Dynamic Dunescapes
Sand Dune Managers Handbook

June 2021

THE SAND DUNE MANAGERS HANDBOOK

Produced by UKCEH, Liverpool Hope University, and Dynamic Dunescapes partners; Natural England, Plantlife, Natural Resources Wales, National Trust and The Wildlife Trusts, with support from the European LIFE programme (LIFE17NAT/UK/000570) and the National Lottery Heritage Fund (HG-16-08643).

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[1] UK Centre for Ecology & Hydrology

[2] Liverpool Hope University

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Contents

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.

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[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

[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.

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 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?

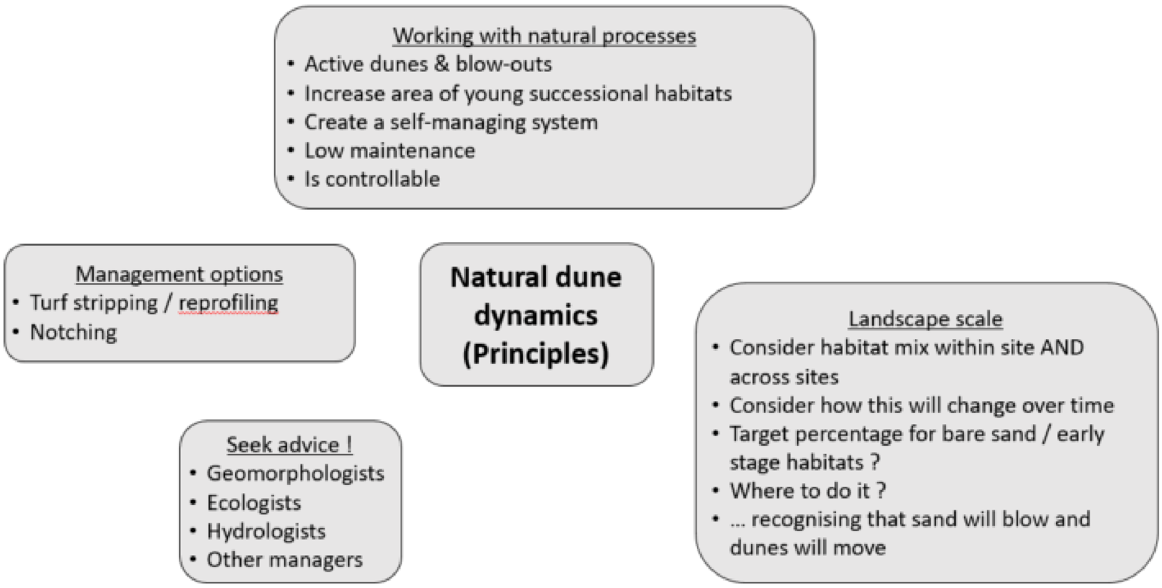
6.3 Management options

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

[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.

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.

7.5 Threats (on and off-site)

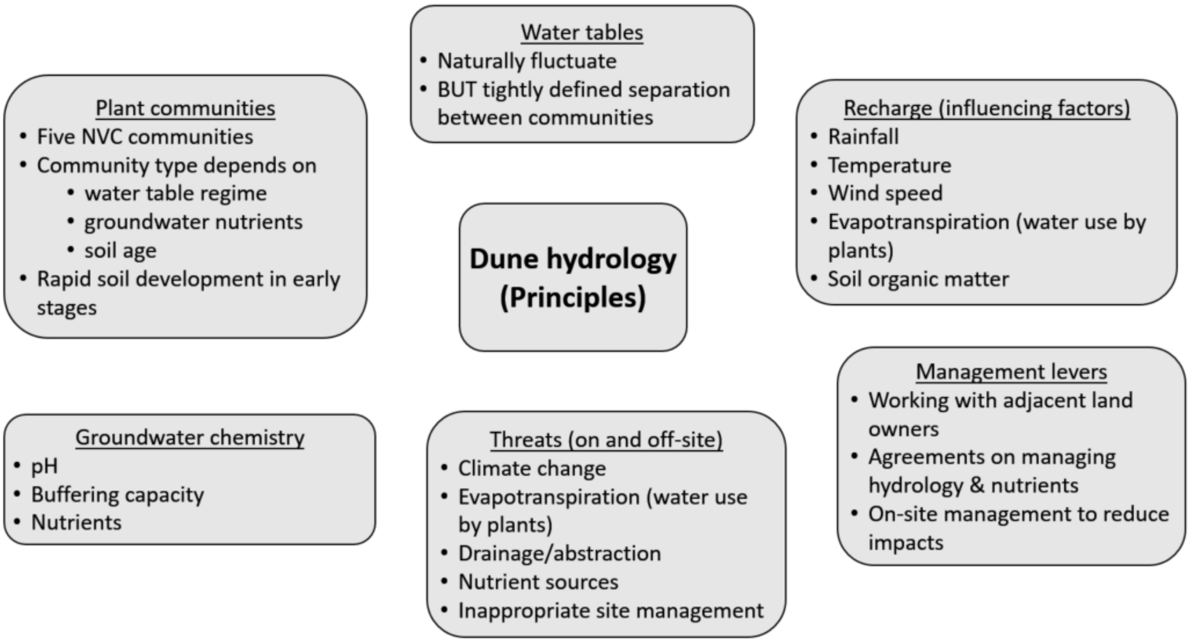
Things that alter the hydrology will also alter the plants, insects and other animals that live in slacks. Some aspects which influence hydrology occur on site, but many are activities that happen off-site. The main threats are:

- 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.

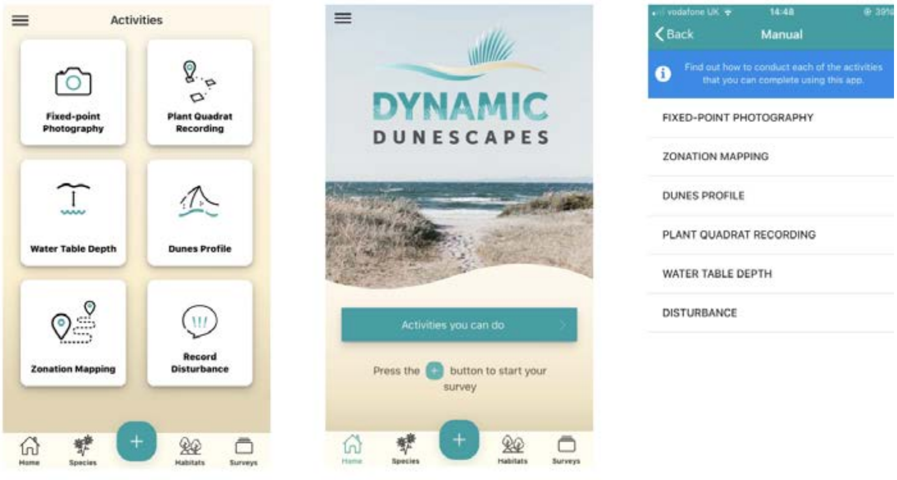


Figure 7. the Dynamic Dunescapes Citizen Science App

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].

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.

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[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.

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.

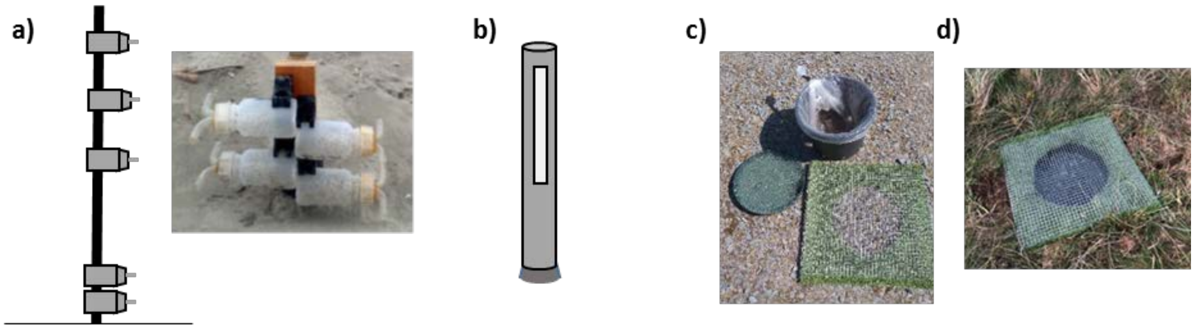


Figure 9. Wind-blown sand collection devices: a) vertical pole with sample collection bottles (as shown in inset photograph[5]*) attached at various heights; b) vertical PVC tube with mesh covered slit and detachable bung to base; c) components of horizontal collector including sample collection bucket 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.

[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

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

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.

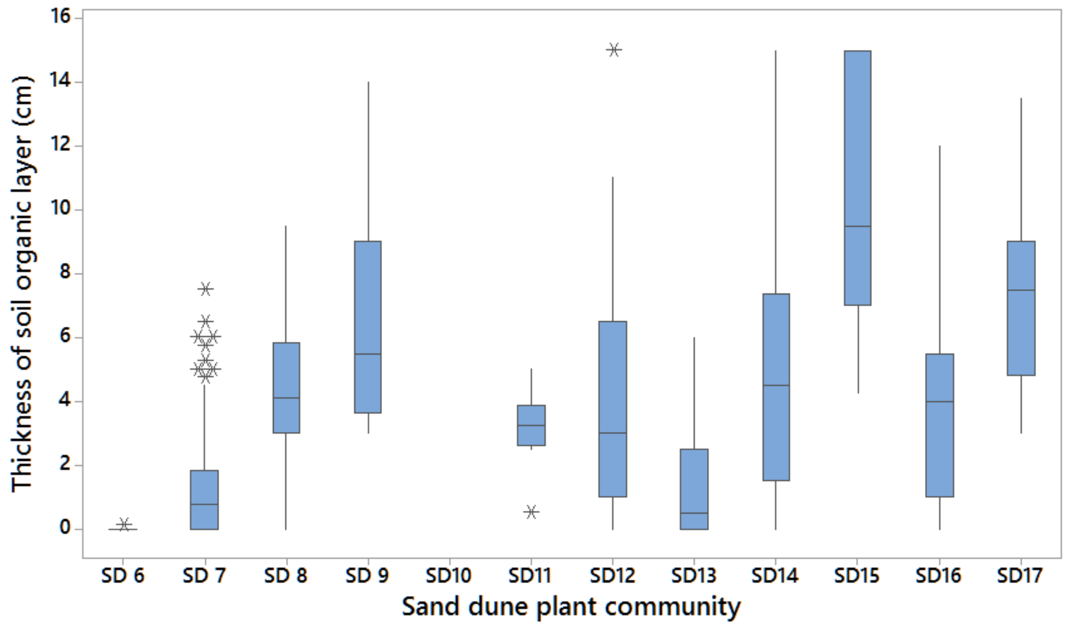


Figure 11. Thickness of soil organic layer (cm) in dune plant NVC communities (SD6 – SD7 are mobile and semi-fixed dunes; SD8 – SD12 are dune grasslands; SD13 – SD17 are dune slacks). Horizontal line in each bar shows the mid value (median), boxes show the range of the most common values (inter-quartile 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*.

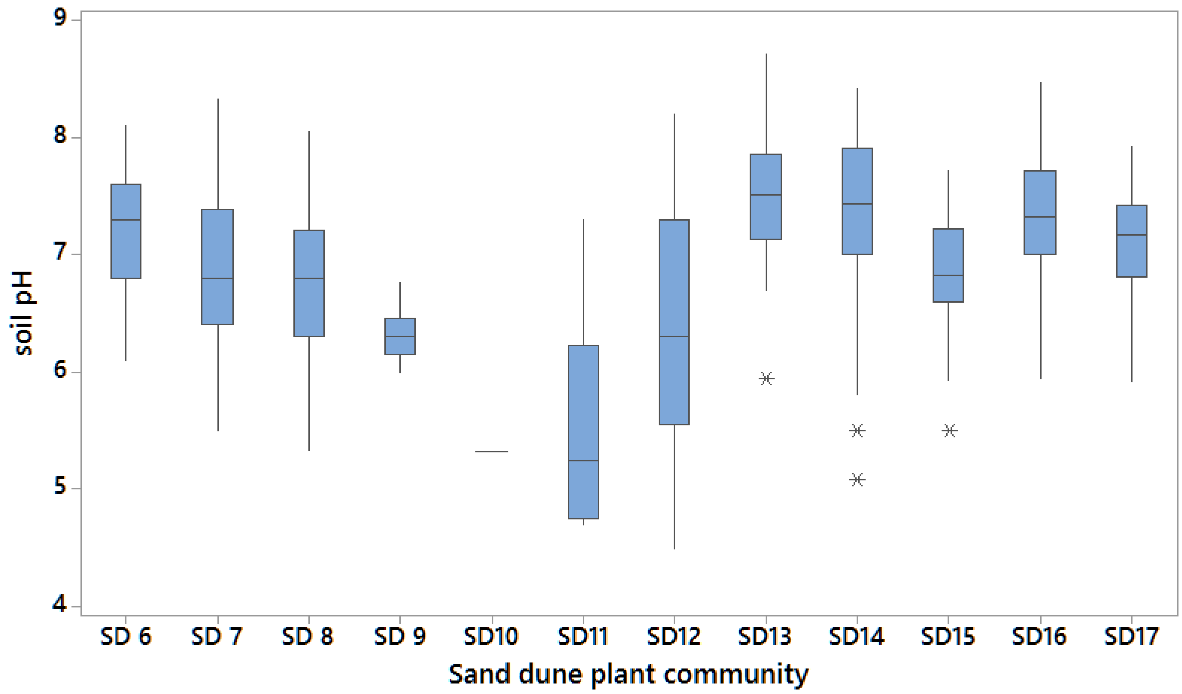


Figure 12. Soil pH ranges for plant communities in UK sand dunes (pH of bulk soil 0-15 cm depth, measured in deionised water). Horizontal line in each bar shows the mid value (median), boxes show the range of the most common values (inter-quartile range: 25% to 75%). Asterisks show unusual extreme values (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*.

