attract large numbers of spectators even in remote sites (eg 4000 at Dunnet, Caithness, for sand yachting), and this concentration of people at any one time – especially in the growing season – can result in permanent damage.

2.5.4 Human trampling

The most widespread human impact on dune vegetation in England and Wales (as opposed to Scotland), at the present time, comes from human trampling (Plate 9). All unfenced parts of the dune system not covered by impenetrable scrub are freely accessible to walkers, and high dunes are particularly likely to attract attention as viewpoints. The distribution of people in different zones of Brittas Bay dunes (Co Wicklow, Ireland) has been analysed by Quinn (1970). She showed that 93% of visitors in August 1969 were at the shore,

Plate 9. The main growth period of strandline vegetation (June-July) coincides with the start of the tourist season. On intensively trampled shores like Studland, Dorset, England, strandline growth is inhibited locally near main access points.
(Photograph D S Ranwell)

and the distribution as a whole was as follows:

Beach	380 people ha^{-1}
Frontal dune	392 people ha^{-1}
Middle dunes	82 people ha^{-1}
Back dune	32 people ha^{-1}

Most people reach the shore through the dune system and concentrate pressure on access routes. Strandline (Plate 10) and coast dunes are zones of naturally high mobility and relatively resilient to trampling, providing numbers are not excessive and the tourist season is not too prolonged. However, constant and increasing pressure of people year after year significantly reduces vegetation density, height, capacity for regeneration, and the rate of dune building. These are all matters of serious concern to the coast protection engineer.

Plate 10. The presence of well-developed strandline vegetation, with plants like sea rocket, on a wide backshore, indicates potential for the growth of a new coast dune. Storms, or trampling damage may prevent this potential from being realized. Holme-Next-Sea, Norfolk, England.
(Photograph M Hardy)

There is another especially vulnerable zone in larger dune systems (Figure 1). This zone is about two-thirds the way landwards where soil humus is still limited in amount, leaching of mineral nutrients by rain has reduced fertility, and seasonal drought occurs frequently. Such zones may attract people who find the shore too distant, or sun-bathers who seek seclusion and may enlarge erosion hollows in the sand.

Boorman (1976) found that 10 human trampling passes per month reduced dune turf height by 66% at Winterton, Norfolk, and 40 passes per month reduced height by more than 75%. It was estimated that bare ground would appear in dune turf when the trampling level approached 80 passes per month, and that 150 passes per year would produce 50% bare ground (Boorman & Fuller 1977).

2.5.5 Golf courses

The recreational use of coastal dunes as golf courses restricts public access to a level which does not damage the vegetation. It also brings on-site, year-round, positive management in the form of dune turf maintenance, scrub control, and rabbit control. However, modern techniques of 'improving' the sward with fertilizers and irrigation destroy the original dune sward and produce vegetation vulnerable to salt water incursion, or exceptional drought. This 'improvement' can result in failure of the modified vegetation when weather conditions are critical. In contrast, natural dune turf suffered no visible damage from temporary flooding with sea water at Cinques Ports Golf Club (Deal, Kent), after the floods had subsided. Course layouts can restrict the options for coast protection. For example, the siting of greens, tees and fairways close to the shore makes it difficult to adopt the useful options of allowing localized erosion to produce a new and more easily defendable shore line.

2.6 CULTIVATION

Direct cultivation of duneland is practised in the hinterland of most large dune systems, and much closer to the coast on shallow lee slopes of coast dunes on machair land in Scotland. Of the 6000 ha of machair in North and South Uist (Outer Hebrides), some 2000 ha are permanent short turf pasture, and approximately a third of the remainder is cropped in any one year (Knox 1974). Ploughing exposes the thin humus layer to more rapid oxidation. In the past, this exposure was compensated by mulching with seaweed. Currently, there is increased use of artificial fertilizers, but these add no organic matter to the sand, and are rapidly leached out of rooting zones within 30 cm of the surface. The only viable alternative to cereals appears to be increased pasture (Dunn 1981).

Even in the 1270 mm rainfall climate of these north-west sites, Knox (1974) warns:

'Management of machair must be good. Mis-use can cause serious damage. Over-grazing, rabbit damage, inopportune ploughing, and drought can lead to severe erosion, especially if accompanied by strong winds. Breaks in the surface should always be sealed up as soon as possible. Work has been done recently to revegetate a 40 acre (16 ha) blow-out at Bornish, South Uist ...'

Elsewhere in Britain, cultivation is mostly confined to the most landward, low-lying parts of dune systems and presents no problems for coast protection, providing it is kept out of more seaward areas.

2.7 GRAZING

2.7.1 Stock grazing

Stock grazing affects coast protection in a number of ways. Cattle both trample and graze on strandline vegetation and slow up dune regeneration (people tend to walk between strandline plants and are less damaging). A cow's hoof exerts a pressure of 7–10 kg cm^{-2} and a cow treads one ha of pasture some 8 to 9 times a year. The hoof of a sheep exerts 4–6 kg cm^{-2} pressure, but a sheep treads one ha of pasture 20 times a year (Frame 1971). That is to say, sheep exert 25% to 45% more total impact per unit area than cows, because, among other factors, their hoof area is so small in comparison with their weight. Annual grazing intensities of 0.5 cattle per ha and of 4 sheep per ha can be supported by dune turf. No simple relationship between density and area for rabbits has been found (D Bellamy, pers. comm.). Sheep graze more closely than cattle and reduce the sand trapping capacity of dune turf. They also range more widely over the uneven topography of dune systems and cause erosion on pathways and lairs associated with steeper slopes. Grazing reduces rooting depths and these are critical in mid-summer drought conditions (Band 1979). Further, part of the productivity cropped by stock is lost to the system when the animals are folded, representing a loss of organic matter which would otherwise contribute to stability in the form of soil humus. Sheep grazing has been largely discontinued in the more southerly, and drier, English and Welsh systems, but persists in much of Scotland, especially in the higher rainfall areas which are less sensitive to erosion. Band (1981) has shown how rapidly dune turf can recover when sheep are excluded from experimental plots.

2.7.2 Rabbit grazing

Farming of rabbits in warrens was carried on in English and Welsh dune systems for centuries after their introduction in Norman times, but only during the last 200 years in Scotland. Moist cohesive sand, never far below the surface in British dune systems, provides an ideal burrowing medium for rabbits. When management control of warrens declined, rabbit populations expanded. In spite of myxomatosis disease since 1954, rabbits continue to exert a powerful influence on the vegetation of most dune systems – especially since the decline of trapping in recent years. Rabbit burrowing and scraping activities are of more immediate concern than their grazing, for holes are rapidly enlarged by wind erosion and soon link up to form enlarged hollows, and eventually craters up to 10 m deep or more (Plate 6). Rabbits also have a direct effect on the growth of the 2 pioneer dune grasses, lyme-grass and sand couch-grass. The shoot bases of these plants are rich in stored sugar in winter and are excavated by rabbits when other food is scarce. This excavation significantly reduces flowering and seeding of much of the crop, and therefore the capacity of these grasses to regenerate dune growth at the strandline.

Under-grazing can also bring problems. For example, following myxomatosis, large areas of closely cropped turf were replaced by tall, rank, grassland and scattered shrubs at Newborough Warren, Anglesey (Hodgkin 1984). Uncontrolled shrub development not only shades out dune turf species, but can also result in increased fire risk, eg where gorse (*Ulex europaeus*) becomes established.

2.8 AFFORESTATION

Several of the largest dune systems in England and Wales have been at least partly afforested with conifers, eg Ainsdale (Lancs); Pembrey (Carmarthen); Newborough (Anglesey); Whiteford (Glamorgan). Macdonald (1954) estimated that some 10 000 acres (4048 ha) were planted in Britain from 1922 to 1952. Plantations create effective shelter belts and reduce wind strength for distances up to 25 times their height. They are also accompanied by active rabbit control, at least within the afforested area. However, trees also shade out most of the underlying vegetation, are prone to fire, and increase the water table depth (by large-scale transpiration of ground water). As the plantations are even-aged and in quite large blocks, much bare ground can be exposed to erosion when the crop matures and is clear-felled, or when there is a fire. Little or no marram grass survives beneath the shade of pine trees. When tidal erosion cuts back to afforested zones (eg on parts of Culbin dunes, Moray), viable rhizome fragments of marram are no longer available to fall to the shore and regenerate dune growth.

Afforestation can result in a large influx of introduced species to a dune system, and some species may be undesirable from a coastal protection point of view.

2.9 MILITARY USE

Military training activities in the past have proved highly destructive to dune systems (Hewett 1970; Pizzey 1975). Sand was mined to produce concrete anti-tank and block-house constructions, tracks were bulldozed to open up access to the shore or remote parts of the system, vehicles capable of movement on all types of terrain were introduced, and missiles exploded. Such activity left a legacy of damage for many decades and required major restoration activities to restore effective coast protection (Kidson & Carr 1960). Military use does, however, restrict or prevent public access, and, in peace-time at least, care is taken to reduce damage so far as this is compatible with military requirements.

2.10 TRANSPORT

A number of dune systems in the British Isles have been levelled for aerodromes (eg Valley, Anglesey; Macrihanish, Argyll; Benbecula, Outer Hebrides). Any permanent roads, runways, and other installations built in a dune zone bring additional responsibilities for coast protection. Public access is restricted on aerodromes in current use, but disused roads encourage access at abandoned sites and result in localized pressure on adjacent vegetation.

The road structure associated with dune systems often relates to past, rather than present, use. Like groynes, roads are perpetuated often for no better reason than that they were there to start with. They call for positive decisions on management in relation to access policy at the site.

2.11 HOUSING

2.11.1 Housing development

Housing and permanent-standing caravans on dune systems bring a particular responsibility to the coast protection engineer. Apart from direct risks to life and property, such development brings a year-round impact from people on to the dune system so that it may have little chance to recover from one season's damage to the next (Plate 11). Such development also brings increased risk that undesirable plants may be introduced to the system in the form of garden rubbish, and there is increased risk of fire. At Talacre Warren (Flint), for example, high-density caravan use was coupled with serious threat of fire, according to Brown (1973).

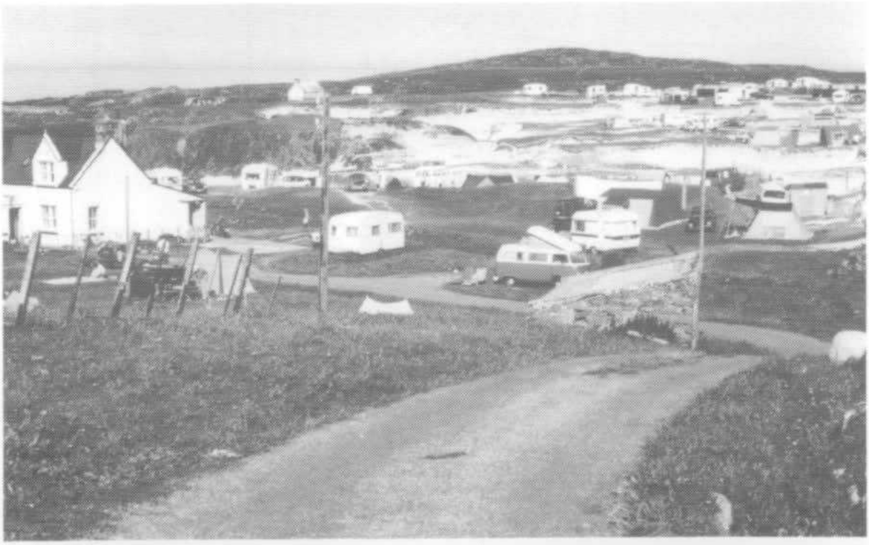


Plate 11. Intensified recreational use of sand dune systems in recent years has led to destruction of vegetation, and the underlying thin layer of soil humus. Once the sand is exposed, wind erosion rapidly enlarges breaks in the sward. Clachtoll, Sutherland, Scotland.
(Photograph W T Band, Countryside Commission for Scotland copyright)

2.11.2 Sewage pipelines

Service pipes (eg for sewage effluent) may need to be laid through dune systems, in association with housing development. Such trench-lines are narrow and readily stabilized by planting after refill. They should generally follow low-elevation routes. Species for replanting need to be chosen carefully in low-lying areas as environmental conditions can change over distances of a few metres, according to depth of the water table.

Sewage effluent is carried to sea by a 0.5 m pipeline, for a distance overland of 4.8 km at Cronulla (New South Wales). For most of its length, the pipeline lay below the surface of unstable dune sands. This instability resulted in exposure of the pipe by erosion, and 5 major breaks (due to the unsupported weight) occurred in the first 2 years after laying. Along another section, just behind the coast dune, rough seas breached the dune in 4 places, and winds enlarged these into blow-outs many metres across, leaving the pipeline exposed. Again, it collapsed. The cost of relocating the pipeline was prohibitive, so the Soil Conservation Service was asked for advice. A close mat of brushwood was used to stabilize the bare sand temporarily, and then sand spinifex *(Spinifex hirsutus)* was planted through the brush. It was watered by tapping off the effluent. The treatment was very successful, the vegetation has persisted, and the pipeline has remained buried (Fleck 1967).

2.12 INDUSTRY AND ENERGY

Industrial or power station development on, or adjoining, dune systems brings localized risk of damage to the vegetation from air- or water-borne pollutants (eg dumping of chemical waste at Sandscale, Lancs). It may also bring special requirements for erosion control in relation to damage to industrial plant from abrasive wind-borne sand. For example, an industrial plant built on levelled dunes at Calais was unable to operate until vegetation had been reintroduced to control sand blow.

2.12.1 Sea-borne oil pollution

Undoubtedly, the most significant pollutant likely to affect the coast protection properties of coastal dune systems is sea-borne oil. The direct effect of oil is to smother any vegetation in the intertidal zone such as strandline growths. This effect could delay dune regeneration for a year or more. Many dune coasts are also high amenity shores, and there is strong pressure to disperse oil by mechanical clearance or chemical dispersants. Mechanical clearance may result in the removal not only of oil, but also of the buried rhizomes of dune grasses, such as sand couch-grass, at the shore, as happened on the Norfolk shores following the 'Eleni V' oil tanker spill. Use of chemical dispersants may kill such growths, but their toxic effects are not likely to be long-lasting in such porous soil.

Oil decontamination activities involve movement of heavy vehicles through the dune system. Unless these movements are carefully planned and controlled, they can do as much damage as the oil.

2.12.2 Oil and gas pipeline landfalls

The recent growth in the North Sea oil and gas industries requires pipeline landfalls in low-lying soft coast areas such as dunes (eg at Cruden Bay and St Fergus, Aberdeenshire). The Cruden Bay operation (Forties oil pipeline) involved the deliberate breaching of a 3 m high coast dune and trenching for a 0.81 m diameter pipeline through the backshore (22 m wide), the coast dune, and the dune system to landward. The whole operation was completed successfully in 4 months at this comparatively sheltered bay dune site (Ritchie 1975). However, pipe laying may result in a time lag up to one year between the time the coast dune is breached and restoration of the topography following trenching (Ritchie 1978). The joint gas pipeline landfall from the Frigg and Brent fields at St Fergus was a much more massive operation than that at Cruden Bay. It involved the deliberate breaching of a 40 m wide gap in a 14 m high coast dune on a much more exposed coast than at Cruden Bay. Spoil from the breach was piled up in a massive wedge behind the coast dune to allow access to the 120 m long sheet-piled trench from higher ground to landward. At both Cruden Bay and St Fergus, the excavation of the beach was left to the last possible moment before pipe pulling, and was rapidly filled in afterwards (Ritchie 1981). The restoration of the landfall of the Cruden Bay pipeline among the coastal dunes, using standard planting techniques (see Section 3), was so successful that disturbance was scarcely discernible a year or 2 later.

3 TECHNIQUES

3.1 DIAGNOSING THE PROBLEM

This Section reviews the techniques available for coast protection. Many of the physical techniques used by engineers can, and should, be used, in combination with vegetation techniques. Even the design of a sea wall will differ according to whether or not it is backed by vegetated coast dunes. However, it is in combination with the more flexible engineering techniques, such as gabions and fencing for example, that vegetation techniques are most commonly used.

Engineers seek to know what problems can be solved by vegetation. Vegetation can:

1. check wind erosion of sand surfaces;
2. stop mobile dunes moving landward;
3. build bulk sand supplies at the coast.

They also want to know what can be done landward of dunes to prevent or repair damage to turf. Vegetation can be used to:

1. regenerate growth in bare areas;
2. control public access (eg by the planting of shrub barriers);
3. thatch worn paths (eg by using cut shrubs).

This Section attempts to supply the knowledge needed to achieve such solutions. It starts with information on the diagnosis of problems. Physical techniques are considered so far as they relate to, and can be combined with, vegetation techniques. Visits to sites and discussions with coastal engineers have shown, time and again, that lack of information on the use of vegetation for securing engineering works is a frequent contributory cause of subsequent deterioration in the effectiveness of coast protection. Consequently, particular emphasis is given to bridging this gap between the physical and biological approaches. The Section concludes with details of vegetation techniques available.

Problems most frequently encountered relate to the amount of sand reaching the dune system, or moving within it. The amount of sand reaching the system depends on basic geological and physiographical factors, while the amount of sand moving within the system depends on the exposure of the system and the amount of animal or human disturbance to the vegetation. More localized problems may arise from high salinity, oil pollution, drought, soil infertility or plant disease.

3.1.1 Lack of sand supply

The most serious problems in dune coast protection arise from inadequate sand supply to feed the beach, as is evident where little or no backshore exists (no dry beach sand at high water mark), and dunes are continually undercut by tidal action, resulting in vertical cliffing. Lack of supply may be geological (eg source material exhausted and/or adverse land and sea level adjustment) or it may result from human influences (eg source material closed off by sea walling or diverted by engineering structures, such as jetties, moles and groynes). While nothing can be done about the basic causes when these are geological, the technique of beach feeding has been used to mitigate their effects. Much can, or could, be done to reduce human interference with sources of supply by better co-ordinated planning of engineering activities on interacting sections. Though outside the scope of this Guide, it is worth emphasizing the need for local authority eningeers to recognize the extent of interaction of their section of the coast with adjoining sections, as for example that of the Holderness coast in Yorkshire with the Lincolnshire coast (Phillips 1964), and to pay close attention to outside engineering activities likely to influence the shore for which they are responsible.

3.1.2 Intermittent sand supply

Intermittent sand supply may be purely seasonal, for example where the coast dune becomes cliffed in winter and where the sand is restored in summer. Problems arise where more persistent vertical cliffing occurs and unpredictable storm damage results in the loss of beach material which may not be replenished for many years. While all sandy shores are so affected, supply problems are especially acute in small sandy bays isolated between rocky headlands.

It would be very instructive if the coastal engineer were able to calculate, easily, quantities of sand drifting along the shore, and therefore capable of being trapped in coast protection measures. Svasek and Terwindt (1974), building on the earlier work of Bagnold (1941), have developed a formula for the measurement of sand transported by wind on a natural beach. However, this formula depends on knowledge and detailed analysis of frequencies of wind force and direction on the beach (rarely available), and takes no account of inputs of sand brought in by waves during storms, which are even more difficult to measure. Beach profile studies initiated by Clayton (1980) have given drift values varying from 200 000 to 1 000 000 m^3 yr^{-1} in different years on the Happisburgh to Yarmouth (Norfolk) coast. This result gives some idea of orders of size in relation to intermittent sand supply.

Intermittent sand supply problems, in general, call for use of flexible physical techniques (eg fences and gabions). Such techniques enable the engineer to plug gaps relatively quickly and to capitalize on temporary sand accumulation, which can then be secured by vegetation-planting activities.

3.1.3 Excess sand

The problem of excess sand is immediately recognizable from the large areas of bare sand present in a dune system, the sparseness of vegetation on leeward slopes, and the overwhelming of property to landward in extreme cases (Plate 3). It is a much less serious problem than limited sand supply, because relatively inexpensive fencing and planting techniques can bring it under control rapidly. It may arise naturally from abundant shore supplies, or as a result of excessive trampling on coastal or inland dunes. Any measures used to control excess sand should start at its source, eg at the coastline, or at the windward edge of bare sand areas further inland.

3.1.4 Over-grazing

Evidence of over-grazing is not as easily recognized as evidence of sand supply problems. Stock may not be on the site during coast inspection visits, records of grazing intensities are not generally available, and rabbit warrens are often invisible in patches of scrub. Lack of grazing is not generally desirable as it may lead to fire hazard. Frequency of animal tracks, droppings, rabbit burrows, and very short mossy turf are the best guide to grazing intensities. If present in high frequencies, these are useful warning signs of impending instability. Grazing damage is especially acute when stock are left out to overwinter in coastal dunes when the vegetation is most vulnerable to grazing and trampling. Clearly, stock should be fenced in to low-lying landward areas resistant to erosion in such situations. Stock grazing use should not be encouraged in exposed west coast sites, or in the drier parts of southern Britain. In sites dominated by stock grazing, rabbit grazing was found to be of minor significance (Band 1981). However, where rabbits are the principal grazers, their burrowing activities are likely to lead to extensive erosion in west coast sites. Their populations can be controlled very effectively by traditional trapping techniques (Ranwell 1981), but these may have to be subsidized where there is little call for wild rabbit meat.

Despite problems associated with rabbit burrowing activities, moderate levels of rabbit grazing are beneficial in encouraging species diversity in the dune system. By controlling invasive shrubs (like sea buckthorn), rabbits also help to preserve a good cover of trample-resistant turf.

