Geo Factsheet

Number 119

The Geography of Coastal Sand Dunes

Introduction

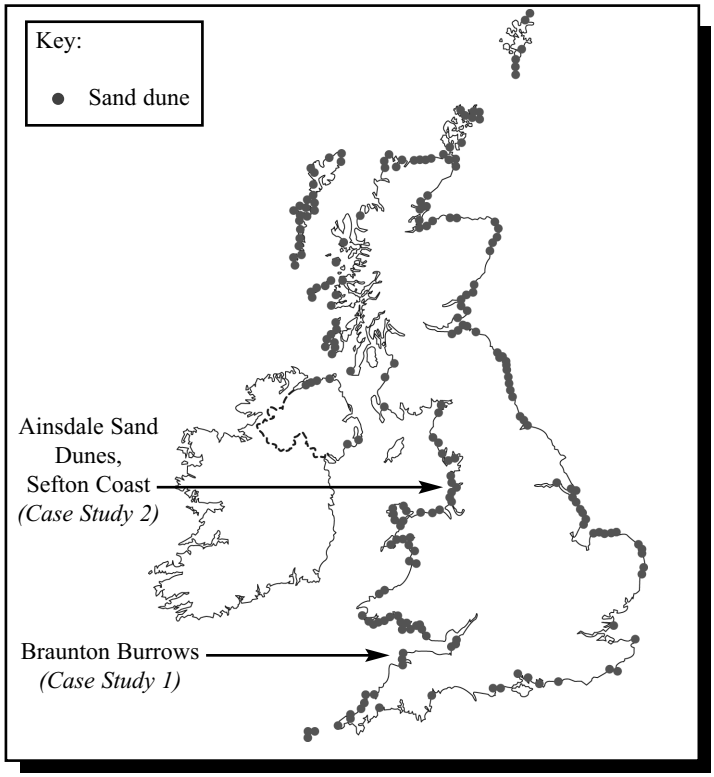
Sand dunes are simply accumulations of sand grains, shaped into mounds or ridges by the wind under the influence of gravity. Sand dunes are found wherever loose sand is windblown: in deserts, on coasts, and even some eroded and abandoned farm fields in parts of north west India and the south western United States. They tend to be less well developed in tropical and subtropical zones due to lower wind velocities and damper sand.

Until thickly vegetated, dunes are a very fragile environment, and heavy use - through recreation, for example - may cause the break-up of the roots, ultimately causing the destruction of the dune system. They are, therefore, a very dynamic system. Dunes can be classified as true dunes formed without vegetation, or dunes such as coastal dunes which are formed in conjunction with vegetation.

Formation of coastal sand dunes

Coastal dunes are found where beach sands have been reworked by the wind. The predominant source of material for dune creation is the sea bed and rivers which flow into the sea or through coastal areas. **Macro-tidal** environments (large tidal range) combined with onshore winds and wind-driven currents provide the ideal conditions for dune evolution. These are likely to form in zones of net sediment accumulation. In some areas, such as East Anglia, complex sediment transport systems can cause material which is eroded in one part of the coast to be transported, and eventually deposited in another location, sometimes fuelling the development of new dunes. *Fig. 1* shows the distribution of sand dunes in the UK. Note that sand dunes are found on all British coasts, but they are more sparsely distributed in the south and south east.

Fig. 1 Distribution of UK sand dunes.



Coastal sand dunes are diverse ecosystems, involving a complex interaction between plant communities **(biotic)** and environmental **(abiotic)** conditions. Sand dunes should be regarded as dynamic entities, with stages and interplays between building phases and erosion. Their appearance is very variable depending on climate, underlying relief and past and present management.

Succession and Zonation

The **structure** of the sand dune ecosystems is constantly changing. All plant communities and environments are subject to periodic disturbances, ranging from events that have only localised effects, such as the fall of a tree, to those which have catastrophic effects, such as huge storms which pound the coastline. Each new disturbance creates an opportunity for a new species to colonise the area. New 'invaders' will also modify the character of the environment, creating an environment that is suitable to other new species. By this process, known as **succession**, the structure of the community evolves over time.