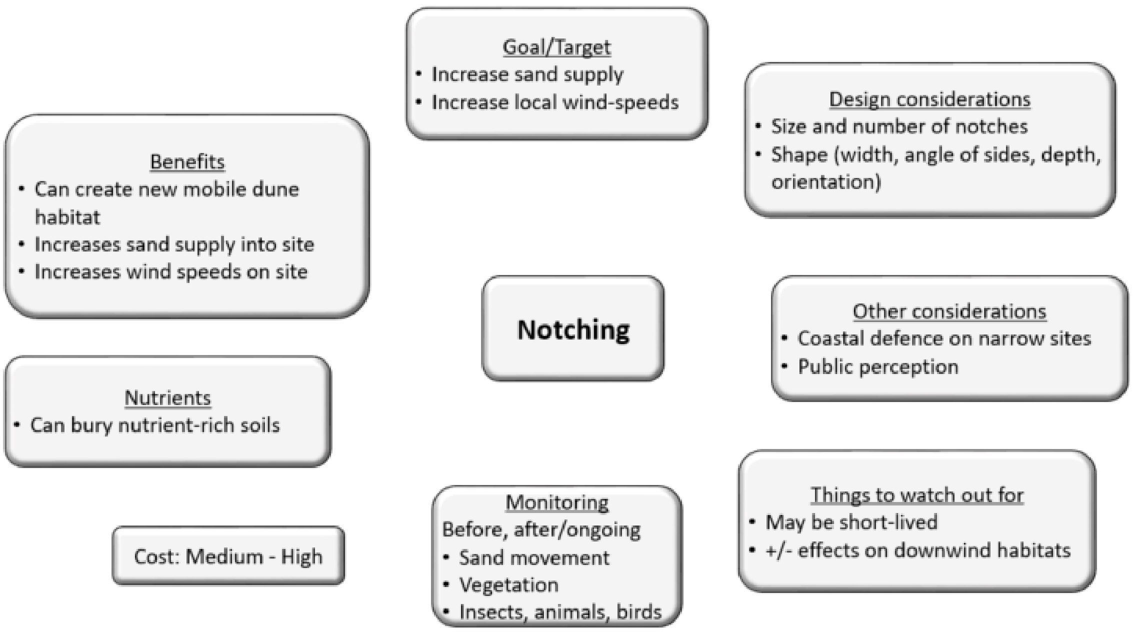
Other relevant overview sections: [Turf stripping and re-profiling]()

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*

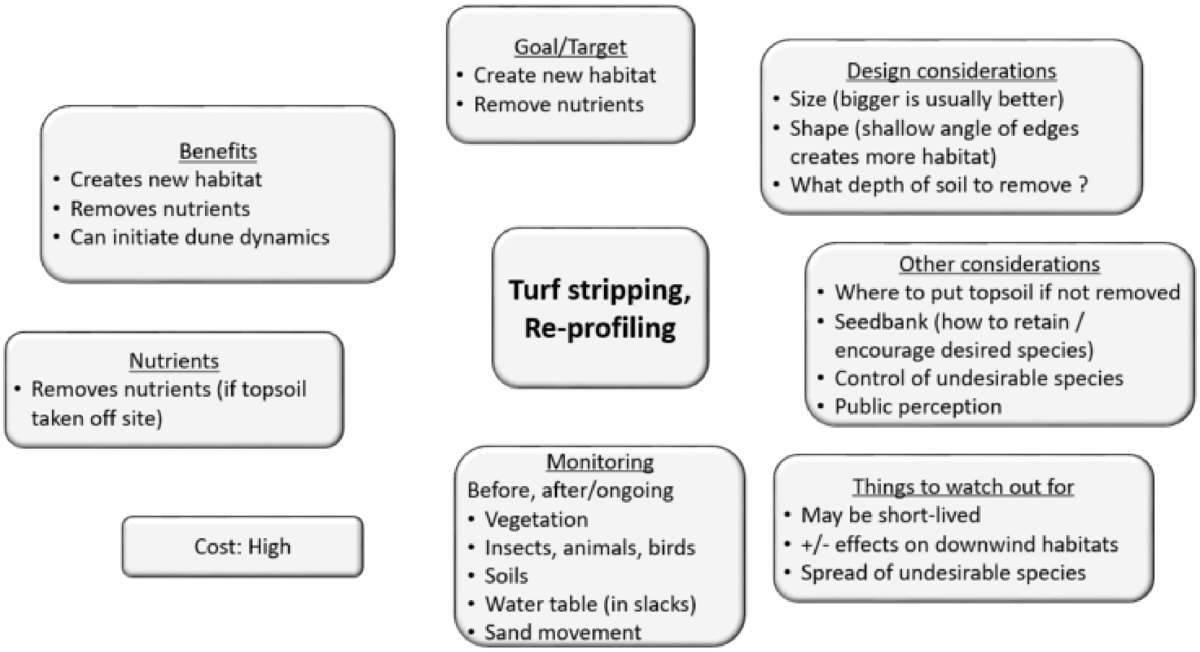
The main goals of turf stripping are: to increase the amount of bare sand, to remove organic matter and associated soil nutrients, or decalcified (acidified) surface soil layers, to get back to earlier stages of succession, or to bring the ground surface closer to the water table.

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*.

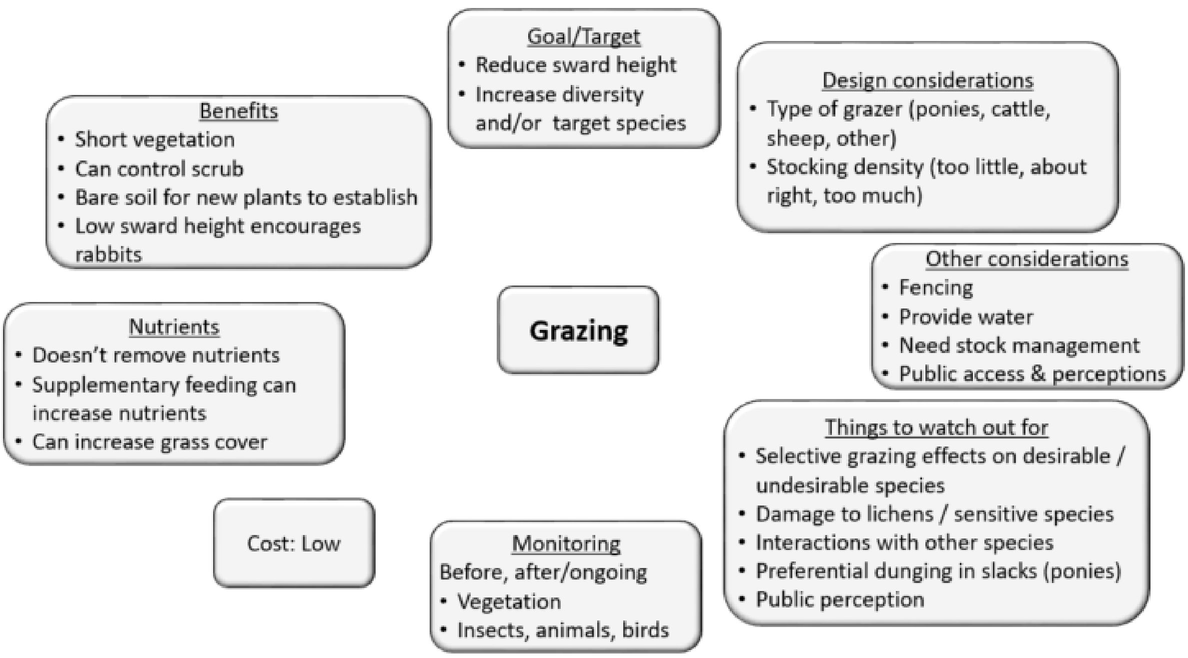
Other relevant overview sections: Mowing and cutting

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

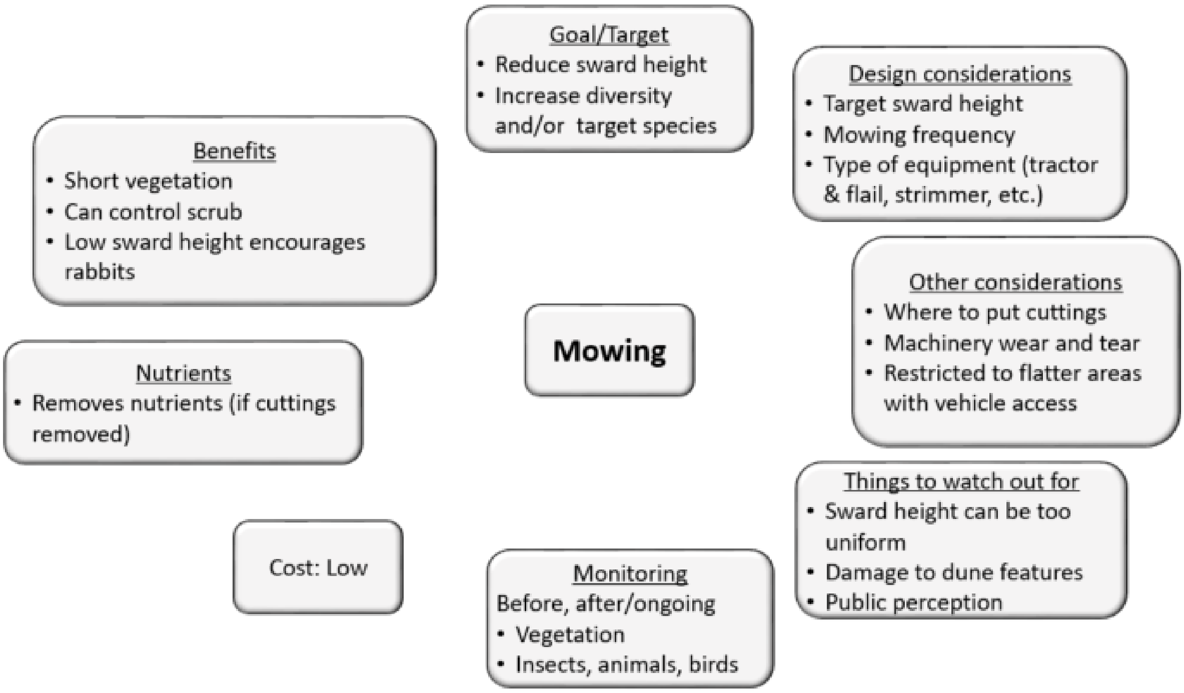
This section covers techniques like mowing, cutting and strimming. More detail on this technique can be found in *Section 22*.

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.



15 SCRUB CLEARANCE

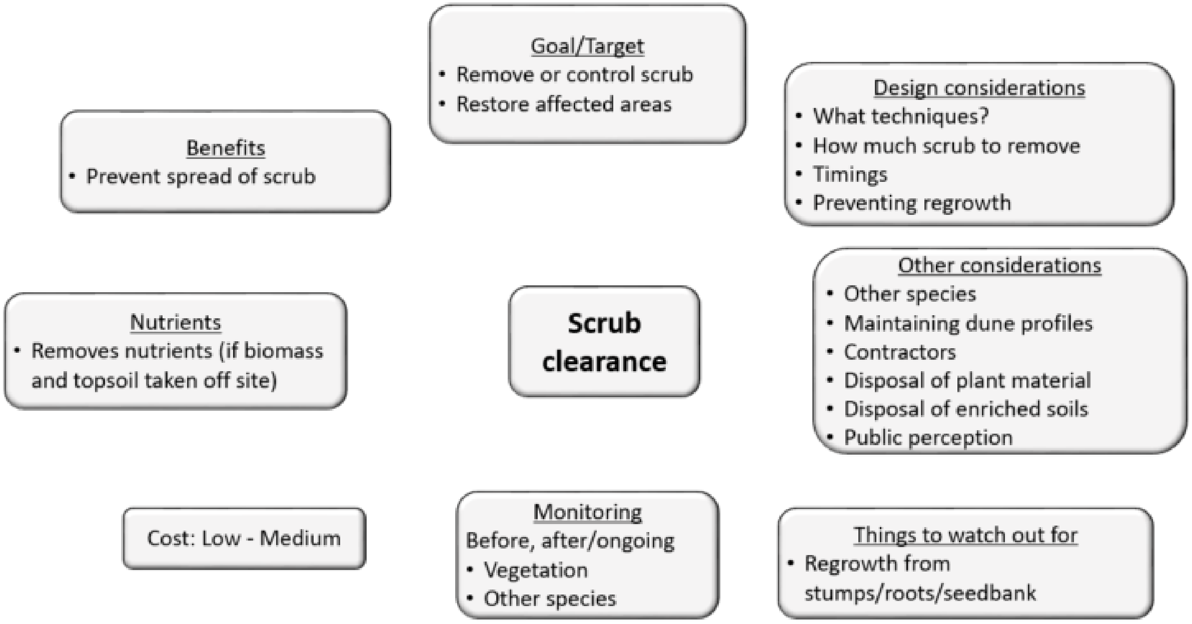
This section covers issues around clearance and control of scrub on sand dunes. More detail on this technique can be found in *Section 23*.

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

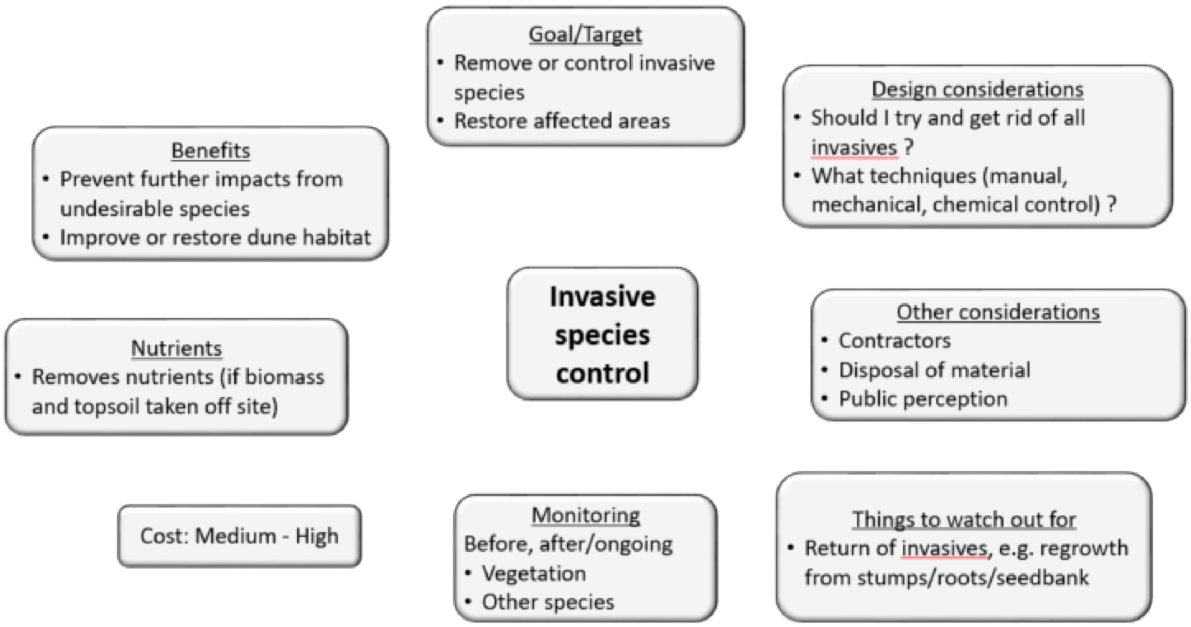
This section covers issues around control of invasive species on sand dunes. More detail on this technique can be found in *Section 24*.

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.



DETAILED OVERVIEW OF EACH TECHNIQUE

This part of the handbook starts with some more detailed background knowledge on natural dune dynamics and on hydrology, which are relevant to more than one management issue. It follows with comprehensive information about each management technique introduced earlier, to provide a look-up resource for managers.

17 NATURAL DUNE DYNAMICS

17.1 Goals / targets

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 dune systems have lost the youngest habitats, with large parts of many sites now progressing towards stabilised older habitats. These older habitats are also valuable, but there needs to be a balance of habitat ages across a site (or group of sites).

Ultimately the goal is to create a dune system which is largely self-managing (or at least a low-maintenance system), where the use of natural dune processes allows the site to adapt naturally to change. These processes won't solve every problem as some require more direct intervention like control of invasive species. However, by creating a matrix of new and old habitat and working with natural processes, dunes are able to keep pace with change.