3.1.5 Trampling

The absence of vegetation on a backshore may be solely the result of human trampling, and does not necessarily reflect its inability to grow there. This fact can be simply demonstrated by planting up a small wired-off section of backshore with sand couch-grass and putting up a notice asking people to keep out. Experience at Caister (Norfolk), Camber (Sussex) and Woolacombe (Devon) suggests that there is a reserve of goodwill among the public to localized fencing enclosures on dune coasts, so long as their purpose is explained on a notice board, and they continue to have access to most of the shore and the sea.

Cars can be kept off dune grassland by the use of low timber barriers, eg as at Findhorn (Moray), or by use of roadside ditches as at Aberffraw (Anglesey).

3.1.6 Salinity

It is a common fallacy that high salinity is found in coastal dune soils. There is normally little more than 400 ppm sodium in coast dune sand (cf 10 000 ppm sodium in sea water). Salinity is high temporarily in backshores overwashed by high tide, and salt-tolerant species should be used in such situations, not marram grass. In the special case of artificial sand dams built from dredged marine sand, it is necessary to wait until at least 6 cm of rain has leached out most of the salt before attempting to establish vegetation by seed. Even then, the seed mixture should contain salt-tolerant grass varieties (Adriani & Terwindt 1974). Elsewhere in dune systems, including the lee slope of coast dunes, salinity problems only arise after major incursions of the sea (as in the east coast floods of 1953).

3.1.7 Soil infertility

It has been demonstrated that dune grassland on lime-rich soil is marginally more resistant to treading than that on acid soil (Westhoff 1957). However, dune soil is inherently of low fertility, and its vegetation is adapted to the low fertility. Application of fertilizer is recommended in special cases, eg raising strong nursery planting stock rapidly, or in conjunction with the use of mulches (eg peat) to help restore surface humus layers destroyed by excess trampling.

3.1.8 Drought

On the Peruvian coast, vegetation is unable to survive at all in large areas of dunes subject to very low rainfall. Vegetation is sparse in coast dunes of the eastern Mediterranean. Even in Britain, the density of marram grass shoots is distinctly higher in the wetter climate of north-west Scotland than in south-east England. In Britain, there is always adequate moisture in the mobile dune sand near the coast to support marram, for sand mobility limits competition from other species for moisture. It is a different matter in the landward dunes where a closed turf is present between vestigial clumps of marram grass, and, here, drought may be a contributory cause of marram decline. Plantations in such zones are likely to suffer high mortality from drought if planted between May and July. Seed mixtures sown in bare ground in landward dune grassland are more likely to suffer from drought if sown in spring than in the autumn.

3.1.9 Disease

So far, we have been fortunate in Britain in finding no evidence of serious disease or parasite damage in marram grass (Huiskes 1979). It may develop ergot fungus (*Claviceps purpurea*) which produces black sausage-shaped outgrowths up to 1–2 cm long on flower heads locally, but plant vigour and survival do not seem to be seriously affected. Lyme-grass is affected by smut fungus (*Ustilago hypodytes*), but again attacks are neither widespread nor serious, though they appear to be most commonly found when the plants are already damaged by trampling. Trampling also seems to encourage attacks to flower buds of sand couch-grass by the larvae of an insect (*Tetramesa hyalipennis*). Another fungus disease (*Marasmius* sp.) and the scale insect

Eriococcus carolinae do have a serious effect on American beach grass, particularly when it is transplanted beyond its normal geographical limits (eg in North Carolina), and is in an unfavourable climate (Woodhouse *et al.* 1976). We would therefore be unwise to introduce this grass to British sites. Sea buckthorn, growing on lime-deficient soils, is prone to attack from defoliating caterpillars of the browntail moth (*Euproctis chrysorrhoea*).

Symptoms of disease, or sub-optimal growth, leading to vulnerability to parasitic attack, often go unrecognized. It is in the interests of coast protection that obviously unhealthy vegetation should be reported to specialists. As disease can spread rapidly in large populations of a single species, mixed planting of 2 or more species should be encouraged wherever possible.

3.2 PHYSICAL AIDS TO ESTABLISHING VEGETATION

In this review of techniques, engineering solutions are considered briefly only so far as they interact with vegetation techniques. The emphasis throughout is on the creation of healthy, stable, vegetative cover and/or dune build-up, wherever this can be achieved as an aid to other forms of coast protection. Much of the information derives from Dutch (Adriani & Terwindt 1974) and English (Brooks 1979) experience, but relevant literature outside Europe is used to augment this information.

3.2.1 Sea walls

Dune vegetation cannot survive seaward of high vertical sea walls as these are invariably associated with low foreshore levels and high wave energies. However, considerable lengths of sandy coasts have been protected with low sea walls. Where these walls have a gradual seaward slope or even a vertical concave face, wave reflection and scour are reduced, and backshore sand capable of supporting vegetation can accumulate to seaward, as at Caister (Norfolk) for example. Compared with the broad expanse of a salt marsh, narrow bands of backshore vegetation have negligible power to damp wave energies. However, such vegetation can build up sand at rates up to 0.5 m year or more, and hence help to protect a wall from toe erosion.

The problems of wall terminal erosion are well known to the engineer, and the general principle of faring the end of the wall smoothly into adjoining natural coast deposits (whether vegetated or not) is accepted. Part of the problem of keeping such junctions well vegetated arises from the sudden drainage and temperature changes at such boundaries. Vegetation of different types, on aggregates of diminishing size, could help to stabilize the transition from the end of the wall to adjoining naturally vegetated dune coast.

Splash aprons at the top of sea walls can reduce wave splash sufficiently to allow vegetation to survive directly to landward. In such situations, the more salt-tolerant grasses can help to seal in the back of the splash apron and reduce erosion.

High dune overlying a sea wall, as on parts of the Winterton (Norfolk) coast, usually implies adequate sand feed and no problem. The need here is to maintain the extensive natural dune system as a Nature Reserve, undisturbed so far as possible, and the wall, erected after breaches during the 1953 floods, serves as an additional safeguard. However, at Sea Palling, just north of Winterton, sand supply is more limited and the wall protects a single bank of sand which is effectively a stable lee slope incapable of further vertical development, and therefore an integral part of the defences. The maintenance of effective vegetative cover in such a situation is a vital aid to the protection of the wall from erosion on the landward side which can result from over-topping in storms. This was the cause of so much damage in the 1953 floods. A partial reinforcement of the landward side of such banks is achieved with a honeycomb wall-facing, as on parts of the Deal (Kent) coast. Such an open network with sand in the interstices allows vegetation to grow in close association with concrete, and provides a combined form of surface protection.

The more recent technique of 'point hardening' to reduce wave energies on adjoining coasts by altering wave refraction patterns has obvious implications for extending vegetated coast protection further into coast sections where previously engineering techniques had to be used.

3.2.2 Beach renourishment

Beach renourishment with an appropriate grain-sized sediment is an effective way of raising beach levels and reducing wave attack on the coast (Newman 1976). The purpose of the operation is that of a coast protection measure and, as such, it enjoys the benefit of a coast protection grant under the Coast Protection Act 1949. A successful scheme was carried out in Poole Bay for depositing sand along the Bournemouth frontage in 1974 and 1975 using 2 differing techniques. Investigations carried out jointly with the Hydraulics Research Station indicated that sediment placed on the sea bed 450 metres offshore west of Bournemouth Pier would find its way naturally on to the intertidal zone, but that material placed in a similar position east of Bournemouth Pier, due to the wave and current regime, would not migrate in the same way. The lowest tender accepted for the works reflected these points in that the price of bottom-dumped sand offshore west of Bournemouth Pier was 42p m^{-3}, whereas the price of sand placed on the beach east of Bournemouth Pier was 91p m^{-3}. The more expensive operation involved dumping offshore by the primary cutter-suction dredger close-by to a secondary pontoon type reclamation dredger, and the lifting and pumping ashore via a steel pipeline, partly floating, to the beach head – a much more plant-intensive operation compared with the purely ship-borne exercise of bottom dumping.

Beach nourishment has been used on a large scale in Florida. However, in nearly all cases, the beaches concerned are so heavily used for recreation that the potential benefits for improving vegetation growth at the top of the beach have not yet been realized. On more sparsely used coasts, eg Rosslare (Wexford), beach feeding activities are associated with plans to trap sand with dune grass plantings on the backshore and coast dunes. This has been done most successfully on a large scale at Surfers Paradise and at Noosa Bay, Queensland, Australia (Appendix 8).

There would seem to be great scope in Britain for beach feeding in association with dune vegetation establishment. Combined programmes of this type would not only help to widen the bank of protective sand on vulnerable sections of coast, but also to improve the quantity capable of being trapped elsewhere following temporary removal from such sections during storms.

3.2.3 Shore protection with geofabrics

Foreshore sand is too mobile to support macro-vegetation. Experiments with artificial (plastic) seaweed at Bournemouth to damp wave energy and cause sand deposition failed when all the material was washed on to the tide line in rough weather. Nevertheless, there may be more sheltered situations in which less fragile synthetics, more effectively anchored, might succeed. Such techniques might be particularly useful in retaining sand in isolated bays between rocky headlands, in more sheltered Cornish coves for example. In such situations, sand once lost out to sea may never be replaced. A further step in this direction is to protect the nearshore sea bed from erosion with plastic sheeting. This method has been tried at tidal inlets in Holland, at Thyboroen inlet, Denmark, and also on parts of the Florida coast.

3.2.4 Groynes

Wooden groynes, normal to the shore, are frequently used to build up beach levels locally and reduce toe erosion of sea walls, coastal dunes, or soft cliff coasts. Unless long enough, and graded down in size at the seaward ends, they can produce scour at their seaward ends. The more massive structures are costly to maintain and their fixed positions, often dictated by shore conditions which have changed since their original erection, present difficulties for engineers working to tight budgets who have to decide whether to maintain or abandon them. Such considerations are beyond the scope of this report, except in so far as groynes are an aid to producing backshore levels suitable for plant growth. Where groynes, normal to the shore, are combined with others running parallel to the shore near mean high water level, sand derived from longshore drift and accumulated by the seaward-running groynes may be partly cast to landward of the groynes running parallel to the shore, and retained. This technique can be particularly useful where backshores of only 5–10 m wide provide a very limited sand feed to a low coast dune, as on the Rosslare shore. However, the erection of groynes on narrow foreshores restricts shore access for maintenance vehicles to the backshore and inhibits natural regeneration of strandline vegetation and embryo dunes.

The use of groynes on the backshore itself seems less desirable, even if abundant supplies of cheap timber, as at Culbin (Moray), are to hand in conifer plantations on the dunes. At this site, short zig-zag solid timber groynes promote scour locally. Erosion at Culbin has cut back to afforested areas where marram grass has been shaded out, so there is little in the way of dune grasses to regenerate dune growth, although recent backshore conditions seem suitable for this regeneration. In such a situation, porous fencing and dune grass planting would seem to be indicated, not groynes.

3.2.5 Gabions

Stone-filled plastic mesh gabions are a more flexible groyne material, especially suitable for use on more sheltered shores. They have been used successfully to check toe erosion of low dune coast, eg at Brancaster (Norfolk), and on the east side of Pilmour Links, St Andrews (Fife), facing comparatively low wave energy, shallow-flooded, sandy flats of the Eden estuary. The gabions are used in conjunction with coast dune plantings. Gabions are also particularly useful in blocking off small breaches in coastal dunes where the shore level is temporarily below mean high water level. Gabions do have the advantage of providing additional shore protection if they break up and shingle is released to the beach.

Plate 12. Physical aids are often needed to check erosion and accumulate sand in gaps in coastal dunes. Brushwood is a cheap material, ideal for building porous fences that are effective in trapping wind-blown sand. Natural materials of this kind also add valuable organic matter to the sand.
(Photograph W T Band, Countryside Commission for Scotland copyright)

3.2.6 Fencing

Fencing is used to accumulate sand and to extend the width and height of dunes. It is also used to enclose stock, and to exclude people, in order to reduce grazing and trampling damage to vegetation.

Any form of solid fencing promotes scour at the base of its windward edge and wind funnelling at the ends of the fence. Porous fencing (Plate 12) absorbs, as well as deflects, wind energy and causes sand in the airstream to fall and accumulate at, and either side of, the fence (Plate 13). Optimum porosity for sand accumulation is around 50%, and such fences accumulate most sand within a distance twice the height of the fence either side of it (Manohar & Bruun 1970).

Dead plant material (brushwood, forestry trimmings, and wooden palings) is most suitable for dune fences, and local availability, production and transport costs determine the type chosen. Such material is biodegradable and augments organic material for plant growth on the strandline if the fence is damaged. Plastic materials have been used with variable success (Savage & Woodhouse 1968; Brooks 1979), but do not have these advantages.

Single fences are usually the most cost-effective, particularly at lower windspeeds, but double fences are likely to trap sand faster at higher windspeeds (Woodhouse 1978).

The distance between mean high water and the first sand fence should, ideally, be 100 m or more for rebuilding a storm-flattened coast dune in the barrier island conditions of North Carolina (Woodhouse *et al.* 1976). The minimum recommended shore level of the most seaward fence used in reconstituting a coast dune on European shores is 1 m above mean high water level, according to Adriani and Terwindt (1974). In practice, Brooks (1979) recommends 2 m above mean high water to escape most storm damage.

Fence dimensions vary according to the problem. If the object is to increase dune width, then fences 1 m above ground should be used. If the object is to build dune height, then fences up to 2 m above ground can be used. Useful details of fence construction are given by Brooks (1979).

Fence designs for increasing dune width or building dune height are illustrated in Figure 5. It is not desirable to restore a coastal dune to the natural profile with a steep windward face, but to build a more shallow windward face to improve long-term stability. This result is achieved by using 1 m high fences placed 4 m or more apart to develop width, and 2 m high fences on top towards the landward edge to increase height.

Where the backshore is narrow, box-shaped enclosures of entrenched brushwood can survive occasional storm damage, and help trap and retain sand on the backshore. Where the prevailing, and/or dominant, wind is oblique to a narrow backshore, short spur fences 10 m apart extending to 15 m seaward from fences parallel to the shore help to maximize sand catch. Where such winds are normal to, and onshore, maximum sand accumulation is achieved with fences

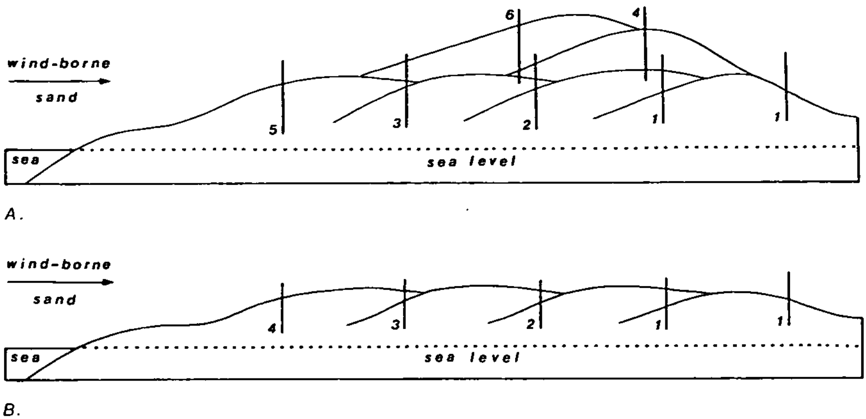


Figure 5. Placing of fences A, to gain height, and B, to increase width of coastal sand accumulations (after Adriani & Terwindt 1974)

parallel to the shore. Following extensive damage to a dune coastline, it is most important to re-establish sand control at the shore line and to restore a smooth line following the general run of the coast. Such a consideration far outweighs attempts to maximize sand catch on individual lengths of fencing by orientating them at 90° to the dominant wind direction. The success of this practice is, anyway, unpredictable in any particular season, and piecemeal approaches to fencing simply lead to increased wind funnelling locally. The ends of fences should always be graded into adjoining dunes to prevent terminal scour.

Given adequate backshore sand supplies, fences can accumulate 0.9–1.8 m of sand a year (Brooks 1979). At Dunnet (Caithness), fences have trapped as much as 3 m of sand in 3 months (W T Band, pers. comm.) Chestnut paling fences with 50% porosity accumulated 0.6 m of sand in only 2 months (in spring) at Newton (Northumberland). Examples of actual profile changes of fence-built dunes on Texas and North Carolina shores are given in the shore protection manual (Anon 1977), and on Queensland shores in Anon (1980).

Just as groynes, once filled, trap no further sand, the same is true of fences. It is therefore essential to follow up sand-fencing activities with dune grass plantings to convert the system either to a stable surface, or to an actively growing one, depending on sand supply. Failure to follow up with plantings has led to subsequent destruction by winter storms, eg as past experience at Mablethorpe (Lincolnshire) has shown.

3.2.7 Thatching

Thatching with brushwood directly on to sand surfaces is most effective in checking wind erosion. Steep sand slopes (1:2 or 1:3) are difficult to stabilize with normal planting techniques alone, in our exceptionally windy climate. In such situations, brushwood – part-embedded, wired down, or pegged to the surface – checks windspeeds, holds sand in place, and provides a more humid climate for the establishment of naturally occurring plant seedlings. As the brushwood gradually breaks down within a year or 2, organic matter is added to the sand. This process helps to provide nutrients, improve water-holding capacity, and encourage plant growth. Webber (1956) estimates that 90–100 t ha^{-1} of brushwood are required for surface thatching.

Slopes should be thatched working from top to bottom, with the thicker ends of branches embedded and orientated downwards, and the natural curvature of the branches faced into the slope. On slopes of 30° or less, brushwood can be conserved by thatching in 1 m wide network patterns. Such work has been successfully combined with planting on the Northumberland coast, and is fully described and illustrated by Bacon (1975). An extract from this paper on output, labour and costs (1975 prices) is given in Appendix 5.

Large areas of steep bare sand at Newborough (Anglesey) were stabilized with brushwood and with roadside grass cuttings. The latter not only checked wind erosion and provided a mulch, but also seed of many native plants capable of contributing to vegetative cover on the dunes. There are long-term benefits from building up the soil organic matter in this way, but, unfortunately, the old side-arm roadside verge cutters have been largely replaced by mowers which leave no harvestable cut grass crop. Wood chips are excellent for reinforcing pathways (Plate 14).

3.2.8 Contouring

In situations of very high sand mobility, and minimal surviving vegetation, residual clumps of vegetation promote wind funnelling until they are themselves eroded out. The logical treatment here is to iron out the irregularities by contouring, providing this is followed up immediately by a planting programme. Ideally, contouring should aim to produce slopes of 1:20 to 1:10, but in practice they may often have to be much steeper.

When faced with a breach in a narrow coast dune, it is common practice to bulldoze sand into the breach to restore coast protection as soon as possible. In such situations, sand should be drawn from the landward side of the dune or either side of the breach, not from the backshore, as this will reduce wind-blown sand supplies and increase wave activity at the toe of the coast dune. Mechanical contouring should not be used in situations landward of the coast dune where a century or more accumulation of soil humus at the surface will be destroyed, or buried, by such activities.

3.2.9 Binding

Various chemical binders have been used to protect sand surfaces from erosion, especially in association with seed sowing. They have the advantages of providing rapid temporary stabilization, conserving moisture already in sand, and reducing extremes of temperature fluctuation which can damage seedlings.

Though they may have application to desert dunes, their value has not yet been generally proven on British coasts. Their disadvantages include high cost, difficulties of application, increased runoff of rainfall, tendency to crack and lift off in high wind, and uncertainty to what extent substances released from them may have unfavourable effects on plant growth. Controlled experimental studies on an artificial sand barrier in Holland showed that bitumen emulsion and an emulsion on a synthetic rubber base, while successful in stabilizing sand (which plantings alone can do), had negative rather than positive effects on growth of marram and Baltic marram (Adriani & Terwindt 1974). Details of binders used in Britain are given by Brooks (1979). Armbrust and Dickerson (1971) reviewed the cost and effectiveness of 34 materials used in soil erosion control in USA, and concluded that liquid polymers were most efficient on a soil containing 90% of sand. Band (1979) concluded, from trials on dune sites in Scotland, that several chemical stabilizers were suitable for seeding on sand, but peat applied as a surface dressing could achieve the same effect.

3.2.10 Mulches

Mulching involves the addition of organic matter to the sand surface to check erosion, improve soil water retention, and increase plant nutrients. Mulches are particularly useful in large-scale restoration schemes where erosion, and/or contouring, has removed natural organic matter, and where access to the site for spraying machinery is easily available. Mulching the surface of contoured and planted dunes on the Northern Ireland coast with organic compost at 1 kg m^{-2} resulted in a 4–5-fold increase in marram height over a 4-year period (Wilcock & Carter 1977). Materials used include chopped straw, peat, soil, woodland leaf litter, grass cuttings, seaweed, wood pulp, farmyard manure and sewage sludge. Chopped straw has been applied at 5–6 t ha^{-1}, seaweed at 6 t ha^{-1}, and manure at 6 t ha^{-1} (Brooks 1979). Peat and wood pulp have the advantage of boosting organic matter, without (as the others do) artificially raising nutrient levels and/or introducing alien plants. Dry seaweed tends to blow away unless well anchored. Sewage sludge should be checked for heavy metals or other toxic substances, before being used. It has the dubious advantage of being sufficiently repellent to keep people off, without the need for fencing.

3.3 USE OF VEGETATION

Four types of plants are useful in binding sand: strandline annuals, dune-building grasses, turf plants, and woody species. They occur in that sequence from the beach to inland mature dunes, and each has characteristics best fitted to the particular zone in which it occurs naturally. However, their use is not necessarily confined to a particular zone and the use of plants from a more seaward zone may be indicated where disturbance has temporarily thrown a more landward one back to an earlier stage of development (eg the use of marram from the coastal dunes to fix a blow-out).

