THE SAND DUNE MANAGERS HANDBOOK

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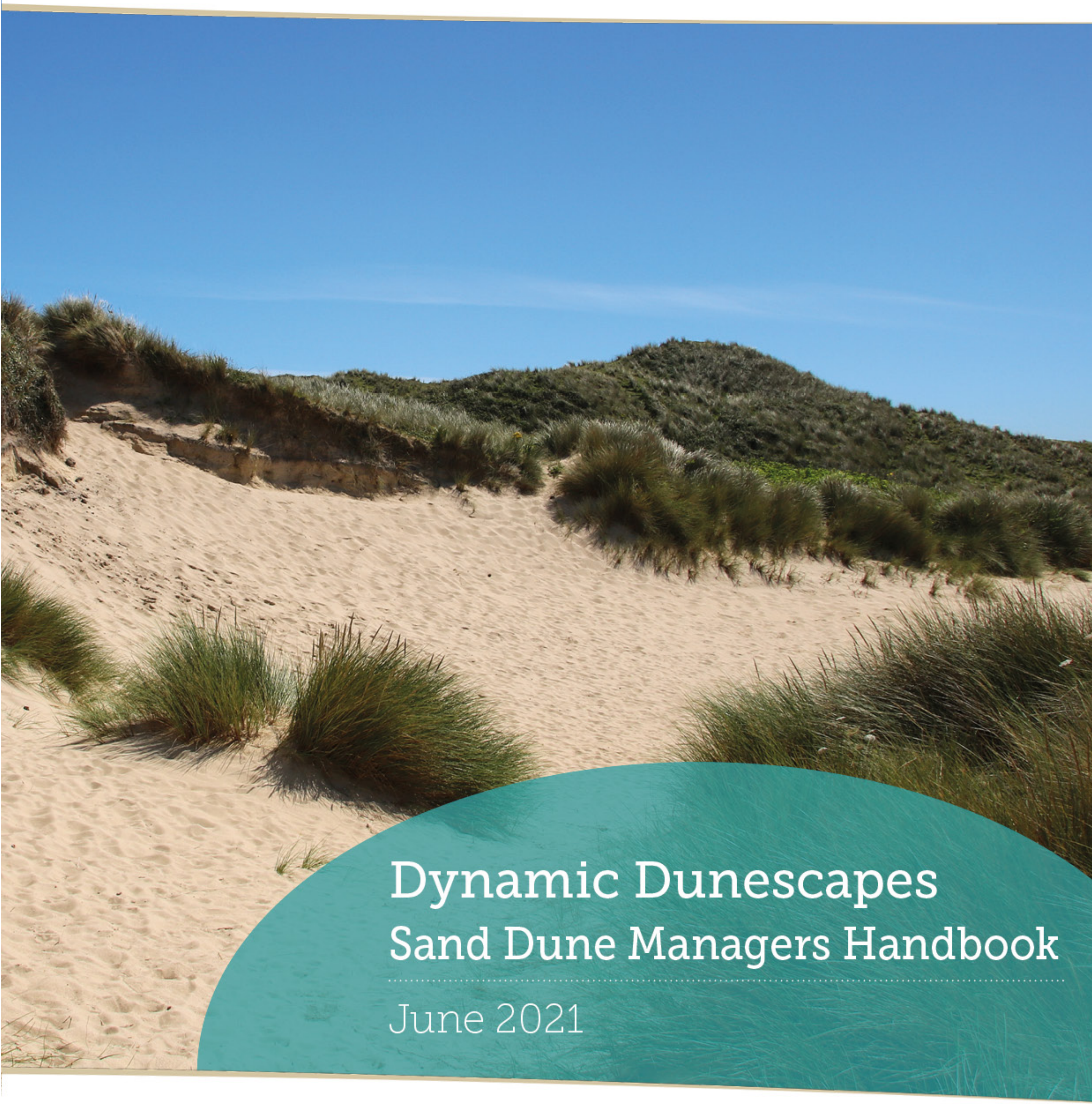


Dynamic Dunescapes
Sand Dune Managers Handbook

June 2021

1. INTRODUCTION

Coastal sand dunes are found on coastlines around the world and support a high level of biodiversity, including many threatened plant, insect and animal species. These dynamic ecosystems are shaped by four key elements: sand, wind, water and vegetation. Sand is the basic material dunes are made of; wind speeds need to be fast enough to pick up the sand grains and move them; groundwater near the soil surface is necessary for dune wetlands to form; plants themselves are the fourth agent, which helps create different types of dune. Together, these forces shape dune landforms and the plant and animals that live in the dune system.

Unfortunately, dynamic dune systems with naturally blowing sand no longer occur across most of the UK and north-west Europe. Most dune systems now consist of stabilised dune landforms covered in vegetation. This has resulted in loss of habitat and a decline in many rare species.

Fortunately, there are a wide range of dune management options available to address these issues. This handbook aims to keep our management techniques up to date for the needs of dune conservation in a variety of situations.

2. Sand, wind, water and plants

Sand, wind, water and plants are the four major components that influence the dynamics of a sand dune system.

2.1. Sand

Coastal dunes require an adequate supply of sand. Currents, tides and waves all bring sand to the beach from the sea. From there, the wind blows it inland. The beach acts as a sand store, with sand being deposited up the beach in normal conditions, but in storms it can be eroded seawards by waves. After a storm the eroded sand often forms a sand bar below the low tide level, ready to be slowly moved up the beach again, but in big storms it can also be taken further out to sea and lost to the beach system. This exchange of sand between the sea and the beach is the first part of the dynamic system.

Moving sand is the basis of all dune landforms, whether mobile dunes, blowouts, or forming dune slacks. These are described in the next sections.

2.2. Wind

At low tide, onshore winds blow sand from the beach into the dunes, but only when wind speeds are faster than 4 metres per second. This blown sand can become trapped among debris on the upper beach or between pioneer plant species to create embryo dunes and foredunes. Strong winds can also carry sand much further inland. Wind is a constant force in dune systems, and because dunes need wind to form, they are often found along exposed coasts in combination with a good sand supply. Wind causes lines of dunes to migrate inland (mobile dunes), with sand slowly being blown over the top of a dune and cascading down the other side. In this way, the dune can slowly creep inland, at long term average rates of around 1-2 metres per year. Wind also causes 'blow-outs', where a small section of dune starts moving, forming an individual 'parabolic' or 'crescent' shaped dune, or the wind may begin to excavate a hollow where the turf layer is broken. Dune features tend to be oriented in relation to the dominant winds, but once established they can lead to local variation in wind direction around individual features. Their orientation can also be quite resistant to change, even when there are longer term changes in wind direction. These are natural processes in a dynamic dune system, and part of a natural cycle which creates new younger dune habitat.

2.3. Water

Water helps shape dune systems in a number of ways. The most obvious is that near the coast, the groundwater (the water table, which is fresh water) is often near the surface of the dune system. One indication of this is when you can see the groundwater seeping out along the beach at low tide. When the wind is blowing away surface sand in a blowout or on the windward edge of a mobile dune, this is called wind-scour. If the water table is near the surface, then the wind-scour stops because wet sand doesn't move as easily as dry sand. This results in a low-lying flat area which tends to flood in winter, but is dry in summer. These areas are called dune slacks and often have high levels of diversity and specialised species living in them. The seasonally fluctuating water table is one reason why dune slacks are so good for species like Natterjack toads [*Epidalea calamita*]. Because they are not permanently flooded, many of the natural predators of natterjack tadpoles like fish are unable to live there. The height of the water table and its natural variation within a year partly govern the plant species living in dune slacks. However, other aspects such as the chemistry of the groundwater, and the age of the dune slack are also important.

Another way that water affects dunes is through rainfall (inputs) and evaporation (outputs/losses). The seasonal patterns of rainfall play a large role in how much rainfall is available for plants during the summer, how much rainfall reaches the water table, and how much is lost through evaporation. Summer drought can control the vigour of plant growth. Some of our less common plant species, such as the grass Sand cat's tail [*Phleum arenarium*], have adapted to dry conditions by flowering early and having a very short life cycle so they can set seed before the summer starts.

2.4. Plants

Plants play a dual role, they can play a major role in shaping dunes and their growth can be dictated by dunes. Embryo dunes are formed when sand collects around plants growing on the strand line. The seeds of species like Sea sandwort [*Honckenya peploides*], can be dispersed by the sea and get caught in strandline debris and start to grow there. As the plants grow, they trap more sand and a small dune forms. The same principle applies to the larger mobile dunes that form along the sea edge. Marram grass [*Ammophila arenaria*] is the main dune-building plant species in the UK that forms high dune ridges, with extensive root systems that help bind the sand and a rapid growth rate which means that it can keep pace with rapid sand burial, of up to 1m a year. The growth form of different plant species can actually influence the shape of the dune that forms. Plants like Marram with long root systems and rapid lateral spread can form long lines of dunes. Other more tussocky plants like Creeping willow [*Salix repens*] form rounder hummock-shaped dunes.

Figures 1, 2. Marram grass (Ammophila arenaria) in mobile dunes

3. Why do we need to manage dunes ?

Left alone, dune systems will respond to changes in climate or other pressures, but this may mean a loss of rare species that we value, or a loss of complete habitat types such as dune slacks (which is a possibility under some predictions of climate change).

Thousands of years ago, before we had changed the UK landscape on a large scale through farming and woodland clearance, there were many dune systems, often much closer together, meaning species could move more easily between sites, and with a chance of finding suitable habitat somewhere nearby.

Dunes in the UK today are now mostly stabilised due to a range of factors, with very well-established vegetation cover and few of the young (or early succession stage) habitats which are so important for dune specialist species. As a result, many of these specialist plant, insect and animal species like petalwort [*Petalophyllum ralfsii*], sand-mining bee [*Colletes cunicularius*], sand lizard [*Lacerta agilis*] are now quite rare, and in many cases the remaining populations are only maintained through targeted management.