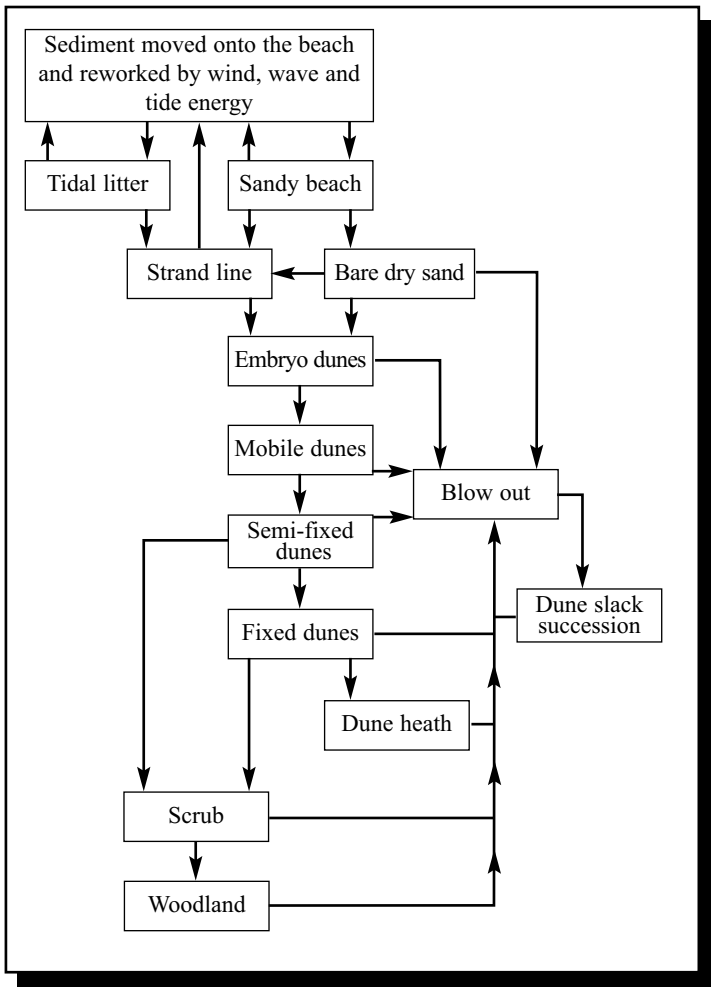
There are two different types of succession: **primary** and **secondary**. Primary succession occurs in essentially lifeless areas - places in which the soil is incapable of sustaining life such as recently glaciated areas and newly formed sand dunes. Secondary succession occurs in areas where an ecosystem that previously existed has been removed. This type of succession is typified by smaller-scale disturbances that do not eliminate all life and nutrients from the environment, for example the burning of heathland vegetation on fixed dunes.

Primary and secondary succession both create a continually changing mix of species within communities as disturbances of different intensities, sizes, and frequencies alter the landscape. The sequential progression of species during succession, however, is not random. At every stage, certain species have evolved life histories to exploit the particular conditions of the community (niches). This situation imposes a partially predictable sequence of change in the species composition of communities during succession. *Fig. 2 (on page 2)* helps identify the process of succession in a sand dune system or **psammosere**. Initially only a small number of species from surrounding habitats are capable of thriving in a disturbed habitat and harsh environment. As new plant species take hold, they modify the habitat by altering such things as the mineral composition of the soil. These changes allow other species that are better suited to this modified habitat to succeed the old species. These newer species are superseded, in turn, by still newer species.

Zonation refers to the variation of species or communities over a particular area. For example, variations in salt spray, inundation and the height and salinity of the water table will result in different species occupying (or tolerating) different areas of the dune. In *Fig. 3 (on page 2)* you can see the dune slacks.