3.3.1 Strandline annuals

Strandline annuals colonize sandy shores above the summer high water mark from May to September. They are characterized by fleshy leaves with a tough cuticle able to withstand sand abrasion, high salt tolerance, and fast, but limited, horizontal and vertical growth in mobile sand. They are of use to the engineer in delineating shore zones where there is potential for fence line sand accretion and dune growth. However, their absence (eg as a result of trampling) is not necessarily a negative indicator for fence location. By trapping sand, they raise shore levels marginally above tide level and reduce unwanted sand blow on to roads, bowling greens, and golf courses, where these lie directly behind the shore line. Bulldozing sand from the shore to fill breaches in a coast dune may remove tidal litter vital for the regeneration of strandline plants. The principal species are sea rocket (Plate 10), goosefoots (*Atriplex* spp.) and saltwort and they are widely distributed all round the coast of Great Britain. There is much circumstantial evidence to suggest that their establishment and growth are impeded on beaches heavily used for recreation (Plate 9). Techniques for harvesting seed, protecting them from trampling (and grazing), and building up populations of these plants have not yet been developed, but there is considerable potential for carrying out field trials on these lines.

3.3.2 Dune-building grasses

Dune-building grasses are perennials and persist all the year round (though lyme-grass dies back in winter) on high-level shores subject to very occasional tidal inundation, or in mobile coastal dunes. They are characterized by long, narrow leaves, resistant to sand abrasion and moisture loss. They have unlimited horizontal rhizome growth, and greater capacity for vertical growth than strandline annuals. Most important is their capacity to regenerate from rhizome fragments torn off by wave action, or by gravity falls, when the coast dune is undercut. They are of use to the engineer in helping to increase the dune bulk and height, and in checking erosion of surface sand. Marram and sand couch-grass are generally distributed round our coasts, while lyme-grass and hybrid marram are more commonly found on the east coast of Great Britain. In addition, American beach grass has been introduced (with limited success) to Newborough Warren, Anglesey.

Techniques for harvesting and planting marram grass and American beach grass are well established (Appendix 6), and marram has been widely used in Europe, for centuries. Use of the other species has been more limited, and their potential, especially in association with marram, scarcely realized until recently.

3.3.3 Perennial dune turf grasses

Perennial dune turf grasses colonize the more landward parts of the dune systems, together with a wide variety of herb species where sand accretion is minimal (< 5 cm yr^{-1}). The grasses are characterized by short wiry leaves, and

Plate 13. Wooden paling fences of 50% porosity are effective in trapping wind-blown sand. Gaps in the coast dune resulting from trampling can be quickly heeled with sand fences followed up by planting. Note parts of 1 m high fence almost buried only 2 months after fence erected.
(Photograph M J Hudson, Nature Conservancy Council copyright)

Plate 14. Dune pathways surfaced with wood chips not only check erosion but add moisture-retentive organic matter to the soil. Marram grass plantation (right) is protected from trampling by fencing. Nepean State Park, Victoria, Australia.
(Photograph D S Ranwell)

Plate 15. Mr Brian Mason, head of the Beach Protection Authority's South Stradbroke Research Station, propagating nursery stock for both field trials and for large-scale plantings (eg Noosa Bay). A small, on-site nursery facility like this can supply high-quality planting material for a large region. South Stradbroke Island, Queensland, Australia. (Photograph D S Ranwell)

Plate 16. Dunes mobilized by military activities, and subsequent uncontrolled recreational use at Camber, threatened to overwhelm roads and buildings to landward. After re-contouring, the dunes were mulched with chopped straw and then hydraulically seeded with seed, fertilizer and water. The revegetated dunes were protected from trampling damage by fencing. Camber, Sussex.
(Photograph P Stuttard, Nature Conservancy Council copyright)

the capacity to tiller freely under grazing, and they form a tight turf which is very effective in protecting underlying sand from erosion. The annual death and regeneration of new roots help to build up a moisture-retentive humus layer near the surface, enabling turf to withstand the dry conditions of summer on these freely draining soils. The main species are creeping fescue (*Festuca rubra*), meadow-grass (*Poa pratensis*), rye-grass (*Lolium perenne*), and bent-grasses (*Agrostis* spp.). These turf grasses (or suitable commercial strains of them) are useful in reseeding more sheltered and flatter parts of a dune system where over-grazing or trampling has destroyed the vegetation. Leguminous herbs such as white clover (*Trifolium repens*) and birdsfoot-trefoil (*Lotus corniculatus*) are also useful, because bacteria in nodules on their roots fix atmospheric nitrogen and improve the fertility of the soil. All of these species occur commonly on dune systems throughout the British Isles. Techniques for their use have only recently been explored (Appendix 6), but it is already becoming evident that once original dune turf is lost by erosion it is no easy matter to regenerate it, and especially to regain the soil humus which supports it.

3.3.4 Woody perennials

Woody perennials are normally associated with the oldest and most stable parts of dune systems. There, sufficient soil fertility has built up to support their growth, wind exposure is reduced, and sand movement is negligible. However, a few shrubs are adapted to growth in younger and more mobile zones. These species are characterized by potentially unlimited horizontal growth, and the capacity to grow up through vertical sand accretion of up to 0.5 m yr^{-1}. The main species are sea buckthorn (*Hippophae rhamnoides*) and white poplar (*Populus alba*). Privet (*Ligustrum vulgare*) and willows (*Salix* spp.), and a great variety of other shrubs of more limited horizontal growth, are also found in more sheltered situations, especially in moist hollows. The growth of all tall woody plants is severely restricted in the exposed (and often heavily grazed) northern parts of the Scottish coast, so shrubs are primarily of use on English and Welsh coasts. They are of use to the engineer as sand traps, as effective barriers to public access, and as a source of thatching material for bare areas. Sea buckthorn has become so invasive on Nature Reserves, eg at Whiteford (Glamorgan) and Braunton Burrows (Devon), that a policy of extermination has been undertaken (Venner 1977, Appendix 4). Details of the management of sea buckthorn on dunes are given by Ranwell (1972b).

3.3.5 Planting stock

Planting stock of dune-building grasses should be obtained as near to the planting site as possible from vigorous clumps in relatively sheltered positions. Lyme-grass is best dug from sheltered hollows leeward of the coast dune, or, in more exposed sites, from isolated clumps raised above the general level and liable to promote wind-gullying in their vicinity. Sand couch-grass can generally only be obtained from foredunes, but these are relatively flat, low-lying areas. As a large amount of planting material can be obtained from a relatively small area, it is most economic to take it from one or a few sites, and to replant as soon as possible. Planting material should be dug deep enough to capture the uppermost rhizomes with active roots (Appendix 6). This is most easily done where leaves are almost fully exposed and not half buried by new-blown sand.

Recent studies have shown that lengths of rhizome with many potential bud-producing sites (nodes) not only produce more shoots, but can also respond to repeated disturbance, by a dormancy mechanism which, at any one time, holds all but the primary bud in reserve (Harris & Davy 1986). In addition to adequate lengths of rhizome, planting units should have at least 6 shoots on European shores (Adriani & Terwindt 1974), though in the better growing conditions of the south-east United States, 3 shoots are said to be sufficient (Anon 1977).

Planting units are best dug and planted the same day. In hot weather, or if there are delays in using them, they should be heeled into damp sand (20 cm below the surface). Marram stored in open-ended plastic bags remains viable for up to 6 months. After 3 months, it begins to sprout and may go into growth faster than freshly planted material (Bacon 1975). Plants dug during winter dormancy have been stored at 1–3 °C and used successfully in late spring planting in the United States (Anon 1977).

It is important to work systematically in a team when handling planting stock, and to ensure that material is stacked in convenient bundles in an orderly fashion with shoots and roots aligned for easy handling. American experience (Davis 1957; Jagschitz & Wakefield 1971) suggests there are considerable advantages in cultivating planting stock in a special nursery adjacent to a heavily used dune area. Fertilized, vigorous, and much more easily harvested material can be raised in this way.

A total of 50 clones of American beach grass were selected for trial in New Jersey (Gaffney 1977), from which 9 strains were grown on to test their relative performance. One strain, known as 'Cape', was found to be superior in size and vigour, and has been marketed commercially. Trials with marram in Britain have shown that foredune plants have greater inherent variability, and higher response to fertilizers, than plants from mature dunes (Gray 1985). The implication is that mature dune stock should not be used in foredune situations.

The propagation of turf grasses by vegetative offsets in dunes is unlikely to be an economic proposition, except in very small areas. This propagation can best be achieved using whole turves (eg as in the repair of small eroded areas on golf courses).

3.3.6 Planting dune grasses

There are 2 main reasons for planting dune grasses: (i) to promote sand accretion in foredune situations, and (ii) to stop sand surface erosion. Hobbs *et* *al.* (1983) have demonstrated that, when plants are liable to 20–30 cm sand accretion in their first year, upward growth is favoured by planting the rhizomes vertically. Where accretion is negligible (eg at erosion sites), more horizontal rhizomes, and hence more widely spaced shoots, are produced by planting the greater part of the rhizomes horizontally.

Dune-building grasses should be planted to a depth of 15–20 cm in domino-5 pattern, with a spacing between plants of 0.3–0.9 m according to exposure and steepness of slope. Closer spacings are recommended in exposed west coast situations, or on really steep slopes (up to 1:2). The widest spacing would only be suitable for relatively sheltered or very shallow slopes. On intermediate terrain, a spacing of 0.45 m is adequate. Adriani and Terwindt (1974) recommend planting lyme-grass at 0.25 m intervals amongst marram or sand couch-grass, as lyme-grass is partially deciduous in winter. Mixed plantings are strongly recommended where sand supply is limited, especially on less exposed east coast sites. Marram should be used wherever there are large bare sand areas, as such plantings can check erosion instantly. Hybrid marram can be used in association with any of the other species, but it should not be planted alone as it is a sterile hybrid and relies solely on vegetative reproduction (Rihan & Gray 1985).

The best time for lifting and planting marram is in February to early April (not later because of drought risks), but any of these grasses can be planted from October to April. Experience at Scolt Head Island, Norfolk, suggests that sea lyme-grass, planted in August or September, can benefit from autumn precipitation and get a chance to establish before winter dormancy (R Chestney, pers. comm.).

Slopes are best planted from top to bottom. It is essential to firm in all plantings with a strong jab of the heel, if they are not to be ripped out by the first strong wind. Dune grasses have been planted mechanically on large barrier island sites in the United States, using a tractor-drawn root planter. A cabbage planter has been used to plant marram on the East Lothian coast, but 10 people were needed to supply it with plants. Shoots had to be chopped before going through the machine (Brooks 1979). The commonest cause of failure in plantings is from subsequent trampling damage in plantations. Where possible, people should be fenced out from planting areas, or, alternatively, fishing nets may be supported on stakes 0.3 m above the ground surface over plantations to keep people off. This method has proved effective at Gullane, East Lothian.

Data from Holland (Stege 1965) indicate that the seaward limit of sand couch varies from 0.45 m to 0.7 m above mean high water mark on wide (120–200 m), shallow-sloping (1:155 to 1:645) shores. The seaward limit for marram and lyme-grass varies from 2.5 m to 3 m above mean high water mark on narrower (40–60 m), steeper (1:25 to 1:40) shores. These limits indicate the levels at which plantings are likely to succeed, though observations on the East Anglian coast suggest that both lyme-grass and hybrid marram might succeed at levels down to 1 m above mean high water mark on wide, shallow-sloping shores.

Woodhouse (1982) recommends perseverence with plantings in different sites: 'Sites that are impossible one year may often be readily plantable the next season'. He points out that there are sites that have been very successfully restored after several attempts. He emphasizes that: 'Close and constant attention to the details of plant quality and planting procedures is the best way to ensure success'.

3.3.7 Planting shrubs

Little information is available on planting shrubs on British dunes, but horticultural experience in coastal areas suggests that such planting is most likely to succeed in sheltered sites. In more exposed sites, artificial shelter (eg fencing) is essential to prevent wind-rocking during the longer time that shrubs, as opposed to grasses, take to establish. Experience at Les Landes (Gascony), on the Atlantic coast of France, has demonstrated the necessity of maintaining an uncropped low 'protection forest' of conifers (*Pinus maritima*) in a 4 km wide zone seaward of the commercially cropped forest, on this exceptionally large and exposed west coast dune system (Fenley 1948). Sea buckthorn is best planted in February–March, but can be planted from September to January. Well-rooted plants should be dug and planted the same day and put in to a depth of 25 cm, or deeper to 40 cm (in the case of rooted suckers on dry sites), at 10 m planting intervals (Adriani & Terwindt 1974). Male and female flowers normally occur on separate plants in sea buckthorn. By planting one sex only it is possible to reduce seed output to a minimum (male and female flowers do occur on the same plant occasionally), and so reduce spread beyond the areas where plantations are required.

The vegetative propagation of woody shrubs is usually achieved by rooting cuttings. Poplar and willow are established in this way on Belgian dunes. Naturally rooted offsets, or 'suckers', are freely produced by sea buckthorn, and can be pulled up for propagation. The technique of growing shrub and tree seedlings in narrow tubes to promote uniform, deep-rooted, easily handled planting stock has many advantages. Mason (Plate 15) has demonstrated the values of this approach at the Beach Protection Authority's laboratory at South Stradbroke Island, Queensland (Appendix 8).

3.3.8 Seeding coast dune grasses

Seed of coast dune grasses is not available commercially at present, but can be harvested by hand from wild sources from mid-July to mid-August. Thornton and Davis (1964) found that up to 4.5 kg of American beach grass seed could be collected by one person in one 10-hour day. Cut seed heads are dried in sacks before threshing with a flower-seed threshing machine. Seeding has only proved successful where there is no significant sand drifting on to the site, no flooding for 6 months after sowing, and where a mulch (eg of chopped straw) is successful in preventing sand from blowing away (Adriani & Terwindt 1974). These conditions are rarely met on exposed British shores.

Seed is best sown (raked into the sand below the surface) from mid-March to the end of April, but summer and early autumn sowings have been successful. Marram seed can be sown mechanically on slopes < 1:5, but sand couch-grass has to be sown by hand as it cannot be completely separated from broken lengths of the flower spike. It is not practicable to sow less than 20 kg ha^{-1} of seed mechanically. Adriani and Terwindt (1974) recommended a sowing density of 100 fertile seeds m^{-2}, and note that the weights of 1000 seeds of marram and sand couch are 4 gm and 25 gm respectively. They give the following formula for calculating weight of seed for sowing per hectare:

$$\text{Wt of seed (kg ha}^{-1}) \frac{100}{\%\text{ seed content}} \times \frac{100}{\%\text{ seed fertility}} \times 10^3 \text{ wt of 1000 seeds}$$

3.3.9 Seeding dune turf grasses

Both existing commercial mixtures and specially made up mixtures of turf grass seed have been used successfully to stabilize mature dune areas worn bare by trampling. However, it must be emphasized that available evidence suggests that seeding may result in only temporary close cover, which is liable to degenerate into very sparse cover within a few years as a result of drought and rabbit damage. Contoured, and completely bare dunes have been

Plate 17. Hydraulic seeding at Mellon Udrigle, Ross-shire, Scotland. This method is useful in difficult sites where rapid stabilization is required, but it is expensive compared with traditional methods of sand stabilization.
(Photograph W T Band, Countryside Commission for Scotland copyright)

successfully fixed (Plate 16) by disc-harrowing chopped straw into the surface sand, spraying on a mixture of seed, fertilizer, and water, and keeping this mixture in place by spraying a slurry of chopped straw and bitumen emulsion (Pizzey 1975). The success of such measures depends on freedom from excessive wind disturbance in the first few months after sowing, and on fencing people out of the area for 2 or 3 years at least. Reseeding, even in fenced, relatively sheltered and levelled Scottish coast sites (Plate 17), gave an overall cover of only 20%, while seed raked into a peat-treated plot gave 50% cover (Band 1979).

Seed mixtures vary according to the site. Salt-tolerant rye (*Secale cereale*) has been used as 60% of the mixture on saline-dredged sand successfully in Holland (Adriani & Terwindt 1974). Marram at 25% of the mixture was used on seaward slopes (eg at Camber). Boorman (1977) seeded eroded dune turf sites at Holkham (Norfolk) with mixtures containing up to 60% S.23 perennial rye-grass, 20% S.59 creeping fescue and the rest made up with fast-cover species like Westerwold rye-grass (*Lolium perenne* x *italicum*) or close-growing turf species like fiorin (*Agrostis stolonifera*). In general, mixtures with few species, rather than multi-species mixtures, have proved most satisfactory, because initial success depends on bulk germination and quick cover. For example, Band (Appendix 6) recommends a simple mixture of 60% creeping fescue (Dawson or Oasis), with 30% rye-grass (Caprice or Lamora), 5% smooth-stalked meadow-grass, and 5% white clover, for reseeding dune pasture sites in Scotland. Seed should be covered with sand and the surface mulched to retain moisture for germination. A sowing rate of 100 kg ha^{-1} is recommended.

3.3.10 Seeding shrubs

Tree lupin *(Lupinus arboreus)* has been sown successfully on dunes amongst marram, but is a short-lived shrub. Like sea buckthorn, it has bacterial root nodules which help to add nitrogen to the soil. Sea buckthorn can be sown on sheltered sites with some bare sand, but this results in establishment of both male and female plants and the risk of unwanted spread.

3.3.11 Fertilizers

Dune soils are naturally poor in nutrients, compared with average agricultural soils. They also have low capacity to retain nutrients in the rooting zone because they are deficient in organic matter and subject to rapid leaching of soluble fertilizers during rainfall. Fertilizer applications which promote growth in moist seasons can become lethal to dune grasses when nutrient concentrations become increased in the root zone in dry seasons. These factors account for the highly variable results of fertilizer trials on dune vegetation and limit the extent to which results from different climatic regions, or even from season to season, can be applied reliably to any particular site. Zak (1967) found that planting shrubs with starter fertilizer in the root zone gave lower survival than untreated controls. Attempts to transform the nutrient status of undisturbed dune soils to permanently higher levels with use of fertilizer markedly reduce species variety and the susceptibility of the vegetation to drought.

Bearing in mind these provisos, fertilizers can be useful in raising vigorous planting stock and in thickening growth in new plantations or recently seeded areas (Adriani & Terwindt 1974).

There are 2 main classes of inorganic fertilizers – fast and slow release. Readily soluble fast-release granular formulations are most suitable for use in older, more stable dune situations, where increased soil humus improves nutrient-holding capacity. Less soluble slow-release granular formulations have been used successfully on younger, humus-poor dunes in Scotland (Charlton 1970), though American experience has shown varied responses to slow-release fertilizers (Anon 1977).

Organic fertilizers include sewage sludge and fishmeal. They tend to release their nutrients more slowly than fast-release inorganics, but less slowly than slow-release inorganics. They are useful, therefore, in younger, humus-poor dunes, and, in addition to nutrients, provide a surface mulch.

Replicated marram grass trials (in Oregon, USA) with 3 types of inorganic, and 6 types of organic fertilizer, each adjusted to supply 45 kg ha^{-1} (40 lbs ac^{-1}) of nitrogen, demonstrated that nitrogen was the key element improving growth and biomass production. Nitrogen was most effective in terms of net increase in number of stems of marram when supplied in the form of ammonium compounds (Brown & Hafenrichter 1948). The many extensive trials carried out on a variety of dune grasses since have confirmed the importance of nitrogen and, to a much lesser extent, the value of phosphate, when applied in spring (Nash 1962; Jagschitz & Bell 1966; Woodhouse & Hanes 1966; Zak 1967; Charlton 1973; Adriani & Terwindt 1974; Johnson 1979).

Fertilizer can be supplied direct to the planting hole where it is safe from erosion but this method is time-consuming and, where possible, it is best drilled into the surface sand. Application is usually carried out at planting time and repeated, either once in spring, or 3 times in the first growing season after planting. Appropriate application rates will vary according to location and season, and there is insufficient information to give categoric advice. Examples of fertilizers and dosages which have proved successful are given in Appendix 7.

In restoring dune turf with seed mixtures (Plate 18), it is advisable to add a mulch at the time of sowing to hold moisture for germination and help restore organic matter. Fertilizers should not be applied at the time of sowing because they may be leached or blown away before seed has germinated. They are best applied shortly after germination has taken place, when seedlings are established, and in active growth. With an autumn sowing, fertilizer can be applied in March or April; with a spring sowing, fertilizer can be applied in April or May.

Plate 18. Experimental layout of turf grass seeded plots at Mellon Udrigle, Ross-shire, Scotland.
(Photograph W T Band, Countryside Commission for Scotland copyright)

4 CASE HISTORIES

This Section describes a series of condensed case histories showing what problems have arisen and how they have been dealt with. Well-documented sites have been selected and problems chosen which relate to the special attributes of each site. The objectives are to demonstrate how problems may arise, and to outline effective solutions likely to be applicable elsewhere. The treatment is not comprehensive for a site as this would result in much redundant information. Locations of sites are given in Figure 6.