Figure 3. Petalwort (Petalophyllum ralfsii), Ainsdale Sand Dunes National Nature Reserve © Natalie Hunt

Figure 4. Sand-mining bee (Colletes cunicularius) © Jürgen Mangelsdorf, Flickr

Figure 5. Female sand lizard (Lacerta agilis) at Studland Bay, Dorset

Dune habitat is also fragmented, and has a much smaller area than previously, meaning that the chances of suitable habitat occurring nearby are lower than before, and it is harder for species to spread between sites. Threats therefore need to be actively managed if we are to safeguard dune habitats and species.

There are many threats to sand dunes. Here, we summarise some of the key threats which can operate within a site. Other pressures leading to loss of dunes in unprotected sites (e.g. being built on for caravan parks, or converted to new golf courses or agricultural fields) are an increasing issue[1], but are not discussed here.

Over-stabilisation is probably the biggest problem currently in UK dunes. The vast majority of UK dunes are over-grown by vegetation, with very little bare sand and few areas with natural dune processes occurring. This is a part of a much larger pattern across north-west Europe. Causes of this include: nitrogen pollution from the atmosphere leading to higher levels of nutrients in the soil; a reduction in grazing or other large-scale management at many dune sites; climate change, where warmer temperatures lead to greater plant growth. In general, these factors all lead to a similar outcome - faster plant growth of certain species – usually those which prefer nutrient-rich conditions, and smothering of slower-growing dune species, with a resulting loss in diversity.

Invasive species are often a major problem, particularly at sites close to large urban areas where accidental or deliberate release of ornamental plants can become highly invasive. Even though such ornamental species may look pretty, they can smother rare natural dune species, leading to a loss in diversity.

[1] Jones M.L.M., Angus S., Cooper A., Doody P., Everard M., Garbutt A., Gilchrist P., Hansom G., Nicholls R., Pye K., Ravenscroft N., Rees S., Rhind P. & Whitehouse A. (2011) Coastal margins [chapter 11]. In: UK National Ecosystem Assessment. Understanding nature's value to society. Technical Report. Cambridge, UNEP-WCMC, 411-457.

Visitor pressure can be an issue. Certain areas of dunes can be sensitive to the effects of trampling and disturbance. These include bird-breeding sites, strandlines with embryo dunes, older acidic dunes with rich lichen communities. Excessive pressure from recreation activities can reduce the ability to achieve conservation objectives. While dune erosion can occur in focused areas where lots of people congregate or access the beach or facilities, this is not necessarily a major issue, providing it is contained. In some areas, small-scale or localised disturbance by visitors can help maintain some open sand, and help rare species survive.

Falling water-tables can result in the loss of dune slacks. This may happen due to climate change, or management on-site which alters the drainage in some way, abstraction of groundwater or reductions in the amount of rainfall reaching the water table. Such changes are already happening in UK dunes. A survey of dune slacks at the largest dune sites in England has shown a loss of 30% of the area of dune slacks in a 23 year period[2]. The remaining slacks have shifted from wetter to drier vegetation types. Changes in the nutrient levels of the groundwater can also cause major changes in dune slack vegetation.

4. Management techniques past, present and future

We briefly discuss a timeline of management techniques in dune systems, looking back and then looking forward, as dune managers increasingly recognise that there is a need to work with natural processes and to manage these processes alongside directly managing habitats or species.

4.1. Past

Up until the 1970s, the focus was on stabilising any blowing sand. Moving sand was seen as a threat and to be controlled at all costs – a sign of the system being out of control. Measures such as installing sand-fences, marram planting and afforestation were acceptable management techniques within the UK and widely encouraged. In fairness, many areas were suffering from high visitor pressure caused by an increase in seaside holidays and increasing mobility of families who could now own their own car. However, all conservation efforts had a similar focus on preventing mobility. At the same time, the conventional thinking on preventing coastal erosion in the UK was to use 'hard engineering' approaches such as rock armour, gabions and concrete sea walls. These often led to increased sand loss from beaches, or transferred erosion problems further down the coast due to interruption of the natural chain of sediment supply.

4.2. Present

We learned from this that it is possible to stabilise dunes at a large scale, but this may have unintended consequences on the features of dunes that we value and want to protect. Since the 1990s, perceptions of sand dune conservation have changed. In some locations, Marram planting and fencing is still ongoing but perhaps on a small-scale to meet particular site objectives. However, the importance of sand dune remobilisation has now come to the forefront of sand dune management but this is still mostly done on a small scale. Even in the late 2010s, management practices mainly revolved around grazing to keep biomass low, and turf stripping in small areas to create patches of bare sand. These practices have improved biodiversity and are relatively low cost but don't tend to address the key underlying issues of a lack of natural dune dynamics and natural

[2] Stratford, C., Jones, L., Robins, N., Mountford, O., Amy, S., Peyton, J., Hulmes, L. Hulmes S., Jones, F., Redhead, J., Dean, H. (2014). Survey and analysis of vegetation and hydrological change in English dune slack habitats. Final report to Natural England.

dune processes. These small-scale management actions are usually not self-sustaining. In the early 2020s, larger scale interventions are now happening, primarily through restoration projects funded by the LIFE programme and Heritage Lottery Funds, such as the Dynamic Dunescapes project.

4.3. Future

The objective of restoration projects is that we learn to unpick the problems created in the past and have clear examples to follow that can provide benefits across the whole dune system and will allow better adaptation to climate change, and other challenges. More holistic approaches to sand dune management need to be embraced, where sand, wind and water are all considered with the aim of encouraging a self-regulating system that requires relatively little intervention. This doesn't come cheaply nor quickly. It requires long term thinking and a willingness to consider adaptive management and planning approaches. The tools available include a range of established methods along with larger scale and more ambitious rejuvenation techniques that are increasingly being adopted by site managers in the UK. Future Flood Risk Management will make more use of coastal processes, accepting some natural variation in the dune toe position and in beach-dune sand exchange.

5. Structure of the handbook

The handbook is structured as follows:

- 'Before you start' introduces some of the principles and ideas relevant to many of the management techniques in this handbook.
- 'Quick overviews' provides a short overview of each management technique, and a visual 'map' to the topics covered in the detailed sections describing each technique.
- 'Detailed overview of each technique' serves as a reference guide for each management technique.
- A series of 'case studies' covering a range of themes and activities are described in detail on the Dynamic Dunescapes website www.dynamicdunescapes.co.uk

Before you start

This section provides a quick overview of the topics covered in more detail later. The first set of these are in the form of guiding principles to consider for particular issues (rejuvenation, hydrology, engaging with the public, monitoring and a brief discussion of other issues). The second set are a brief introduction to specific management techniques. Each of these sections is covered in more detail later in the handbook.

6. NATURAL DUNE DYNAMICS (Principles)

This is a short overview of some of the wider considerations around management to enhance natural dune dynamics, the more detailed text including diagrams can be found in the second part of the handbook, which focus on individual management techniques such as notching, turf-stripping and re-profiling, both as Quick Overviews or Detailed Overviews.

6.1. Working with natural processes

The aim of encouraging natural dune dynamics is to achieve a healthier balance of bare sand and early successional habitats compared with older habitats. Both are valuable and support their own groups of species, but at the moment most dunes systems have lost the youngest habitats, with large parts of the site slowly progressing towards stabilised older habitats.

There are many benefits of using natural dune dynamics. For example, a moving dune initiated near the sea will very slowly travel inland. As it does so, it will bury older and intermediate–age habitats, but create new habitat in its wake. The areas of bare sand are ideal for early colonising species which are adapted to the harsh conditions but are not very good at competing with the species found in older habitats. New dune slacks are created as a migrating dune leaves bare sand behind it, and these will automatically form close to the new water table. This helps dune systems adapt naturally to changing water tables under climate change. In a similar way, small and large blowouts will create areas of bare sand and lead to sand being deposited on nearby habitats. This can help maintain high soil pH and cover existing vegetation allowing dune pioneer species to grow which are adapted to grow in accumulating sand.

Ultimately the goal is to create a dune system which is largely self-managing through natural processes. The desired balance of succession can be maintained by routine low maintenance management. It can also be more directly controlled if there becomes a need to take a different approach.

6.2. Landscape scale

These processes work best at large scale: too small and they can rapidly be colonised by plants from the edges. As a result, planning should consider a broad range of questions: What else exists on the site and at other nearby sites, thinking about a mix of sites at a landscape scale? How big do we need to work? Should we do this at only one site, or across many? Where is the need greatest? Where on the site should we start this? Where will sand blow to, or a dune migrate to, and over what timescale? What is our long-term vision for the amount of bare sand on a site, and the balance between habitats of different ages?