17.2 Benefits

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 existing habitats, but create new habitats in its wake. Putting the rates of dune movement into context, which is typically 1-2m per year as a long-term average, it took 150 years for a dune ridge at Newborough Warren to migrate ~250 m into the site (*Figure 13*).

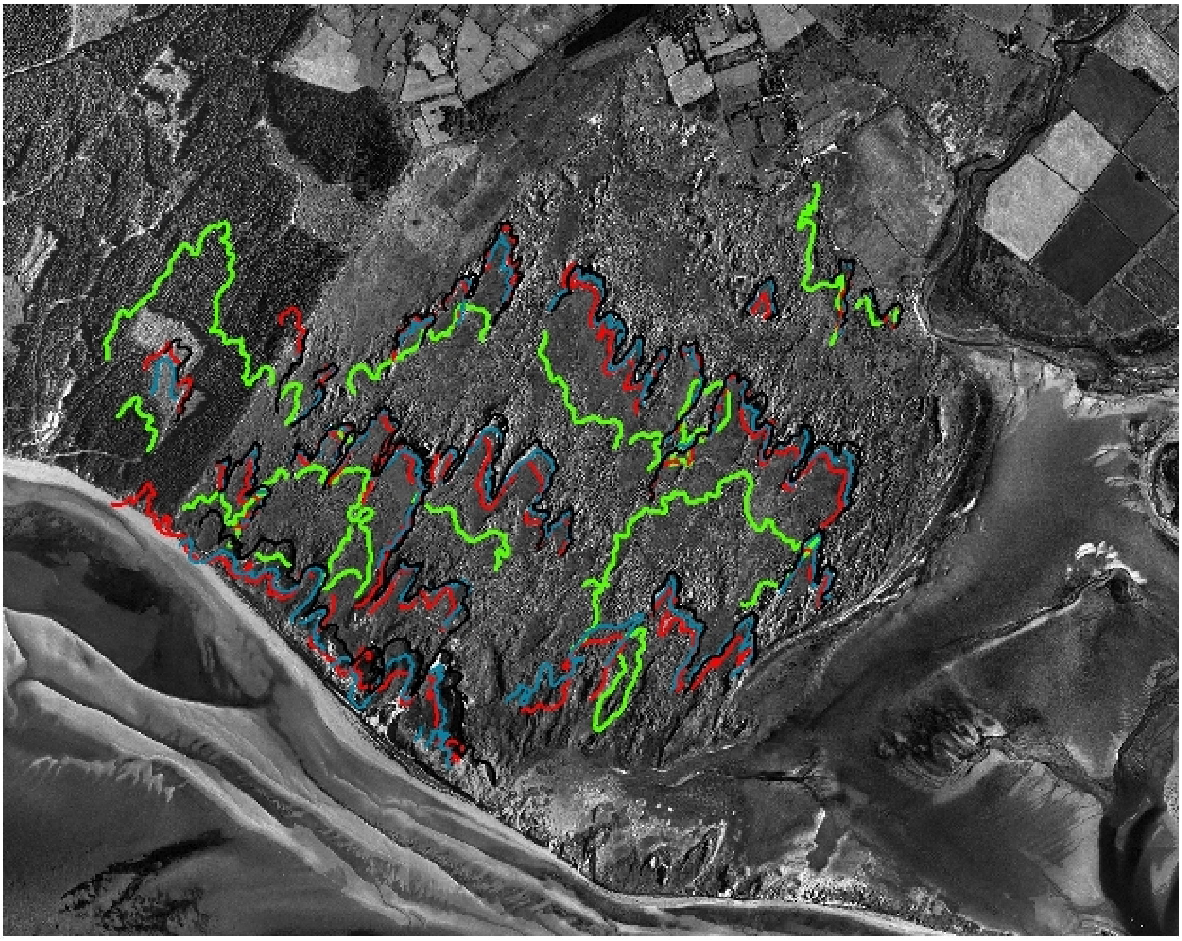


Figure 13. Image of Newborough Warren. Position of coloured lines show migrating dune ridges over a period of 150 years, from green (ca. 1850) to red (1951) to black (2000). Prevailing wind direction is from the South West.

Another benefit of this approach is that creating new areas of dry dune or dune slack habitat allows the dune vegetation to adapt naturally to climate change. New dune slacks will form at the current level of the water table, not the level it used to be decades ago. In this way, ensuring new habitat is always being formed means that at least part of the site has the chance to develop in equilibrium with current conditions.

Where successional change or acidification of surface soil layers has been speeded up as a result of excess nitrogen deposition from the atmosphere, new habitat formation allows the system to start again.

Once set in motion at a large enough scale, this approach could be self-managing. However, the approach is also controllable if we need to take a different approach, or wish to slow down or halt a moving dune.

17.3 Landscape scale

These processes work best at large scale. Small-scale interventions are rapidly colonised by plants from the edges, particularly if the weather in a particular year favours stabilisation rather than sand blow.

As a result, planning should consider the whole site but also other sites nearby as part of a much larger landscape. This helps define questions like:

- How big an area should we work across?
- 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 area covered by habitats of different ages or successional stage?

Some of these questions have a wider scope, for example a target of up to 30% bare sand is being discussed as appropriate for dunes in the 'Dunes Roadmap'[7], but differs considerably from targets defined in Common Standards Monitoring guidance for sand dunes[8] and related definitions in Natura 2000 guidance. Thinking at large scale and taking account of change over time also helps to plan management of the system to ensure the long-term survival of rare/specialist species and high biodiversity, whilst also taking account of archaeological or other landscape features.

17.4 Other considerations

Since this is often a large-scale activity, it provides both opportunities and challenges.

Removal of topsoil off-site helps take accumulated nutrients out of the system. Moving large quantities of soil is expensive, and may require permits or licences, but at the same time provides opportunities for sale or use of this material as a commercial product, for example as a soil improver in topsoil.

If removal of soil off-site is not an option, where to dispose of it on-site needs careful consideration. Using turfs or organic material as part of new piles of sand can lead to nutrient-rich hotspots. If these are placed along the edge of a restoration area, this can have a number of unintended outcomes. Firstly, the nutrient rich soil allows plants to grow and spread rapidly, creating a very stable edge to the restoration. Secondly, the type of plants that grow on these soils are often nitrogen-loving species adapted to disturbance, such as sow thistle, creeping thistle. Many of these species are wind-dispersed which means there is a source of seed from problem species growing vigorously right next to the rejuvenation area.

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[7] Houston, J. (2020) Conservation of dune habitats in the Atlantic Biogeographic Region: the Dune Roadmap for knowledge exchange and networking 2016-2020. In L. Jones, T.A.G. Smyth & P. Rooney (eds.) *Proceedings of the 2017 Littoral conference 'Change, Naturalness and People'* (pp. 36 – 53).

[8] JNCC (2004) Common Standards Monitoring Guidance for Sand Dune Habitats. Peterborough https://hub.jncc.gov.uk/assets/7607ac0b-f3d9-4660-9dda-0e538334ed86

In large-scale turf-stripping, ensuring that the right species you want to recolonise the area are available nearby and have the ability to spread into the opened up area is important. Small islands of vegetation can be left as a seed source, seed can be sown or green hay scattered, or topsoil containing a desirable seed-bank spread very thinly in key areas.

Likewise, control of problem species should be considered. Existing problem species are quite likely to survive the turf stripping if they have deep roots or rhizomes which can re-sprout or regenerate from fragments. Examples include horsetail [*Equisetum* spp.], bramble species [*Rubus* spp.], and common reed [*Phragmites australis*], all of which can rapidly spread through a cleared area. Other species with wind-blown seed can also colonise, such as sow-thistle [*Sonchus* spp.], ragwort [*Jacobaea vulgaris*] or rosebay willowherb [*Chamerion angustifolium*]. Control of these problem species can be undertaken beforehand, or afterwards, but may need to consider chemical control methods and would be subject to relevant regulations.

17.5 Management options

The two main options are notching of the foredune for locations near the sea, and turf stripping / reprofiling on a large scale for areas away from the foredunes, ideally done in combination. Notching increases wind speeds and sand supply into certain parts of the site. Turf stripping removes the stabilising vegetation and organic matter from areas of the site, while ideally trying to retain the underlying dune landforms. Each technique is described in more detail in *Section 19* (Notching) and *Section 20* (Turf stripping / re-profiling).

17.6 Monitoring

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

- Sand movement
- Vegetation
- Hydrology

18 HYDROLOGICAL MANAGEMENT

Dune slacks are seasonal wetlands which are flooded in winter (or have the water table very near the surface) and dry out in summer. This annual fluctuation in water table is a key feature in maintaining a high biodiversity status. It provides breeding grounds for toads and frogs in seasonal pools which are free of major predators like fish because they dry out in summer. The frequent changes in water table also help preserve the low nutrient levels, allowing diverse plant communities to develop, and supporting many rare species including orchids.

However, they are also vulnerable to changes in hydrology either due to man's activities, climate change or even coastal change (they are affected by both coastal erosion and accreting coastlines).

Management for hydrology may need to take into account how a particular slack was formed and particularly whether the slack is underlain by permeable sand with input from a larger groundwater area, or is bounded by a clay or other impermeable layer (as in sites where sand overlies estuarine sediments, or glacial boulder-clay sediments).

18.1 Water tables

Water tables in sand dune systems fluctuate naturally. Water tables are usually highest in late winter and lowest in late summer. In a typical year, the water table might drop by 40 – 70 cm in summer, but over longer timescales might vary by 1.5 m from wet years to dry years (*Figure 14*). The pattern of rising and falling water tables is called the 'hydrological regime'.

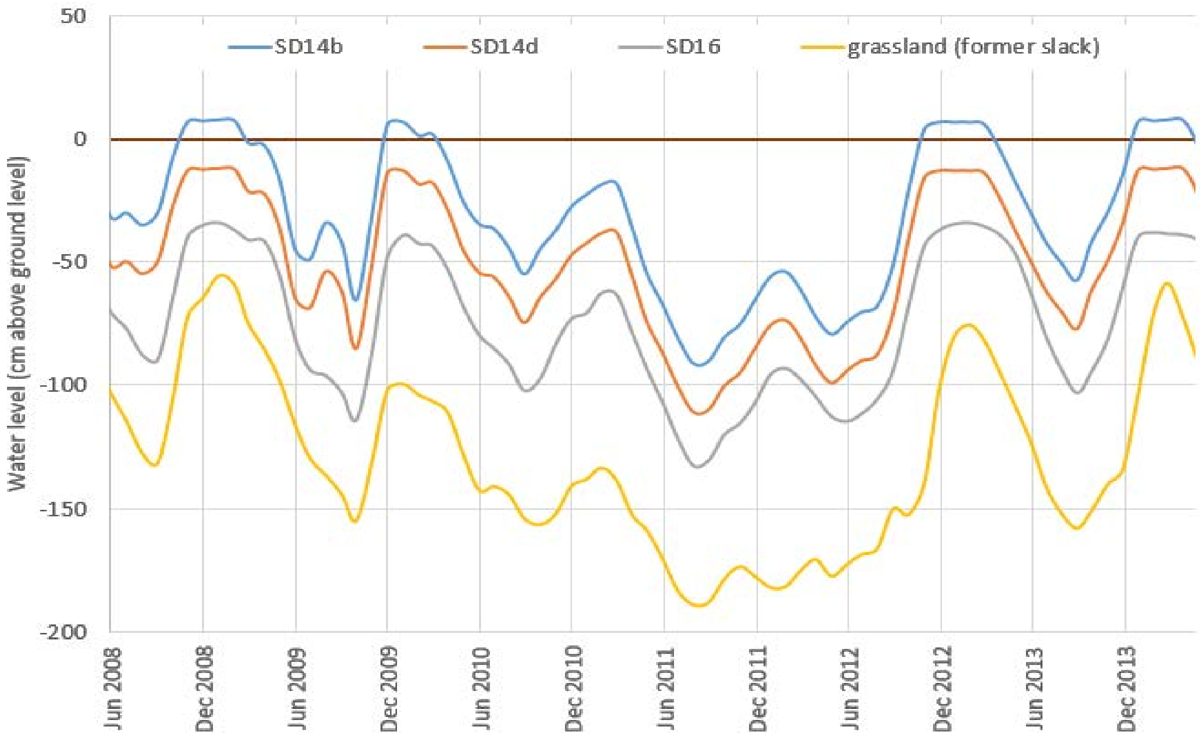

Figure 14. Six years of hydrology data showing winter to summer differences, and variation between years. Measured hydrology under four plant communities shown: SD14b wetter version of Salix repens-Campylium stellatum, SD14d drier version of Salix repens-Campylium stellatum, SD16 dry dune slack Salix repens-Holcus lanatus, and SD8 dry dune grassland Festuca rubra-Galium verum. Data from Newborough Warren.

In larger sites, there is often a domed water table which is maintained by rainfall (e.g. Braunton Burrows, *Figure 15*). With a domed water table, the dune groundwater is separate from groundwater 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. As a result of the 'dome', the annual range from winter to summer will be greater on a large site than a small site, and will be greater towards the middle of the dome, than near the sea or at the edges.

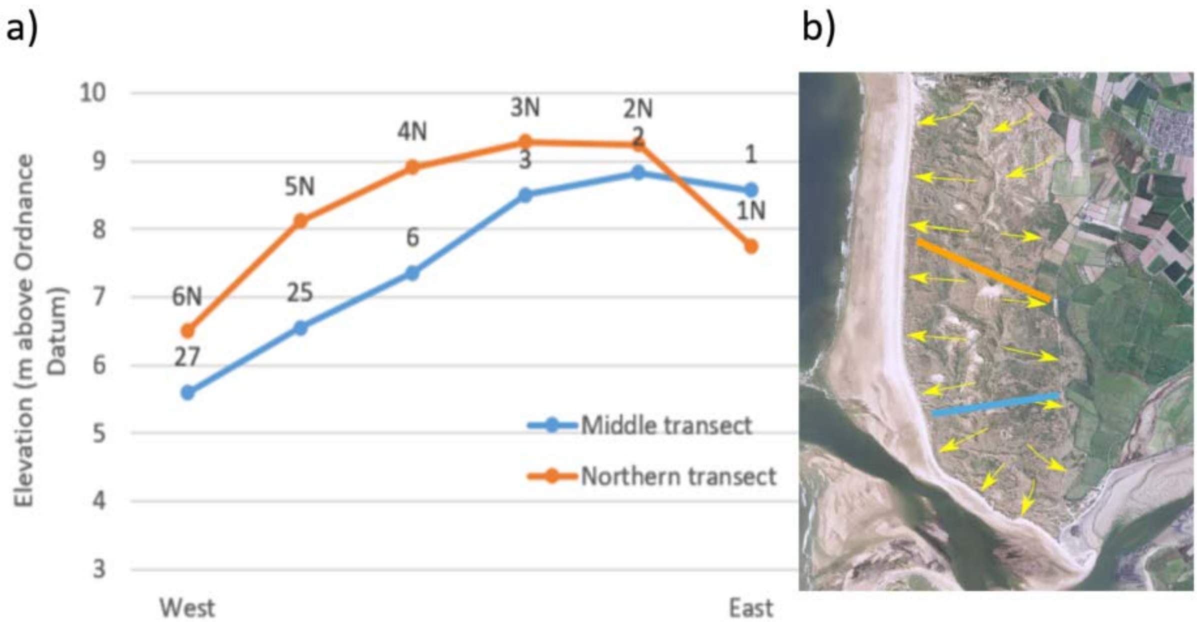

Figure 15. a) Domed shape of groundwater profile in two transects West to East across Braunton Burrows, showing mean spring water level in 2007 relative to sea level. Numbers on the graph are the dipwell codes; b) shows approximate location of transects, with yellow arrows showing estimated direction of groundwater flow. Hydrological data courtesy of Justin Gillett, map extracted from Jones et al. (2013)[9].