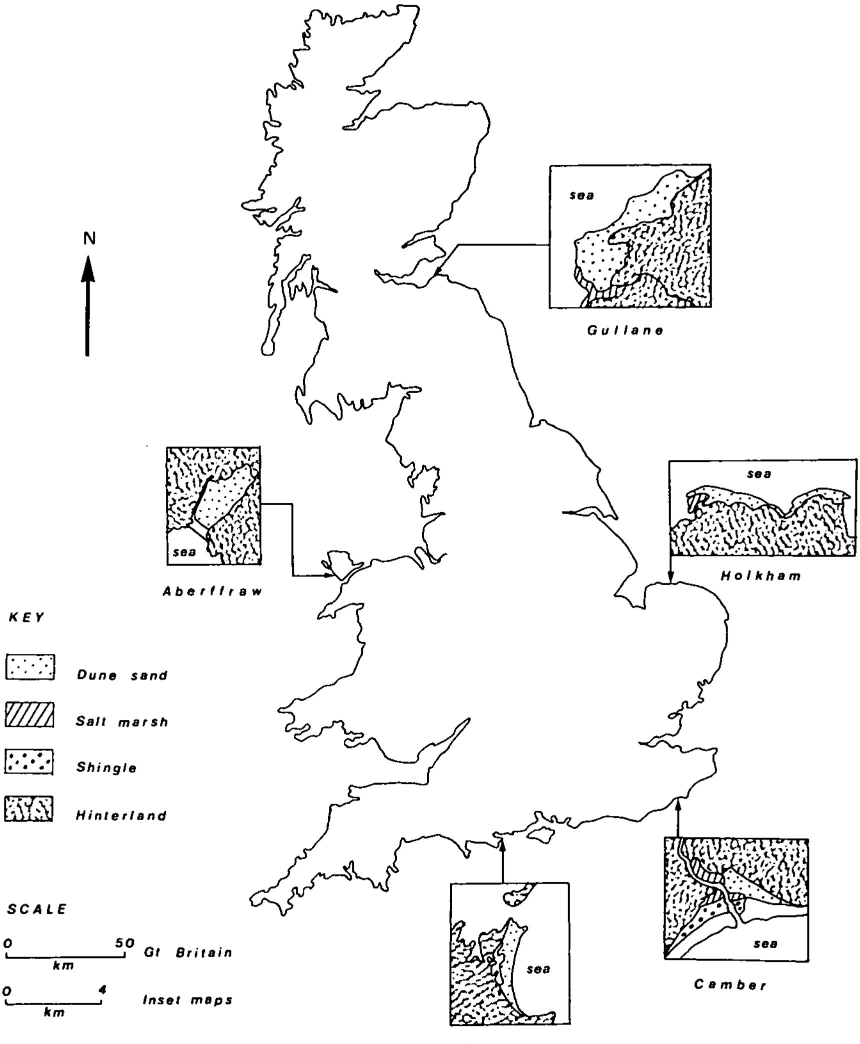


Figure 6. Locations of case history sites

4.1 GULLANE, EAST LOTHIAN

Site specification

Shore length – 6 km	Car park capacity – 690
Area of whole system – 405 ha (1000 acres)	Sunday peak cars – 1970 – 742 – 1980 – 595
Area of dune restoration – 42 ha (104 acres)	Chalets – None
	Caravans – None
Shore faces – NW	
Maximum fetch – 32 km WSW	

Gullane is a medium-sized bay dune system (associated with Aberlady dunes to the south, and West Links golf course to the north), with hindshore dunes up to 2 km inland. It is situated on the southern shore of the Firth of Forth. The shore (unusually for an east coast system) faces north-west and is exposed to prevailing westerly winds, but the actual fetch is very small. The shore is narrow and provides little sand feed at present. Most of the sand in this system is out of circulation, hindshore. The system has unusually extensive thickets of sea buckthorn, and, although it has been deliberately planted locally, this shrub is known to have been present at Gullane since at least the 1830s (Groves 1958). Sea buckthorn brushwood has been put to good use in building sand fences, thatching blow-outs, closing off paths, and in designing shelter belts for picnic places.

The coast dune was 9–12 m high in the 1930s, but much subject to trampling. Cars were allowed on the dunes and hundreds of beach huts were present at the time. Sand mining (stopped in 1977) was in progress in 2 places. The site (already weakened by these early recreational activities) was used by the War Department as a practice ground for heavy vehicle recovery in the 1940s, and this use resulted in almost total loss of the coast dune and mobilization of sand in the western and central part of the system. Sporadic attempts to check the loss of coast dune by planting sea buckthorn, and to stabilize the dunes with 4000 planted Corsican pines (*Pinus nigra*) did not succeed, largely because of lack of understanding of the dynamics of the system, and incorrect design of plantings used in stabilization (Anon 1970b).

Successful restoration was achieved in the 1960s by an overall and ingenious plan (Skinner 1962–69). Two important principles were that (i) control could best be achieved by starting marram planting at the western, up-wind end, and (ii) it was essential to reinstate the coast dune. The bare central hindshore section was left unplanted to act as sand feed for brushwood and paling fences used to rebuild the coast dune. Thus, in the absence of significant amounts of shore sand to recreate the coast dune, the internal instability of the system as a whole was harnessed to achieve this end. Marram plantings at the west end were protected from trampling damage by strong, 15 cm mesh, plastic trawl nets (factory discards) stretched 30 cm above the ground surface. Buckthorn brushwood or wooden palings were used to build a 3.6 m high coast dune in

6 years at a cost of £7,500 (1968 figures). This dune was planted on the seaward side with lyme-grass, and on the landward side with marram. Blow-outs at the eastern end were contoured locally using a bulldozer, and the smoothed surfaces planted with marram. Relatively flat areas were machine-planted using a cabbage planter pulled by a crawler tractor, which had the great advantage that row width, and plant to plant distances within a row, could be easily modified to suit local conditions. The disadvantage was that, with the labour available, it took 3 weeks to lift sufficient planting material to keep the machine supplied for only one day's planting (I D Fullerton, pers. comm.). The overall cost of this successful restoration at Gullane was £10,500 up to 1969, and over the next 10 years the average annual expenditure was about £2,300.

The total cost of £24,000 over the last 10 years included 75% exchequer grants and £6,000 net cost (I D Fullerton, pers. comm.). The policy of keeping caravans and campers off this sensitive site has since resulted in the stabilization of visitor numbers, and an actual fall in numbers of Sunday peak cars in the last decade (see above).

4.2 CAMBER, SUSSEX

Site specification

Shore length – 2.9 km
Area of whole system – 101 ha (250 acres)
Area of dune restoration – 57 ha (140 acres)
Shore faces – S
Maximum fetch – 200 km SW

Car park capacity – 1700
Sunday peak cars – 1700
Chalets – 1200
Caravans – 900
Holiday camps – 3 (capacity for about 164 000 persons each summer)

Camber is a small bay dune system (partly developed as a golf course), associated with shingle spit formation on the east side of the Rother estuary, near Rye. It has a south-facing shore exposed to prevailing south-westerly winds, and abundant supplies of sand from the higher parts of the 50 ha sand flats exposed at low water between the Rother estuary and the east end of the dune system. These dunes have probably been subjected to more disturbance than almost any other system in Britain; they are distinctive also in the rapidity with which they were brought under control, once the correct principles of restoration were applied.

Cars had access to the shores in the 1930s, and in 1936 a total of 4600 vehicles were recorded at Camber in a single day. Chalets and shacks were spread over the system and trampling had killed vegetation locally. In the 1940s, amphibious vehicle-training activities created gaps in the coast dune, and by 1945 most of the dune vegetation had been destroyed (Pizzey 1975). Multi-ownerships made it difficult for local authorities to gain control of the rapidly rising recreational use of the site in the 1950s. By the 1960s, the whole centre section of the dunes was practically bare, and sand was invading roads and buildings to landward. From the amount of surplus sand removed, it was estimated that the central section of the dunes was receiving some 7500 m^3 of sand annually (Metcalfe 1977). A comprehensive programme of restoration was adopted in 1967, and within 4 years the system was under control once more.

Shore line fencing following the arc of the bay was established by 0.9 m chestnut spiles held by 4 rows of galvanized wire, supporting posts at 3 m centres and smaller support posts between (Metcalfe 1977). Above the spiles, a single strand of barbed wire stretched between the posts to discourage people climbing over the fence. There was a dramatic improvement in sand catch when the permeability of the fence was reduced from 69% to 42%. In every 11 m of shore line fence, 1.2 m high spur fences, 15 m long and angled at just less than 90° to the shore line, were extremely effective in trapping sand blown alongshore. The recreated shore line dune was planted with marram. The rest of the dunes to be restored were bulldozed to smooth contours, fenced in paddocks (with pedestrian access routes between), and stabilized by hydraulic seedling. This process involved disc-harrowing chopped straw into surface sand, spraying seed and fertilizer in a water slurry, and topping off with another layer of straw secured with bitumen. The seed mixture contained 40% creeping fescue, 20% Westerwold rye-grass, 20% perennial rye-grass (S.23), 5% common bent-grass (*Agrostis tenuis*), 5% meadow-grass, 5% broom (*Sarothamnus* spp.) and 5% white clover (Pizzey 1975).

Some 85 000 m^3 of excess sand invading roadways to landward was removed overall, and much of it used in the construction of nearby Dungeness Nuclear Power Station. Control of the dunes at Camber has cost £100,000, and the annual budget at 1977 was £6,000 (Metcalfe 1977).

By 1980, a coast dune up to 6 m high had been raised by fences and planting, and the shore line had advanced 5–10 m seaward. Marram had established sparsely within paddocks, but, in spite of regular maintenance and fertilizing with slow-release fertilizer annually in spring, turf growth within them remains sparse, and mosses (characteristic of young dune soils) are abundant. Clearly, the lack of moisture and, above all, nutrient-holding organic matter is delaying formation of a closed turf, and the system remains highly vulnerable to trampling and rabbit damage.

4.3 ABERFFRAW DUNES, ANGLESEY

Site specification

Shore length – 0.8 km
Area of whole system – 357 ha (882 acres)
Area of dune restoration – 81 ha (200 acres)
Shore faces – SW
Maximum fetch – 7000 km
Car parking capacity – 63
Sunday peak cars – 110
Chalets – None
Caravans – 23 (none officially)
Holiday camps – None

Aberffraw is a medium-sized hindshore system on the south coast of Anglesey. Its shore line faces directly south-west and is extremely exposed in this direction with an uninterrupted fetch to South America. Consequently, under the influence of SW-prevailing winds, sand from the comparatively short length of shore has been driven landward as much as 3 km, to the point where it disappears into the shallow dune lake characteristically marking the landward limit of this type of system. Rocky headlands, however, do give some protection from winds from other directions.

At least 3 successive dune ridges have built at the shore line and then moved inland under natural erosive forces over the past 3 or 4 centuries. The present coast dune (5–10 m high) has reached maturity and is beginning to erode. Until it has moved landward, there is no room for strandline vegetation to initiate a new coast dune to take its place. Unlike Camber and Gullane, Aberffraw has been (and still is) subject to stock grazing, and rights for grazing up to 0.6 sheep ha^{-1} and 0.08 cattle ha^{-1} exist. The effects of a recent decline in grazing (especially since myxomatosis in 1954 reduced rabbit populations) have been offset by increased recreational activities of tourists in the post-war period. Aberffraw dunes were declared a Site of Special Scientific Interest by the Nature Conservancy in 1957, and wildlife interests need to be taken into account in planning decisions relating to access and coast protection activities. Changes in path density (Figure 7) between 1960 and 1970 provide clear evidence of rapidly increasing damage to vegetation from trampling and car tyre wear (Liddle 1973, 1975a, b). In 1969, up to 600 cars could be seen scattered through the seaward one third of the system. Control of car access since (see below) has reduced car park numbers to little over 100 in August.

Restoration work began in 1969 with trimming of cliffed dunes and protection of bare sand surfaces by brushwood underplanted with marram. Gaps in the coast dune were blocked with brushwood fences (Richards 1978). However, it is becoming recognized that such partially successful restorative measures may not be entirely appropriate, or even necessary, in a system with such high natural mobility, and where no property is threatened by sand inundation to landward (roads can be kept clear by licensed sand mining when a dune reaches them). Car access to the landward dune pastures was prevented effectively in 1971 by the construction of a low ridge along the roadside and adjoining ditch (0.45 m deep and 0.3 m wide). Discussions have been held about protecting the seaward area from car wear, the siting of car parks, and the route of tracks to the shore to avoid vulnerable and rare plant communities. Estimated cost of dune works (fencing, thatchings, marram planting and signs) was £895 in 1979–80.

4.4 HOLKHAM DUNES, NORFOLK

Site specification

Shore length – 6.6 km　　　Car parking capacity – 1300

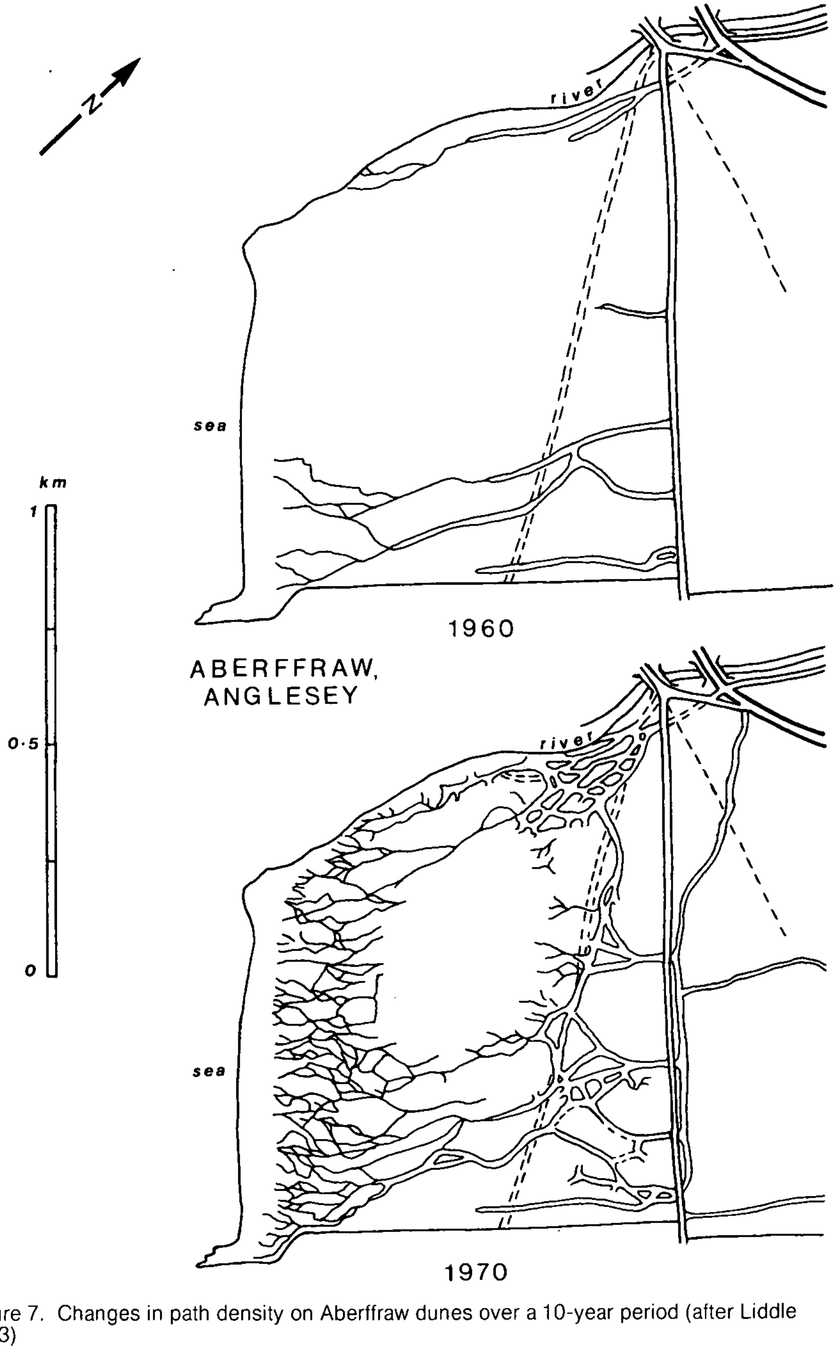


Figure 7. Changes in path density on Aberffraw dunes over a 10-year period (after Liddle 1973)

Area of whole system – 121 ha (300 acres)
Area of dune restoration – 8 ha (20 acres)
Shore faces – N
Maximum fetch – 6000 km N

Sunday peak cars – 1500
Caravans – 600

In complete contrast to the Aberffraw dunes with their short shore length and deep landward penetration of sand, the Holkham dunes have a very long (6.6 km) shore length and are nowhere more than 0.5 km wide. They originated as offshore island dunes, but were subsequently tied to the mainland of the north Norfolk coast by reclamation banks in the period 1639 to 1859. They face an exceptionally large fetch to the north (virtually across the Pole to Siberia) and the dominant winds are from the north-east. Apart from their island origin, these dunes are of particular interest for the interactions they show between coast protection, afforestation, recreation, and wildlife interests.

Corsican pines and some Scots pine (*Pinus sylvestris*) were planted during the latter half of the 19th century along most of these dunes to stabilize them, improve the soil, provide shelter from sea winds, and check sand blow on to reclaimed land. They have thrived and spread by seedlings on to younger dunes to seaward, and large areas of the older plantations have now reached maturity. There was some military vehicle use of the site during 1940–45, but the extent of damage is not known. Erosion at the High Cape region was brought under control with a network of faggot groynes on the shore in 1949 (Webber 1956). In the 1953 east coast floods, the dunes were islanded (for several weeks) once more, but significantly it was the reclamation banks, not the dunes themselves, that were breached. The site (with adjoining coasts) was declared a National Nature Reserve in 1967. Visiting car numbers trebled between 1960 and 1970 (Morley 1971), and by 1980 up to 250 000 people were visiting the site each year. Access is limited to 3 points: west end (foot access along reclamation bank); central (car park); and east end (car and caravan park).

One of the consequences of combining recreation with afforestation on dry dune sites is an increased risk of fire, and on 24 May 1970 3.2 ha (8 acres) of dune grass and 1.6 ha (4 acres) of young pines were burnt. Recovery of the vegetation was measured on transects and was rapid. Marram shoots reappeared only 7 days after the fire, and the percentage cover of marram increased from 20% to 50% between June and September the same year. Fortunately a forest canopy fire did not develop, and shelter from the main forest helped to reduce wind disturbance to the bare ground to a minimum.

Storm damage in the 1970s cut back the shore line (already weakened by excess tourist trampling) at the eastern end of the system, to the point where mature pine trees were eroded out and toppled to the shore. Their shade had completely killed out dune grasses like marram, and therefore no grass fragments reached the shore to start dune regeneration. Erosion at the High

Cape region again gave cause for concern and was controlled by the erection of 10 groynes and some marram planting at a cost of some £50,000 (A E Marsden, pers. comm.). A proposal (in 1972) to erect a concrete wall along this section at a cost of £250,000 was never endorsed.

Excessive trampling at the central access point has been partially overcome by use of a wooden trackway. Attempts to establish turf from seed in fenced-off parts of this area (Boorman 1977) have been hampered by rabbit grazing. Rabbit exclosures at this site have demonstrated that the flowering and seeding of pioneer dune grasses on this coast are severely inhibited by rabbit grazing. It is possible to raise more flowering spikes of lyme-grass annually in a 20 x 20 m rabbit exclosure than are found outside it on the whole 6.6 km length of the Holkham dunes. However, the amount of viable seed set within the exclosure is highly variable from year to year.

Much of this coastline has very broad expanses of high-level sandy foreshore (up to 2 km wide at low spring tides), at the present time, and pioneer dune grasses are prograding locally on to beach ridges, in spite of recreational pressures on this shore.

4.5 STUDLAND, DORSET

Site specification

Shore length – 5 km	Car parking capacity – 3000
Area of whole system – 200 ha (494 acres)	Sunday peak cars – 5000
Area of dune restoration activities – Nil	Chalets – 40
Shore faces – ESE (Part N)	Caravans – None
Maximum fetch – 200 km ESE	Holiday camps – None

Studland (or South Haven Peninsula as it is also called) is a small spit system at the southern mouth of Poole Harbour, Dorset. Its main shore line faces ESE with a fetch of 200 km to the north coast of France. It is well protected to the west by a cliff promontory. The site has features common to other east-facing systems. It tends to prograde seawards, has low relief, and is built of sand so low in lime content that heaths can colonize the acidic sand on the landward side of the coast dune. Such acid systems do not, as here, support significant stock grazing, and the woody growths that result are especially prone to fire.

The landward limits of the system, banked up against the rising ground of a spur of ancient (Tertiary) sand and gravels, were formed at least 250 years ago. Since then, an arm of the sea has been enclosed by dunes (and become fresh), and 3 successive ridges with wet hollows between have formed. This growth is thought to have been associated with erosion of the Bournemouth cliffs and sand supplies from offshore (Carr 1971). A training wall (built in the 1870s and subject to maintenance repair in the 1920s and 1930s), near the mouth of Poole Harbour, is thought to have had only local effects on sand movement and the development of the system is mainly natural. Three main influences have affected the site since then. The area was used for military battle training in the 1940s, and mine clearance subsequently involved burning the greater part of the vegetation at the end of the war. The site became increasingly popular for recreation post-war. In 1 962, most of the southern half of the system (including the lake) was declared a National Nature Reserve.

It is remarkable that, in spite of the war-time damage and intensive recreational use, the site has survived with remarkably little damage (Teagle 1971) and virtually no coast protection activity. There is no doubt that effective fire control results from regular wardening, though fires (usually small) do occur every year. In spite of the fact that currently 10 000 to 15 000 people may visit the site on a summer Sunday, the last few decades have witnessed the development of a new slack and ridge, continuing the natural trend of 3 centuries. The robustness of this particular system depends on its relatively sheltered position, adequate sand supply for maintaining beach levels, fire control (as mentioned above), and effective restriction of access to the 2 ends of the system. The lake and dense scrub act as effective barriers to access from the landward side in the central (Nature Reserve) area. Visitors concentrate at the southern and northern car parks, which are connected by a toll road leading to a ferry at the north end.

Strandline vegetation on the first 200 m north of the southern car park was virtually eliminated by trampling in 1966, when up to 2400 people used this section at peak holiday periods (Teagle 1966). Comparatively few are prepared to walk the 200 m north or south from the ends of the system, so the central 1 km length remains comparatively undamaged and able to prograde normally as in the past. From time to time, the main road to this site has had to be closed to visitors as car parking facilities became saturated. Thus, the site is at the limit of visitor capacity, and unable to accommodate more.