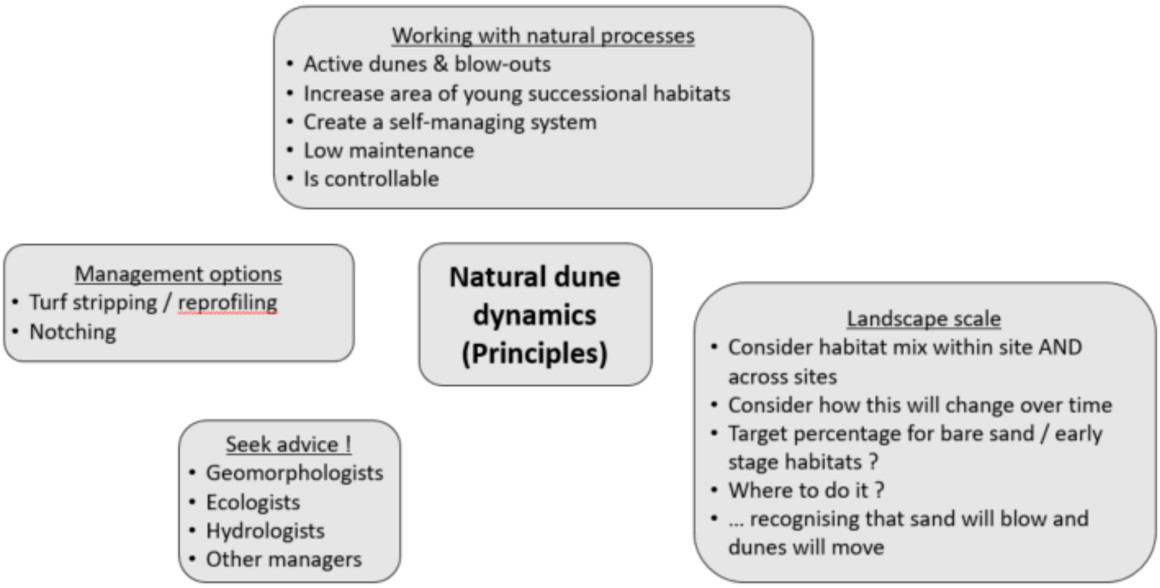
6.3. Management options

The two main options for reinstating natural dune dynamics are turf stripping/reprofiling on a large scale for sites inland, and notching of the foredune for locations near the sea. Notching increases wind speeds and sand supply into certain parts of the site, while turf stripping removes the vegetation and soil that has stabilised parts of the dunes. Each of these techniques has a short introduction later in this section, and is described in more detail later in the handbook.

6.4. Seek advice

When planning this kind of management it is important to consider the whole dune function and seek specialist advice at an early stage. You will need to identify the questions and objectives at a site level, and probably commission experts to gather relevant information and check what is possible and desirable, and where to carry out these activities.

It is important to gather information from multiple experts, listening to just one expert may lead to adverse outcomes for other parts of the dune system: **Geomorphologists** can help choose optimum locations from a wind and landscape perspective. **Ecologists** can help advise how to ensure the dune system and key site features will continue to meet conservation objectives. They can provide specific advice on preventing damage to protected species, managing undesirable species and on survey and licencing requirements. **Hydrologists** can help advise on issues related to water tables and groundwater chemistry which are the most important factors controlling the type of dune slack that will form. **Other site managers** with experience of these techniques will have a wealth of practical knowledge to offer.



7. DUNE HYDROLOGY (Principles)

Hydrology in dune systems is often seen as a mysterious, complex problem which can't be managed. It is certainly not straightforward, but with a few guiding principles, this should help you understand the basics, and the options available to influence it. This is a short overview, the more detailed text including diagrams can be found in the second part of the handbook.

7.1. Water tables

Water tables in sand dune systems fluctuate naturally. Where the water table is near the surface you get dune slacks or other types of wetland. Water tables are usually highest in late winter and lowest in late summer or early autumn. In a typical year, the water table might drop by 40 – 80 cm in summer, but over longer timescales might vary by 1.5 m or more from wet years to dry years. Drying out in summer actually helps Natterjack toads to breed successfully because many of their predators like fish are not able to live in dune slacks. Where dune wetlands hold water all year round, these form other types of wetland (mires or swamps) or lakes and are not called dune slacks. The pattern of rising and falling water tables is called the 'hydrological regime'.

In larger sites, there is often a domed water table which is maintained by rainfall. The dune groundwater is often separate from groundwater coming from outside the site, and less likely to be influenced by nutrients or other contaminants. However, the water levels can still be affected by things happening outside the site, such as ditches which alter drainage, or evaporation by vegetation on the site.

7.2. Groundwater chemistry

Water chemistry can be very different both within a site and from one nearby site to another. It depends on the geology around the site, the type of sand (with or without lots of shell fragments which influence the pH) and whether the site has a domed water table. Nutrient contamination of groundwater can be a problem, causing changes in vegetation and soils.

7.3. Recharge

On all dune systems, the water table is maintained by rainfall. More accurately, it is the difference between what falls as rain, and what is evaporated away from soil or used by plants (together called evapotranspiration). The water that is left filters down through the sand and becomes part of the groundwater. We call this 'recharge'.

7.4. Plant communities and succession

There are five different dune slack plant communities in the UK, according to the UK National Vegetation Classification (NVC)[3]. The type of community will depend on the hydrological regime, the pH and chemistry of the groundwater, and the age of the slack. Plant communities can be quite sensitive to hydrology and a 20 cm difference up or down in the long-term average hydrological regime will shift one community to another.

Succession is the natural process of one slack vegetation community changing to another as conditions change over time. The first changes are usually in plant cover and then the accumulation of soil organic matter. Succession can be quite rapid in dune slacks and soil can develop quite quickly. Over longer timescales, soil chemistry may also change, becoming more acidic. The rate that this happens also depends on the chemistry of the groundwater itself and the water levels.

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[3] Rodwell, J.S. and Pigott, C.D., 1991. British plant communities: Volume 5, Maritime communities and vegetation of open habitats (Vol. 5). Cambridge University Press.

7.5. Threats (on and off-site)

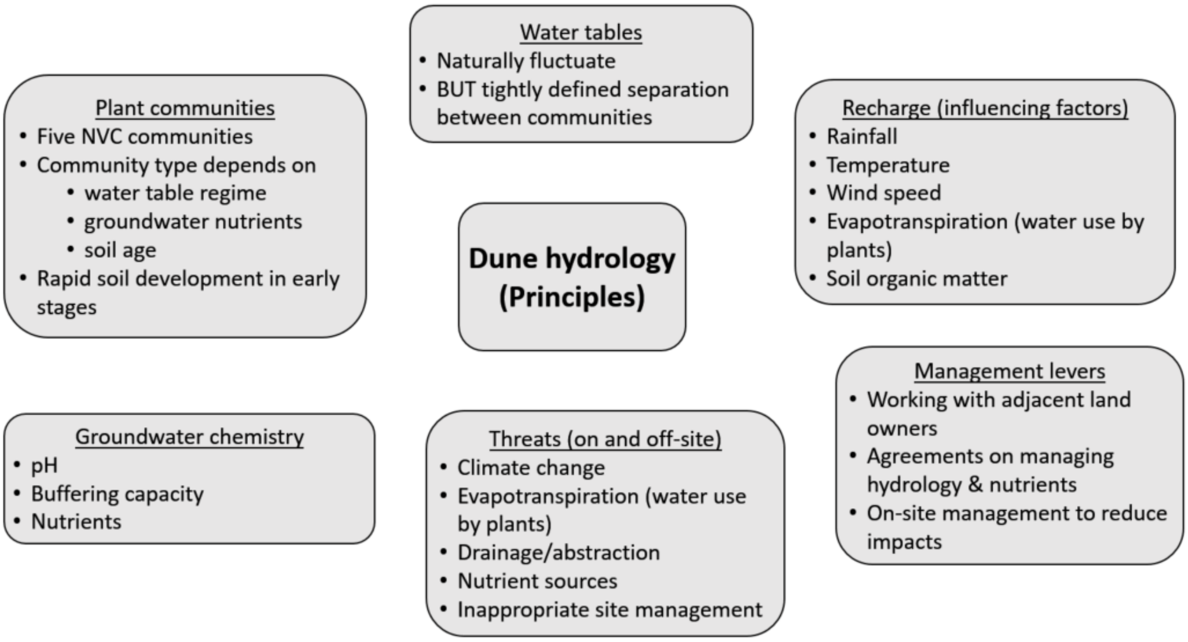
Things that alter the hydrology will also alter the plants, insects and other animals that live in slacks. Some aspects which influence hydrology occur on site, but many are activities that happen off-site. The main threats are:

- Changes in hydrological regime
- Climate change
- Nutrients
- Lack of management of vegetation in slacks, and elsewhere on site.

7.6. Management levers

Although not always obvious, there are management levers which can be used to influence hydrology. They need to be targeted on where the threat is happening, both on- or off-site. The solutions are likely to be different for each threat, but they come under the following main options:

- Working with adjacent land owners
- Agreements on managing hydrology and nutrients
- On-site management to reduce impacts



8. ENGAGING THE PUBLIC (Principles)

This section briefly summarises the need for keeping the public on-side, informed and understanding what is happening and the need for it, especially in the context of large-scale management.

Consultation and engagement are key to getting the public informed and on-side. Bad publicity and co-ordinated opposition can completely derail restoration projects. This is a complex area and it is best to consult with experts prior to starting large activities which may be contentious, including drawing on expertise from other countries where similar work has been undertaken. Early and positive countering of mis-information is also important. Explaining the benefits for specific rare species on the site can be used to help public understand the reasons for restoration. Ways of approaching this are outlined below.

Public Engagement

Individuals and communities love their dune sites but may not express their opinions and feelings until there is 'change' or the prospect of change.

Examples of change include practical conservation work, alterations to access arrangements, installation or removal of infrastructure, introduction of livestock or a new recreation activity or event.

If people have not been told about the need for change, opposition can be strong, disruptive, stressful, delay conservation works and result in long-term resentment, suspicion and lack of trust.

It is important to work with local communities and site users from an early stage. They can become invaluable allies. People are more likely to support site conservation aims in the present and long term, if they understand what is going on and why.

An effective approach is 'co-design' – working together with users and local communities to identify, design and implement solutions to problems, be they perceived or real.

In your planning, you might want to consider the following:

Conducting preliminary research.

- Find out why sand dunes are important to communities/users. What is special about the dunes for them?
- What do people enjoy?
- What stops them from enjoying or visiting the dunes?
- What issues do they identify?