As succession is a slow process (and change in soil and vegetation often takes many tens or hundreds of years at any one location), zonation is often used in sand dune studies to show how successions can work. This assumption is simply based on the fact that the dunes nearest the sea or coast are young and they become progressively older as the distance increases inland.

Fig. 2 Schematic diagram showing the development of a dune system.



Sand dune structure

While the nature of dune systems varies considerably both spatially and over time, the following components may be present (refer to *Figs 2* and *3*).

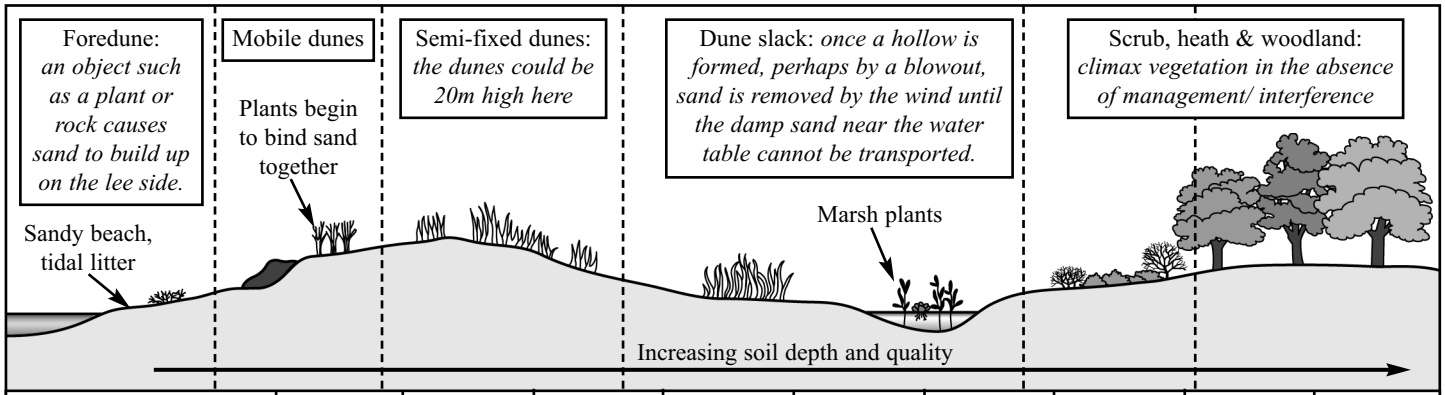
1. ***The Strand Line (youngest dunes).*** Extreme high tides or storm tides may leave a zone of several metres landward of the normal high-water mark. Sand is an inhospitable substrate for plant growth – it is dry, salty, unstable and lacks nutrients. Only highly specialised plants – **pioneers** – can colonise such environments, e.g. Sea Rocket *Cakile maritima* and Prickly Saltwort *Salsola kali*. These annual plants may form miniature dunes as sand gradually accumulates around the plant body (which is able to grow upwards through the accumulating sand).

2. ***Embryo Dunes.*** Sand accumulation which persists above the high tide line may be suitable for colonisation by the first perennial plants in dune succession which are specialised grasses, e.g. Sand Couch *Elytrigia juncea* and Lyme Grass *Lymus arenarius*. Both of these grasses are able to grow upwards through accumulating wind-blown sand, and as a result low, hummocky dunes are formed. The substrate is still extremely inhospitable for plant growth.

3. ***Fore-Dunes (or mobile dunes).*** Upward growth of the embryo dunes allows the dune surface to be raised so that it is out of reach of all but the highest storm tides. Incursion of rainwater results in a slightly less salty substrate so that Marram Grass *Ammophila arenaria* is able to colonise and becomes the dominant species. This remarkable plant is able to grow upwards through accumulating sand at rates of up to 1m/yr. The dead leaves of Marram add organic matter to the soil, increasing its water-holding capacity and releasing plant nutrients. On the more sheltered landward site of the frontal dunes, plants such as Sea Holly *Eryngium maritimum* and Sea Spurge *Euphorbia papalias* become established. The gradual amelioration of conditions results in increasing **species diversity** and less bare ground.