Although strandline and coast dune vegetation has been destroyed locally by trampling, it could be argued that expenditure on coast protection was not justified at such a site. However, the chance combination of a serious fire and dry easterly gales could certainly damage National Nature Reserve interests, and call for active protection measures.

4.6 CONCLUSION

The most obvious common features of the dune systems described (and of most others in Britain) are the serious damage they have all suffered: uncontrolled recreational use pre-war; military use in the 1939–45 war; and escalating recreational use post-war.

Engineers today have therefore inherited grossly mis-used dune systems with much of the centuries-old surface humus destroyed.

In spite of achievements in sand blow control, and a growing understanding of the need for people control, these systems are still in a highly vulnerable state.

It becomes evident that, however much the amounts of sand, orientations of shore, and degree of disturbance differ, dunes nevertheless behave to a set of coherent and intelligible rules. It pays to understand these rules so that time, effort, and money are expended where most needed and not on situations which are inherently self-healing.

In addition, there are some simple rules in restoration activities, such as: (i) working from the coast to inland, (ii) working from the top of slopes to the bottom, and (iii) working up-wind to down-wind. There are no rules when it comes to choice of materials as aids to vegetation establishment, because local availability, suitability for a particular purpose, and fluctuating cost all vary enormously from site to site and can only be determined effectively by considering a particular site at a particular time. It therefore pays to check that traditional procedures are reviewed frequently. The value of organic material on-site for use in restoration activities cannot be stressed too strongly, especially if, like gorse or sea buck-thorn, it is present in excess and needs to be controlled anyway.

5 MANAGEMENT

In this final Section, some practical suggestions relevant to management for coastal protection are put forward. The Section is divided into 3 parts: 1. access and interpretation, 2. conflicts of interest, and 3. management planning. General problems of sand dune vegetation management in Europe are discussed by Boorman (1977), Maarel (1979) and Ranwell (1972a, 1975, 1979), and in the United States by Godfrey and Godfrey (1974), Leatherman *et al.* (1978), Woodhouse (1982), and Salmon *et al.* (1982).

5.1 ACCESS AND INTERPRETATION

The North Berwick Study Group emphasized the importance of access facilities in a set of dune management precepts published in Anon (1970a) (see also Appendix 1). It was concluded that:

'The key to successful dune management lies in the scale and nature of access facilities and these should be carefully considered since it is very much more difficult to retrieve a situation once damage has been caused. Public access should be allowed to the fullest extent consistent with the aims of any given area. Motor vehicles and caravans are particularly inappropriate and destructive of dune vegetation and should be excluded from dune areas wherever possible'.

Since that was written, planning authorities have become more and more conscious of the undesirability of cars and caravans on dunes, and in many places car access has been prevented by roadside ditches or low wooden barriers. Caravan sites have been set back to landward, and car parks specially designed to help regulate access.

The hard standing of car parks and the soft surface of sandy shores can take a high level of human use. Access problems arise in the highly vulnerable dune vegetation that lies between. Wherever possible, access routes should follow low ground (more resistant to wear) to the shore. Directions should be clearly given at the car park to reduce numbers of people wandering off into the dune system.

Routes through the coast dune or other sensitive areas should be paved with wooden boards, or plastic netting, and should enter the shore at an oblique angle to the prevailing and/or dominant wind (Plate 19).

Heavily worn routes should be rotated with alternative rested ones. High dune view points will attract extra wear and people can be diverted from them temporarily, by cut sea buckthorn or other thatching material unattractive to walk on placed on approach routes. Useful practical details of path design and maintenance are given by Roberts and Venner (1974) and Brooks (1979).

There is obviously a limit to the number of people that a particular shore can hold and, in the interests of coast protection and good planning, car park capacity should be designed with this limit in mind. It is equally important to divert old access routes (that may have arisen as a historical legacy) away from sensitive areas. This diversion is better achieved by creating more attractive access facilities where they are needed, than by blocking off old traditionally used routes.

Plate 19. Timber walkways, angled through the coast dune to counter wind-funnelling, are an effective way of channelling large numbers of people to the beach. Fencing along the base of the coast dune is lifted during the winter to avoid storm damage, and put back in summer to keep people off the coast dune. Woolacombe Bay, Devon, England. (Photograph R Storeton-West)

The special nature of dune systems needs to be explained to people using them. Their goodwill is best enlisted where they enter the site by a notice at the car park couched in positive, not negative, terms. Useful advice on signs is given by Brown (1974). In general, people respond to well-designed notices describing simply, and diagrammatically, the nature of coast protection activities, and the reasons for fencing off specific areas (Plate 20). There is bound to be some vandalism of such notices, and financial provision for their replacement from time to time should be made. Costs are negligible compared with the valuable support and goodwill of the majority of the general public they engender (Appendix 3).

Where extensive coast protection activities are in progress (eg at Camber), this activity has even encouraged a local holiday camp to take visitors on a guided tour of the dune restoration works. There are possibilities for improving relations with the public via local schools and through voluntary or paid work groups.

For more specialized use, explanatory illustrated leaflets are particularly valuable because they can be readily updated. The bulletins and leaflets issued by the Beach Protection Authority at Brisbane, Queensland (Appendix 8), and leaflets on dune grass planting and dune turf seeding issued by the Countryside Commission for Scotland (Appendix 6) are excellent examples. The latter are available from the Countryside Commission for Scotland as part of a series of information sheets on plants and plant materials.

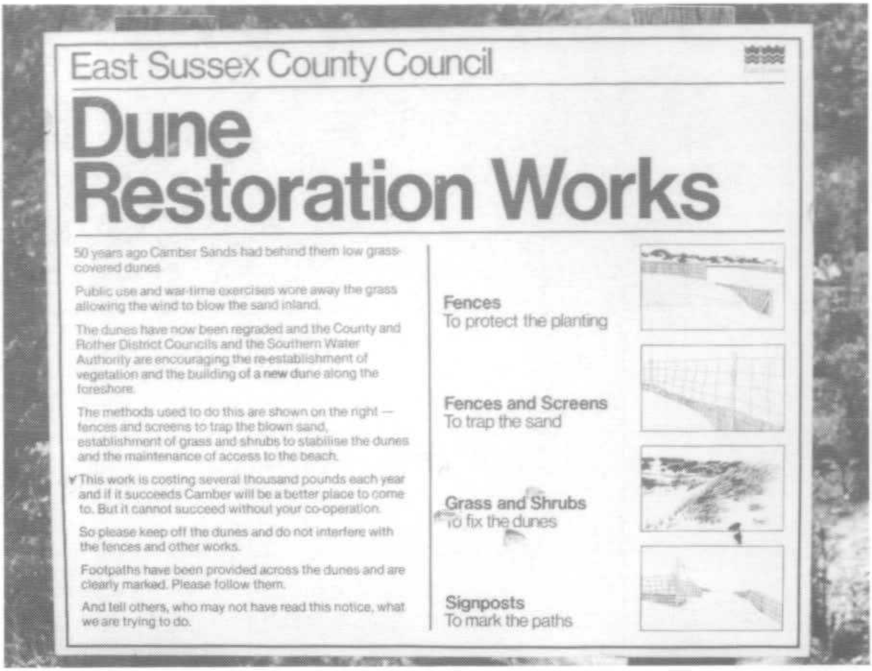


Plate 20. Notices explaining dune restoration activities are a valuable aid to management, especially when they are as clear and informative as this one at Camber, Sussex. (Photograph P Stuttard, Nature Conservancy Council copyright)

5.2 CONFLICTS OF INTEREST

The aims of dune coast protection are to preserve and build up bulk sand defences in a controlled manner, in order to protect people, property, and land, from invasion by the sea or mobile sand. These aims are not always compatible with those of the land developer, the farmer, recreational interests, and wildlife interests.

Considerable debate is in progress at this time about the problems of coast protection arising from the extensive, uncontrolled, property development that has taken place on offshore dune barrier islands along the eastern seaboard of North America (Leatherman *et al.* 1978; Nordstrom & Psuty 1980). Attempts to protect such property and service roads from tidal inundation on a largely submerging shore line are unlikely to be successful in the long run. Rational management in the future would seek to exclude property development in the potentially mobile dune zone near the coast. In this country, we seem to have largely avoided extensive and valuable property development on dunes, possibly because of the long history of tidal flooding and sand inundation disasters that overwhelmed early settlements in the past. Between the wars, there was extensive temporary development in the form of caravans, huts, and chalets, eg on the north Wales coast, but since then the area has been partly cleared as a result of planning control. The legal steps by which this control was achieved on the Lincolnshire coast by Lindsey County Council make fascinating reading (Sheail 1977).

Conflicts of interest arise, especially, in the management of the mobile dune zone. Escalating land values and agricultural grants for fencing have encouraged farmers to extend grazing paddocks deep into the mobile coastal dune zone (eg on the Aberdeenshire coast). This development will inevitably lead to calls for costly coast protection in the future, yet given space and time the dunes would ultimately stabilize themselves (Plate 1). The construction of golf course tees and greens too close to the coast leads to similar problems.

Dunes occupy less than 0.2% of the land area of the British Isles, and are a diminishing national resource of coast protection value and exceptional recreational and wildlife interest. Management for these purposes, in particular, should therefore take precedence over cropping for agriculture or forestry – especially as their nutrient-deficient soils, poor fertilizer-holding capacity, and exposed situations make them of only marginal value for agricultural use. The low productivity of dune soils also limits the carrying capacity for stock grazing, and in northern areas severe winters reduce the length of the grazing season. Coast protection interests are, therefore, best served by ensuring that cultivation does not spread seawards under the impetus of rising agricultural land values. Grazing stock should be effectively fenced out of shore and mobile coast dune areas.

There is some conflict of management interests between coast protection and wildlife preservation so far as rabbits are concerned. Much of the diversity of the dune flora is favoured by the patchy grazing, checks on shrub growth, and distinctive warren habitats associated with rabbit activities. Much of the damage to strandline grasses (couch-grass and lyme-grass) and the initiation of erosion at burrow mouths derive from rabbits. However, rabbits exert no significant trampling effect, they do not take organic matter out of the system (unless trapped for food on a large scale), and can be useful in preventing shrubs from shading out turf grasses.

Coast protection and wildlife interests are both best served by a positive approach to rabbit population management. This approach requires knowledge of the distribution of warrens; effective means of estimating the annual rabbit population; definition of acceptable populations; and effective control methods. The means to achieve these desirable objectives are not easily available. Although rabbits spend much of their time near their warrens, there is evidence that they range long distances in severe weather. At such times it is suspected that a few rabbits can do great damage to large populations of couch-grass and lyme-grass because they only seek a small but vital part of each plant (ie sugar-rich growth tissue). The significance of grazing can be demonstrated easily by enclosing a small area of these grasses in a rabbit-proof cage, and comparing the vigorous growth and seeding these plants exhibit with those outside the cage. Problems of grazing are second only in importance to those of access, and should be dealt with in a similar positive way in the interests of coast protection.

Width of backshore is equally important to tourist and coast protection interests, but for very different reasons. There seems to have been very little study of the conflicts that must arise in the use of this zone – whether primarily for people, or primarily for plants. The balance is clearly in favour of people the closer the approach to a seaside resort. While it is appreciated that most holiday-makers want to 'see the sea', and tourist committees favour an uninterrupted view, the policy may be in direct conflict with coast protection and highway engineers who have the responsibility of keeping roads and drains clear of blown sand. The size of this problem is indicated by an estimate in 1980 that it cost some £45,000 per annum to clear 50 000 tons of sand blown landward of the beach in the District of Great Yarmouth, Norfolk. There does seem scope here for establishing low, sand-trapping hedges of shrubs, such as tamarisk (*Tamarix gallica*) or white poplar, at the top of the beach, kept low by annual pollarding, which both species sustain well.

Coast protection and wildlife interests may also be in conflict, for example where access to the shore for maintenance involves disturbance to bird breeding areas. Such conflicts can be minimized by effective consultation procedures. More far-reaching management problems arise in connection with major pipe-laying operations for essential services, when these are planned to pass through Sites of Special Scientific Interest (SSSIs) or National Nature Reserves. For example, the preferred route of a sewerage pipeline was planned to pass through the heart of the Merthyr Mawr (Glamorgan) SSSI. In the case of Cruden Bay and St Fergus (Ritchie 1978, 1981) oil/gas pipeline landfalls, the main requirement was to keep the sea out of the coast dune breach, control sand blow, and restabilize the surface with marram or turf grasses. At Merthyr Mawr, the requirement was not only to control sand blow and restabilize the surface, but to put back the original flora so far as possible. Such a requirement demands very careful planning, involving pre-disturbance survey of the vegetation along the route; topsoil stripping as close to a thickness of 0.1–0.2 m as the excavating machinery can achieve; reduction of vehicle movements to the absolute minimum; stabilization of exposed sand surfaces with marram; and restoration of topsoil as effectively as possible. The Australian sand-mining companies go one step further and have developed nurseries to obtain plants of dune shrubs that do not regenerate from seed in the topsoil, for planting on the restored sites

(Lewis 1976, 1980; Lewis & Brooks 1980).

5.3 MANAGEMENT PLANNING

It pays to know as much as possible about the size and nature of the natural resources (sand, water, vegetation, animal stock) in the dune system as a basis for management planning. The extent, height, and depth of sand behind the shore are often not deducible from air photographs alone, yet this sand is part of the bulk defence on which coast protection relies – not just the coast dune.

Knowledge of the disposition and depth of the water table is important as they control the potential depth of wind deflation in the system. The extent and distribution of scrub are of interest in relation to its use in control of access, as a source of thatching material, and a harbour of rabbit warrens. The location of sensitive wildlife areas or archaeological sites should be known. Basic information of this kind is often lacking and the engineer is usually far too busy to use valuable staff time in collecting it. He can provide simple facilities (records, copies of maps, loan of air photographs, access permission) for the many amateurs and professionals who enjoy collecting and organizing such information.

Coast protection activities are often directed towards the consequence of change rather than its causes, as a matter of expediency. There is not enough time to browse through historical records, or even keep adequate records of current activities, not enough personnel to carry out beach profile surveys with the frequency required to record significant transient events, and not enough money to mount the costly investigations needed to study onshore/offshore sediment transfers that could eventually lead to reliable predictive models of beach processes.

In these circumstances, coastal engineers are forced to work with empirical models, orders of size, and to concentrate on highly selective aspects of change that can be easily and rapidly measured or observed. Short period changes in inshore sand banks can be monitored from satellite remote sensing; changes in path density or in proportion of shrub to grassland can be measured at 3–5 year frequency from air photography (Figure 7); and recreational population changes can be estimated from annual or seasonal car park revenues, or inexpensive light aircraft, hand-held, oblique air photography.

The options relevant to coast protection may be summarized as follows:

1. Restoration	4. Introduction
2. Protection	5. Extermination
3. Modification	6. No action

They can be checked out in the form of a series of questions.

1. Has the site suffered long-term or short-term damage requiring *restoration*? For example, there may be a case for restoring humus to encourage turf growth (as at Camber), or to restore a new dune in a gap in the coast dune with fencing and planting.

2. Does the site need special *protection* against anticipated future damage? For example, is there a case for access path rotation?
3. Is there a need to *modify* the existing management of the vegetation? For example, should the grazing regime be changed?
4. Is it desirable to *introduce* new species? For example, should lyme-grass or sand couch-grass be included in coast dune plantings to improve natural regeneration of dunes on the shore line, or should shrubs be introduced as an aid to access control?
5. Is there a need to reduce, or *exterminate*, certain species that may be destroying the native sand-binding vegetation? For example, has sea buckthorn or other shrubs or trees shaded out marram at the coast, leaving none to regenerate new dunes?
6. Is the site felt to be in a satisfactory condition after all the options have been considered? If so, then a positive decision to take *no action* can be made.

These are the sort of options a specialist in dune management would consider, and advice from such a source should be sought in difficult cases.

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APPENDIX 1

DUNE MANAGEMENT PRECEPTS

The North Berwick Study Group concluded that the following precepts should be adopted by all bodies concerned in dune management.

1. Dunes are a valuable and limited local and national resource of great potential, and everyone concerned should take a responsible attitude toward them. Where they are used by the public, local authorities should be prepared to take over their management, including direct ownership if necessary.
2. It is vital that, before any action is taken, a survey is made of the physical nature of the dunes themselves and the processes affecting change in the dune system. It is important that a record is kept of the wildlife and plants for which they may provide a last refuge, and that the pattern of human use is known.
3. It must be appreciated that dunes are only part of an integrated and evolving system which may be dependent on the supply of sand from adjoining areas. Work on one section of the coastline, particularly that involving artificial structures such as sea walls, groynes to trap sand or offshore dredging, may have a far-reaching effect on other beaches in the area.
4. There are 3 main interests in the dune systems – coast protection, conservation of nature, and public recreation. Any scheme could embrace all these interests, but it is important that priorities should be explicitly stated and approved.
5. These coastal dunes are often visited by many more people in the year than are urban parks, and there should be a similar annual budget for their maintenance. This budget need not be large if steps are taken before erosion has stripped the dunes of their natural vegetation. As their use increases, so must the budget to balance the human 'wear and tear'. The maintenance costs can, in many places, be met by car parking revenues.
6. The key to successful dune management lies in the scale and nature of access facilities, and these should be carefully considered as it is very much more difficult to retrieve a situation once damage has been caused. Public access should be allowed to the fullest extent consistent with the aims of any given area. Motor vehicles and caravans are particularly inappropriate and destructive of dune vegetation and should be excluded from dunes areas wherever possible.
7. It is essential that the public's reaction is considered when dune conservation measures are being taken and their co-operation sought. The public will appreciate the dune landscape if they are informed by nature trails, interpretative booklets and, above all, by the personal approach of a ranger.
8. Sand extraction is seldom justified as it opens up areas to wind erosion, alters the water table, and removes the bulk sand which may be necessary to retain the dune system. Where there is no new sand coming into the area, this can never be replaced.
9. The correct methods for protecting and restoring dunes can only come from a full appreciation of the forces of sea, wind and human use, and the resources available.

Extract from Anon (1970a).

APPENDIX 2

RECOMMENDATIONS FOR CONTROL OF OFF-ROAD VEHICLES (ORVs) ON BEACH AND DUNE

A. Beach

1. *ORV use should be restricted, whenever possible, to the outer ocean beach, seaward of the drift line zone and expanding dune edge.* Such areas are subject to the greatest environmental change due to natural causes and are therefore less likely to be permanently damaged by ORV use. Also, if damage does occur, recovery would be most rapid in this area. However, other factors must also be considered with regard to use of the outer beach, such as conflicts with pedestrians, swimmers, foraging or resting shorebirds, and marine life in the sand beach.
2. *Prohibit driving in the upper backshore area, particularly in the areas of drift.* These drift lines are the precursors of new sand dunes on accreting beaches and can also moderate the rates of erosion when new vegetation is established at the base of a dune scarp.
3. *Close beaches that are so narrow as to force drivers to run along the very toe of the dunes at high tide.* Provide adequate bypass routes around such areas.
4. *Close beaches to vehicles during periods of exceptionally high tides, which force drivers to travel along the face of dunes or through shorebird nesting sites and embryonic dunes.* This can be an important safety measure, as well as protect the leading edge of the dunes and help to prevent damage to shorebird colonies. Access points to the beach should be closed at these times and posted accordingly.
5. *Nesting areas of least terns and other colonial shorebirds must be protected by (a) fencing, (b) posted signs, (c) restriction of beach traffic to marked tracks, and (d) strict enforcement of leash laws for pets.* The shorebird (tern) management program, including the function of tern warden, in the seashore is successful and should be continued. Interpretive signs should be placed at beach route entrances to (a) alert drivers to watch for active terneries, (b) explain briefly the life history of the least tern, and (c) request visitor cooperation in protecting the terns. Signs calling attention to the colonies themselves should be posted at least 100 feet on either side of a colony, and visitors urged not to approach any closer. Vehicles can pass by somewhat closer, but people leaving their vehicles will scare the birds and can lead to nesting failures. Dogs in particular must be kept from the nesting areas since the birds are much more alarmed by dogs than by people approaching on foot.

B. Dunes

1. *Prevent vehicle entry into previously closed dune regions.* Wherever possible, provide public transportation to inaccessible areas or allow only walk-in use.
2. *Where ORV access is necessary, tracks should be carefully planned to avoid the most sensitive areas.* These include:
   a. drift lines and embryonic dune areas;
   b. the leading edge of expanding dunes;
   c. older, stable dune areas where drivers would be inclined to leave the tracks;
   d. heathlands and hairgrass/lichen communities – particularly beach heather *(Hudsonia).*
3. *Wooden ramps should be built and maintained over dune lines, providing beach access through the dune zone.* Such ramps are most critical where lowering of the dune line might lead to greater storm hazards for habitats or facilities behind the dune. New routes over dunes to the beach should not be allowed without adequate ramps that will protect the dune system.
4. *Dune routes should be oriented in such a way that prevailing winds cannot create blow-outs.* Specifically, open trails should not face the prevailing winds. Properly placed borders of vegetation can help to prevent wind erosion.
5. *Dune routes should be designed to avoid sharp turns or climbs up steep grades.* Otherwise, drivers are likely to make new, unofficial trails that are easier for them to negotiate, which tend to increase the total area being impacted.
6. *Restrict traffic to marked routes with borders of cable or dense, impenetrable shrubs.* Such tracks should be established only after careful study to avoid or minimize environmental impact. Most trails should be permanently closed, and only those absolutely necessary should be retained.
7. *Vehicle trails must be controlled and maintained.* Deterioration of the track (especially washboarding) often spurs drivers to leave the established trails and impact surrounding vegetation.
8. *Close off deteriorated dune routes and institute management programs to repair the damage, especially where natural regrowth would be slow.* Most dune species can be readily transplanted, and thus vegetation can be restored.
9. *Close all sensitive habitats such as heathlands and shrublands.* Habitats with slow-growing species, that experience stress due to drought and lack of nutrients, are likely to be the most severely damaged and must be protected from vehicles.