Creating opportunities for engagement

These may be face-to-face or online. The aim is to create space for conversations about site issues, solutions and how people can get involved.

Activities could include:

- Guided walks on site
- Talks and presentations
- Family events
- Arts and creative events
- Volunteering events
- Events with local schools/colleges
- Events with particular community groups

Communicate effectively

You might like to include the following in discussions with local communities or site users:

- Explain what the site issues are from your perspective
- Explain what you are hoping to achieve (e.g. to improve biodiversity, access)
- Explain why this is important (e.g. benefits for wildlife, for conservation, for access & enjoyment, for people)
- Ask people for their input and feedback – what ideas do they have?
- Ask people if and how they would like to help/be involved based on their skills and experience
- Describe potential solutions (to stimulate discussion)
- Share how, where and when people can get involved (volunteering, monitoring, running events, becoming community ambassadors)
- Update people during and after any works that you do. It will help maintain their interest and involvement with you and your site.

When engaging with local communities and site users, you may find areas of common concern or interest or things that you have never considered. Combine this information with what you know.

Notice boards adjacent to the restoration can illustrate the successive stages of the restoration project and help visitors to understand the benefits visually and in situ. This can be linked to social media content, for example via QR codes which provide additional information online.

Figure 6. Examples of temporary signage used to engage with the local community and help visitors understand the reasons behind, and benefits of, the work taking place

Citizen science apps allow volunteers to help with recording species or other information about sites or restoration activities. Social media has been effectively used as a way to engage people with sand dune ecology and species, and with restoration work. Examples include encouraging the public to post pictures of the project over time, in different seasons and/or at different stages after restoration activity is complete. This helps to educate people that are not on site and to encourage a positive association around particular management techniques. See the [Dynamic Dunescapes Citizen Science App](#).

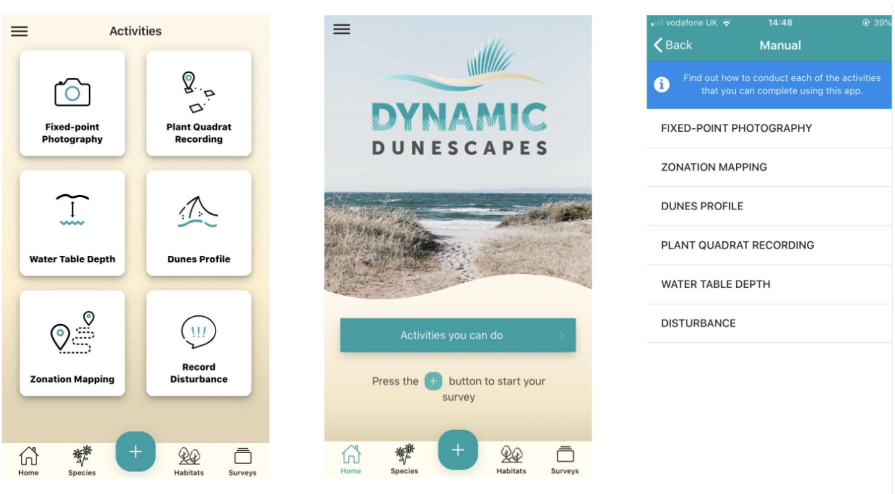


Figure 7. the Dynamic Dunescapes Citizen Science App

9. MONITORING (Principles)

This section gives an overview of a wide range of monitoring techniques. Many of these are described in more detail elsewhere, including in the citizen science manual linked to the Dynamic Dunescapes Citizen Science App.

9.1. Vegetation

The plants growing in a dune system are a useful 'sentinel' for changes happening on the site. Their abundance changes from year to year depending on the weather, but they also reflect what is happening in the soil and respond to longer-term influences such as climate or nitrogen deposition. For example, this might show up as an increase in nitrogen-loving species over time, a decrease in wetland species in dune slacks that are slowly drying out, or increasing numbers or spread of invasive species.

The most useful information comes from permanently marked quadrats. These allow you to revisit the exact monitoring location each year, and see changes in which species are present, and how abundant they are. If you don't use permanent plots, then differences in soils and vegetation over short distances (especially in dune systems which are highly variable) mean that it is very difficult to see change over time because the plot is in a different spot.

Ideally at least five permanent plots should be recorded in each main habitat type across the site. A typical size for vegetation monitoring in grassland, heath or wetland habitats is 2x2 metre, with larger plots in woodland. Ideally record all species present (including mosses and lichens if possible), and not just indicator species. This allows you to interpret the changes in vegetation in different ways in future, if another pressure becomes important at the site.

Permanent plots are marked in some way, such as with a post or metal marker, and the location is accurately recorded with a high-precision GPS system. Markers that protrude above the ground will interfere with mowing, but metal markers can be buried in the ground and can be relocated with a metal detector. Improvements in GPS technology mean that plot locations can be recorded with an accuracy below 3m with relatively cheap GPS systems. If a marker post is used, then it should be located a few metres away to avoid disturbance caused by livestock on site who use them as scratching posts. Position them in a consistent way, e.g. exactly 2 metres south of the south-west corner of a plot.

Walked transects or survey routes (as used in Common Standards Monitoring) are useful for showing change in less common species or invasive species, but should be used in addition to permanent plots as they don't provide enough detail to monitor changes in plant communities over time for changes such as drying out of dune slacks or changes in nutrient status[4].

[4] Jones, L., et al. 2016. A decision framework to attribute atmospheric nitrogen deposition as a threat to or cause of unfavourable habitat condition on protected sites. JNCC Report No. 579. JNCC, Peterborough.

Figure 8. A vegetation quadrat location is marked by a wooden post at Studland Bay, making it easier to find in dense vegetation and improving the reliability of data collected at this quadrat.

9.2. Sand movement

Monitoring sand movement can be done with a variety of methods. Changes in bulk sand storage or sand dune profiles can be measured simply using transect surveys with ranging poles, tape measure and a clinometer, or in more sophisticated ways using e.g. total station DGPS, terrestrial laser scanning, or with drone-based sensors to build up a detailed 3-dimensional picture of the sand surface. Changes in sand movement over time can be tracked using repeat digital images (taken from fixed ground locations or aerial views).

Monitoring quantities of blowing sand is best done using sand traps installed along transects (or in a grid pattern) following the prevailing wind direction. The horizontal and vertical distribution of sediment transport, as well as sand creep can be measured.

Vertical methods (*Figure 1*) involve mounting collection devices at various heights on poles, or using tubes with collection slits. However these methods have the disadvantage that they inevitably disturb the air currents which reduces their collection efficiency. Sedimentation trays installed to be level with the ground surface produce better results. The collection trays/buckets should be circular to eliminate effects of wind direction changes. A filter system (e.g. marble layers over a sieve) should be included to stop collected sand from being removed during rainstorms and to reduce insect infiltration. Depending on the climate and frequency of sample collection the trays may also need to incorporate drainage. To reduce sand creep into the sedimentation tray uniform matting can be placed around the edge. To measure sand creep, as opposed to deposited sediment, a box is buried in with only a narrow (~1 cm width) slit opening. Installation of this trap causes disturbance to the ground so the slit should be closed during placement and opened after a period of 'naturalization'. Consistency of method employed is required as the techniques vary in their collection efficiencies and it should be noted that horizontal collectors installed on inclines generally underestimate deposition.

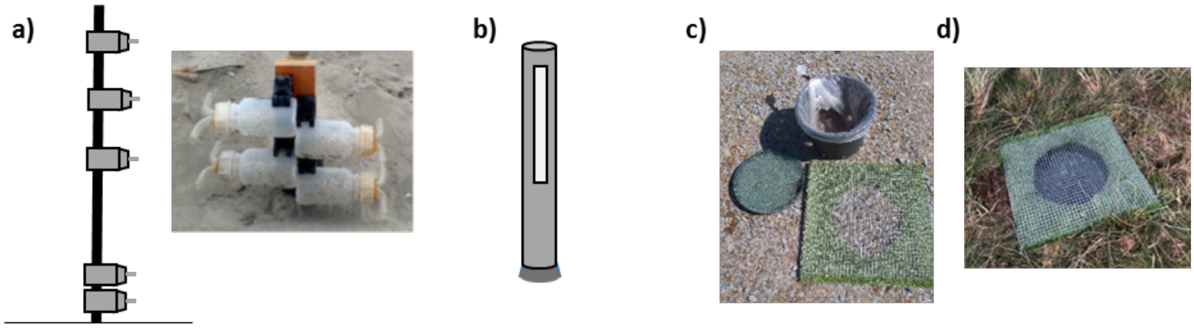


Figure 9. Wind-blown sand collection devices: a) vertical pole with sample collection bottles (as shown in inset photograph[5]*) attached at various heights; b) vertical PVC tube with mesh covered slit and detachable bung to base; c) components of horizontal collector including sample collection bucket with liner, marble filter top, and uniform matting surround; d) horizontal collector installed at ground level with sample bucket buried beneath the marble filter top. The latter approach was used in the SoLIFE project*[6]*.*

9.3. Hydrology

Water table depth in dune slacks influences the type and health of dune slack vegetation and the abundance and breeding success of species like Natterjack toads and many insects that also use dune slacks or damp sand.

Monitoring water table depths and fluctuations can be carried out by installing dipwells into the dune slacks. The water table depth can then be measured by site staff or volunteers with monthly or bi-weekly readings, or you can install automated data-loggers which are expensive, but can store hourly readings for as long as a year. Occasional manual measurements are still necessary to supplement automated systems as a separate check on the data in case they develop faults.

Manual measurements can use a variety of equipment ranging from cheap but fiddly to those which are easy to use but expensive. These are described in the **Dynamic Dunescapes citizen science training resources**. Water table measurements are useful for three purposes, introduced below, with more information in *section 18*.