4. ***White or Yellow Dunes (semi-fixed dunes).*** If conditions remain stable, mosses will cover bare sand patches between the Marram and plants, such as Restharrow *Ononis repens* and Sand Sedge *Carex arenaria,* will become common. Species diversity should continue to increase.

Fig. 3 Idealised dune system



Site number/description	Strand line (1)	Embryo dunes (2)	Fore dunes (3)	White/yellow dunes (4)	Fixed dunes (5)	Dune slack (6)	Dune scrub (7)	Dune heath (8)	Woodland (9)
Distance from the sea (m)	0 - 20	20 - 80	80 - 150	150 - 300	300 - 500	500 - 700	(400) variable	700 - 2500	2500+
Approximate age (years)	-	0 - 50	50 - 100	100 - 125	125 - 150	150 - 250	-	250 - 400	>400
Soil colour	-	Yellow			Yellow / Grey		Grey	Brown	
Soil surface pH	8.5	8.0	7.5	7.0	6.5		6.0		4.5
% Calcium carbonate	10	8	8	5	1	<0.1			
% Humus	<1			2.5	5	10	20		>40
Dominant plant species	Sea Rocket, Saltwort	Sand, Couch, Lyme Grass	Marram Grass, Sea Holly	Marram, Sand Sedge	Harebell, Willow	Creeping Willow, Common Sallow	Birch, Brambles	Heather, Gorse	Pines, Oaks

5. ***Fixed Dunes (stabilised dunes).*** When the vegetation has developed so that it forms a cover on the substrate, the dunes are said to be 'fixed'. This is still a stressful environment with low nutrient status (nitrogen limited) and a risk of plant desiccation. In addition to these, the dunes may be influenced by grazing and trampling. However an organic layer has started to form on the soil surface. If the dunes are grazed by rabbits or sheep, a fixed dune grassland will develop. Together with a number of flowering plants, mosses, lichens, fixed dune grassland can be a very species-rich vegetation, e.g. Ladies' Bedstraw *Gailium verum*, Wild Thyme *Thymus polytrichus* and Harebell *Campanula rotundiflia*. These areas are of considerable conservation importance. In areas which are not so heavily grazed, plants such as Creeping Willow *Salix repens* can become dominant. The resulting vegetation has a larger biomass but a lower diversity. In many places the lack of grazing permits the establishment of tall woody plants, which will form **scrub**.

6. ***Dune Slack.*** Depending on the height of the water table, areas between sandy hills may be damp or even contain standing water. Often such areas are well defined and constitute 'dune slacks'. Receiving nutrients leached from the surrounding dunes, they may be occupied by lime-loving species (Calcicoles) and can be floristically rich with local or national rarities (Natterjack toad). Orchid species may sometimes be prominent members of dune-slack communities. The height of the water table is likely to be important. The classification shown in *Fig. 4* is sometimes used.

Table 1

Semi-aquatic habitat	*Water table never more than 0.5m below the soil surface, flooding the surface from winter to spring. Aquatic plants (hydrophytes) strongly represented in the flora.*
Wet slack habitat	*Water table never more than 1m below the soil surface. Plants have their roots within reach of adequate moisture supplies in all seasons. Few grass species, dominated by mosses.*
Dry slack habitat	*Water table lies between 1-2m below the surface during all seasons. Grasses are abundant, also lichens if the area is grazed by rabbits.*
Dune habitat	*Water table never rises above 2m below the surface, so most plant growth is independent of it. Xerophytic species are common (adapted to dry places).*

7. ***Dune Scrub.*** In the absence of grazing animals, succession proceeds within the dune system and tall woody plants such as Birch *Betula spp.* and Hawthorn *Crataegus monogyna* form natural invaders. The dune-scrub areas tend to be species-poor, so in many areas management has focused on the clearing of scrub and introduction of grazing animals to maintain the open dunes.