10. *Institute public programs and displays that are aimed at educating the public to ORV damage.* The public needs to be made aware that "dune-busing" and "wheeling" are extremely damaging to dune systems, and severe penalties for such activities should be enacted. When given the reasons behind ORV regulations, most people will accept them.
11. *The concept of "no carrying capacity" should be emphasized when planning for ORV use.* A few vehicle passes through dune vegetation can create substantial problems, and once a trail is open for use, there is little difference between very light use (i.e., a few hundred passes) and very heavy use (thousands). For this reason, establishing a few, well-managed, "heavy-use" trails is preferable to many "low-use" trails.
12. *All ORV use of the high, migrating dunes in the Province Lands must be terminated until such time that the dunes can be stabilized and nondamaging routes created.* The present use patterns will keep the dunes unstable and migrating. If ORV trails through the high dunes area are necessary, they should be relocated and designed so as to prevent or at least minimise erosion.
13. *Whenever possible, ORV use should be restricted or eliminated entirely in the dunes and coastal habitats.* In general, ORV use in these areas is not compatible with the natural processes and adaptations of organisms to this environment.

C. Salt marshes and tidal flats

1. *Close all salt marsh and tidal habitats to vehicle use.* The system is much too sensitive for such recreational purposes; it has no carrying capacity for vehicles. ORVs are a major stress to this environment, detrimental in all aspects, and it is clear that vehicles should be excluded from such environments. Once closed, the salt marsh/tidal flat system will begin to recover, but it must be patrolled and regulations enforced. Only a few illegal passes through protected areas will substantially set back recovery of vegetation.
2. *Prevent traffic from using the border zone between salt marshes and dunes.* Provision should be made for bypassing the marshes and flats by developing a series of carefully located upland trails.
3. *Establish a series of interpretive displays that show how vehicles damage marine resources.* Such information can help visitors understand why these areas must be closed.

Extract from Leatherman and Godfrey (1979).

APPENDIX 3

SIGNPOSTING

For details on signposting in the countryside, see Brown (1974) and the Countryside Commission Waymarking Code leaflet, 'Waymarking Public Paths, a Practical Guide'. A few points should be kept in mind to make signposting effective.

a. Signs with a positive, explanatory emphasis usually work better than those that simply prohibit.
b. Dune restoration works should be explained in detail by signs at major access points and by small, briefly worded 'reminder' signs fixed every 20 yards or so along perimeter fences around planted or seeded areas.
c. Signs restricting access should be as inconspicuous as possible, given the need to convey the message. At Ainsdale Sand Dunes NNR, Merseyside, discreet 'No Entry' signs on 2′ (0.6 m) posts are placed along footpaths and beside gates in the dune woodlands, but some way back so that only people who stray from permitted paths come across them. This negative signposting is balanced by positive routemarking along the paths themselves.

d. Many site managers feel that cheap-looking, mass-produced signs are more likely to be vandalised than carefully hand-routed signs in materials such as pine, which are sympathetic to the local environment. But any signs may become damaged, and it is always important to consider the number of signs involved and to weigh up the time and cost of replacement when choosing between different materials. Where it is not possible to give each sign the hand-made touch, it helps to have pasted-on maps, etc, which can be easily and cheaply replaced when ripped off. Whatever the material, good design is essential to provide a readable sign which is in keeping with the setting.
e. In tern nesting sites it is important to post explanatory signs near the zones of heaviest traffic, eg along the tide mark. If signs are posted for example at the foot of sand dunes behind the nesting beach, people may walk straight through the nest area to read the signs, completely unaware of the damage they are causing.

Extract from Brooks (1979).

APPENDIX 4

CONTROL OF SEA BUCKTHORN *(HIPPOPHAE RHAMNOIDES)*

This most invasive plant is the cause of much concern on many coastal sites. Unlike any other dune plant, it seems to grow well and fast from the foredunes, through slacks and up to the top of high dune ridges. The rapid spread of seedlings and colonies gives a blanket cover after a very few years that eradicates all other flora and can, in a small number of years, change an open dune system into an impenetrable thicket.

From experience on the Braunton Burrows sand dune system, it is quite clear that once both male and female plants are present over large areas there is no practical method of control. An attempt to clear the female plants to stop berry production is impossible, as most stands contain both sexes and a selective cull would take longer than to cut down all the stand. It is not easy to tell male from female plant before berry production starts at about 5 years, so by the time that the sex is established the colony has already had an effect on other flora and animal life.

Although where buckthorn is well established over many acres the task is a daunting one, the answer is total eradication from the site if it is considered that the plant is causing, or will in time cause, a major change in the habitat. Experience at Braunton has proved that this task is not so difficult and many acres can be cleared and killed with a very small staff involvement.

Before listing the seasonal work programme that has developed here, a little information on the Braunton situation will help to give an idea of the scale of operation which has been undertaken so that others can compare this with their own problem.

The Braunton Burrows National Nature Reserve covers the southern 1500 acres of the system and since 1970 a rear-guard action has been fought to stop the spread of seedlings (bird-born), from the northern section of the dunes outside the Reserve where buckthorn was planted in 1937 and since that time has been allowed to spread unchecked. Each year the problem became greater and required more person hours to keep down the seedlings and to stop the start of colonies. In 1975 the Nature Conservancy Council was given permission from the owners of the dunes to clear the whole system. Outside the Reserve there was an estimated 18 acres of mature buckthorn in stands up to 4 acres in size and to 38 years old, together with innumerable small colonies and carpets of seedlings. A programme was worked out with a view to total eradication within 5 years. In fact, now after only 2½ years all the main stands have been cut down and cleared and by the end of

1977 the problem should be reduced to an annual sweep to 'mop-up' the odd seedlings.

The seasonal work programme which has developed has moved most satisfactorily. The cutting has been done by the Warden with 'task force' help from other NCC staff, and the summer spray work has been done by the Warden with the help of a seasonal Warden for 3 weeks in August.

Cutting

The Braunton dunes rise to 120 ft in a series of ridges. Most of the mature buckthorn stands have been on very steep ground quite beyond the use of any tractor wheeled or tracked. So we have not used any of the 'bush-hog' type of machines and in fact I do not know of any machine which could tackle mature stands without causing major erosion and leaving the site impossibly rough for the follow-up spray work.

During the winter months as soon as the leaf is off, we have cut down the mature stands, starting with the oldest to give the trunks the maximum time to dry out. For this job we have used the Husqvarna Clearing Saw which has proved to be a very robust tool and 'made for the job'. In stands up to 25 years old, a good man can cut down up to one third of an acre in a day if clean and not matted with bramble and creeper. With stems over 25 years in age we have had to use a chain saw but this is no problem as plants of that age have no ground under cover and few low branches, so they can be cut off close to the ground.

Burning

The cut material is left to dry out until the end of February and then a bulldozer is used to push the thorn up into wind rows — in line with the wind – for burning, or to move into hollows as sand fencing or 'people stoppers'. Where the thorn has been cut down on a very steep ground, it is little trouble with pitch forks to roll it down hill to a position where the 'dozer can reach it.

There is no spark from burning buckthorn so there is little chance of starting a grass fire so long as the burn is not done on a very windy day. It is necessary for the older trunks to have had several winter weeks to dry out, as then the burn will leave nothing but a small line of ash. This job must be done before birds start using the cut material for nest sites. The main point is that the site must be cleared for the follow-up spray programme.

Spraying

From mid-July to the end of September we spray any buckthorn which can be reached with a back pack, that is to say seedlings, small colonies, the edge of large stands and the lush regrowth from the stands cut down in the winter. EVERY leaf must be covered as there is no translocation in buckthorn. I try to go round each site again in a few weeks' time to spray the odd leaf that has been missed in the first application. After some experimentation we now use with 99% success a brew of SBK 2, 4-D/2, 4, 5, T at 1 part chemical to 120 of WATER. This very weak solution has proved to make a far better kill than the stronger brew as recommended by the manufacturers with oil.

Pulling by hand any buckthorn other than first year seedlings is a waste of manpower as the odd piece of root left in the ground will grow again. In fact, in areas where there are many first year seedlings we use the sprayers as it is much quicker and 100% sure.

This is in brief the annual routine. One thing to bear in mind is that there is a temptation to cut down in the slack winter period more acres than one can hope to spray in the summer, when Reserve staff are fully committed with the usual holiday period problems. This has been done on Braunton Burrows and it was found that after 2 years the regrowth from cut stumps was so lush that it was not easy to kill with spray. In fact, a half-acre stand had to be cut for the second time and sprayed again the following summer.

Safety

I am sure you know that buckthorn is really grim material to deal with but now over the years we have got 'geared-up' and the thorns are no longer a problem. We now use the clothing as recommended by the Forestry Safety Council when using the clearing saw – FSC 1 (1974). For cover below the waist we have some 'chaps' made up in really good leather. These are the answer and they are now used for cutting and spraying. No trouser would 'turn the thorns' and this meant that one had to look before moving; now one can bash on and a thorn below the middle is a thing of the past.

Cutting buckthorn stands down is a very heavy work and there is a great temptation to strip off and hope for the best. This has been done time and again on Braunton when a team of men are in the mood and really getting 'stuck in'. The result is always the same, someone ends up with a thorn in so deep that it is beyond hope probing and ends up with a trip to hospital. This is the ideal job for really cold weather and for men with experience in forestry work. Not a job for the odd school party.

J Venner, Nature Conservancy Council, 12 January 1977

APPENDIX 5

OUTPUT, LABOUR AND COSTS (AT 1975) FOR THATCHING AND PLANTING MARRAM GRASS

OPERATION	RATE OF WORK									
	MAXIMUM WORK RATES					MINIMUM WORK RATES				
	Closed work			Open work		Closed work			Open work	
1. PREPARATORY WORK										
(a) **Brash collection**										
Output in bundles/hour	10					5				
Hours required/acre		75		25			150		50	
Hours required/hectare			187		62			375		125
(b) **Grass collection**										
Output in bags/hour	6					3				
Hours required/acre		17		23			34		45	
Hours required/hectare			42		58			85		112
(c) **Transport**										
(I) **Brashing**										
Output in bundles/hour	30					20				
Hours required/acre		25		8			38		13	
Hours required/hectare			62		21			94		32
(II) **Grass**										
Output in bags/hour	50					35				
Hours required/acre		2		3			3		4	
Hours required/hectare			5		7			7		10
TOTAL HOURS PREPARATION										
Hours per acre		119		59			225		112	
Hours per hectare			296		148			561		279
2. COMPLETION WORK										
Planting										
Input of brash, bundle/hour	7				3	4				2
Input of grass, bags/hour	1				3	1				2
Input of straw, bales/hour	0				1	0				1
Planting time in hours/acre		120		80			200		120	
Planting time in hours/hectare			300		200			500		300
TOTAL HOURS & ALL OPS.										
Hours per acre		239		139			425		232	
Hours per hectare			596		348			1061		579

Figures given above were the rates obtained under varying working conditions, including the use of voluntary labour.
Assuming labour costs of 75p per hour, then the estimated costs are:-
Closed work, maximum cost - £318 per acre, minimum cost - £180 per acre.
Open work, maximum cost - £174 per acre, minimum cost - £105 per acre.

NB Costs at 1975
Current costs for planting marram vary from
£0.25/m^2 (Lincolnshire) to
£1.00/m^2 (Scotland)

Extract from Bacon (1975).

Countryside Commission for Scotland
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INFORMATION SHEET PLANTS **5.2.1**

Vegetation Management Coastal Vegetation

DUNE GRASS PLANTING

The traditional method — used over many centuries — of stabilising mobile sand dunes is to transplant the naturally occurring dune grasses to the eroded sand areas, using either marram grass *(Ammophila arenaria)* or sea lyme grass *(Elymus arenarius)*. These grasses are amongst the few plants that thrive at the coast under conditions of sand blow, and they grow into upstanding tussocks with a full foliage which provides shelter from wind at ground level and stabilises the underlying sand. A programme of dune grass planting will often be undertaken along with other dune protection works, such as sand fencing or the creation of footpaths. This sheet is concerned only with the techniques of dune grass planting.

WHERE TO PLANT

Dune grasses have long running roots or rhizomes which extend downwards for several metres into the sand, binding together the dune soil and rendering the plants resistant to drought. Their foliage traps wind-blown sand and the grasses thrive on growing upwards through new sand deposits. Thus dune grasses may be planted on dry open sand areas where other vegetation cannot establish because of the incidence of blown sand, and indeed they will only grow vigorously if some wind-blown sand persists after planting. In environments which are too sheltered to provide this sand supply, as in pastures behind the dunes, a speedier and more economical method of achieving vegetation cover may be to re-seed with turf grasses. Conditions suitable for dune grass planting are usually to be found in eroding hollows, embankments and cuttings within active dunes and on adjacent areas onto which sand is spilling. In these conditions, transplants of dune grasses will grow rapidly, sending out new roots and shoots into intervening spaces, to provide a full vegetation cover within two or three growing seasons.

PLANTED AREAS MUST BE FREE FROM

Trampling:
Dune grasses will not withstand trampling by people or animals. Where areas under public pressure are to be planted, the young transplants should be protected by fencing or suspended netting.

Grazing:
Although dune grasses are less palatable than pasture grasses, they may be eaten during winter where other herbage is scarce. Sea lyme is particularly susceptible.

Wind Scour:
Planting will usually be contemplated on eroding sand slopes or hollows which are subject to some degree of scouring by the wind. An important question to be asked is: once the plants have established and a leaf canopy is present, will this be sufficient to stop further erosion? On steep slopes facing the winds, or on ground being undercut at the side the answer may be no. In planted areas where some wind scour is expected until a full leaf canopy is established (which may take two or three years) the sand surface may be protected from erosion by thatching with brushwood before planting, or by the use of a sprayed stabiliser immediately after planting.

Sand Inundation:
Dune grasses thrive on being inundated by 10-30 cms of sand each year. However, if in a first year excessive sand deposition threatens to inundate plantings by more than this amount, which may happen, for example, on the lee slope of a very active dune, then the transplants are likely to be overcome. For this reason areas sheltered by sand fences should not normally be planted until a final sand profile has been achieved.

Tidal Inundation:
Although sea lyme planting may survive an occasional inundation by the sea, plantings are normally only secure if they are well clear of the highest spring tides.

WHICH GRASS TO PLANT

If the area to be planted is not grazed and is clear of high tides, then either marram or sea lyme grass may be planted, and the best guide to choice is usually the existing dune grass cover which may be one or the other species or a mixture. Sea-lyme grass is more tolerant of salt spray than marram, and on the east coast it is found on the seaward edge of dunes. Marram grass is the more usual grass in high dune areas. Exceptionally, sand couch grass *(Agropyron junceiforme)* may be planted in areas subject to severe salt spray, such as the seaward toe of a dune, but stocks of this species for uplifting are often limited.

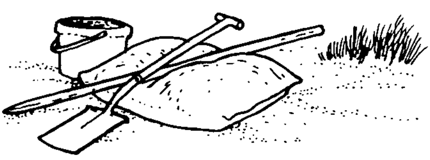
WHEN TO PLANT

Like trees and shrubs, dune grasses should be planted during the winter months when they are relatively dormant. By far the best period is early March, when the plant will develop new foliage within a few weeks of planting, protecting the underlying sand from wind erosion, and 100% planting success may be expected on suitable sites. Outwith March/April, the planting success can be more variable, dependent on the exposure of the site and its location. Midsummer planting will have no success at all in dry easterly locations, but can have partial success (say, 40%) in damper north-westerly locations. On relatively stable and sheltered sites, planting in November through to February is almost as good as in March/April, but if the site is open to wind erosion, burial by sand, or salt spray or grazed by rabbits or stock, this success can be drastically reduced. The risk of damage becomes progressively less as the winter months pass.

October-January	***	Avoid if erosion or burial or grazing likely during winter.
February	****	Conditions often too severe for planting comfort. Avoid frosts.
March	*****	By far the best for all sites.
April-May	**	Dependent on cool, spring weather.
June-September	*	Avoid on east coast; moderate success on north or north-west coasts.

TOOLS AND LABOUR

Planting is labour-intensive. On an easily worked site, where plants are readily available for uplift, a good work rate is 100m² per man-day. The only tool required is a spade, to undercut the tussocks before uplifting and to make slits or trenches for the plants. In soft dry sand, or when planting among brushwood or debris, a large straight crowbar or similar tool makes planting holes more easily than a spade. A standard garden dibber is too blunt and light to make holes of the required depth. A bucket is also required for spreading fertiliser after planting.



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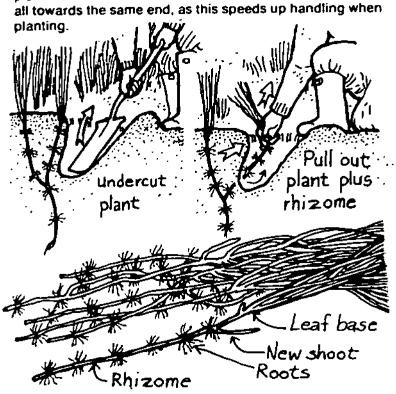
UPLIFTING PLANTS
With owners' and occupiers' consent, plants can usually be uplifted from nearby areas of dune. In a few large dune systems there may be prohibitory bye-laws or other legal constraints on the uplift of marram, dating from earlier centuries in which erosion was attributed to the practice of cutting marram for thatch; in such areas clearance should be sought from the appropriate authority.

Lift plants from sheltered areas of undamaged dune, where further erosion problems will not be created by thinning out the vegetation. Remove less than half of the existing vegetation cover. Choose an area where there is a vigorous growth of dune grasses, either devoid of other vegetation or with only a sparse cover of vegetation between the plants. Digging isolated dune grasses out of a knitted turf is too time-consuming to be practical. Also, avoid areas of heavy sand accumulation, where the plants will be partially buried and will require deep digging to extract.

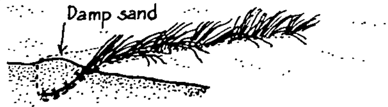
Undercut a tussock with a spade. Apply a steady pull to a cluster of a few plant stems towards this void until the rhizomes break below spade depth. The exact level at which the rhizomes will break depends on the vigour of the growth; in a stable site, the rhizomes may have rooted 10 cms or less below the surface while on a very active site, 30-50 cms of rhizome may be pulled up with the plant. Either type of plant is satisfactory, though the lengthy rhizome may be a nuisance while planting and may have to be broken off. The ideal plant has a full 15 cms of healthy rhizome, with two or three nodes (swellings of the rhizomes from which new shoots or roots may develop) and a full spray of foliage. In dry sand, clusters of plant may pull up without any digging, but if the underlying sand is damp the rhizomes will break too close to the surface. On slopes, plant rhizomes are often pushed outwards as sand has settled down the slope. Always quarry below a tussock, rather than above, as a spade inserted uphill of a tussock will slice off such rhizomes. After extracting plants from an area of half a square metre or so, move on to a new adjacent area of dune so as to thin out the vegetation cover, but leaving at least half the original cover.

Uplifting is best done individually. To keep plant roots from drying out, someone should tour the uplifters every 10 or 15 minutes, collecting the uplifted plants and delivering them to the work site or transport vehicle. Ensure that plants are collected and stored with the roots of a bundle all towards the same end, as this speeds up handling when planting.



When uplifting is completed, the uplift areas should be given a top dressing of nitrogen fertiliser to encourage recovery of the vegetation. Even if half the surface vegetation has been removed, there is still an abundance of broken rhizomes left in the gaps from which new plants will grow, and after one full growing season the areas from which the dune grasses were uplifted should not be discernible.

HANDLING PLANTS
Plant roots should be covered with damp sand as soon as possible after uplifting, for example, after being carried to the work site or while being stored in a vehicle awaiting transport. Overnight, or for a period of a few days, the plants should be bedded in a damp trench in the sand.

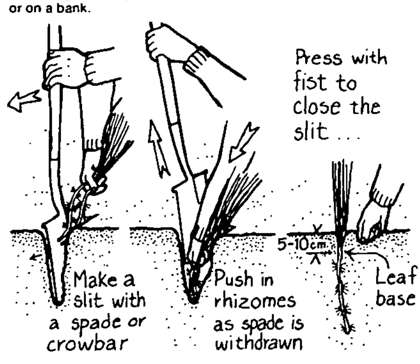


PLANTING
The most important point to observe during planting is that the active growing point — hidden among the leaf base — must be placed 5-10 cms below the sand surface. A dune grass develops vigour as the stem grows upwards to a new sand surface, branching and developing new roots and foliage as it does so. If the leaf base is placed at or above the surface, the plant stagnates.

For marram grass, two planting techniques are recommended, depending upon the sand activity of the site. Marram grass continues to propagate in the direction of the planted rhizome: if this is placed vertically the plant is well able to grow upwards through heavy sand accumulation, while if it is placed horizontally the plant is better able to spread outwards under a stable sand surface. Sea lyme grass can develop in all directions, and either technique may be employed.

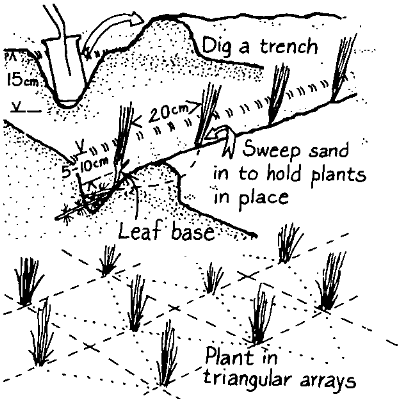
Active Sites — Expected Sand Accumulation more than 20 cms in first year.