I. To record change over time and better understand the hydrological regime at a location, or a site

5 Poortinga A., Keijsers J.G.S., Visser S.M., Riksen M.J.P.M. & Baas A.C.W. (2015) Temporal and spatial variability in event scale aeolian transport on Ameland, The Netherlands. GeoResJ 5: 23–35

6 Holder, A.J., Fitch, A., Robinson, I., Pinder, A., Brentegani, M., Allender, S., van der Schatte Olivier, A. & Jones, L. (2021). Sands of LIFE Sand dune ecological and physical monitoring: Soils report. NRW Evidence Report Series Report No: 456, Natural Resources Wales, Bangor

II. Having a number of dipwells allows you to model the shape of the water table across the site and how it changes over time. For this purpose, the absolute water level height (expressed as height above sea level, or height above Ordnance Datum) is needed. Dipwells may be arranged in transects perpendicular to the sea and parallel to the sea to represent the whole site.

III. Lastly, water tables can help understand the condition of the dune system, especially for vegetation and for species like Natterjack toad This is a powerful way to guide management and restoration efforts. For this last purpose, water levels are calculated as depth above or below ground surface.

Figure 10. A dipwell installed at Ainsdale Sand Dunes National Nature Reserve.

9.4. Soil

Soils change relatively slowly so do not need frequent monitoring. However, knowing some basic properties of your soil at a site can be very useful to help guide management options.

Simple measurements of soil properties include the thickness of the organic layer and soil pH.

The thickness of the organic layer tells you how much soil has accumulated. The organic layer is the dark brown humic layer that includes bits of decayed moss, plant roots and soil, often mixed in with sand. It gives a rough indication of how fertile the site is (thick organic matter on a sand dune is not usually a good thing). Where there is a deep organic layer, this can mean it is easier for invasive species to spread, and easier for fast-growing plants to shade out important species such as orchids.

But, note that each plant community will have different amounts of organic matter, and that dune slacks are wetter and therefore will have much thicker organic layers. See the typical organic matter profiles in *Figure 11* for *s*and dune soils collected from across the UK.

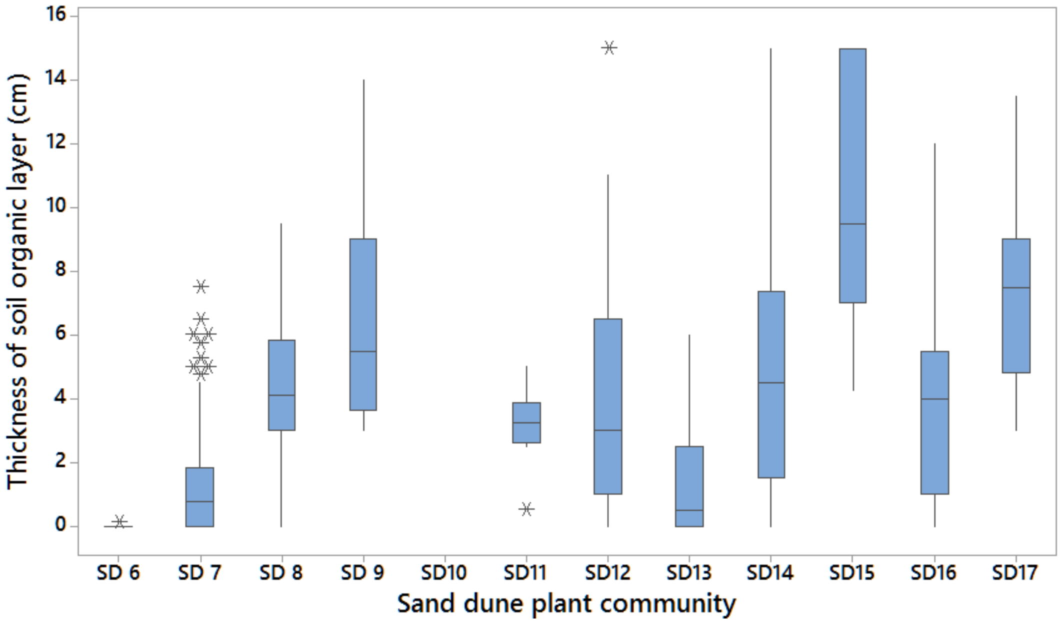


Figure 11. Thickness of soil organic layer (cm) in dune plant NVC communities (SD6 – SD7 are mobile and semi-fixed dunes; SD8 – SD12 are dune grasslands; SD13 – SD17 are dune slacks). Horizontal line in each bar shows the mid value (median), boxes show the range of the most common values (inter-quartile range: 25% to 75%). Asterisks show unusual extreme values (outliers). Data from 21 sites.

A few UK sites have naturally acidic soils (low pH), due to the chemical properties of the sand off-shore (mostly in Norfolk and parts of Scotland). However, the sand in most UK sites starts off as calcareous (also called base-rich, or non-acidic) with a higher soil pH. Over a long period of time, the calcareous material (chemical materials in the sand grains, and bits of shell) is leached away and the sand becomes acidic. The vegetation will then also start to change. It is useful to know your soil pH as it might mean choosing different management techniques or restoration actions.

Soil pH can be measured with home-testing kits that you can buy online or in gardening centres, or can be measured more accurately in a laboratory. See typical soil pH ranges for soils of different plant communities in *Figure 12*.

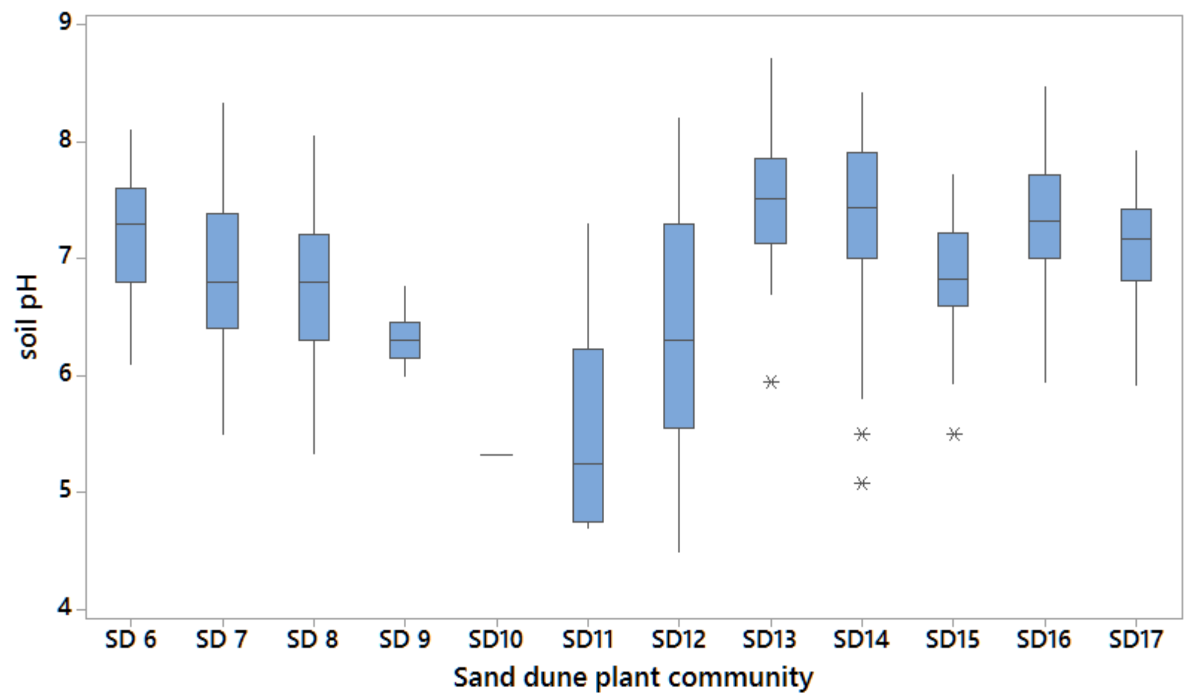


Figure 12. Soil pH ranges for plant communities in UK sand dunes (pH of bulk soil 0-15 cm depth, measured in deionised water). Horizontal line in each bar shows the mid value (median), boxes show the range of the most common values (inter-quartile range: 25% to 75%). Asterisks show unusual extreme values (outliers). Data from 39 sites. NVC codes SD6 – SD7 are mobile and semi-fixed dunes; SD8 – SD12 are dune grasslands; SD13 – SD17 are dune slacks.

9.5. Animals, birds, insects, etc.

Techniques to monitor a wide range of species can be very specialised. Please consult experts and organisations which run existing monitoring activity for these species groups.

9.6. Photo-monitoring

Photo monitoring is useful to record change over time in a consistent way. Photo-monitoring could be of a particular dune feature, the margin of invading scrub, the edge of a dune slack, or a vegetation monitoring point. To be most useful, the location should be marked in some way (perhaps by a post) to allow exact re-location, and clear instructions provided, e.g.

- Take the photograph at eye level for views/landforms, (or adapt the guidance depending on the purpose)
- Take your photograph in the direction indicated
- Refer back to the original photograph (if available), so that the framing includes any useful reference points (e.g. trees, fences, dune features, buildings)
- Record the location, time and date it was taken so that it can be identified and stored correctly.

10. OTHER TOPICS (Golf courses, forestry, archaeology, unexploded ordnance)

This section briefly explores a number of relevant topics for dune systems. In each case, more information should be sought from coastal specialists who have built up experience with managing them.

10.1. Unexploded Ordnance (UXO)

This guide does not replace advice from specialist consultants, but it does provide an overview for managing the risk of UXOs (also known as Explosive Ordnance (EO)).