8. ***Dune Heath.*** If grazing pressure from sheep or cattle prevents the development of a scrub or woodland, then the fixed dune grasslands will eventually develop a different vegetation type. This is known as a plagio-climax because it results from human actions. The vegetation is dominated by plants which are adapted to grasslands and heathlands (calcifuges), tolerating the dry, acid and nutrient poor substrate. A common invading plant to the dune heath is Heather or Ling *Calluna vulgaris*.

9). ***Woodland.*** Deciduous woodland is the natural climax vegetation of the dune system. Trees such as Oak *Quercus Robur* or Scots Pine *Pinus sylvestris* are able to readily colonise the scrub. However the landward margins of many dune systems are typically highly managed, often as golf courses ('links') or as agricultural land, or else natural woodland has been replaced by plantations, e.g. Scots Pine. These are examples of plagio-climax vegetation.

Fieldwork: Ecological Investigation & Impacts

It is usual to use a transect to study sand dune zonation and succession. Starting from the strand line (nearest the sea) a tape is set down at appropriate intervals recording data such as vegetation cover, gradient, soil depth / colour / pH etc. It is important at the design stage to consider the following:

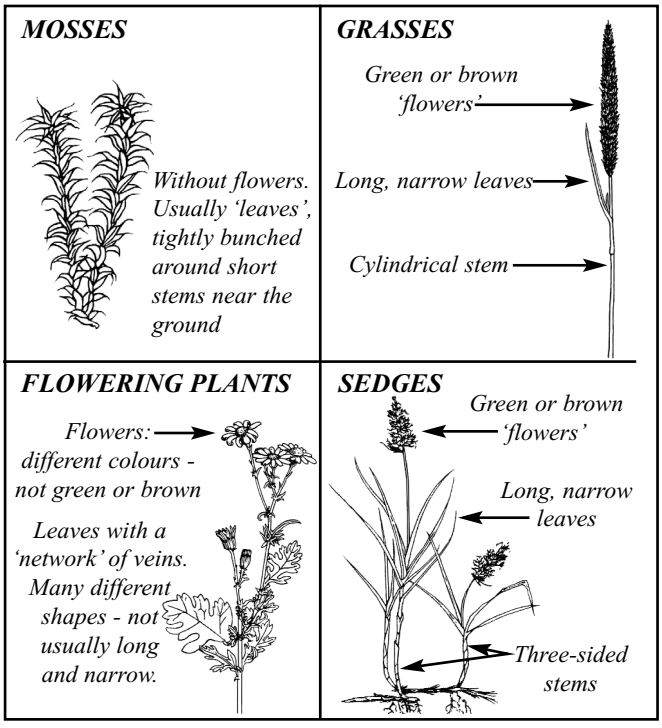
- *What size of quadrat should be used (normally 0.5 x 0.5m is ideal)*
- *What distance should there be between the sampling points – 5, 10, or 20m for example?*
- *Should the distance between the sampling points be regular (implying a systematic approach) or stratified, whereby the interval distances are modified according to the changes taking place. In other words if there are few changes in the data collected, the interval can be extended, but if there are many changes occurring in a short space of time, the sampling interval should be shortened.*
- *What type of vegetation data will be collected: % cover, % frequency of occurrence, height? See Fig 4 which is an aid to plant identification. This is necessary for looking at species occurrence and diversity.*
- *What other abiotic variables are important: gradient, soil type, microclimate (wind, °C)*

Make sure that before the study is carried out, all the appropriate equipment is available and recording sheets are prepared. It is usual to carry out an initial risk assessment of the site prior to collecting any primary fieldwork data and to obtain written permission to visit the site if necessary.