18.2 Groundwater chemistry

Water chemistry can be very different within a site and can be different at one site compared with another. It depends on the geology around the site, the type of sand on the site (with or without lots of shell fragments) and whether the site has a domed water table. Dissolved chemicals like Calcium and Magnesium help maintain the 'base-rich' nature of calcareous dunes (calcium-rich). Base-loving plants in successionally young dune slacks are a particular conservation focus. As time progresses (typically over centuries), rainfall draining through the sand dissolves much of the calcium and other minerals and it ends up in the groundwater. Over time, the surface soils then become acidic. However, if the base-rich groundwater floods the site in winter, this temporarily replenishes the soil with these minerals, allowing the base-rich species to survive in these slacks for longer.

[9] Jones, L., Stratford, C., Robins, N., Mountford, O., Amy, S., Peyton, J., Hulmes, L. & Hulmes S. (2013). Braunton Burrows. Site report for "Survey and analysis of vegetation and hydrological change in English dune slack habitats" project. Report to Natural England, May 2013.

Nutrient contamination of groundwater can be a problem, and the nutrients in the groundwater reach the dune soils in the same way, during winter flooding.

18.3 Recharge

On all dune systems, the water table is maintained by rainfall. In fact, 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'.

Recharge is influenced by rainfall as the amount of water coming in, the amount lost to evapotranspiration is governed partly by temperature but also by wind speeds and by the vegetation and soils right across the site. Some plant types capture more water on their leaves than others, and this evaporates before it reaches the soil, some plants have higher rates of water use than others. Trees and shrubs generally have higher evapotranspiration rates than grass or low vegetation, meaning less recharge to the groundwater. Thicker layers of organic material in the soil also hold more water which can be used by plants before it gets a chance to filter down to the groundwater.

18.4 Hydrological guidelines for dune slack vegetation

There are five different plant communities in UK dune slacks. 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 in average hydrological regime will shift you from one community to another. The wettest of these communities is only separated from the driest by 40 cm and this highlights the sensitivity of these communities to changes in hydrology[10]. *Table 1* and *Figure 16* summarise the hydrological guidelines for most UK dune slack communities. In experiments, a drop in water table by as little as 10 cm has also been shown to alter the balance of species preferring wet conditions, compared with those preferring drier conditions[11]. This highlights the importance of understanding water table variation at the site.

However, these guidelines reflect long-term hydrological patterns, but short-term variation can be considerable. While dune slack plant communities seem to be sensitive to 10-20 cm differences in average hydrological regime, we know that water levels vary by much larger amounts over annual and decadal timescales (See *Figure 14*). We don't yet know how long it takes for the vegetation to respond to those sort of changes, and for one set of species to be lost, and replaced by other species. There is on-going research work to try and understand these time-lags better. What is clear is that long-term changes in hydrology will affect the plant communities. For example, at Ainsdale dunes there are perfectly shaped dune slack features which clearly used to be slacks, but now only support dry dune vegetation. These slacks mainly occur at the edge of the woodland which was planted in the 1890s.

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[10] Curreli A., Wallace H., Freeman C., Hollingham M., Stratford C., Johnson H., Jones L. (2013). Eco-hydrological requirements of dune slack vegetation and the implications of climate change. Science of the Total Environment 443, 910-919.

[11] Rhymes, J., Wallace, H., Tang, S.Y., Jones, T., Fenner, N., Jones, L. (2018). Substantial uptake of atmospheric and groundwater nitrogen by dune slacks under different water table regimes. Journal of Coastal Conservation 22 (4). 615-622. https://doi.org/10.1007/s11852-018-0595-z

Table 1. Hydrological guidelines: Typical water levels for dune slack communities (cm above ground surface). Data are calculated from 9-year averages (2006-2014) using dipwell and quadrat data from Newborough Warren and Ainsdale. * MSL is average of water levels in Mar, Apr and May.

NVC code	Mean Spring Level – MSL*	Winter/ spring maximum	Average	Summer/ autumn minimum	Plant community name	Description
SD 13	*Insufficient data*	*Insufficient data*	*Insufficient data*	*Insufficient data*	*Sagina nodosa-Bryum pseudotriquetrum* community	Early successional stage, rich in mosses and liverworts, usually with bare sand. Fairly drought tolerant.
SD 14					*Salix repens-Campylium stellatum* community	Frequently species rich and associated with persistently humid soils and base-rich groundwater.
SD 14b (wetter)	-15	9	-26	-66		
SD 14d (drier)	-33	-13	-47	-83		
SD 15					*Salix repens-Calliergon cuspidatum* community	Late successional stage, generally species poor. Less dependent on base-richness of water, but strongly related with flooding.
SD15b (wetter)	-13	9	-27	-64		
SD 15a (drier)	-46	-33	-61	-93		
SD 16	-48	-34	-63	-96	*Salix repens-Holcus lanatus* community	Dry slacks. Often dominated by fescue and other grasses, and creeping willow. Soils generally still base rich.
SD 17	-29	11	-32	-71	*Potentilla anserina-Carex nigra* community	Species composition reflects damp habitat, recalling fen meadows. Forbs-rich, with a sparse shrub cover. Soil may be slightly acidic.
Dune grassland	-89	-70	-103	n/a	*e.g. Festuca rubra-Galium verum* community	Dry / damp dune grasslands, including former slacks that have dried out

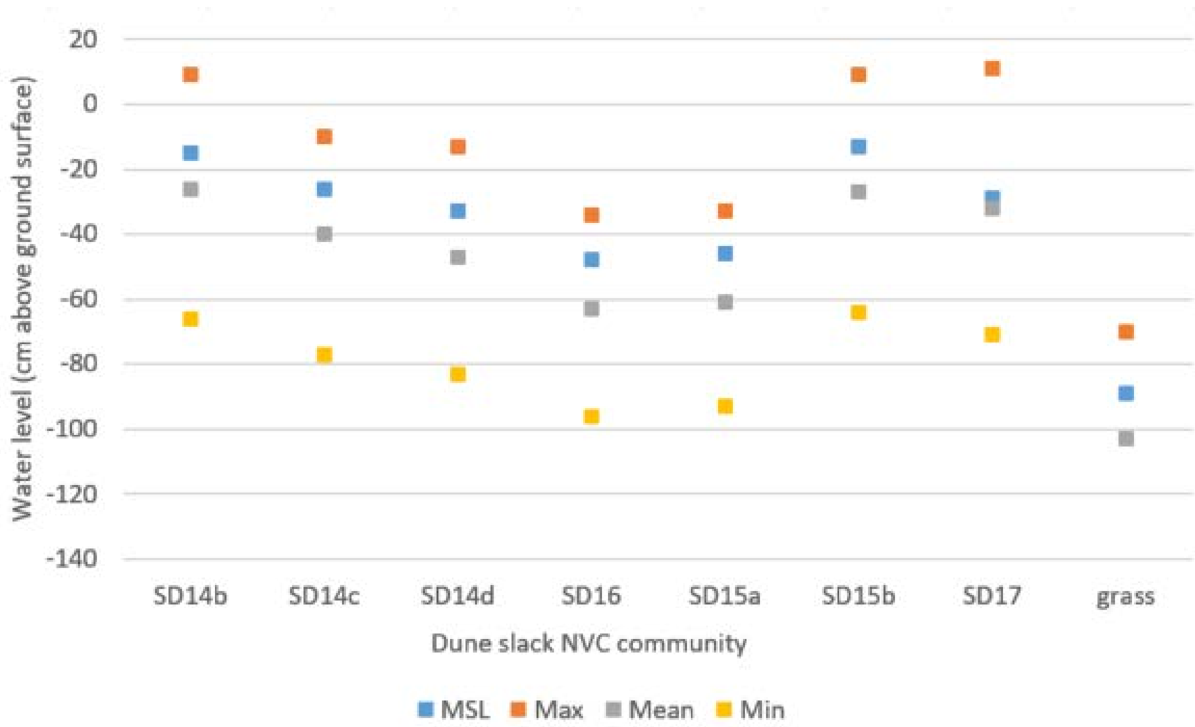

Figure 16. Hydrological guidelines for the dune slack communities in Table 1 (shown in graph form).

18.5 Nutrient regulation

The low nutrient status of these habitats is regulated by the fluctuations in water tables. Changing water tables can increase denitrification (the conversion of nitrate in the soil to a gas, lowering nitrogen levels in the soil). In flooded soils, the breakdown of organic matter slows down, meaning less nutrients are available for plants to grow. These fluctuations and the loss of nitrogen through denitrification help to prevent the more competitive species from dominating the slacks and allows more of the rare species that are characteristic of dune slack habitats to thrive. Drying out of dune slack soils as a result of lowered water tables can lead to the release of stored nutrients (called internal eutrophication), allowing nitrogen-loving species to take over. Where nutrient contamination is already an issue, this is likely to be made worse by a fall in water tables.

18.6 Threats to hydrology

Water tables are at threat from drainage, on-site water abstraction and/or climate change. Additionally, for sites that are not hydrologically isolated they may also be at threat from other activities that take place within the wider catchment area.

18.6.1 Water abstraction and drainage

Water abstraction is where water is removed from the sand dune aquifer which significantly lowers the water table. Water is typically extracted for irrigation of agricultural land or golf courses, but water use by trees and scrub on forested sites will also lower water tables. In The Netherlands, where abstraction occurs to supply drinking water, there is a wealth of evidence to show a significant loss of biodiversity through lowered water tables. In the UK on-site water abstraction for golf course management is likely to be smaller scale and localised, but can still have impacts.

Drainage can also substantially alter water tables, even where the drain is at the edge of a site, since this lowers the water table throughout the site. Drains are often dug to lower the winter water table on golf courses, or to divert drainage that is flowing into low-lying adjacent areas (fields or houses).

18.6.2 Climate change

An emerging threat to dune slack habitats is that of climate change, with the potential to alter sand dune hydrology. Water table depth is largely affected by groundwater recharge, which is regulated by the balance between rainfall and evapotranspiration. With a global increase in temperatures and a predicted higher frequency of extreme weather events it is likely that groundwater recharge is going to be affected. There are predictions that dune slacks located in the North West of England are likely to experience lowered water tables by up to 100 cm by 2080 which poses a serious threat to dune slack species.

18.7 Management levers

When deciding on a hydrological management for a site it is important to take a holistic approach that considers the wider catchment and nutrients.

The principles are:

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

Techniques where site managers may have local influence:

18.7.1 Ditch management

Ditch management should reconsider the original purpose of the ditch – is it still needed? If so, then can you change the way it is managed. For example by adding a sluice or control device so it only operates when it is most needed at the highest water levels.

18.7.2 Managing abstraction

Abstraction from dune water groundwater should consider whether alternative water sources are available (as long as they are free from nutrients and chemicals). Irrigation of golf courses with water from off-site can help counteract lower water tables caused by drainage or pumping in winter.

18.7.3 Artificial recharge of groundwater

Raising groundwater levels for conservation purposes with infiltrated water from rivers has primarily been carried out in the Netherlands in an attempt to restore dune slack habitat. This has yielded good results, in combination with other management techniques such as turf stripping. There have been cases however where high nutrient levels in the infiltrated water have led to eutrophication issues.

18.7.4 Forest management

Removal of plantation forestry from dune sites can improve the hydrology of adjacent dune habitats and allow restoration back to dune habitat. Other options include thinning of forest to open up the canopy and reduce water demand, but the science behind this is still relatively untested. Large-scale tree felling can result in strong negative reactions from the general public. This requires a positive and proactive public engagement process from an early stage where such work is planned.

18.8 Monitoring

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

- Hydrology
- Vegetation

Co-located monitoring points should combine hydrological and vegetation monitoring so that any effects of changes in hydrological regime can be detected in the vegetation. Vegetation quadrats should be located within 7 m of a dipwell (beyond 7 m the water table at the quadrat location may not accurately reflect measurements at the dipwell).

19 NOTCHING

This section covers Notching, which involves cutting a 'V' or 'U' shaped notch usually in a leading mobile dune next to the sea.

Other relevant sections: Turf stripping and re-profiling

19.1 Goal/Target

19.1.1 Goal & benefits

The goal of notching is to increase wind speeds and sand supply into the site. The faster wind speeds help increase mobility of existing sand within the site and supplying fresh sand. It can also create new mobile dune habitat landward of the notch.

19.1.2 When to use

Notching is increasingly being considered where sites are over-stabilised and there is a need to increase natural dynamics within the site. It tends to be used on larger sites where breach of the leading foredune helps to bring sand into the interior of the dune system. This technique is often used in combination with turf stripping within the dunes, for optimum benefit.

19.2 Design considerations

19.2.1 How to

Notching uses excavators and trucks to move the sand according to an agreed design. Large volumes need to be moved as the notch cuts through the foredune. Estimating the sand volume is needed to cost this accurately. *Figure 17* shows a notch at Kenfig a few years after creation. *Figures 18* and *19* show the creation of a notch in the foredune at Oxwich Burrows in 2021.

Figure 17. Dune notch at Kenfig, a few years after creation. Sept 2014. Photo, Laurence Jones.

Figure 18. Arial image of foredune at Oxwich, prior to notch being created January 2021. Photo, Natural Resources Wales.

Figure 19. Arial image of notch creation and turf stripping in foredune at Oxwich, January 2021. Photo, Natural Resources Wales.

19.2.2 Where to locate, and is there a good supply of sand?

The idea is to create pathways through which i) wind can blow and ii) to transport sand beyond the foredunes to support the presence of early successional stages. If the aim of the notching is to increase success of turf stripping / re-profiling by increasing local wind speeds and/or enhancing sand supply, then locations will be determined by those needs.

Location on some sites may be restricted by proximity to, for example, roads, residential areas, sites of archaeological importance and/or areas used for recreational activities. Notching may not be suitable on east coast dunes due to the direction of the prevailing winds. If sand supply is the main reason for creating notches, then ensure there is a plentiful supply of sand on the beach and in the sub-tidal zone.

19.2.3 Shape, size and number of notches

The size and number of notches to be excavated will vary depending on the site in question, and the goals of the notching. In most cases bigger is better; since the effects are longer lasting and more effective. Their size can range from 10m to 100m in width and typically the distance of sand travelling inland can range from 30m to 150m over a 5- to 20-year period. Depth of the notch depends on the height of the foredune, but should not go below the height of spring high water, unless inundation by seawater is one of the goals.