Background

UXOs present a significant threat to habitat management projects across the UK. Past military activity has left the potential for dangerous items to remain undiscovered in the ground today. The location, terrain and lack of other major land uses made sand dunes ideal sites for military training, rifle, tank and bombing ranges, camps, coastal defence posts, airfields and decoy installations. This in turn made them targets for aerial bombardment. In addition to this, ordnance manufacture and storage also took place, including the offshore dumping of ordnance.

What are UXOs?

Ordnance can include but are not limited to, bullets, grenades, mortars, rockets, anti-tank missiles and even high-explosive bombs. In rare cases there may even be chemical weapons. Most of the ordnance is not dangerous (e.g. metal fragments, solid shot projectiles and empty shells), but live ordnance may also be present, and this can become more unstable over time. Should a live item explode, the impact could result in serious personal injury or even death, as well as severe reputational harm.

What is the risk?

Generally, ordnance is stable whilst left buried and undisturbed. It only becomes unpredictable and possibly unstable, if subjected to movement.

Vibration during heavy plant or vehicles use could disturb or strike an ordnance, however in most cases, the primary risk relates to ground-penetrating management operations such as excavations, turf stripping, fencing, stump extraction, digging of dipwells, sample pits or the use of mowers and clearing saws.

In sand dunes and coastal environments UXOs can move over time due to erosion, migration within the sand column or coastal currents bringing items onshore. This means members of the public, including metal detectorists, or site managers may discover ordnance on or near the surface as part of normal activities.

Risk Management

UXO hazards are covered by standard health and safety legislation, including the Health & Safety at Work etc. Act 1974, the Management of Health & Safety at Work Regulations 1999, the Corporate Manslaughter & Corporate Homicide Act 2007 and the Construction (Design and Management) Regulations 2015.

As with all other health and safety hazards, it is essential that UXOs are effectively assessed and managed by employing appropriate risk mitigation strategies.

The industry standard best practice is laid out in a set of Construction Industry Research and Information Association (CIRIA) guidance. It is highly recommended that managers and contractors read this guidance as a starting point. See:

- Unexploded ordnance (UXO) risk management guide for land-based projects, R. Bowman et al., 2019, CIRIA C785
- Unexploded Ordnance, A Guide for the Construction Industry, K. Stone et al., 2009, CIRIA C681
- Assessment and Management of Unexploded Ordnance (UXO) Risk in the Marine Environment, Cooper, N et al., 2016, CIRIA C754

Preliminary Risk Assessment

The first step is to ensure that any potential UXO risks in the area where works are to take place are properly assessed by a professional UXO consultancy. Do not assume that there is no UXO risk based on anecdotal information or past practice. Consultancies usually provide a concise Preliminary Risk Assessment or a Detailed Risk Assessment (or equivalent), depending on the likely history of military activity or aerial bombardment. A good risk assessment will present historic evidence and give a simple and clear rating of whether the area of interest is of Low, Moderate or High rating for UXO risk, for the activities planned.

Low Risk: A Low risk rating may not require any further specialist mitigation. The preliminary risk assessment and the CIRIA guidance will have more information on this.

Moderate or High Risk: If the site/activity is deemed to be of Moderate or High risk, then it is likely that active mitigation will be needed. The requirements should be laid out clearly in a risk mitigation strategy or plan prepared by the consultant.

General mitigation measures might include:

- Written safe method of working on site, for all, including for those not undertaking penetrating works
- Toolbox talk/safety briefing for those working on site, to explain the risks and what to do if an item of UXO is found
- Creating and implementing a robust emergency response plan
- Ensuring all parties, particularly contractors are made aware of the risks and controls.

Specific on-site mitigation is generally:

- Non-intrusive magnetometer (metal-detection) surveys – a scan of the area where ground penetrating works will occur, which can be done in advance of works taking place. However, this is not viable if the work area is inaccessible due to dense scrub, flooding etc.
- Watching brief – a UXO consultant is on site while the works are underway, watching for any suspicious objects being unearthed. If an object is found works must stop until the item is identified and, if necessary, the area is made safe.

Often, a combination of mitigation measures will be used, particularly for deeper excavations or if many items of ordnance are found. Some consultants may be able to offer alternative specialist methods for circumstances which warrant them.

Any finds (whether live or not, including domestic scrap such as old fence wires and drinks cans) will need to be excavated, identified, removed and, if necessary, made safe and disposed of by the consultants or the Ministry of Defence (MOD). This may involve a controlled explosion or other means of disarming a dangerous item. Arrangements and costs for this should be agreed in advanced as not all consultants will carry out disposal.

Costs

Effective management of UXOs can be expensive. However, these can be managed by having a good understanding of the standard practices, your specific needs, and developing a trusted working relationship with a reputable consultant, contracting each stage at a time, and agreeing costs in advance as far as possible.

Finally

Each site is different, so the UXO risk needs to be managed according to its own unique set of circumstances. A consultant should ensure that the risk is managed to as low as reasonably practicable (ALARP) but no mitigation methods can provide a 100% guarantee that no risk remains. Workers must remain alert and ready to implement the sites emergency response plan.

10.2.Golf courses

The perspectives around golf courses on dunes are complex and contain both negative and positive aspects. Many dune systems have been converted to links golf courses and historically this has been a major cause of the loss or deterioration of dune systems in the UK. Any conversion to a golf course, regardless of the mitigation measures taken, will result in changes to the morphology and hydrology of the dune system, a loss of habitat extent and quality, and reduced habitat for the species they support. The main impacts come through stabilisation of blowing sand, essentially ‘fossilising’ a dune system, re-working of dune land forms, adding nutrients and chemicals to greens and surrounding areas, and drainage or abstraction of the groundwater. These are outlined very briefly below. However, when managed sensitively, existing golf courses can also have conservation benefits. Some rare species such as lizard orchid [*Himantoglossum hircinum*] or habitats such as dune heath can persist on golf courses when they have disappeared elsewhere through habitat loss to agriculture or development.

Fertilisers are added to ensure even growth of the right grass species. Enlightened courses keep nutrient levels low which is best for the fine-leaved grasses (*Agrostis* and *Festuca*) which make for the best play. However, additional nutrients can be added unawares if using water from nearby drainage ditches or groundwater which already has high nutrient levels. The chemistry of any irrigation water should ideally be tested and used as a basis for adjusting any fertiliser nutrient applications where necessary. Irrigation water may also be the wrong pH, or contain agricultural contaminants like pesticides or fungicides which can also damage dune species. Patches of high nutrients can also be created on-site by dumping grass clippings – this can lead to excess nutrients, so care should be taken to select appropriate locations where this is necessary, and consider both the local eutrophication effect and any possible leaching to groundwater and where that groundwater is flowing to.

Water management is also a key issue. Courses often dig and maintain drainage channels to avoid high water levels disrupting play in winter. This has adverse impacts on dune slacks and the drainage will lead to lower water tables in all areas down-gradient of the drains. Conversely, in summer irrigation water is applied to keep the grass green. If abstraction occurs from the dune groundwater this further lowers water tables, while if abstraction occurs from off-site areas this can introduce nutrients and other contaminants, as described above. *See also section 7 on dune hydrology.*

10.3. Forestry on dunes

Forestry plantations were often planted on dunes historically to stabilise blowing sand. This has had direct and indirect impacts. The biggest impact is on water tables because trees use more water than grasses and shrubs. Water tables underneath woodland are typically around 70cm lower than elsewhere, which is enough to result in complete drying out of dune slacks, but the effect on water tables extends beyond the edges of the woodland into the surrounding dunes. *See also section 7 on dune hydrology.*

Forestry with conifers can acidify dune soils more rapidly. There is on-going debate about whether Atlantic dune woodland (broad-leaved woodland on dunes) is a natural feature of UK dunes, and whether it is desirable or not. Trees can also reduce wind-speeds locally.

Forestry on dunes can support some rare species (examples include populations of Dune helleborine [*Epipactis dunensis]*, Red squirrels [*Sciurus vulgaris]* and Raven [*Corvus corax]* roosts), but usually they support generalist woodland species, which comes at the expense of rare dune species. However, lone trees and patches of non-invasive scrub on a site can be useful habitat for birds and provide cover for rabbits.

10.4. Archaeology

Dunes can be important archaeological sites, and some sites have restrictions on any activities which will disturb the soil. This includes taking soil samples, installing dipwells and conducting restoration measures such as reprofiling, or removing roots or stumps of scrub or invasive species.

QUICK OVERVIEWS

These provide a very brief overview of goals, when to use, and how to carry out the management. The diagram summarises key issues, all described in detail in dedicated sections later in the handbook.

11. NOTCHING

This brief overview covers notching of the foredune. More detail on this technique can be found in *Section 19*.