It is also possible to carry out fieldwork investigations which consider the impact of visitors or aim to establish the 'quality' of different aspects of the dune system. These can be linked to visitor surveys and questionnaires. Some ideas or themes might include:

- *What is the impact of trampling by visitors on the plants within the sand dune system?*
- *What would be an appropriate management plan for maintaining plant diversity?*
- *What is the economic importance of tourism in sand dune area X?*
- *Construction of an impact matrix to determine the effects of visitors in sand dune area T.*

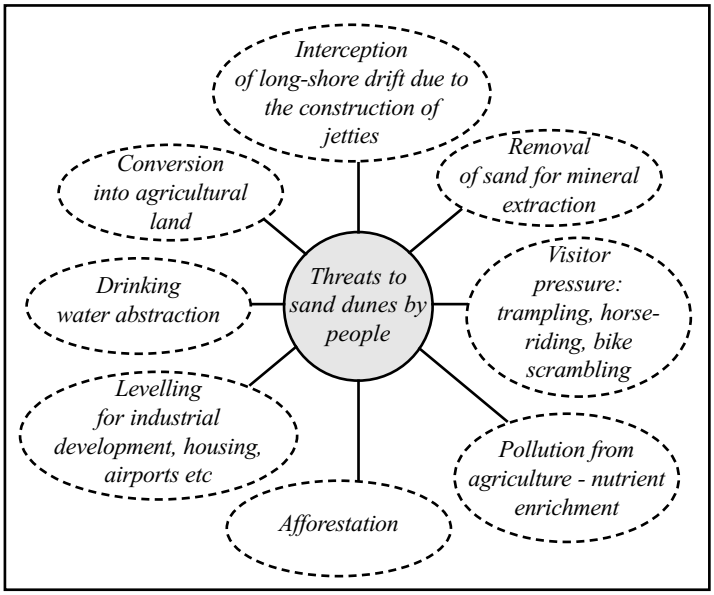
Fig. 4 Examples of dune plants.



Management of sand dune habitats

Sand dune development is largely about increasing stabilisation of loose sand. Sometimes this stabilisation is hindered or even reversed, often through human activity, though more natural coastline erosion is a feature in some areas, notably in East Anglia. *Fig. 5* identifies some of the human-induced threats to sand dunes.

Fig. 5 Human threats to sand dunes.



Destruction of vegetation, exposing the underlying sand to wind, often causes a **blowout**. Once one is initiated, the margins of a blowout may continue to erode, resulting in extensive areas of open sand within what was previously a stabilised zone *(see Fig. 6 right)*. Blowouts, however, are an important element of the dynamic system and can create new **niches** for important flora and fauna.