The direction of the prevailing wind will govern the angle at which the notch is created. Trials in the Netherlands have shown that positioning the notch at an angle from the prevailing winds rather than head-on yields a longer lasting result and funnels the wind through the dunes more efficiently. Typically notches are V-shaped to resemble the natural shape of a blow out and to perform in the same way as a natural blow out.

19.3 Other considerations

19.3.1 Contractors

Typically large scale rejuvenation is carried out by contractors. The excavation of notching needs to be done with some precision by taking into account the shape, size and number as discussed above. It is advisable the contractors work with GPS systems and are briefed with all the necessary details and have an ecological/geomorphological clerk of works present throughout the activity.

19.3.2 In combination with turf stripping

Utilising notching and turf stripping together will yield desirable results much quicker than utilising notching alone, as the techniques complement each other. By increasing wind speeds, notching improves the local conditions for sand movement, making turf stripped areas less likely to stabilise too soon.

19.3.3 Coastal flood risk management

Notching may not be appropriate on sites where a single foredune forms the main element of coastal flood risk management. However, on slightly wider sites with at least two dune ridges including the foredune, carefully controlled notching of the foredune is a viable option for rejuvenation. In these instances, smaller and fewer notches are the best approach, conducting small trials first. Discussion with the Environment Agency (or equivalent in devolved administrations) may be needed regarding the need of a Flood Risk Permit.

19.3.4 Public perception – key messages

This type of management intervention may appear to the public as destructive. It is therefore key to prepare the members of the public for this change. A key message is that this management is part of a long term management plan where results do not happen overnight. In the short term there will be larger areas of bare sand, but over time, a healthier dune system will be the result, with new and intermediate habitats forming over a 15-30 year time period. Explanations could include information about the species that would be lost without such forms of restoration.

19.4 Things to watch out for

19.4.1 May be short lived

Where there is not enough sand supply from the beach, the excavated sand alone will provide some bare sand into the site for a couple of months, but beyond that it may stabilise rapidly. The notch itself may fill in with sand blown from the beach or driftwood washed up by tides. Some ongoing maintenance may be necessary to keep the 'mouth' of the notch clear.

19.4.2 +/- Effects on downwind habitats

The movement of bare sand landwards may smother habitats inland of the foredune. Planning of the activity should have already insured no sensitive habitat or species will be lost (*Figure 20*). In the short term there will be a loss of some dune habitat, but the longer-term gains from this management outweigh short term losses. The improved mobility of the dunes and the movement of the sand may also cause issues on sites that are located in close proximity to residential areas and roads.

Figure 20. Sand burial of a formerly orchid-rich slack after creation of a dune notch, Newborough Warren 2015. Photo, Laurence Jones.

19.5 Nutrients

Notching can help redress some acidification of surface soils by supplying a fresh input of calcareous sand, which raises the soil pH. It may also bury some vegetation and soil in the immediate vicinity of the notch. However, it won't remove nutrients from the site.

19.6 Monitoring

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

- Sand movement

Some national LIDAR products are available, but will not give sufficient vertical resolution or repeatability over time for assessment of the success of notching procedures.

Bespoke air-borne LIDAR surveys are expensive. Monitoring used for large rejuvenation projects often use new (terrestrial laser scanning, or drone-based) methods. This is a surveying method used to produce 3D-images of the site.

19.7 Cost

Notching is relatively expensive as it requires heavy machinery. It also requires advice from geomorphologists, ecologists and hydrologists on optimum locations, and there may be costs associated with public engagement.

19.8 Seek advice

Due to the nature of notching, in order for it to be successful in mobilising dunes it is essential to have the potential locations surveyed by a geomorphologist to maximise results and to identify and avoid risks. However, be aware that a geomorphological survey will only inform you about the movement of the sand and how the site will change physically over time. Ecological experts will be able to advise on implications for the vegetation, reptiles and amphibians, insects, etc. Hydrologists can advise on any possible impacts on the dune groundwater. Impacts on site visitors should also be considered, possibly by conducting some form of survey on likely public opinion. Check the need for permits (Flood Permit – from EA) and consent/assents (for works on SSSIs). Habitat Regulations Assessment, protected species licences/method statements may be needed. You may also need to inform LPA and potentially the MMO.

20 TURF STRIPPING AND RE-PROFILING

This section covers techniques like turf stripping (also called sod-cutting), scraping and re-profiling. They are techniques that can be used in both dune slacks and in dry dunes. For simplicity in the following text we refer solely to turf stripping, but will clarify where differences in technique might be relevant. They involve removing surface vegetation and often surface soil, particularly organic matter, and additional shaping of dune features or deeper excavation of dune slacks in the case of re-profiling.

Other relevant sections: Notching

20.1 Goal/Target

20.1.1 Goal & benefits

The main goals of turf stripping are: to increase the amount of bare sand, and to remove organic matter and associated soil nutrients, or decalcified (acidified) surface soil layers. Together, these have multiple benefits. The increase in bare sand provides early successional habitat of open character, suitable for many of our rare species. This also encourages sand movement, and natural dune dynamics. The removal of vegetation and organic matter reduces the fertility of the soil and reduces its capacity to hold water. Removing acidified surface soil layers can help with rejuvenation of early-successional plant communities which prefer less acidic conditions. All these aspects help to slow down subsequent succession, meaning that the open habitats are maintained for longer.

In dry dunes, removing organic-rich soil layers can provide bare soils for colonising pioneer species, or can help instigate natural mobility.

In dune slacks, the removal of organic-rich soil layers usually lowers the ground surface closer to the water table, benefitting slacks which are drying out. Taking the soil level down to bare sand also encourages sand mobility, meaning the system becomes self-regulating and can ‘chase the water table’ naturally. In dune slacks, turf stripping is often used to create seasonal ponds for Natterjack toads. The amount of material to remove should be guided by what you want to achieve, and a good understanding of the hydrology at the site, discussed below.

Figure 1. Turf stripped and re-profiled slack at Newborough Warren, leaving islands of habitat containing rare species. Sept 2013. Photo, Laurence Jones.

Figure 22. Turf stripped using heavy machinery at South Walney Nature Reserve, Jan 2021. Photo, Cumbria Wildlife Trust

20.1.2 When to use

Turf stripping is typically used when there is a desire to increase natural dune dynamics on sites which are over-stabilised, to remove accumulated nutrients in soil, to get back to earlier stages of succession, or to bring the ground surface closer to the water table.

20.2 Design considerations

20.2.1 How to

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 deposited elsewhere on the site, or removed off-site. The depth of soil removed depends on considerations like: how much organic matter or decalcified surface soil needs to be removed, and the need to lower the ground surface closer to (or below) the water table for dune slacks. This needs to be balanced against the loss of soil seed banks of target species.

Topsoil inversion is a particular technique which uses a deep-plough pulled by a tractor. This inverts the soil profile to about 1m depth, burying organic rich surface material above a deep layer of mineral sand. In this technique the organic material is buried in-situ rather than being removed off-site. Leaving material in place can cause later problems (*see section 20.5*).

20.2.2 Size, bigger is usually better

Turf stripping can be done at small scale (scrapes in individual slacks) or at much larger scale. The size of intervention depends on the purpose, but in general, the bigger the area of intervention the longer it will last, and the more successful it will be in achieving the objectives. A number of reasons contribute to this: The vegetation surrounding a small area will provide seed and allow vegetative spread of species leading to rapid colonisation of the bare sand. Wind speeds are likely to be greater over larger bare areas as there is no vegetation to slow wind speeds. This leads to more active sand movement which has downwind benefits through rain of fresh sand, and the higher levels of soil disturbance also slows colonisation by plants. Turf stripping in slacks will often be constrained by the size of the slack. However, small scale features such as blow-outs can still have positive ecological benefits. The diagram in *Figure 23* shows how a small-scale blowout influences the vegetation and soil nearby.

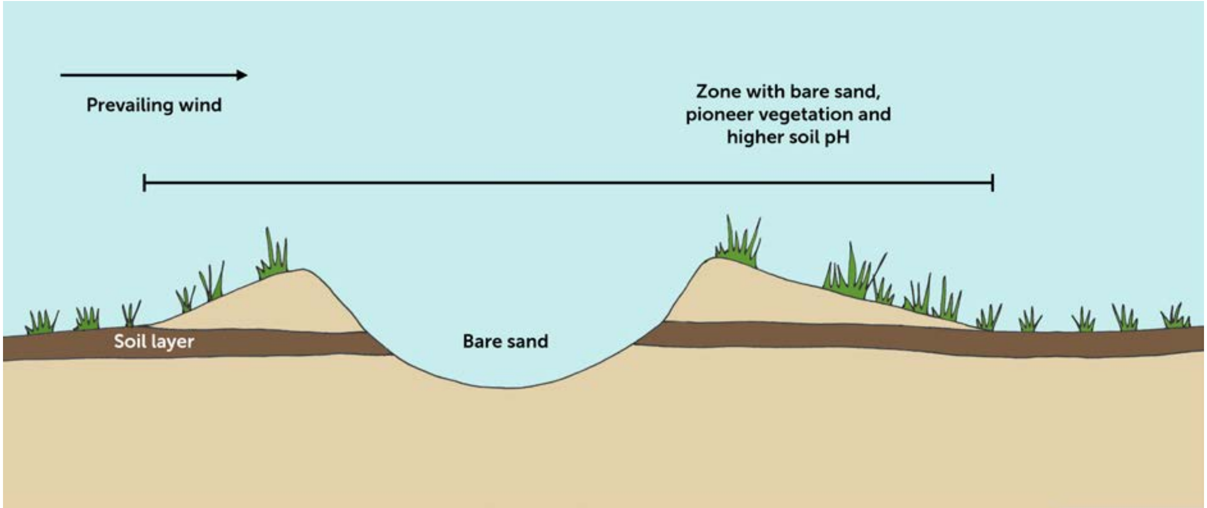

Figure 2. Diagram showing the influence of small blowouts on vegetation and soil characteristics nearby. Adapted from Van Til et al. 2019

20.2.3 Shape (shallow angle of edges creates more habitat)

In dry dune grasslands, soil removal should follow existing landforms wherever possible. If the aim is to increase natural dune dynamics, then the location should be planned to take advantage of natural wind funnelling and wind direction, and consider any likely positive and negative effects downwind.

In dune slacks, soil removal should naturally follow the topographical boundary from the slack to slopes. Using natural slack boundaries looks more natural than a uniform square shape and can reduce the negative perception sometimes associated with this management.

It is also important to create shallow angles at the edges of the slack to maximise available habitat. This provides a much greater area of microhabitats for sensitive species with very specific hydrological requirements, as shown in *Figure 24*, compared with photo in *Figure 25*.

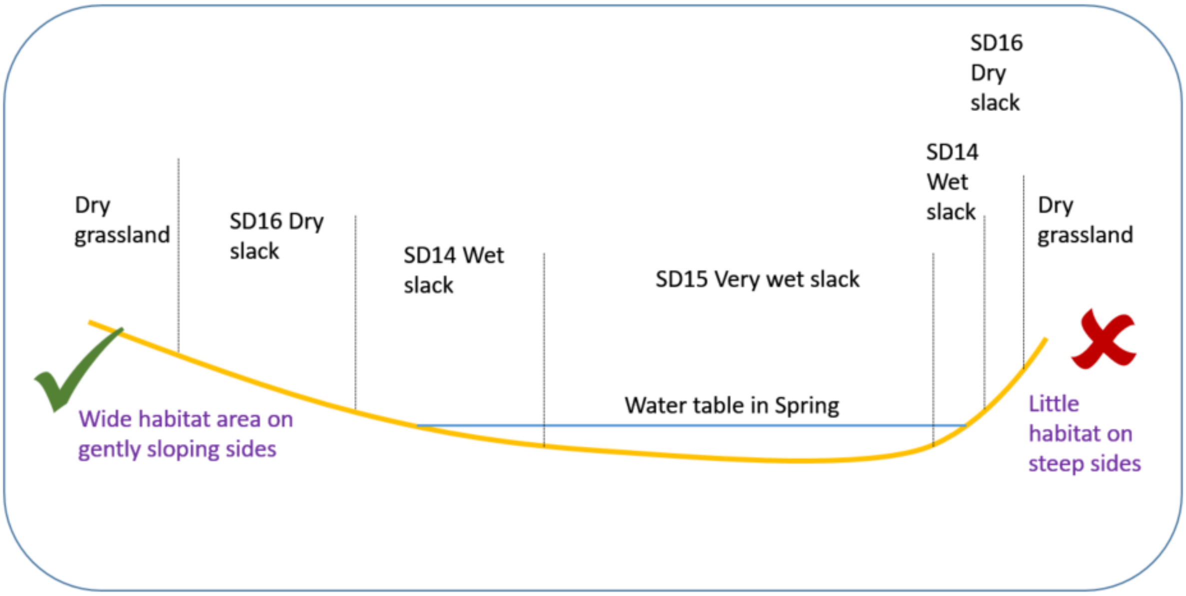

Figure 34. Schematic illustrating available habitat for a slack with shallow sides compared with steep sides.

Figure 4. Steep and square edges to re-profiled slack at Sandwich Bay, Kent, 2015. Photo, Laurence Jones.

20.2.4 To what depth?

The depth of soil removal is very important, and depends on the purpose of the intervention. For removal of organic matter, nutrients, or acidified soils, this should aim to remove as much as possible, while balancing requirements to maintain a source of seeds and propagules, if required. Simple soil cores, or a small hole dug with a spade or trowel, across the slack can establish the existing depth of the humic / organic soil layers, and so help guide what depth of sand to remove.

For rejuvenating dune slacks that have dried out, it is important to know how the water table behaves. Ideally, this should take account of longer-term variability in water levels, and what the water table is doing at present. For example, at Birkdale Sandhills on the Sefton Coast, scrapes were dug deep during a particularly dry year. In subsequent years, water tables returned to a more normal level and those scrapes are now permanent ponds and are not the dune slacks originally aimed for.

Note that 20 cm difference in height can shift you from one dune slack community to another, and 40 cm can shift you from a dry slack to a very wet slack. Typically, the wetted sand layer starts at 30-40 cm above the water table itself.

20.2.5 Planning excavation depth for dune slacks

Planning the excavation depth should be guided by your end-goal. For example, **what dune slack habitat, or Natterjack toad breeding requirements are you aiming for?** This also needs some understanding of water table behaviour. The text below summarises key decisions, and suggests two approaches to follow. The decision process is summarised in a flow chart (*Figure 26*).

- Decide on the target vegetation community (or water level regime for other species) which represents your long-term restoration goal.
- If there is a good quality example of your target community on site (your 'Reference community'), then follow **Method A**.
- If there is hydrological data for your site, follow **Method B**.
- (If there are both, it is suggested to use Methods A and B to check that they give a similar answer – if they don't agree then it is safer to follow the method using hydrological data)
- If the site has no good quality reference vegetation and no hydrological data, then find the nearest site which meets one of these criteria and follow the appropriate method. (A dune slack community in poor condition should NOT be used as a reference because an altered hydrological regime may be the reason why it is in poor condition).