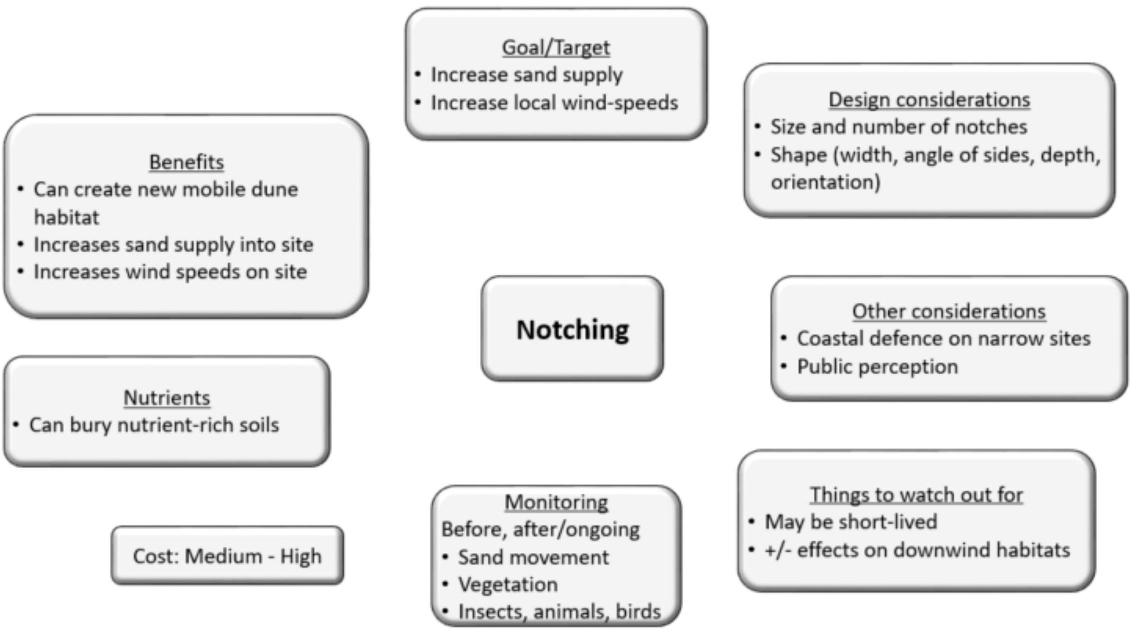
Other relevant overview sections: Turf stripping and re-profiling

The main goals of notching are to increase wind speeds and sand supply into a site.

Notching is typically used on sites that are overstabilised, where there is a need to improve the conditions needed for natural dune dynamics. This is often used in combination with turf stripping of areas within the dunes. A constant supply of blown sand can help keep soil pH high, and encourages early-successional dune species that prefer bare sand. However, it may not be suitable on e.g. East coast sites where the prevailing winds blow offshore.

This technique cuts a notch into the foredune to funnel wind into the site at a particular focal point. Considerations include where along the foredunes to locate the notch or notches, and their width, depth, angle of slope and orientation. Over time the notch may widen and slowly fill in, or it may create a blow out in the dune – a small mobile dune that travels inland.

The technique uses large machinery.



12. TURF STRIPPING AND RE-PROFILING

This brief overview covers techniques like turf stripping (also called sod-cutting), scraping and re-profiling. For simplicity in the following text we refer to turf stripping, but will clarify where differences in technique might be relevant. More detail on this technique can be found in *Section 20*.

Other relevant overview sections: Notching

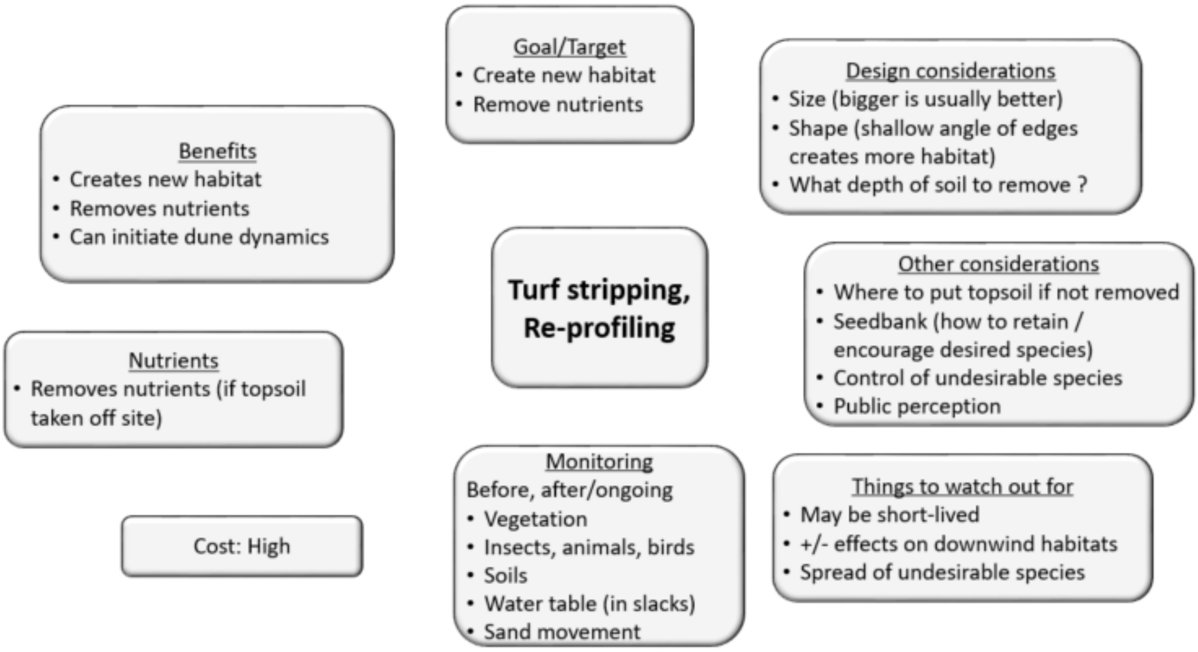
The main goals of turf stripping are: to increase the amount of bare sand, to remove organic matter and associated soil nutrients, or decalcified (acidified) surface soil layers, to get back to earlier stages of succession, or to bring the ground surface closer to the water table.

Turf stripping is typically used to increase natural dune dynamics on sites which are over-stabilised, to provide habitat for pioneer or early successional species (fauna and flora), to remove accumulated nutrients in soil, and to address issues relating to dune slacks drying out.

Turf stripping is almost always done with large machinery such as diggers. A surface layer of vegetation and soil is removed mechanically. It can be piled or buried elsewhere on the site, or ideally removed off-site. The depth of soil removed depends on the reason for doing the management, and needs to be balanced against the loss of soil seed banks of target species.

Topsoil inversion is a technique which uses a deep-plough pulled by a tractor. This inverts the soil profile to about 1m depth, burying organic rich surface material below a deep layer of mineral sand. In this technique the organic material is buried in-situ rather than being removed off-site.

Re-profiling may be done in combination with turf stripping, and involves using heavy machinery to re-shape dune features, or to deepen or re-shape dune slacks.



13. GRAZING

This section covers grazing by domestic stock (cattle, sheep, ponies and other animals) as well as grazers considered to be 'natural' like rabbits. More detail on this technique can be found in *Section 21*.

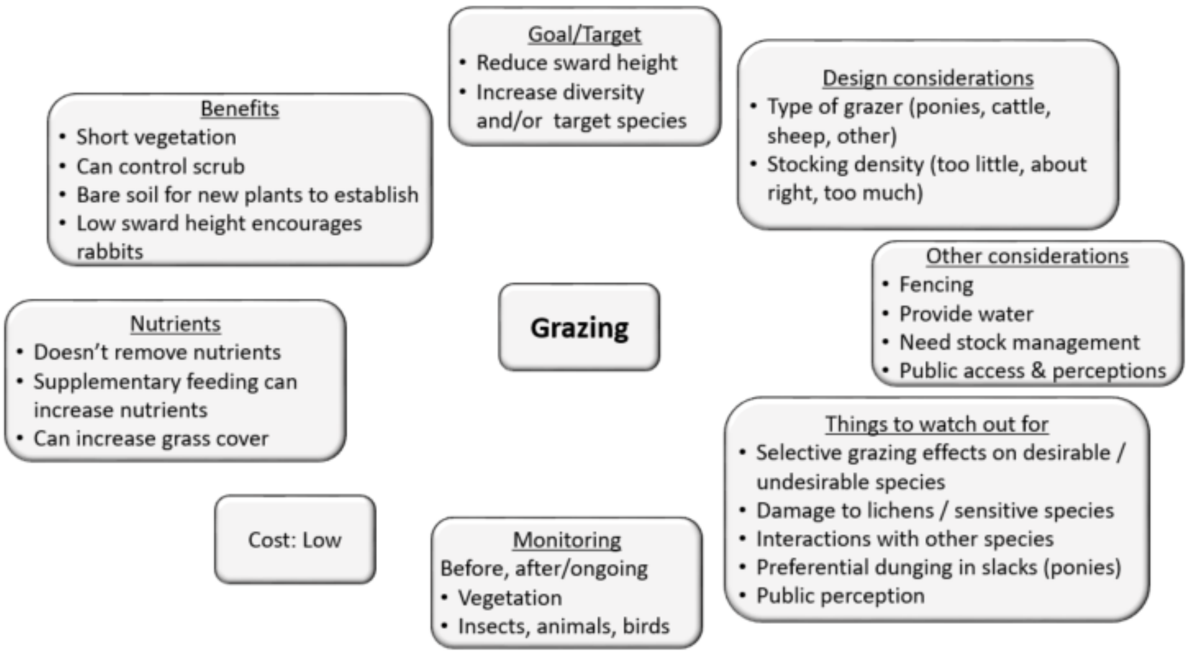
Other relevant overview sections: *[Mowing and cutting]()*

The main goals are to keep vegetation short and to control scrub growth. The shorter vegetation allows more light to reach the ground which helps our rarer, less competitive species, to persist. Disturbance by grazers also creates small patches of bare soil which encourage germination from the seedbank, which helps to maintain plant diversity. Managed stock grazing can keep the sward low, which encourages 'natural' grazers like rabbits. Rabbit grazing can keep the sward very short, but tends to be patchy. This, together with fresh bare sand from their burrows helps create a mosaic of different habitats.

Grazing is typically used when a site is over-stabilised, where natural grazers like rabbits are not present, or rabbit numbers are too low to be effective, and where scrub encroachment is becoming a problem.

Grazing is largely carried out with domestic livestock. This is often run by contacting local graziers willing to put stock onto the site, but is sometimes run by conservation organisations with their own stock and stock managers, or a combination of the two approaches.