Dig the spade into the sand, and lever it forwards to reveal a slit. Slide a pair of plants down the back of the spade and push the rhizomes into the bottom of the slit as the spade is withdrawn. Press the sand behind the slit with a fist to close the slit. Repeat at 40 cm intervals in a triangular array, or more closely in exposed places or on a bank.

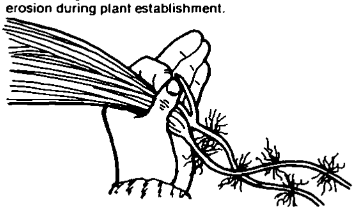


Stable Sites — Expected Sand Accumulation less than 20 cms in first year.

Dig a vee-shaped trench 15 cms deep. Lay the rhizomes of single plants along the base of the trench, gently curving each stem to lead the foliage upwards out of the trench. Sweep sand back into the trench to hold each plant in place. Repeat at 20 cm intervals along the trench. Dig the next trench 40 cms from the first, or more closely in exposed places or on a bank.



One of the trickier points to specify is how much plant material constitutes a single plant, given that what is uplifted may vary from a single stem to a complete tussock all branching from a single rhizome. Roughly speaking, a pair of plants suitable for the first planting technique should occupy the space between finger and thumb as shown below. Large branching plants may be sub-divided, or several single stems without much foliage may be bunched together to achieve this guideline. In the second planting technique, meagre stems may simply be planted more closely. One must ensure that there is a sufficient spray of foliage above ground that the combined effect of all the foliage will protect the sand surface from wind erosion during plant establishment.



Planting is best undertaken in two-man teams, one member of the team digging the slips or trenches and the other sorting and planting the plants. Start at and work away from any boundaries: time is lost trying to plant in confined areas up to boundaries. On a slope, start at the top and work downhill in rows across the slope. Allocate each two-man team a 'work line' 10-15 metres long: too short, and teams get in each other's way; too long, and time is lost unnecessarily in journeying to the plant stockpile.

NUTRITION
The main nutrient shortage in sand is nitrogen, which is washed through the sand in a relatively short time. Top dressings of nitrogen fertiliser should be given periodically over the establishment period. They may be phased out once full cover has been achieved. Apply fertilisers as follows —

> As top dressing in April, June and August of first year, and again in April of second year:
> 30 g/m² of 'Nitram,' 'Nitrashell,' 'Nitro-Top,' or other all-nitrogen fertiliser at 10 g/m² nitrogen.

AFTER PLANTING
Fences and netting which serve to protect the planted area from trampling should be checked regularly as in dune areas both may become submerged by sand accumulation and nets may work loose in the wind. At the end of a first growing season, expect 50% leaf cover, with the plants still appearing in their planted rows, while by the end of a second or third growing season, the plants should have spread into the intervening spaces and the leaf cover should be more or less entire.

CONSULT for additional details the following sheet:
2.7.1 Four Dune Grasses

SEE ALSO sheet:
5.2.3 Sand stabilisation by Spraying

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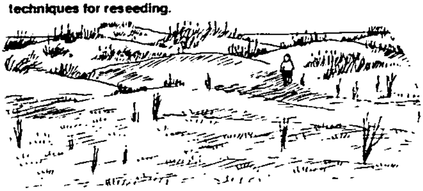
BEACHES: RESEEDING OF DUNE PASTURES

Usually sand beaches are backed by dunes, or accumulations of wind-blown sand, clothed almost entirely in marram or sea lyme grasses, and readily identifiable by their hummocky relief. Often, however, sandy soil extends far landward of the dunes, and in relative shelter from fresh blown sand the dune grasses lose their vigour and become replaced by turf grasses or shrubs. Sometimes, at beaches where the quantity of sand is limited, the grassland or shrubland extends forward to the shore and there may be no dunes. In much of Scotland these dune pastures are known as links, while on the west coast and on the islands the Gaelic word machair is applied. Within dune pastures, where there are eroded hollows or other areas of bare sand in need of revegetation, plantings of dune grasses, marram and sea lyme, may not thrive because there is insufficient wind-blown sand to keep them nourished. Reseeding with turf grasses is likely to be more effective and much less labour-intensive. This sheet deals with the various techniques for reseeding.



CONDITIONS FOR SUCCESSFUL RESEEDING

Reseeding with turf grasses should prove successful provided that, in any year of growth and most especially the first, the area is not inundated by more than 2-3 cm of blown sand. The likely level of local inundation by sand must be assessed in the light of the new level of stability created by the reseeding operation: within a large erosion hollow, remote from other sources of blown sand, there may be considerable movement of sand before the reseeding is done, and indeed dune grasses may have established naturally, nourished by sand won from adjacent unvegetated parts of the hollow. Total stability may none the less be achieved if the whole hollow is reseeded at once.

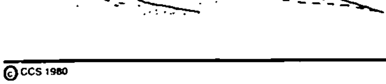
It will be some time before the reseeded bare sand becomes bound by a fibrous root mat which can accept the weight of human foot or animal hoof without damage. Thus, for a period which will depend upon whether topsoil or a mulch or neither is used, reseeded areas should be protected from trampling or grazing.

On sites directly facing wind-borne sea spray, seedings may not establish. Normal levels of salt spray will be tolerated by established grasses, but the germination period is a critical one.

Often wind blow of a sand area is only halted when the excavation reaches the ground water and the sand at the foot of the hollow is thus kept moist and unable to blow. This may lead to flooding in winter, and growth may be swamped if flooding is prolonged.

GROUND PREPARATION

Normally sand needs no preparation other than to flatten out any lumps and holes. Upstanding mounds of old turf are better demolished completely. Where there are sand cliff edges bordering the area, they should be graded back to provide sand slopes of gradient below 1 in 3 for seeding. Bear in mind that newly-worked sand will compact in the course of time by about 10-20% of it's original volume.



USE OF MACHINERY

Most dune areas are undulating and the sandy soil easily disturbed by vehicle tyres, so that machinery other than those with crawler tracks or balloon tyres are not readily used. In practice, small areas of 0·1-1 Ha (depending on the method) can be economically treated by hand and the details that follow, with the exception of those on hydraulic seeding, refer to manual reseeding of small areas. The only item of machinery which may be required is a portable sprayer where a stabiliser is applied. On larger areas where the use of crawler-tracked vehicles is economical, seed may be cross-sown in drills formed by a Cambridge roller, or they may be harrowed in, or best of all, if the equipment is available, they may be direct-drilled. Mulches may be spread by a muck-spreader, and stabilisers sprayed by vehicle-mounted crop sprayers. There is not a large body of experience in using such equipment on sand and advice from a local agricultural machinery adviser may be sought. An important consideration is the considerable damage which is caused to existing dune and dune pasture vegetation where wheeled or tracked vehicles have to gain access to the reseeding site across such territory.

TIME OF SOWING

Although in agricultural practice seed may be sown from April through to early October, barring the high summer months, in beach areas growth is likely to be retarded by drought, wind, salt spray and nutrient shortage. Two seeding windows can be recommended: early May and late July/early August. Earlier than May there may be a risk to young seedlings and ungerminated seed from salt spray borne by winds at times of high tides. In late May, June and early July there is a high risk of hot weather and drought, in which seed may not germinate and young seedlings may wilt. Early August can be a good sowing time, but any later and seedlings may not develop sufficiently by autumn to ensure winter survival. These limitations become less important as the site is more sheltered.

SEED MIX

Many established dune pastures are lime-rich and support a wide variety of flowering plants. On reseeding bare sand, a balanced soil structure does not exist and it is not possible to reproduce easily the species content of an established dune pasture. In most cases, the objective will be to produce a ground cover, relying on natural processes over a period of years to enable the local vegetation to re-establish at the expense of the sown grasses. However, the sown grasses could well invade the surrounding area, and at sites of high botanical conservation value, use of the following recommended seed, mainly of foreign origin, may be undesirable. In such circumstances, seed may be collected locally, but at much higher cost.

A good basic seed mix is:

- 60% slender creeping red fescue
- 30% perennial ryegrass
- 5% smooth-stalked meadow-grass
- 5% white clover,

which resembles a standard 'with rye' lawngrass mixture, with white clover added.

Red fescue *(Festuca rubra)* is a slow growing, drought-resistant grass, which forms the dominant element of most dune pastures. What is needed is a red fescue which propagates by running roots or rhizomes (thus not a Chewing's fescue), which tolerates salt, and which will accept heavy grazing or heavy trampling or both, dependent on the situation. These qualities are exhibited best by a group of cultivars known as slender creeping red fescues and two particularly salt-resistant cultivars are 'Dawson' and 'Oasis'.

Ryegrass may be added to a seed mix to provide a more rapid ground cover than red fescue can offer in its first growing seasons. As a faster growing plant, ryegrass may

continued overleaf

limit the spread of the red fescue initially, but being less drought resistant than red fescue, it is unlikely to persist in the long term. For consistent cover over the first few years of establishment a perennial ryegrass *(Lolium perenne)* which is slow-maturing and of good winter hardiness should be chosen, and the cultivars 'Caprice', 'Lamora', 'Karin', 'Perma' and 'Springfield' all offer these features. Alternatively, a short-lived Italian ryegrass *(Lolium multiflorum)* may be included as a nurse crop alone, to provide wind shelter during the first growing season only; a Westerwolds variety should be chosen, and a suitable mixture composition would be:

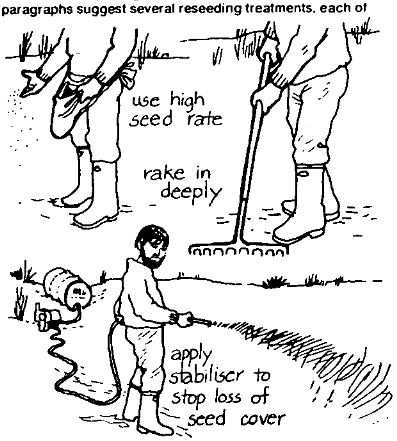
75% slender creeping red fescue
15% Westerwold ryegrass
5% smooth-stalked meadow-grass
5% white clover

Smooth-stalked meadow-grass *(Poa pratensis)* is common in dune pastures, but relative to the other grasses it is slow and poor at establishing from seed. A large number of cultivars are suitably winter hardy and low-growing, among which 'Baron,' 'Bensun,' 'Enmundi' and 'Fylking' are commonly available.

Legumes play a vital role in later development of swards by fixing atmospheric nitrogen and making it available as plant food to the grasses. White clover *(Trifolium repens)* is the most commonly used, and among the commercial cultivars a suitable choice is to use a mixture, in proportion 1 : 2, of a small persistent type such as 'Kent Wild,' and an initially more vigorous but less persistent type such as 'Grasslands Huia.' Other legumes, like bird's foot trefoil *(Lotus corniculatus)* may be included where they occur naturally nearby.

CHOICE OF SEEDING TECHNIQUE

As a soil, sand is an infertile and harsh environment for young seedlings, lacking fine particles to retain moisture and lacking organic matter to harbour nutrients. Do not be misled by lush grassy swards scattered with flowers and clover adjacent to the eroding bare sand area: those swards may be hundreds of years old, years in which rotting plants have gradually built up a rich layer of humus within the sand, a layer completely absent from the nearby eroding areas. Although the technique most assured of success is to import a thick layer of topsoil there may be several disadvantages in so doing. Given the right level of after care a good growth of grass can be produced on bare sand, or by using a surface mulch. The following paragraphs suggest several reseeding treatments, each of which may be appropriate in some circumstances. The choice usually depend both on the resources available and the intensity of use to which the ground is to be put.



Seeding on Sand

If poor germination and slow establishment can be accepted, seeding on sand alone is simple and undemanding on labour. Seed and young seedlings in free-draining sand are liable to be subject to drought conditions over much of the summer. It is therefore important to place the seed deeply in the sand to provide optimum moisture conditions: 3-4 cms is ideal for the grass species listed above, while clover and other species with small seed should not be sown deeper than 1 cm. In practice, the best that can normally be achieved is to rake in the seed and to use a high seed rate to allow for losses.

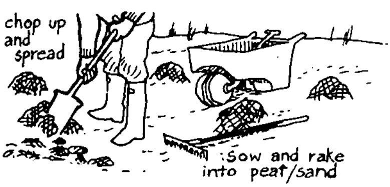
Sow the seed at 30 g/m^2 and rake in deeply. On small areas, a more uniform result may be obtained by covering the seed with surplus sand, hand-shovelled with a scattering action. After seeding, apply a stabiliser to the sand surface to stop wind blow of sand and seed.

Seeding With a Mulch

Moisture retention around the seed can be much improved by using a mulch on the surface. A mulch is not a growing medium; it is merely a surface dressing which holds moisture and which will protect seed from the effects of exposure to wind and hot sun. Many mulch materials have been used, from seaweed to wool waste to sewage sludge, and many have been developed specifically for use in the hydraulic seeding method. Most mulch materials will offer their own benefits in addition to moisture retention: for example, seaweed, poultry manure and sewage sludge provide excellent nutrition, while chopped straw provides wind shelter at the sand surface. There are also a range of chemical preparations, occasionally referred to as mulches, but better described as binders or stabilisers, which do little to retain moisture in the soil, but which increase its resistance to wind and water erosion. They may be needed in combination with a mulch to prevent wind blow. Within limits, the rate of seedling establishment improves with the amount of mulch used and the next two paragraphs describe the use of mulches which are often locally available in quantity and may be spread by hand to a thickness of 1-5 cms, but which are generally unsuited to hydraulic seeding. With this thickness of mulch layer, a stabiliser is not required. The following section describes the use of mulches in the hydraulic seeding method where the mulch layer is only of thickness 0.1-0.5 cms

Bog Peat:

This is a cohesive material with a water content around 60% and is usually available for the asking in north and western Scotland. An uplift site accessible to vehicles must be found and care must be taken not to excavate hollows in the peat which will waterlog and present a danger to grazing animals. The peat may be barrowed to form heaps on site (start at the back, as a wet peat surface is slippery) and chopped up and spread by spade: aim at a 2 cm layer. Inevitably the finish will be lumpy, but even a surface scattered with fist-sized lumps will give remarkably good results. Sow the seed at 25 g/m^2 and rake into the peat/sand surface.

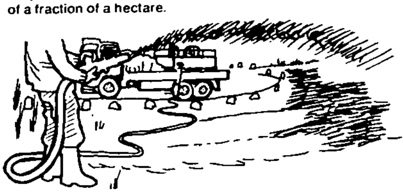


Seaweed:

This is available on many beaches during the high tides of spring but may be in short supply in summer. As the water content is high (around 85%) large quantities are required and usually a tractor and trailer will be used on the beach for collection. Although the seaweed may be stored and allowed to dry and rot, nutritional value is lost and it is better spread wet, in which case seed should be sown at 25 g/m² and raked into the ground prior to mulching so as to avoid direct contact with the seaweed and any salt water. Aim at a 5 cm layer of wet seaweed which will dry out in a period of weeks to form a layer perhaps 1 cm thick. Such a layer may be taken as supplying all the potash requirements for a year's growth, plus half the nitrogen but little of the phosphate.

Hydraulic Seeding

In this mechanical operation, seed, fertiliser, mulch and stabiliser are sprayed in one single operation from a lorry-mounted tank. The mulch material for this method must be finely divided and wood chips, fibre glass, chopped straw, granulated peat, chicken manure and sewage sludge have all been used. There is room for more experience on which form the better mulches. As the mulch layers are generally thin and light, a stabiliser must be incorporated in the slurry. The advantage of the method is that large areas can be treated uniformly with a minimum of labour, and embankments can be seeded without the need to disturb the sand by walking over it. However, the seed are sown virtually at the surface, so that the rate of germination may be slower than for methods described above. The mulch layer is no protection against trampling, and hydraulically seeded areas must be given full protection from pedestrians and animals. The seeding operation is speedy, perhaps an hour per hectare, but a large element of the cost lies in bringing the purpose-built lorry to the site so that the method is uneconomic for areas of a fraction of a hectare.



Seeding With Topsoil

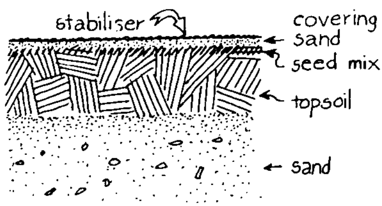
Where an area is required for use by pedestrians or animals within a short period after seeding, a thick layer of topsoil should be used to provide firm rooting for the young grass. Typical areas for which this treatment is desirable are car park verges or eroded areas around camping site toilets. The topsoil should be at least 10 cms thick to accommodate the bulk of the routing system. A stabiliser is unnecessary except on light soils, and on account of the inherent fertility in a topsoil, there is less need for intensive after-care than with other methods. However, apart from cost, there can be several other disadvantages in the use of topsoil. First, it may contain a high proportion of stone, whose appearance above the soil surface is unsightly in an environment which is otherwise pure sand; second, it will contain weeds and weed seeds which will lead to a dumped waste appearance of the resultant sward if not controlled; and third, suitable machinery will be required to spread the soil, except on very limited areas. Lastly, topsoil should not be used in areas where it is hoped that dune grasses will colonise, as their thick rhizome systems may have difficulty in propagating through heavy soils.

Sow seed at 20 g/m², rake in the seed, stone-pick the surface and hand-finish or roll.

Seeding on Topsoil With a Sand Covering

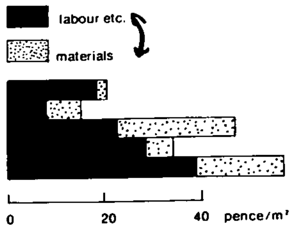
Where the appearance of the seeded area is important, the above treatment may be modified after sowing. Instead of raking the seed into the soil, it may be simply covered by a layer of sand 2 cm thick. In this case, a stabiliser is necessary to stop wind-blow of sand and seed. Although weed species will still grow, the result is to cover the topsoil so that residual stones are buried and so that the area blends well in appearance with adjacent sand areas. The method can be used to good effect on car park verges where a firm substrate is desirable: a firm foundation of hard core may form the base under topsoil.

Pick out larger stones, sow seed on topsoil surface at 20 g/m², cover with a layer of sand by hand-shovelling with a scattering action, apply a stabiliser to the sand surface.



Seeding Technique	Relative resistance to trampling during establishment	Speed of Establishment	Stabiliser
Sand	low	slow	yes
Mulch	medium	medium-fast	no
Hydraulic Seeding	low	medium-slow	yes
Topsoil	high	fast	no
Topsoil and sand cover	medium	fast	yes

An indication of cost 1980 —



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NUTRITION

Initially, a major deficiency of potash and phosphates requires correction in dune soils, while nitrogen requires regular replenishment as it may be washed through sandy soils in a matter of weeks. If topsoil is not used, there is a strong risk of inhibiting germination and young growth by the presence of the fertiliser salts in sand and fertiliser application should be delayed until after the germination period, perhaps a month after sowing and at bimonthly intervals over the growing seasons (mid-April, mid-June and mid-August) with the first application supplemented by superphosphate.

Suitable applications are:

initial dressing 4:10:10 — g/m² of nitrogen : phosphate : potash
subsequent dressings 4:2:2

For example, these correspond to applications of 18 g/m² of 'SAI No. 2,'' UKF No. 5,' or 'Multi-Crop' fertilisers, supplemented by – in the initial dressing – 50 g/m² of 'Potassic Supers,' or 32 g/m² 'UKF No. 11,' or 40 g/m² Double Season PK' fertilisers.

After establishment, nutritional policy depends upon the success of establishment of sown species and upon whether a new topsoil was provided. Where topsoil is used and grass and clover establish well, the sward may need little attention after its first growing season. Where the reseeding is on sand, with or without a mulch, a prime objective should be build up a sound organic layer through productive growth, and to this end the above programme of fertilisation should only be phased out after a few years growth.

AFTER SEEDING

Fences which serve to protect the seeded area from grazing or trampling should be checked regularly, as in dune areas they may become sanded up or undercut. At the end of a first growing season, expect around 70% leaf cover, which will die back in the first winter but which should become entire in the second growing season. The grasses are unlikely to flower in their establishment season but at least ryegrass should do so in the second season. When clover does not establish in the first season, it may be oversown in the shelter of the grass foliage the following spring. Where only a sparse growth of ryegrass survives, it is likely that the area is subject to too much blown sand.

ACKNOWLEDGEMENTS

The advice in this sheet stem from the Countryside Commission for Scotland's own experience in dune pasture reseeding, much of which has been in north-west Scotland, and it places heavy reliance on the experience of the Grassland Husbandry Division of the North of Scotland College of Agriculture and the Sports Turf Research Institute, to whom the Commission extend their thanks. There are few detailed records of the success of reseeding dune pastures, so that the recommendations are no guarantee of success, and records of further experience in this field will be most welcome.