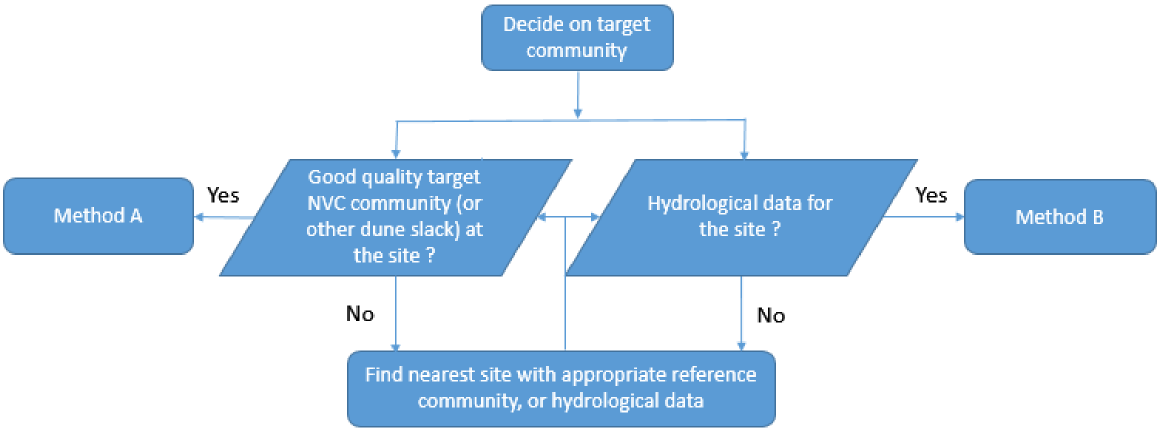

Figure 5. Flow chart summarising actions and decisions to plan target depth for a new dune slack.

Method A - using a reference community in good ecological condition

A1. **Establishing target depth to water table**

- One or two days before your planned excavation, find your reference community and dig a narrow hole down to the water table (or use a soil augur).
- Measure the depth from the soil surface down to the water table – this is your **target depth**.
- Put the waste sand from the hole in a series of buckets or on plastic sheet.
- When you have finished, refill the hole in reverse order, so the sand that came out first is the last to go back into the hole. This keeps the soil layers in the right order (which is important for maintaining the profile of soil pH, organic matter, etc.).
- This should be done the day before your main excavation if possible – water tables can change fairly rapidly over time, so if you do this too early, your target depth will be incorrect.

- If you only have access to a different dune slack community than your target community, use the eco-hydrological guidelines to adjust this (*Table 1*), calculating the difference between your target NVC community and the available NVC community at your reference site

A2. **Marking target depth at excavation site**

- Take a large wooden stake and mark your target depth down from the top of the stake.
- At your excavation site, dig a soil pit down to the water table.
- Hammer in the stake so the depth marker is at the water table. The top of the stake now marks your target soil level for excavation.

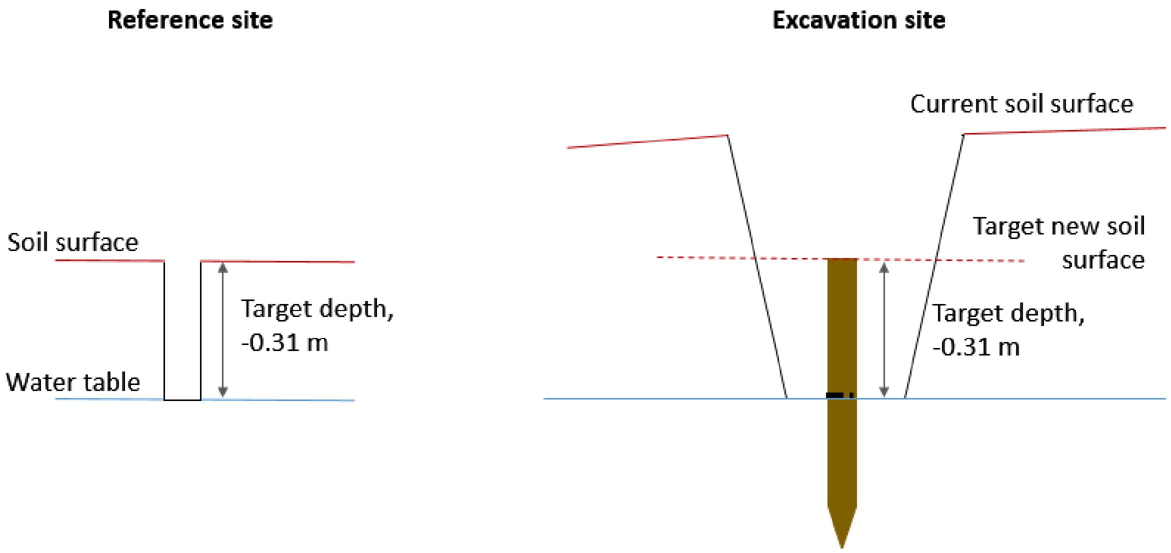

Figure 6. Schematic showing use of a reference site in good condition, as a proxy for calculating excavation depth for restoration action towards a specified target community.

Method B - using hydrological data

For this method you will need the target water level (**Target Mean Spring Level - MSL**) for your chosen community and three other pieces of information:

I. **month offset** to adjust for the time of year in which you conduct the excavation
II. **current year offset** to adjust for the hydrological conditions in the current year, compared with longer-term averages
III. **location offset** to adjust for the water table at the proposed location where work will take place

B1. **Target Mean Spring Level (MSL)**

- Look up the water table metric for your target community from Table 1, to give your **Target MSL**

Once the target community has been decided, and the target hydrological regime identified, the excavation depth can be planned. This depends on the time of year in which the restoration activity is to take place.

B2. **Month offset**

- For your site (or reference site), calculate the median[12] monthly water level profile, and the Mean Spring Level (MSL, average of the long-term March, April and May measurements).
- If possible, choose a dipwell in the same vegetation community as your target restoration community, but this is not essential.).
- A table constructed from dipwell readings should show values below ground level as negative values.
- Decide the month when restoration will take place.
- For your site (or reference site), calculate the **Month Offset** for the month when restoration will take place, using Equation 1 and the long-term water level profile for the dipwell/site. See example in *Table 2* and *Figure 28*. This gives you your **Month Average** water level and the **MSL** for that site/dipwell.

$$MonthOffset = MonthAverage - MSL \quad \text{(Equation 1)}$$

[12] The average is likely to be close enough, but median is preferred.

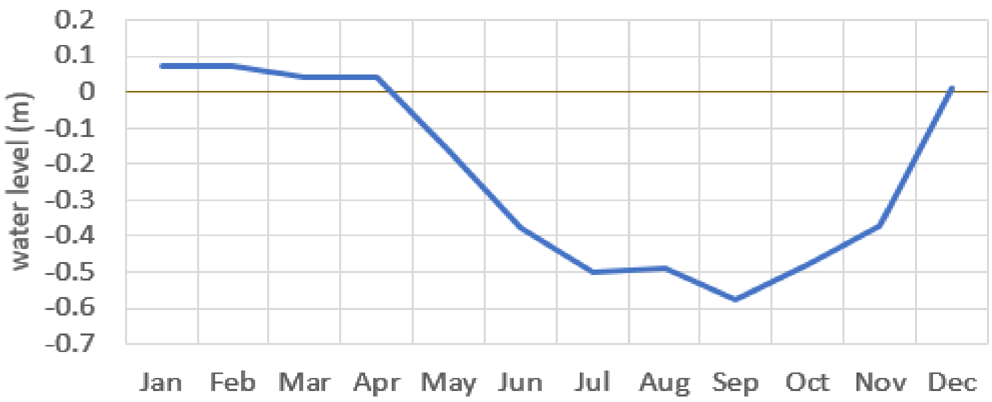

Figure 7. Illustrating monthly profile (median values) of long-term water level records (2006-2019). Example from dipwell NW4 at Newborough Warren.

Table 2. Example monthly profile of water levels (median values 2006-2019, dipwell NW4 at Newborough Warren (from Figure 28 above, presented as a table). MSL is average of water level in Mar, Apr and May.

Monthly average water level (metres above ground level)											
MSL (Mar, Apr, May): -0.03											
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0.07	0.07	0.04	0.04	-0.17	-0.38	-0.5	-0.49	-0.58	-0.48	-0.37	0.01

B3. **Current year offset**

For your site (or reference site), calculate the **Current Year Offset**. This adjusts for how the water table lies for the current year compared with the long-term average.

- At the time of excavation (or within a few weeks), take a dipwell reading from the same dipwell used to calculate the average water level profile. This gives you the **current water level**
- Calculate the current year offset using the equation below, from the current water level you have just measured and the month average used in B2 above.

$$\textbf{\textit{CurrentYearOffset}} = \textbf{\textit{CurrentWaterLevel}} - \textbf{\textit{MonthAverage}} \qquad \text{(Equation 2)}$$

B4. **Location water table depth**

The last piece of information required is the depth to the water table at your planned restoration location.

- At the time of excavation (or within a few days), dig a small pit down to the water table
- Measure the depth to the water table from the ground surface. This may be quite deep, depending on the time of year, and your chosen location.

- This gives your measured **Location Water Table Depth** which is used in the next calculation step. Note, this should be represented as a negative number (i.e. to show depth below ground level).

B5. **Calculating excavation depth**

- All the information collected above allows you to calculate the **excavation depth** for the planned new soil level below current ground surface, using Equation 3 below, and visualised in *Figure 29*.

ExcavationDepth = LocationWaterTableDepth – TargetMSL – MonthOffset – CurrentYearOffset

(Equation 3)

B6. **Marking excavation depth**

- At the excavation site, in the hole used to dig down to the water table, insert a large stake.
- Use a plank or straight length of wood across the top of the hole, and measure directly downwards to measure the depth of the planned new soil level.
- Hammer in the stake so its top is exactly at the level of the planned new soil level.
- This is your easy guide to mark the reference depth for excavation.

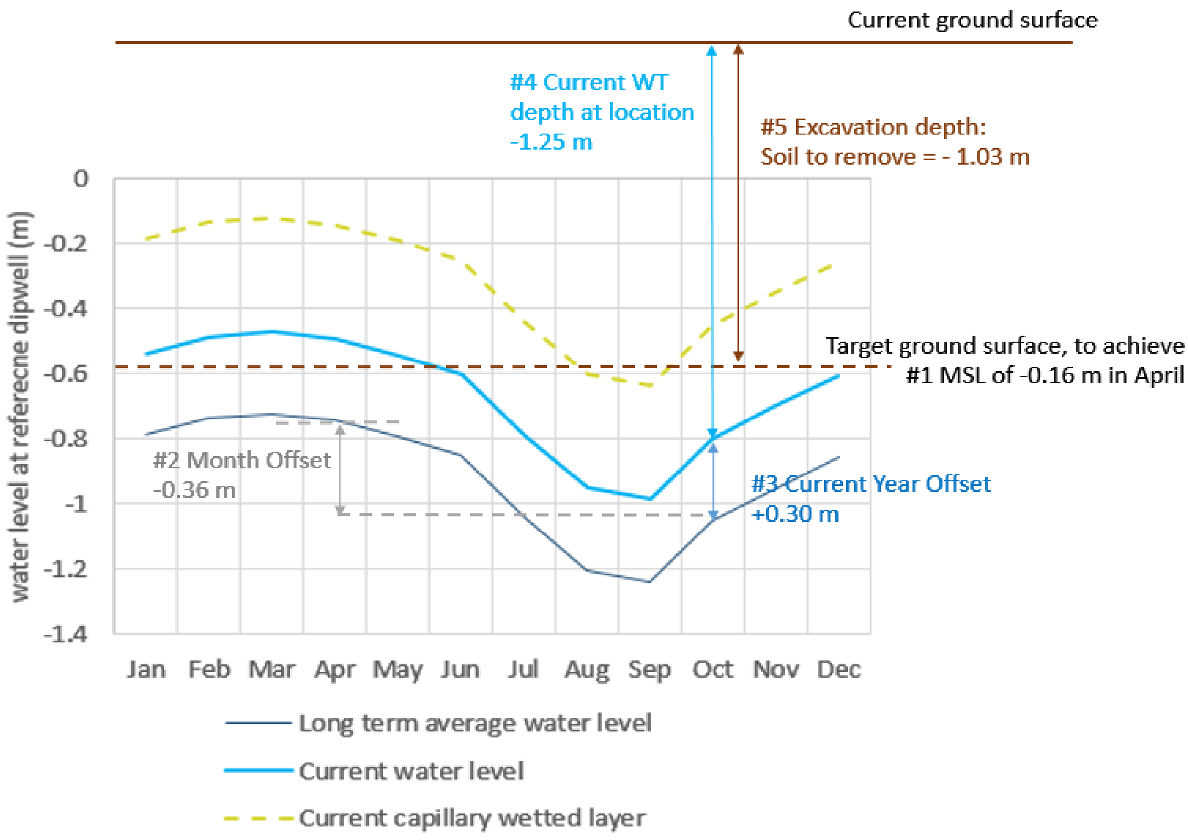

Figure 29.

20.3 Other considerations

20.3.1 What to do with the soil?

Disposal of soil can be expensive or difficult, and may require waste permit licences. There may be a commercial use for the soil, particularly if there will be large quantities available. In some cases, a local buyer has been found for the sand, for use as a soil improver, or for mixing with commercial topsoil.

If the soil is mostly mineral sand without a high organic matter content, then it may be useful to create piles elsewhere on site which can act to help funnel winds in a desired direction, or to act as a source of sand to blow over areas of dry dune grassland which might need slow rejuvenation. Excavated sand can be used to elongate the dune slack arms, which achieves both these objectives.

Thick layers of organic material should be buried deep below mineral sand, or ideally removed off-site. If left on-site, these often become highly 'weedy' areas with lush, nutrient rich plant growth. If disposed on-site, the location should be carefully chosen taking account of: accessibility, distance from restoration area, nutrients leaching from dumped soil, down-wind sand blow from dumped soil, location of sensitive habitats or species.

Ensuring that the material does not fall back into the scraped area is essential, do so by taking the prevailing winds into consideration along with the onsite behaviour of the winds (e.g. does the wind get funnelled in certain parts of the site, and are there areas with stronger winds ?). In the case that the material is not suitable for re-profiling (too stony, too much organic material, contains a seedbank of undesirable species) then arranging for it to be removed from the site is the best option.

20.3.2 Seedbank and propagules

Although the area due to be scraped is likely to be vegetated by an older successional community or by a competitive and problematic species the soil below is likely to still have a younger successional seed bank. It may be desirable to dig down deep enough to reach this seed bank formed when the area was historically vegetated by a younger community. Material can be removed to a greater depth, in which case the storage and subsequent spreading of a little of the soil containing the older seedbank can aid recolonization. However, relatively little is known about the persistence of seed from early successional species in dune soils. Another option is to leave small islands of intact soil to act as a seed reservoir. However, the 'islands' can become very dry and there may be additional wind-scour around the edges due to increased local wind speeds.

When scraping slacks to remove problematic species, a mechanical rake can pull out the rooting system. This can work with some persistent species, but not all. It is best to avoid scrapes in areas with rhizomatous species – plants like Common reed [*Phragmites australis]* and the grass Wood small-reed [*Calamagrostis epigejos]* which will spread quickly and re-grow from small root fragments, unless pro-active chemical or other control is planned.