Sand dune vegetation is of poor grazing quality and modern breeds of livestock which have been bred for rapid weight gain are not suitable and tend to lose condition. More traditional or heritage breeds are therefore more suited to this, and are more willing to browse shrubs and other vegetation than modern breeds. Keeping an eye on animal welfare of stock is important.



14. MOWING and CUTTING

This section covers techniques like mowing, cutting and strimming. More detail on this technique can be found in *Section 22*.

Other relevant overview sections: Scrub clearance; Grazing

Mowing has many similar effects to grazing. The main goal is to remove vegetation, which increases the light reaching the ground and provides an opportunity for short species and slower-growing species to survive. This increases species diversity and benefits many of our rarer species.

Mowing is typically used when grazing is not an option for practical reasons. These include sites that are too small for grazers, where it is not possible to provide water for grazing stock, or where local graziers may not be available, or to encourage stock into an area by making it more accessible. It can also be used to control problem species, and to remove nutrients from a site.

Mowing can be carried out by tractor flail, rotary motors, or by hand with strimmers or brush cutters. It is recommended to remove the cut biomass off-site, as leaving cut material on the surface returns nutrients to the soil which is usually not desirable in dune systems. Cut material left on-site also smothers and shades the vegetation underneath.

Mowing

Goal/Target
- Reduce sward height
- Increase diversity and/or target species

Design considerations
- Target sward height
- Mowing frequency
- Type of equipment (tractor & flail, strimmer, etc.)

Benefits
- Short vegetation
- Can control scrub
- Low sward height encourages rabbits

Other considerations
- Where to put cuttings
- Machinery wear and tear
- Restricted to flatter areas with vehicle access

Nutrients
- Removes nutrients (if cuttings removed)

Things to watch out for
- Sward height can be too uniform
- Damage to dune features
- Public perception

Cost: Low

Monitoring
Before, after/ongoing
- Vegetation
- Insects, animals, birds

15. SCRUB CLEARANCE

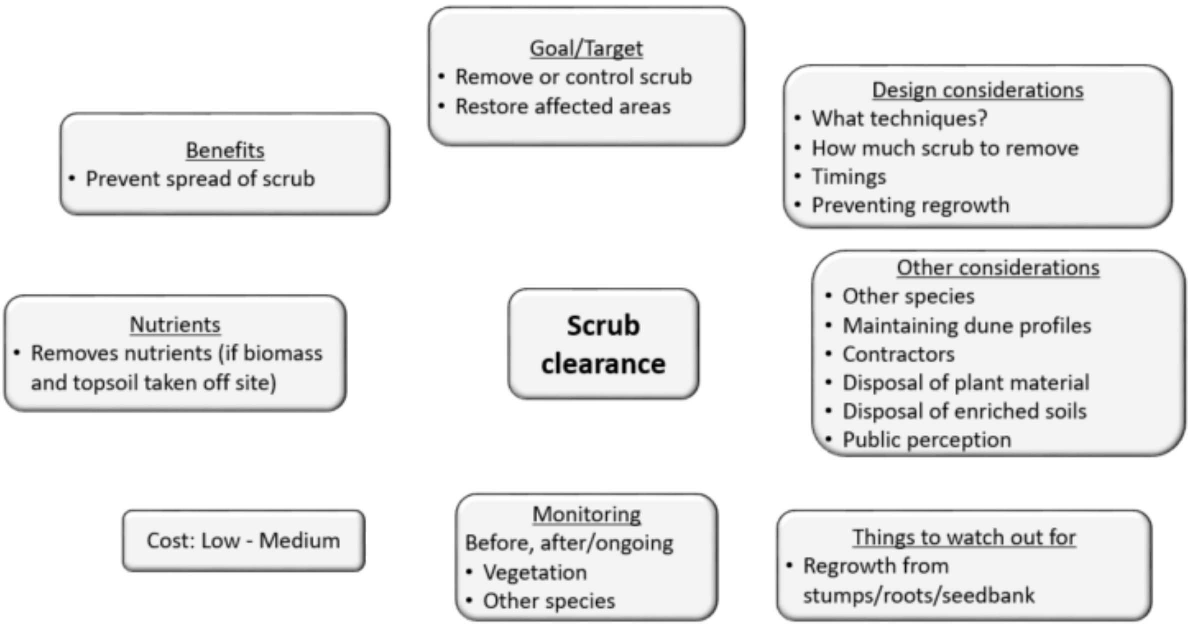
This section covers issues around clearance and control of scrub on sand dunes. More detail on this technique can be found in *Section 23*.

Other relevant overview sections: Turf stripping and re-profiling; Invasive species control

The main goal is to control or remove scrub from a site, to prevent adverse effects of too much scrub (such as soils which are too fertile, and loss of early-successional habitats and the rare species that depend on them, or to increase recharge to the groundwater).

Site managers should decide how much scrub should be retained, taking into account the benefits that scrub provides for many species, against the adverse effects described above and the published conservation objectives for the site.

Scrub removal can take place by hand-cutting, flails, or larger machinery such as tractors. Wherever possible, cut material should be removed off-site, including enriched soil material in some cases.



16. INVASIVE SPECIES CONTROL

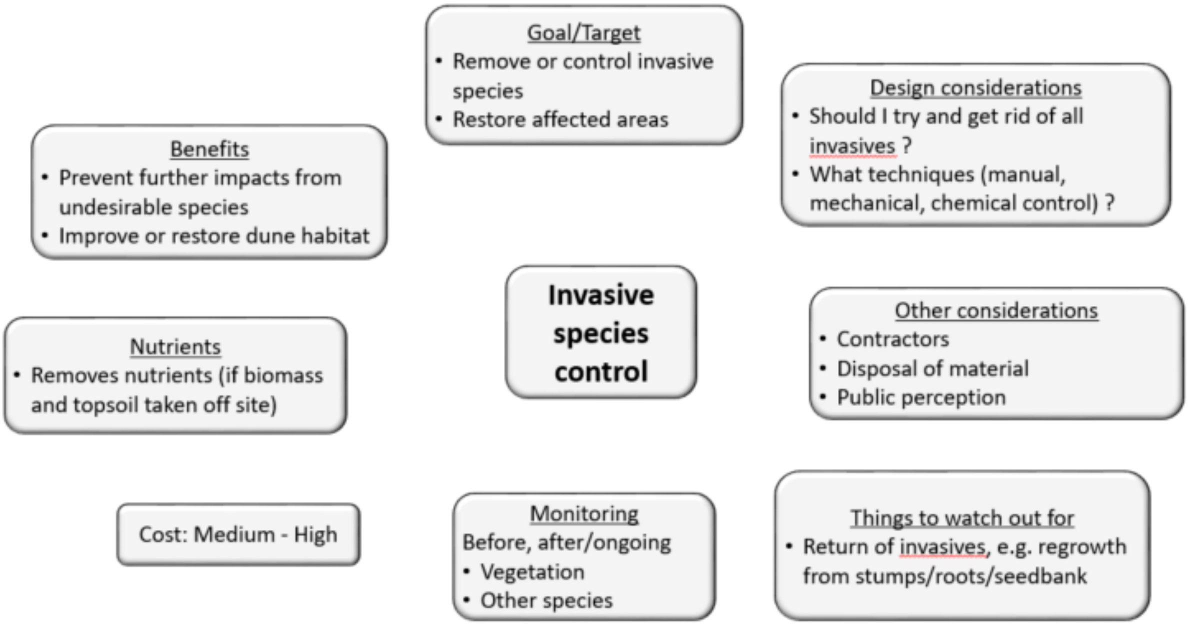
This section covers issues around control of invasive species on sand dunes. More detail on this technique can be found in *Section 24*.

Other relevant overview sections: [Scrub clearance]

The main goal of invasive species control is to eliminate or reduce the spread of problem species and protect species of greater conservation interest. Invasive species can cause substantial ecological damage including a loss of biodiversity, changes in soil fertility, increased water use with local effects on the water table level and sometimes water chemistry.

Many of the species that have colonised over the past century are here to stay; our job is to intervene where it is most pragmatic to ensure our native dune wildlife can still function and thrive. Sometimes we can allow species to co-exist, but sometimes costly interventions and eradication programmes are essential.

The main techniques used are manual and mechanical control, often in combination with chemical control. Care should be taken with chemical control to avoid damage to non-target species and habitats. Seek guidance from a BASIS chemical approved practitioner.



or be brought in again from sources off-site. The same principles to monitoring of invasive animal species.

16.1.Nutrients

Some invasives are nitrogen-fixing (like Sea buckthorn). Others just build up biomass and soil organic matter through their rapid growth. Removing these species and the accumulated soil off-site where possible is important to keep a low nutrient status at the site.

16.2.Monitoring

Monitoring (*see Section 9*) should take account of:

- Checking the invasive species do not return/re-grow
- That native or desirable dune species are recolonising the cleared areas

16.7.Cost

Removal of invasive species can vary from relatively cheap (mostly the time of volunteers) to incredibly costly with use of large machinery and repeated mechanical and chemical control over a period of years. While early action to control problem species may seem expensive, it will save many times that amount of money later to remove invasive species that were left to spread unchecked.

25. List of case studies

Case studies covering a range of themes and activities are described in detail on the Dynamic Dunescapes website www.dynamicdunescapes.co.uk

This list briefly summarises examples of activities at a range of sites, for which more information can be found at the link above:

Kenfig dunes: Turf stripping, reprofiling, notching

Newborough Warren: Turf stripping, reprofiling, notching

Merthyr Mawr: Turf stripping, reprofiling, notching, scrub clearance

Pembrey: Notching, new dune slack creation

Morfa Harlech: Tree clearance, reprofiling

Saltfleetby & Theddlethorpe: Reprofiling, scrub clearance

Saltfleetby: Removal of *Clematis vitalba*

Oxwich Dunes: Notches, turf stripping