CONSULT for additional details the following sheet:

4.5 Soil Stabilisers for Ground Cover Plants

SEE ALSO sheets:

4.4 Fertilisers for Ground Cover Plants
4.6 Mulches for Ground Cover Plants
5.2.1 Beaches: Dune Grass Planting

APPENDIX 7

FERTILIZERS USED IN EXPERIMENTAL TRIALS

Fertilizer	Type and form	Analysis
	Fast-release inorganic	
Ammonium nitrate	pellet	34.5% N
Ammonium sulphate	powder	20.6% N
Sodium nitrate	pellet	16.5% N
Superphosphate	powder	18% P_2O_5
Potassium sulphate	powder	50% K_2O
	Slow-release inorganic	
Gold - N	pellets of sulphur coated urea	32% N
Osmocote (A)	Pellets of resin coated inorganic fertilizer	26% N
Osmocote (B)	"	18% N, 6% P_2O_5, 12% K_2O
Enmag	granular magnesium ammonium phosphate and potassium sulphate	5% N, 24% P_2O_5 10% K_2O, 8.5% Mg
Nitroform	granular urea-formaldehyde	38% N
IBDU	granular iso-butylidene diurea	31% N
	Organic	
Sewage sludge	granular dried digested	2% N
Fishmeal	granular dried	9% N

Prices at July 1979 on 1 tonne order basis

Ammonium nitrate	£4.25
Superphosphate	£5.75
Potassium sulphate	£4.65
Osmacote	£61.00
Gold - N	£15.00
IBDU	£25.40
Enmag	£17.34

Extract from Johnson (1979).

Species	Sand	Couch	Sea	Lyme	Hybrid marram	Marram	
Fertilizer type	Inorganic Fast-release Calcium ammonium salt petre+ superphosphate	Inorganic Fast-release Ammonium nitrate (34.5%N) + superphosphate	Inorganic Fast-release Calcium ammonium salt petre + superphosphate	Inorganic Fast-release Ammonium nitrate (34.5%)	Inorganic Fast-release Calcium ammonium salt petre + superphosphate	Inorganic Fast-release Calcium ammonium salt petre	Inorganic Fast-release Ammonium nitrate (34.5% N)
Composition $N : P_2O_5 : K_2O$	4: 1: 0	1: 1: 0	1: 0: 0	1: 0: 0	1: 0: 0	1: 0: 0	1: 0: 0
Rate kg ha^{-1} yr^{-1}	80N $20P_2O_5$	50N $50P_2O_5$	20N	50N	20N	20N	50N-150N (Optimum 75N)
Application periods	March June Sept	March	March June Sept	March	March June Sept	March June Sept	March
Location	Holland	England	Holland	England	Holland	Holland	Wales and England
Authority	Adriani & Terwindt (1974)	Johnson (1979)	Adriani & Terwindt (1974)	Johnson (1979)	Adriani & Terwindt (1974)	Adriani & Terwindt (1974)	Johnson (1979)

Fertilizer treatments that have given increased growth of dune grass. These are not recommended doses and cannot be relied upon to give good results in other sites and in different weather conditions. Note Johnson's results for sand couch-grass and lyme-grass were obtained on pot plants in greenhouse; the rest are based on field trials.

APPENDIX 8

Beach Protection Authority of Queensland.

Coastal Sand Dunes

Their Vegetation and Management

Leaflet No.III-01
ISSN 0313-7796

IMPORTANCE OF DUNE VEGETATION

Function, characteristics and zonation of dune vegetation

Function and characteristics

Vegetation plays an important part in the formation and stabilisation of coastal sand dunes. Pioneer plants trap and hold windblown sand in the frontal dune and help create conditions which encourage the establishment and growth of other plant communities such as woodland, scrub, heath and forest. All plants, whether they are herbs, shrubs, or trees, either growing singly or in groups, have a role in the development of vegetative cover and together they bring about dune stabilisation.

Windblown sand trapped in the frontal dune by vegetation serves as a reservoir of sand for the beach during periods of wave erosion. In the absence of sand trapping dune vegetation, windblown sand from the beach moves inland and is lost to the beach/dune system. Wind erosion of the beach and unvegetated frontal dunes results in coastline recession.

The above-ground parts of dune plants act as obstructions, increase surface roughness, and cause reduction in the surface speed of sand carrying wind. The reduction in wind movement results in the deposition of sand on and around

DUNE VEGETATION **CAN**	DUNE VEGETATION **CANNOT**
PREVENT WIND EROSION by decreasing wind speed at ground level	PREVENT DIRECT WAVE EROSION – dune sand is not strongly bound by roots under wave attack
BUILD UP SAND DUNES and thus REDUCE THE EXTENT OF RECESSION PRODUCED BY A STORM	SURVIVE DIRECT WAVE ATTACK – much of the seaward vegetation will be destroyed in a storm
REDUCE WAVE EROSION CAUSED BY OVERWASH where dense vegetation exists	TOLERATE EXCESSIVE PHYSICAL DAMAGE – caused by people, stock or vehicles
REGENERATE NATURALLY AFTER STORM DAMAGE – where dune management allows	TOLERATE MISMANAGEMENT such as:–
TOLERATE A HOSTILE ENVIRONMENT – of high winds, salt spray, sand blast, covering by sand, sandy soil and little water	MOWING: which destroys some species and juveniles of others
ACCEPT MASSIVE MOVEMENTS OF THE DUNES both vertically and horizontally	TOPSOILING: which prevents free drainage and is unsuitable for growth of many natural dune species
FUNCTION AS A SELF SUPPORTING COMMUNITY where plants are mutually dependent for protection and nutrient supply	OVERFERTILIZING: which can be toxic to some species
	INTRODUCTION OF UNSUITABLE PLANT SPECIES: some undesirable plants displace natural vegetation – others such as palm trees do not reduce wind erosion and accelerate wave erosion when they fall.

the plant. Sand spinifex grass *(Spinifex hirsutus)* is the most successful sand trapping plant colonising dunes along most of the Queensland coastline. It has the ability to grow through accumulations of windblown sand. Cycles of sand deposition and plant growth result in dune formation and buildup.

The development of vegetative cover on newly formed dunes, if undisturbed, will create conditions which suit the colonisation and growth of a wider range of plant species. The shade produced by plants keeps surface temperatures lower than on bare sand and together with reduced wind movement, helps to lower the evaporation rate from the sand surface. Increasing vegetative cover further reduces wind movement which results in a lower rate of water loss from plant leaves. Dead plants and leaf litter add humus to the sand and act as a mulch.

The accumulation of humus results in improved moisture and nutrient holding capacity of developing dune soils. Thus, with lower surface temperatures and increased moisture and nutrient content, the sand is able to support a greater variety of plants. In this way the vegetative cover on the dune increases and movement of sand by wind is further decreased.

Pioneer plants make up the initial dune vegetation. They are found on the dune nearest the sea where their survival depends on their ability to establish, grow and reproduce in order to colonise newly forming dunes. Pioneer plants must also tolerate salt spray, strong winds, sandblast, and occasional inundation by sea water. Plants with these characteristics are ideally suited as agents for initial stabilisation of dunes.

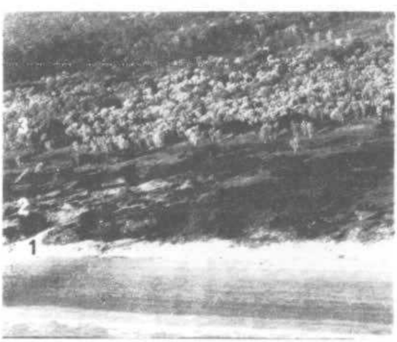
Plant communities such as woodland, scrub, coastal heath or forest occur on dunes landward of the pioneer zone. They are usually in zones roughly parallel to the coastline and the type of zonation present is described below.

Zonation

The aggregation of plants on coastal sand dunes form, in general, three zones of vegetative cover:—

1. A pioneer zone with primary stabilising plants consisting mostly of herbaceous species.
2. A woodland (or scrub) zone with secondary stabilising plants consisting of shrubs, vines, stunted trees and a few associated herbs.
3. A forest (or heath) zone with tertiary stabilising plants composed of trees (or coastal heath).

Variation in vegetation zonation landward across coastal sand dunes is associated with decreases in the degree of exposure to salt spray, strong winds and sandblast, and with improvement in the nutrient status and moisture content of developing dune soils.



Vegetation zonation on coastal sand dunes

1. Pioneer zone
2. Scrub and shrubland zone
3. Forest zone

1. Pioneer zone
2. Woodland zone

Beach Protection Authority of Queensland.

Coastal Sand Dunes

Their Vegetation and Management

Leaflet No. V-08.1
ISSN 0313 7798

MANAGEMENT GUIDELINES FOR DUNE USAGE

Raising tree seedlings in the nursery

Introduction

Several tree species which grow on coastal sand dunes in south eastern Queensland are raised in the nursery at the Authority's Sand Dune Research Station on South Stradbroke Island. Nursery raised tree seedlings are used in planting programs for dune stabilization both on the Island and elsewhere along the Queensland coastline.

Some of the tree species raised were horsetail she-oak (*Casuarina equisetifolia* var. *incana*), coastal banksia (*Banksia integrifolia*), coastal tea-tree (*Leptospermum laevigatum*), paper-

Tubed seedlings of horsetail she-oak and coastal banksia placed on beaches in the open to "harden" prior to planting out on dunes.

barked tea-tree (*Melaleuca quinquenervia*), coastal wattle (*Acacia sophorae*), Brisbane black wattle (*Acacia leiocalyx*) and Cyprus wattle (*Acacia cyanophylla*).

Seed collection

Seed is collected from mature healthy trees growing on coastal dunes. Horsetail she-oak sets seed from November through to April. The round woody cones containing small winged seeds are collected as they lose their green colour and as valves enclosing the seed begin to open. Coastal banksia sets seed from October through to December. The woody cylindrical cones are collected when their colour changes from green to brown and the capsules enclosing the flat, winged seeds begin to open. Tea-tree capsules and wattle pods can be harvested in November and December. Seed cones, capsules or pods are spread out on hessian or plastic sheets and seed is collected as the valves open and shed the seed.

Seed storage

Seed should be treated with insecticide and fungicide to prevent insect and fungal damage and then stored in airtight containers such as screw cap glass jars.

Seed germination

Seeds are planted in seed beds containing a mixture of equal amounts of vermiculite and sand, or loam and sand. Small seeds are sprinkled evenly on the surface of the seed bed and lightly covered with a thin layer of sand. Larger seeds are sown at a depth equivalent to their size. The sown seed beds are kept moist, but not saturated, by watering with a fine spray. During winter the seed beds can be covered with a clear plastic (or glass) enclosure to hasten germination. The plastic (or glass) enclosure should be removed each day during summer. Another method of germinating seed, particularly banksia and wattle seed, is to place the seed between layers of wet hessian. Wattle seeds have a hard outer seed coat which often hinders germination. To promote germination the wattle seeds can be mechanically scarified or dipped in boiling water or dilute sulphuric acid. After treatment germination is more rapid and germinated seeds can be planted direct into tubes or pots.

Transplanting from seed beds

Tree seedlings are transplanted from seed beds into tubes or pots filled with sandy loam or an organically rich sand mix. She-oak, banksia and tea-tree are transplanted when they are 7-8, 3 and 3-5 cms high respectively. Wattles are usually transplanted when the first undivided "leaf" appears.

Care must be taken at transplanting to avoid damaging the seedling roots. Individual seedlings are placed in tubes with the stem of each seedling inserted in the soil to about the same depth as it was when growing in the seed bed. The soil is pressed around the seedling so that it stands erect and firm in the centre of the tube.

Tubed seedlings are then placed in a shadehouse constructed from plastic shade cloth (giving about 50% shade) supported by a wooden or metal framework.

"Hardening" the seedlings

At about 2-3 weeks after transplanting the tubed seedlings are usually sturdy enough to be moved from the shadehouse to outside benches (see photo) to grow and "harden" before planting out on sand dunes. She-oaks are normally ready for dune planting when about 30-40 cms high (after 6 months); banksias when 20-30 cms high (after 4-5 months); wattles when 20-30 cms high (after 2-3 months); and tea-trees when 30-40 cms high (after 4-5 months).

Nursery hygiene, pest and disease control and fertilizer treatment of tubed tree seedlings, are discussed in a subsequent leaflet.

Beach Protection Authority of Queensland.

Coastal Sand Dunes

Leaflet No. V-06.2
ISSN 0312-7796

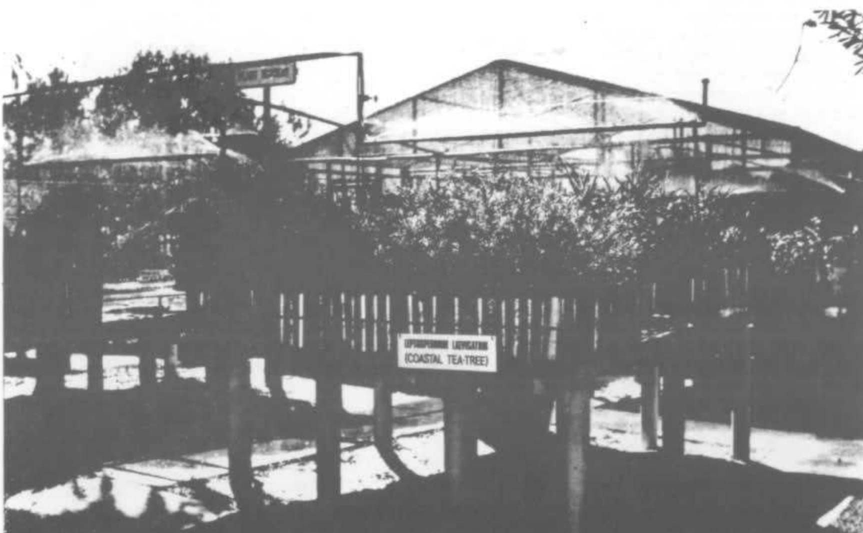
Their Vegetation and Management

MANAGEMENT GUIDELINES FOR DUNE USAGE

Raising tree seedlings in the nursery

Introduction

Tree seedlings for use in planting programmes for dune stabilization are raised in the nursery at the Authority's Sand Dune Research Station on South Stradbroke Island. Some of the tree species raised are listed in Leaflet No. V–06.1 which also contains information on seed collection, seed storage, seed germination, transplanting from seed beds and "hardening" the seedlings. This leaflet briefly describes nursery hygiene, pest and disease control and the application of fertilizer to tubed seedlings.



Watering tubed tree seedlings on outside raised benches at the nursery.

Nursery hygiene and disease control

Seedlings are grown in seeds beds or more preferably in raised seed boxes in the shadehouse. A good growing medium consists of equal amounts of vermiculite, peat moss and organically enriched sand. To remove soil borne pathogens, such as the fungi *Phytophthora cinnamomi* which causes root rot of tree seedlings and *Pythium* spp. which cause damping-off of tree seedlings, it is advisable to sterilise the soil prior to its use. Steam sterilisation is ideal as only the pathogenic organisms are destroyed and the beneficial organisms are not harmed. If steam sterilisation is not possible the soil is fumigated using a soil sterilant such as methyl bromide (e.g. Dowfume Mc.2®).

Having prepared the seed boxes, using sterilised or fumigated soil, and planted the seeds, an application of a systemic fungicide is usually carried out to prevent disease damage to the emerging tree seedlings. Fungicides such as propamocarb (e.g. Previcur N®) are used to control damping-off and fungicides such as metalaxyl (e.g. Ridomil MZ®) are used to control root rot.

Particular care should be taken when applying Ridomil to seed boxes planted with horsetail she-oak (*Casuarina equistifolia* var. *incana*). Damage to young seedlings has been observed with Ridomil applied at the recommended rate of 5 g/m². Ridomil applied at 2 g/m² appears to give good disease control without damaging the seedlings. When ready the tree seedlings are transplanted from the seed boxes into tubes or pots filled with an organically rich sand mix which has been sterilised or fumigated as previously described.

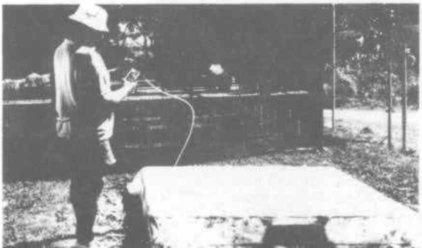
Strict nursery hygiene is the best method of preventing an outbreak of disease. Root rot caused by the fungus *Phytophthora cinnamomi* can cause large losses in stock of many coastal tree species. This disease is transmitted in water. If contamination is suspected the water should be chlorinated before being used in the nursery. All seed boxes and planter tubes should be stored on raised benches so that excess water can drain away quickly. Ideally the nursery and shadehouse floors should be concreted to allow easy cleaning. All equipment used in nursery operations should be kept clean.

Pest control

Insect pests are generally not a problem in the nursery. However occasional attacks by leaf rolling moths (Family *Tortricidae*) can occur. The caterpillar form (pupa) of these moths can cause extensive leaf damage to young seedlings and coastal tea-tree (*Leptospermum laevigatum*) and coastal wattle (*Acacia sophorae*) are particularly susceptible. Spraying the tree seedlings with an insecticide such as endosulfan (e.g. Thiodan®) is a safe and effective means for pest control.

Fertilizing tubed seedlings

The early growth of tubed tree seedlings can be improved by the application of a water soluble fertilizer containing balanced amounts of nitrogen, phosphorus, potassium and trace elements e.g. Aquasol® (23% N: 4% P: 18% K plus trace elements). Fertilizing can start about 2 weeks after the seedlings have been transplanted into tubes and can continue at 4–6 week intervals. Fertilizing should stop about 4 weeks before planting out on the dunes to allow the tree seedlings to "harden". Heavy applications of fertilizers high in nitrogen to wattle and she-oak seedlings should be avoided as this tends to suppress nodulation. The formation of nodules on the roots of these tree seedlings is necessary to allow the seedlings to convert atmospheric nitrogen into soluble nitrates which are used by the plants.



Using methyl bromide to fumigate soil beneath the sealed plastic sheet.

Filling planting tubes with an organically rich sand mix.

Coastal Sand Dunes

Leaflet No. V–06.3
ISSN 0312-7796

Their Vegetation and Management

MANAGEMENT GUIDELINES FOR DUNE USAGE

Planting tree seedlings on coastal sand dunes

Introduction

Information on raising tree seedlings in the nursery is given in Leaflet No. V–06.1 and Leaflet No. V–06.2. This leaflet describes how nursery raised tree seedlings are planted on coastal sand dunes after they have been "hardened" for a suitable period of time on outside raised benches at the nursery. The size and age of tree seedlings planted on dunes varies according to species. For example horsetail she-oak (*Casuarina equisetifolia* var. *incana*) is usually ready for dune planting when about 30–40 cms high (after 6 months); coastal banksia (*Banksia integrifolia*) when 20–30 cms high (after 4–5 months); coastal wattle (*Acacia sophorae*) when 20–30 cms high (after 2–3 months); and coastal tea-tree (*Leptospermum laevigatum*) when 30–40 cms high (after 4–5 months).

Horsetail she-oak trees planted on the crest of the frontal dune at Noosa Beach. Coastal banksia and coastal wattle were planted on the sand dune areas landward of the frontal dune crest.

Planting sites

Tree seedlings can be planted on the crest and landward slope of the frontal dune and in dunal areas landward of the frontal dune. Planting is usually not carried out on the seaward slope of the frontal dune as this mobile zone is more susceptible to the deposition of sand blown from the beach and to removal by wave erosion. Horsetail she-oak (refer Leaflet No. IV–02) is usually planted on the crest and landward slope of the frontal dune because of its ability to grow in areas exposed to strong winds, salt spray and windblown sand. Tree seedlings of coastal banksia (refer Leaflet No. IV–06), coastal wattle, coastal tea-tree and other coastal species are usually planted in protected dunal areas landward of the crest of the frontal dune.

Planting time

Tree seedlings can be planted on coastal sand dunes when there is sufficient moisture in the sand to give the seedling a good chance of establishment. Spring and autumn are usually the best times to plant. Planting during the dry winter months and very hot periods during the summer months should be avoided.

Planting method

The photographs illustrate the method used to successfully plant horsetail she-oak seedlings on coastal sand dunes. The method shown can be used to plant most types of tree seedlings recommended for dune management projects.

Step 1: The sand should be moist and the planting hole should be deep enough to allow the roots to be completely buried with the top of the soil core containing the roots being about 5 cms below the sand surface.

Step 1

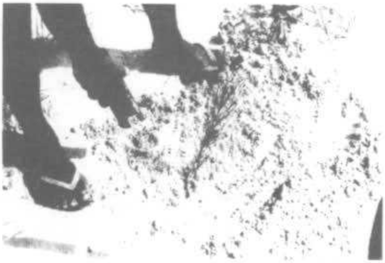
Step 2: The tree seedling is carefully removed from the planting tube ensuring that the soil core containing the roots is not disturbed. If the soil core containing the roots has been kept moist then removal of the tree seedling from the tube is made easier.

Step 2

Step 3: The tree seedling is placed in an upright position against the side of the planting hole which is then filled with moist sand.

Step 3

Step 4: The sand around the planted tree seedling is tamped to set the seedling firmly in the planting hole and to ensure that the soil core containing the roots is in contact with the surrounding moist sand.



Step 4

APPENDIX 9

USEFUL ADDRESSES

Beach Protection Authority,
GPO Box 2195, 231 Turbot Street,
Brisbane, Queensland 4001,
AUSTRALIA.

British Trust for Conservation Volunteers Ltd,
Zoological Gardens,
Regents Park,
LONDON NW1 4RY,
UK.

Countryside Commission,
John Dower House,
Crescent Place,
CHELTENHAM,
Glos GL50 3RA,
UK.

Countryside Commission for Scotland,
Battleby,
Redgorton,
PERTH,
Scotland,
UK.

Institute of Terrestrial Ecology,
Monks Wood Experimental Station,
Abbots Ripton,
HUNTINGDON, Cambs PE17 2LS,
UK.

National Park Service Cooperative Research Unit,
The Environmental Institute,
University of Massachusetts,
Amherst, 01003,
Massachusetts,
USA.

National Trust,
42 Queen Anne's Gate,
LONDON SW1,
UK.

Nature Conservancy Council,
Northminster House,
PETERBOROUGH PE1 1UA,
UK.

United States Army Coastal Engineering Research Center,
Kingman Building,
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Virginia 22060,
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