20.3.3 Briefing contractors and volunteers

Briefing volunteers and/or contractors that are carrying out the stripping with the specific details for size, depth, angles and as to where the topsoil needs to go is essential. There are numerous accounts where this has been overlooked and has resulted in a 'bad job' that doesn't meet conservation needs. Contractors may wish to keep their work uniform and neat but this can lead to uniform square ponds to a uniform depth that don't look aesthetically 'natural' and don't create patchy microhabitats for successful restoration. It is advisable that restoration areas are clearly marked out, that contractors work with GPS systems and are briefed with all the necessary details and have an ecological/geomorphological clerk of works present throughout the activity. Access routes for all machinery onto and transiting parts of the site should also be carefully planned and explained to contractors.

20.4 Public perception – key messages

Turf stripping and re-profiling requires heavy machinery and to be most successful it is usually carried out on large areas. In this instance the work can look destructive as the undesired vegetation is removed leaving bare sand/soil which to the public can be associated with negative environmental impacts. In order to change public perception it is important to warn and prepare regular visitors as to what the stages are to a healthy restoration project. A key message is that this management is part of a long term management plan where results do not happen overnight. In the short term there will be larger areas of bare sand, but over time, a healthier dune system will be the result, with new and intermediate habitats forming over a 15-30 year time period.

20.5 Things to watch out for

20.5.1 May be short lived

If conducted in small areas, or using inappropriate techniques, the benefits may be short lived. These issues can occur as a result of placing the scraped out soil where it will blow back in, not digging deep enough which leaves organic material or acidified soil layers behind. All these factors help colonising plants establish quickly and grow well, leading to rapid succession to older habitat types.

20.5.2 +/- Effects on downwind habitats

Due to this management creating larger areas of bare soil there is likely to be considerable sand movement during periods of high winds. In most cases this is a desirable aspect of the management. In the case that the site is close to urban areas this can have implications where roads may be temporarily covered in sand and affect residents in the close vicinity. These conditions should have been considered during the design phase and should be minimal. Sand blowing over adjacent habitat should be anticipated and planned for. It can be a valuable way to rejuvenate some older grasslands. However, it may also have negative effects where i) it buries or raises the soil level in dune slacks, effectively drying them out, ii) if older acidic dune grasslands are a valued feature of the site, an influx of fresh calcareous sand will damage these habitats. These habitats are often lichen rich and will not be able to withstand both sand burial and the increase in soil pH associated with fresh sand.

20.5.3 Spread of undesirable species

Large areas of bare sand are easily colonised by wind-dispersed species like Ragwort [*Jacobaea vulgaris*], Sow thistle [*Sonchus arvensis]*, Common thistle [*Cirsium arvense]* and Rosebay willowherb [*Chamerion angustifolium]*. These may need to be controlled by chemical means, or by hand-pulling if they appear to be getting out of control. This problem can be made much worse if organic material is spread nearby or within the deposited sand, due to the much higher nutrient levels it contains.

20.6 Nutrients

Turf stripping with removal of the soil off-site is the most effective way to remove nutrients from a site, taking all the accumulated soil nutrients with it. This can be used to get rid of decades of accumulated nitrogen. Where topsoil is buried, there is a danger that sand blow will expose the nutrient-rich soil again. If this happens rapidly, then the buried roots and rhizomes may still be viable and so can regrow, taking you back to square one. This was the case for an experimental topsoil inversion carried out at Talacre Warren. The initial inversion of the soil profile was highly successful, but due to sand blow exposing the organic material, perennial and persistent problem species like horsetail [*Equisetum arvense]* rapidly recolonised and are now dominant.

Bringing the ground surface closer to the water table can help reduce nutrient availability, since nitrogen processing from the breakdown of organic matter is slower in wetter soils. Colonisation by some early successional plant species like Shoreweed [*Littorella uniflora]* can also help maintain low nutrient levels because this species stimulates denitrification (release of nitrogen from the soil as a gas).

20.7 Monitoring

Monitoring (*see also section 9*) should take account of:

- Vegetation
- Soils
- Hydrology

20.8 Cost

This is a high cost management option, due to the need to hire heavy machinery. Disposal of soil off-site may add considerably to this cost, unless a buyer can be found for the soil.

21 GRAZING

This section covers grazing by domestic stock (cattle, sheep, ponies and other animals) as well as grazers considered to be 'natural' like rabbits.

Other relevant sections: [Mowing and cutting]

21.1 Goal & benefits

The main goals are to keep vegetation short and to control scrub growth. The shorter vegetation allows more light to reach the ground which in turn 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.

21.2 When to use

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

21.3 How to

Grazing is conducted by introducing domestic livestock onto the site. 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. It is worth understanding the grazing history of any site and reasons when and why it might have declined or changed: this is often driven by economics. Sand dune vegetation is of poor grazing quality and modern breeds 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 often more willing to browse shrubs and other vegetation than modern breeds.

The type of grazers, stock density and the area grazed should be influenced by your desired targets. For example, utilising grazers to target one species as part of an intensive scrub clearance is different to utilising grazers to keep on top of an already cleared area. It is also key to take an adaptive management approach dependent on your results, as under grazing can lead to rapid succession and over grazing can create too much disturbance and encourage more nitrogen loving species.

21.3.1 Types of Grazers

- Sheep

Sheep are selective grazers, particularly when there is a large variety of species to choose from. However, when there is little choice they are less selective and will generally graze on what is available to them. Sheep are also more likely to graze steeper slopes as they are much more agile than cattle which can improve grazing evenness across the site. Sheep are generally less susceptible to the toxins in ragwort compared to other grazers. On sites where ragwort is prevalent sheep are known to graze on the rosettes in spring, thereby reducing flowering and spread of this species.

Issues can arise with sheep on sites that are heavily vegetated by brambles as their fleece can get caught in the brambles and can lead to losing some animals. It is important to bare this in mind and potentially clear areas with dense brambles to avoid this from happening.

Typically, a hardy breed is chosen for dune conservation as they are of low maintenance and can endure extreme weather, these may include the Soay or Hebridean breed. The Hebridean breed are popular as they can thrive on the poor quality vegetation whilst successfully grazing specifically targeted species. For example there are success stories of eradicated creeping willow with this breed and preventing the re-growth of sea buckthorn. However, they can be difficult to manage as they scatter rather than 'flock' when startled or disturbed, and are good at jumping fences.

A downside of sheep is that they preferentially graze flowers in summer and can decimate orchid flowering spikes in dune slacks. Therefore, they are preferred as a winter grazing animal, rather than summer grazers on some sites. They may also be susceptible to dog attacks.

Figure 30. sheep are used to graze the sand dunes at South Walney Nature Reserve, Cumbria, 2020. Photo, Emma Brisdion.

- Cattle

Cattle tend to prefer the longer grasses but are the least selective of the main grazers used on dunes. Cattle are prone to grazing within the close vicinity of their water access and therefore may not evenly graze the site as well as sheep and ponies do. This can lead to issues with poaching and compaction which should be managed appropriately. Again heritage breeds are regularly used due to their resilience towards harsh environments. The smaller breeds can reduce issues with poaching and compaction, and are generally seen as less threatening by members of the public. Breeds commonly used include Highland Cattle, Galloways, Welsh Black, Dexters, Beef Shorthorn and Vaynol, although Highland Cattle with large horns can be perceived as threatening. These cattle are more tolerant of poor quality vegetation and therefore rarely require supplemented food which should be avoided wherever possible. Supplementary feeding with hay or silage introduces nutrients onto the site, thereby increasing eutrophication problems. Cattle dung is very nutrient rich and causes localised hotspots of nutrients, although these are generally short-lived, except in areas where dunging is frequent.

Figure 31. Cattle are used to graze the sand dunes during the summer months at Saltfleetby-Theddlethorpe, Lincolnshire, 2020. Photo, Owen Beaumont.

- Ponies

Ponies graze extremely close to the ground due to their forward-facing teeth and are selective grazers, but not as selective as sheep. Native breeds that are typically used include the Highland, Exmoor, Dartmoor, Dales, Fell, Shetland, New Forest and Welsh Mountain. These are all hardy breeds that can withstand wetter environments. Ponies are back-end digesters rather than ruminants. As a result, their dung is lower in nutrients and tends not to create nutrient hotspots around the site. However, preferential dunging in slack areas can become a problem.

Figure 32. Exmoor ponies graze the dunes at Penhale, Cornwall, 2021. Photo, Ellie Chidgey.

Other domestic species

Goats have been used effectively for scrub control, but keeping them inside fenced areas can be problematic. European Bison are being used as grazers in The Netherlands.

- Rabbits

Although not strictly native grazers (they were introduced by the Normans in the 12th Century), they play an important role keeping vegetation very short through grazing and in creating bare soil through burrowing. Rabbit populations were heavily hit in the 1950s by the myxomatosis outbreak, and by subsequent waves of disease such as viral haemorrhagic fever. This has heavily reduced or completely decimated rabbit populations at some sites, which has contributed to the growing issue of dune stabilisation. There is often a close relationship between stock numbers and rabbit numbers. Where stock keep the sward short, rabbits are able to persist and thrive. Where stocking densities are reduced, or stock excluded for a short period, rabbits may fail to keep the grass layer short, particularly if their population numbers are reduced by another disease outbreak. Once the sward height rises above roughly 8 cm, rabbits tend not to graze there, and will move to other areas or retreat to core areas with shorter vegetation. Mowing has been trialled at some sites, such as Kenfig Burrows, to keep the sward short and encourage the spread of rabbits, although this has not always been successful. Rabbit re-introductions are also being trialled.

Figure 33. Rabbits graze the dunes at Gwithian Towans, Cornwall, and through burrowing also create areas of bare, mobile sand, 2020. Photo, Andy Nelson.

- Mix of species

Using a mixed community of grazers is most likely to maximise success rates as grazers can be very selective and therefore only target specific areas. A mixed grazing community would increase the variation of species grazed and would ensure that both woody and herbaceous plants are targeted. It also creates mosaic micro habitats by the variation in sward heights grazed. A combination of sheep, cattle and/or ponies would therefore likely yield better results than one grazer alone. Securing stock can however be challenging, as can re-finding animals on large sites.

21.3.2 Stocking density

Stocking density is measured in Livestock Units (LU), which is a way of standardising for the sizes and ages of different grazers. A dairy cow is equivalent to 1 LU, while a beef cow is 0.75 LU, an upland ewe is typically 0.08 LU and a horse or pony is 0.8 LU. Heritage breeds are usually lower than these standards, however. For example, a Welsh Black heifer is only 0.15 LU. Suggested stocking densities for sand dune systems are quite inconsistent throughout the literature. An adaptive approach may be preferred as individual sites will respond differently to grazing designs. A suggested stocking density is 0.1-0.3 LU/ha/year. Depending on results this can be increased or decreased to determine the right balance for an individual site. It is also important to be aware that different breeds of the same type of grazer will behave differently so stocking densities will need to be adjusted to meet desired targets.

21.3.3 Mob grazing

This technique originated in New Zealand. It involves grazing small areas at very high intensity to ensure all plant species are grazed, including the less desirable ones, then the stock are moved on to another area and the grazed area is allowed to regrow completely. Electric or virtual fencing is the best approach to manage this (see section on fencing).

21.3.4 An adaptive management approach

Flexibility is key to the best success. Grazing results should be reviewed frequently and any issues addressed before they worsen. For example, if the aim is to target Sea buckthorn [*Hippophae rhamnoides*] and the livestock don't seem to be keeping on top of it then a different level or approach to grazing may need to be considered.

21.4 Other considerations

21.4.1 Fencing

Fencing will be necessary to enclose grazers to a specifically targeted area, to keep grazers away from the sea and streams and/or for the general safety of site visitors. Rotational fencing allows for the site to be grazed more evenly than a permanent fence whilst also safeguarding grazers and visitors. This is however more costly and labour intensive. The public may cut fences where they object to restrictions on access or dog walking.

Figure 34. Fences installed at Saltfleetby-Theddlethorpe National Nature Reserve, Lincolnshire, to protect important known dune slack pool breeding habitats for natterjack toads from disturbance by reserve visitors and dogs, 2020. Photo, Louise Denning.

A different approach is to use invisible fencing. This is a new and high cost method for keeping grazers within a boundary whilst maintaining easy access to the whole site. This works by fitting grazers with collars that respond to radio signals emitted by cables pre-installed within the dune system. The collars emit an alarm sound when crossing the invisible fence and deters the grazer from going further beyond the alarm boundary. Other collars using similar technologies use GPS signals and this approach allows for more adaptive management as targeted areas can be changed as and when required. It must be noted that this can cause issues for visitors, in particular dog walkers and the relevant signage should be used in car parks and across the site to inform all visitors of the invisible boundaries.

Figure 35. Cattle wearing GPS collars as part of a virtual fence grazing initiative on the dunes at Studland Bay, Dorset, 2021. Photo, Sally Wallington.

21.4.2 Provide water

Sheep and ponies do not require as much accessible water as cattle. Access to water for cattle is essential and in most cases can be provided by troughs or scraped out ponds on site. Cattle therefore tend to graze near to these areas and don't venture too far away from them. This can lead to areas that are heavily trafficked by cattle and can lead to heavy poaching through trampling, and potential eutrophication hot spots from dunging, with an increase in undesired species such as nettles and thistles. To avoid this, troughs can be used on a rotational system where they are moved periodically. This is more difficult when relying on ponds for water access. Pasture pumps may be useful in some circumstances.

21.4.3 Supplementary feeding

Supplementary feeding with silage or hay is a source of additional nutrients which are being brought onto the site. While this may be necessary to maintain stock condition, it is not desirable from a eutrophication perspective and may counter some of the positive benefits of grazing (see also below). Mineral licks can be used to entice stock into an area where you want them to graze. They do not introduce too much additional nitrogen onto the site, but may alter local levels of micro-nutrients, which in turn may mean that the vegetation can use the existing nitrogen better, resulting in similar eutrophication problems.

21.4.4 Stock management

Maintaining condition of stock on the poor-quality herbage of dune vegetation can be an issue. Condition of the stock should be checked regularly. Ideally, supplementary feeding should be avoided, whether on-site or off-site. Even supplementary feeding off-site can lead to transfer of nutrients onto the site via dung and urine, and may introduce the seeds of unwanted species. Parasite treatments given to livestock containing ivermectin may adversely affect invertebrates on the site.

21.5 In combination with other management

Grazing may be used in combination with other management techniques, to help keep on top of re-growth.

21.6 Public perceptions – key messages

Many sand dunes are heavily used by the public. When introducing grazers or implementing new grazing designs it is really important to let visitors know. It is especially important to make dog walkers aware as this can be problematic when dogs are not kept on leads. Dog walkers may therefore not be happy with there being grazers on site, partly because the associated fences may require them to alter their walking routines, and because they may be used to letting their dog off the lead. This may result in considerable local resistance to introduction of grazing. A key message is that there are many positive benefits from grazing.

21.7 Things to watch out for

Direct impacts of livestock grazing on the dune ecosystem may arise through feeding, trampling, poaching and dung and urine deposition. These should all be considered and reviewed when using grazers on site.