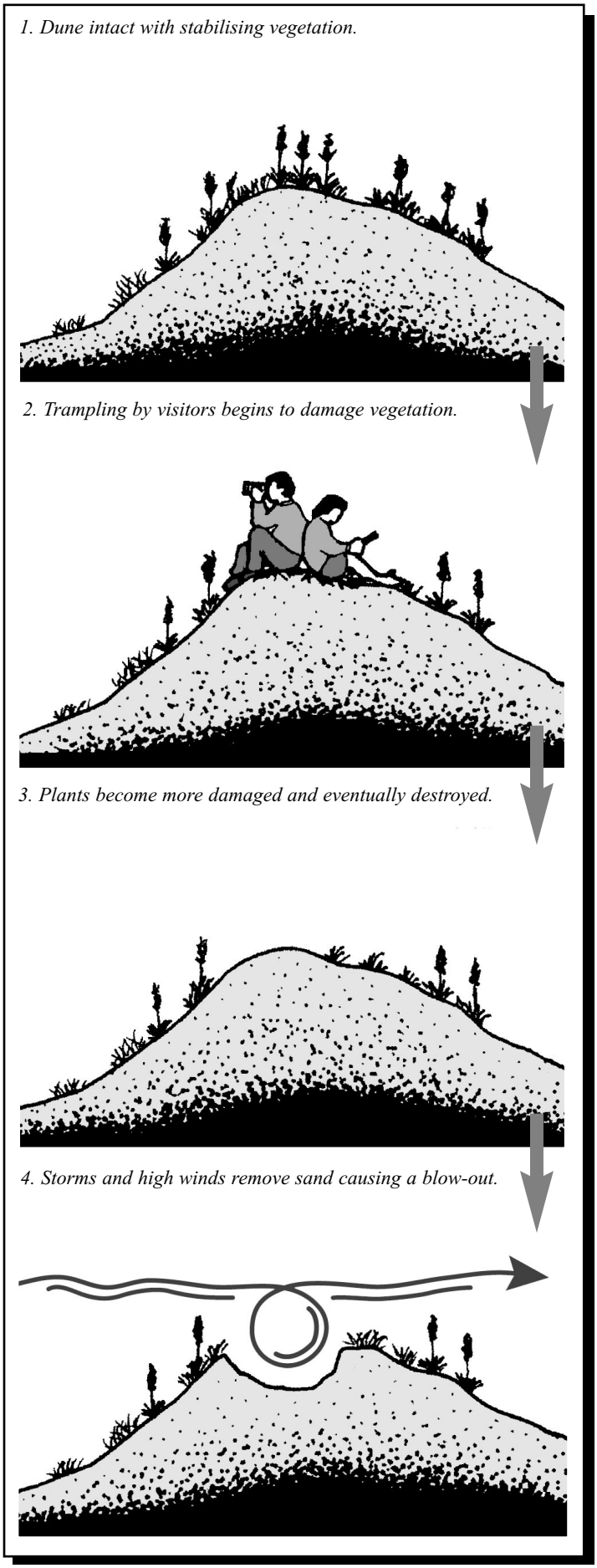
Case Study 1: Braunton Burrows – Conflicts of interest

Despite the wealth of knowledge that exists concerning dune system conservation, some areas still suffer from inappropriate usage and conflicts. Braunton Burrows, in north Devon, is a coastal site famous for its dunes and flowers (Fig. 1). It is one of the largest dune systems in Britain (over 1300 ha) that extends to large dune slacks, grasslands and scrub. It has 400 flowering plant species and 60 species of lichen and is a focal point for migrating birds.

Part of the site was a National Nature Reserve owned by the Christie Estates, yet it has been at the centre of a bitter dispute between the Estate and English Nature. In 1996 an attempt by English Nature to improve the management of the site, through changes to grazing, met with resistance from the Estate. Grazing was to be used to keep down invasive and coarse species and to help maintain the diversity of the flowering plants. The Estate objected to the change in a move that baffled local people and English Nature. The result was that English Nature felt itself forced to remove the National Nature Reserve designation.

It remains unclear whether the site will be re-notified as an NNR in the future. Recently, however, the Environment Agency has reported the successful transplanting of 4000 Marram Grass plants at Braunton Burrows. The area has now been designated as a candidate Special Area of Conservation under the European Habitats Directive and a UNESCO Biosphere reserve.

Fig. 6 Theoretical development of a 'blow-out'.



Case Study 2: Ainsdale Sand Dunes – A Successful Integrated Management Approach

The Ainsdale dunes and foreshore, which include the Ainsdale Sand Dunes Nature Reserve (NNR), have long been recognised as an outstanding area of wildlife interest. The area has many conservation designations, including Ramsar Site, Special Protection Area (SPA), Site of Special Scientific Interest (SSSI) and recently Special Area of Conservation (SAC). A high proportion of the area comprises EU fixed dune priority habitat. Key species include the Sand Lizard, Natterjack Toad and the Petalwort Liverwort.

The area covers approximately 7km² of the 22km long Sefton Coast dune system, with some 5 million people living within 1 hour's drive of the area, putting considerable pressure on this natural resource (see Fig 1). Management of the NNR is controlled by English Nature in conjunction with the Sefton Coast Management Scheme.

Two main threats to this particular resource are identified:

1. ***Scrub and growth of rank vegetation.*** *In particular the invasion of non-native pines and poplars and the establishment of rank grasses and herbs such as brambles.*
2. ***Public pressure.*** *Ainsdale beach is a popular tourist area which leads to dune erosion and loss of habitat quality. Associated activities such as vandalism, fire and the collection of rare species also cause considerable damage.*

The management of this site aims to preserve the range of open sand dune habitats, whilst enabling appropriate public access and informing and educating visitors. This multi-purpose approach is delivered through a range of management strategies:

1. ***Scrub cutting and clearance*** *which is carried out in relatively small areas, due to the labour intensive nature of this activity*
2. ***Mowing*** *to control the height and density of invasive species in the dune slacks.*
3. ***Turf stripping and excavation*** *can recreate the early phases of dune succession, encouraging rare plants such as Petalwort. However this is a destructive and costly approach.*
4. ***Grazing*** *by sheep and cattle has been reintroduced (1990), controlling target species such as Creeping Willow.*
5. ***Dune stabilisation*** *and restoration works have been used in areas where property or infrastructure is threatened.*
6. ***Species management****, for example breeding pools for toads and fencing to separate visitors from the lizards.*
7. ***Visitor management.*** *Visitor management is part of a wider zoning system used on the Sefton Coast as a whole. Honeypot areas (e.g. Ainsdale Beach) are identified along with closed or permit-only sanctuary areas such as the majority of the Ainsdale Sand Dunes NNR. This has the advantage of concentrating tourism in specific areas where intensive management can take place to accommodate the visitors.*

These two case studies hint at the challenges of sand dune management. Successful management often requires a large-scale and integrated approach so that high visitor numbers can be accommodated whilst conserving dune wildlife and spreading an important conservation message. This approach must also accept that changes and instability are an integral part of a dynamic sand dune system.

Further reading

Doody, P. (ed.) 1985 *Sand dunes and their management*, Nature Conservancy Council, Peterborough.
Doody, P. 1986 *The conversation of sand dunes*, Nature Conservancy Council
Carter. 1990 in Nordstrom, K.F. et al. 1990. *Coastal Dunes: Form and Process*, Wiley and Sons, New York.
Hickman, G. and Walker, M. 2001 *Studying Spatial Patterns in Sand dunes*, In Geography Review, Volume 14, No. 4.

Useful websites

www.sandsoftime.hope.ac.uk
www.seftoncoast.org.uk/bestpra1.htm
www.biol.paisley.ac.uk/bioref/habitats/

Practice Exam Questions (AS style)

1. With the aid of an annotated diagram, show how the vegetation changes in a transect across sand dunes from the sea to inland. (10 marks)

2. With reference to a named small-scale ecosystem, examine how human activities can have a damaging impact on the ecosystem. (10 marks)

Advice on answering the question

1. Draw a diagram similar to *Fig. 3* labelling the various dunes (embryo, fixed etc.). Mark on and name typical vegetation types. When writing about the vegetation mention % coverage (bare ground), height of vegetation (layers), diversity of vegetation, age of vegetation etc. Note the command word – show – (describe) not explain.

   Hint: Use the diagram effectively. You must do one but avoid writing annotation which you repeat in your written work.

2. Choose a named sand dune ecosystem, e.g. Ainsdale or Braunton (a named saltmarsh, or woodland, would also be suitable). Describe all the human activities (management, footpath use, grazing, scrambling/trial bikes etc.) and explain how they affect the ecosystem (species, cover, damage etc.).

Both answers will be marked by levels (usually 3 levels for 10 marks).

Acknowledgements;
This Factsheet was researched by David Holmes who works as Geography Advisor for the Field Studies Council. He also teaches at Abbey College in Birmingham and lectures part-time for the University of Birmingham.
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