21.7.1 Damage to sensitive species

Damage to species can occur from animals' hooves, or as a result of selective grazing. Physical damage to slow-growing lichens is a potential issue for acid or decalcified dune grasslands where these form a large component of the vegetation community. Impacts of summer grazing by sheep on flowers has been discussed above, as has the use of anti-parasite treatments such as ivermectin which affect invertebrates.

Grazer disturbance of ground-nesting birds has been identified as an issue on saltmarsh, and may potentially be an issue for sand dunes where grazing pressure is high. However, this should be balanced against the need to keep an open sward which provides the basic habitat required for ground-nesting birds in the first place.

21.7.2 Preferential dunging and nutrient inputs

Sheep disperse their dung evenly across a site which means you don't have to worry about areas receiving more nutrient loading from dung than others. Ponies can display latrine behaviour. On dune systems there are reports of ponies preferentially dunging in slacks, which may lead to localised eutrophication issues. Cattle on the other hand tend to cause the biggest issues with dunging. They do not venture as far from their water access as other stock types. Due to the nature of their large and nutrient-rich dung this can also lead to highly eutrophic hot spots especially around areas of supplementary feeding.

21.8 Monitoring

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

- Vegetation
- (Insects)

21.9 Cost

Grazing is generally a low cost management tool. However, initial outlay for fencing and provision of water may be fairly high. Longer term, there may be costs associated with maintaining health of stock, and of fencing. Financial returns from the sale of meat, or leasing grazing to local farmers, are likely to be low due to the poor quality of dune vegetation as herbage. Some agri-environment schemes provide payments for sand dune grazing and supplements for rare breeds, and to maintain low stock rates. Some funding may also be available for capital payments to reduce impacts to water by stock, and fencing.

22 MOWING and CUTTING

This section covers techniques like mowing, cutting and strimming.

Other relevant sections: Scrub clearance; Grazing

22.1 Goal & benefits

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.

It can also be used to control problem species, and to remove nutrients from a site.

22.2 When to use

Mowing is usually considered when grazing is not an option due to site-specific practicalities. These include sites that are too small for grazers, where it is not possible to provide water for grazing stock, where local graziers may not be available, or where you have a conservation interest such as fen orchid and you do not want grazing stock to damage the plants. On some sites, commoners' rights have ironically hindered grazing introduction, since the rights prevent fencing being erected. Mowing can be a useful way to remove nutrients from the site.

22.3 How to

Mowing can be carried out by tractor flail, rotary motors, or by hand with strimmers or brush cutters. Tractor-driven machinery is quicker, achieves a more uniform result (not necessarily a good thing) but requires vehicle access, while using strimmers provides much greater control of the cutting height and accessibility is not a constraint. 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. Burning produces local hotspots of nutrient enrichment. Cut material left on-site also smothers and shades the vegetation underneath.

Figure 36. Using a robotic mower to clear scrub and vegetation at Cabin Hill National Nature Reserve.

22.3.1 Mowing Design

When you have decided on an area to mow, to improve species richness alone, creating a mosaic of patches with different height will provide more diverse habitats for a larger variety of plants, insects and birds. When mowing is used to control problem species, a more labour intensive approach is required to keep on top of re-growth. In that case, mowing should take place before seed-set, and may need following up with fenced grazing or chemical spraying/stem injection. When cutting there is also a potential issue with nutrient enrichment and it is advisable to use a forage harvester to collect most of the cuttings.

22.3.2 Mowing Frequency

How often to mow depends on the conservation objectives. Mowing once per year will usually allow plants to regrow to their normal height in-between mowing (unless combined with grazing). This reduces the benefit for low-growing species, but allows most species to set seed (see also timings section). Mowing more often will keep the vegetation shorter, providing a greater benefit for plant diversity, and will remove more nutrients (if cuttings are taken off-site).

22.3.3 Mowing timing

Timing of mowing should consider which species are of most interest. In other grasslands, such as hay meadows, mowing typically takes place in late summer once most species have set seed. However, where the purpose is to control, or alternatively to benefit, particular species then mowing times can be adapted to suit. For example, to control a problem species mowing should take place well before seed-set to avoid spreading the seed, but take account that mowing later in the summer will remove more biomass. Varying the cutting time in different years will allow different sets of species to set seed. This will result in a more diverse species mix in the longer term.

22.4 Other considerations

22.4.1 Machinery wear and tear

Mowing machinery is expensive and can get damaged when mowing woody material. Sand also causes considerable wear to moving parts and will shorten the life of cutting blades. The cost of servicing the machinery should be costed into the management budget.

22.4.2 Access restrictions

When using tractor-powered machinery, easy-access for vehicles may restrict the areas that can be mowed. Care should be taken to plan access routes to avoid sensitive habitats or species. Using strimmers or brush cutters is rarely limited by access. Contractors should be thoroughly briefed beforehand on access routes. Sites with features of archaeological importance may have specific guidance on use of vehicles or powered machinery.

22.4.3 Disposal of material

Cut material should ideally be removed from the site to reduce nutrient build up. If necessary, it can be left in place or burnt on site in sacrificial areas. Burning will get rid of material, but the remaining ash leads to a local hot-spot of nitrogen and other nutrients. Some nutrients will also be re-deposited elsewhere on the site through gases (nitrogen oxides) given off during burning. Heaps of grass cuttings will return nutrients to the site in large quantities. Therefore, as a last resort, it can be piled up on a very degraded part of the site which is beyond reasonable restoration. This would also be a preferable location for burning to take place, where feasible. See also *section 22.6* on nutrient removal for more information on the options.

22.5 Things to watch out for

22.5.1 Sward height can be too uniform

Mowing can become too uniform when applied over large areas. Options to avoid this include varying cutting heights either within a year, or in different years to create a mix of short and long vegetation which in turn supports a wider variety of plants, insects and birds. This requires contractors and volunteers to be briefed appropriately. Where mowing is used in combination with grazers this shouldn't be an issue as grazers are selective and small scale variation will reappear.

22.5.2 Damage to dune features

Using heavy machinery can cause soil compaction, or damage to dune slack soils if it takes place when the soil is wet, or the water table is near the surface. Soil compaction can change the water-holding capacity of the sand, which will in turn will alter the plant species growing there. It can also reduce the ability of the wind to move sand around as part of natural dynamic processes. High water tables can therefore restrict the months when cutting can take place.

The mowing blades and the tractor machinery can 'scalp' or erode hummocks and small dunes, leading to a gradual flattening of the complex dune topography. This reduces the 'naturalness' of dune landforms and reduces the range of niches and habitats for plants to grow. This is particularly important in dune slacks where small variations in the topography of the slack floor can provide very different habitats with respect to the water table. Over a difference of 20 cm vertical height you will see a shift from one dune slack community to another.

22.5.3 Spread of competitive species

Where problem species spread by vegetative propagules (stem or leaf fragments), then mowing may not be advisable.

22.6 Nutrient removal

Cut vegetation holds large amounts of nitrogen and phosphorus. Cutting and removing the material off-site is one of the most efficient ways to remove nutrients from a site where eutrophication (excess nutrients) is a problem. A single cut of dune grassland typically removes four years worth of atmospheric nitrogen deposition, for a site receiving 15 kg N ha^{-1} yr^{-1} (approximate UK average for dune systems). If the main purpose is to remove nutrients, the best time to cut is when vegetation is at its highest, but before it starts dying off and returning the nutrients to the root system (typically late summer, July-September).

The following options form a hierarchy of nutrient removal, with the first removing the most nutrients, and creating the greatest benefit to habitat suitability:

- **Mowing with biomass removal, followed by aftermath grazing**. This removes nutrients off-site, brings light to the understorey components of the vegetation, and the subsequent grazing helps keep the light levels high for longer.
- **Mowing with biomass removal, but no grazing**. This removes nutrients, brings light to the understorey, but this only lasts until the vegetation regrows.
- **Mowing, with biomass burning on site.** This removes nutrients from the majority of the site, but the burning will return a substantial part of those nutrients to the location of the burn (some nitrogen is lost to the air, but much of the phosphorus will return to the system). This may create a patchy environment with nutrient hot-spots where undesirable species can rapidly grow.
- **Mowing, leaving cut biomass on the ground**. This improves habitat suitability by lowering the vegetation height, but the resulting cut biomass will also act to shade out vegetation, and the rotting vegetation will return all nutrients to the system. This option may be preferable to no management at all, but is far from ideal.

22.7 Relation to other management techniques

Mowing differs from grazing as it produces a more uniform vegetation height, whereas grazers are more selective in the species they prefer. It does not usually create small disturbed areas and so does not provide as many germination niches for seeds to sprout in the same way that grazing does.

Mowing can be used to take out woody material or problem species, using grazing to keep the vegetation short or selective herbicide application as a follow-up to control problem species.

Mowing can also be used for initial control of species which are less palatable to livestock, as the regrowth is sometimes more palatable than mature material, and grazers may keep the species in check subsequently.

Mowing can be used to encourage rabbits, which generally prefer short open vegetation where they have a good view of potential predators, and because fresh regrowth of vegetation is more nutritious for them. A rough idea of rabbit abundance can be estimated by doing dropping counts in set areas.

22.8 Monitoring

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

- Vegetation
- (Insects)

When considering introducing mowing for the first time, it is important to establish monitoring for flora and fauna beforehand, and then at intervals (1 – 5 years) as you keep going.

Make a note of the cutting height and timing of each patch in each year.

22.9 Cost

Cost varies from low cost (strimming, brush-cutting) to medium cost (tractor powered machinery). It may be easier and cheaper to use contractors to carry out any mowing management.

23 SCRUB CLEARANCE

This section covers issues around clearance and control of scrub on sand dunes.

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

23.1 Goal/Target

23.1.1 Goal & benefits

The goal of scrub control is to remove areas of unwanted scrub from sites in order to maintain a desirable balance of dune habitats.

Scrub is a natural part of most dune systems – the successional stage after grasses have stabilised the sand, and part of a dune's eventual journey to woodland. Scrub is often a rich habitat for wildlife, providing food and shelter to birds, reptiles, mammals and insects. Some scrub on a dune site is undoubtedly good.

But scrub is often a problem too. Longer growing seasons, atmospheric pollution and the loss of traditional disturbance mean scrub increasingly dominates many dunes. The problem with this is threefold:

- Dominant woody shrubs take over the habitat needed by dune specialist species – from Sand lizards and burrowing invertebrates on the dry dunes to Natterjack toads and Fen orchids [*Liparis loeselii*] in the dune slacks. By providing shade and shelter scrub adversely affects the microclimate at ground level, making conditions less suitable for dune specialist plants and insects.
- Scrub speeds up succession, and can represent a tipping point after which dune recovery is very difficult. Deeper root growth of woody species lowers the water table in dune slacks, while increased leaf litter enriches the organic matter build-up in dune sand. Nitrogen-fixing species such as Gorse [*Ulex* spp.] or Sea buckthorn actively enrich soil nutrients – all of which increases soil fertility.
- By anchoring the soil and providing a windbreak, scrub can reduce the power of the wind to blow sand around and keep dunes mobile – the impact can go far beyond the scrub itself.

23.1.2 When to use

There is no fixed amount of scrub that is acceptable. It depends where it is - the older the dunes, the more you might expect. As a rule, if there is more than 5% overall, or if it is encroaching on the younger dunes or into the dune slacks, you should keep a careful eye on it and think about control. There might be a minimum amount too - find out what species benefit from having the scrub there; what would be the impacts of removing it all?

23.2 Design considerations

23.2.1 How to

Cutting and removing from site is best as it ensures that the nutrients don't return to enrich the soil. Hand cutting with bow saws is a great volunteer task, but for larger areas cut-and-collect tractor attachments are more practical.

Flailing using a tractor mounted flail effectively shreds the material and leaves it on site. Remotely controlled flails are an alternative to tractor mounted ones: although slower they are better for complicated terrain and work well on steep slopes or in sensitive areas where a tractor would cause damage. A flail can be quicker and cheaper than cutting and removing but the cut material acts as an organic mulch, rotting down and enriching the soil. If you use a flail, be sure to rake up the material and remove or burn it afterwards.

Root pulling using a tractor to pull individual bushes out or an excavator to dig below the root layer can be ideal as it takes the succession right back to the bare sand. It can be slow, looks a mess and creates a lot of arisings to deal with – but is often the most effective technique in the long-term. By removing the whole plant there is also no danger of regrowth.

Figure 37. Using a tractor and mechanical flail to remove dense areas of scrub from the dunes at Penhale, Cornwall, 2021. Photo, Andy Nelson.

23.2.2 How much scrub to remove

Be clear how far back you want to set succession. If you are just aiming to prevent scrub spreading further and succeeding to woodland, then you can just work above ground – with a combination of cutting, mowing and follow-up grazing or chemical spot control. If you want to restore an earlier dune grassland community, you will probably need to remove the surface organic matter from the soil, particularly if the scrub has been established for a long time.

23.2.3 Timings

As on any other habitat, scrub clearance should always happen outside the bird nesting season, i.e. during September – February.

If you are clearing the scrub by pulling the roots out, or are going to follow cutting up with turf stripping, then it is important to check the area isn't used by hibernating reptiles. If they might be, then divide the work in two distinct phases: clear the scrub above ground between September and February, outside the nesting season; and then strip the soil or dig out the roots when hibernating reptiles will have left, ideally mid March-April or September-October.

23.2.4 Preventing regrowth

Most scrub species will vigorously regrow after cutting. On many sites this is allowed; it is simply cut again on a 10-12 year coppice cycle which retains its value as habitat but prevents it from spreading. However, if your aim is to restore the dune grassland, you need to stop regrowth

Herbicides such as glyphosate are widely used as stump treatments; if scrub is well established it is extremely hard to prevent re-growth without the use of chemicals. Any chemical herbicide comes with an environmental cost, however, and any contractor operating with them needs to understand the ecological sensitivity of the habitat they are working in. If stump-treating it is best to cut scrub about 10cm above ground level so that stumps are easily seen; they can be cut at ground level later on if needed. Using injected herbicides can minimise impacts on wetland habitats– particularly in dune slacks.

Grazing. Few grazing animals will tackle well established woody scrub, but new shoots of species such as Gorse can be palatable and more nutritious than alternative dune vegetation. Hardy breeds of cattle and pony will eat young shoots, as will some deer; even rabbits can keep on top of the youngest growing tips. Grazing alone is unlikely to fully prevent the regrowth of most scrub however – it needs to be combined with periodic recutting or mowing, probably over several years.

23.3 Other considerations

23.3.1 Other species, other factors

Know what species benefit from the scrub before you start. A breeding bird survey and a small mammal survey the season before is important to help decide how much it is right to remove; but also look at records for epiphytic lichens and fungi – it could be that the rarest species in the dunes actually needs a continued scrub presence. Checking for mammals such as badgers may be necessary. Archaeological or UXO considerations may prevent grubbing out of roots.

23.3.2 Maintain dune profiles

If using heavy excavators or tractors, avoid the temptation to smooth out the dune profile as scrub is removed. Complex topography, and a range of slopes and aspects, all create diverse microclimates and microhabitats that are often hidden beneath scrub. Make sure they are still intact after the scrub has gone.

23.3.3 Contractors

Work closely with contractors to ensure they are fully aware of access routes, and the need for bio-security when removing material, especially for material which is able to re-grow from shoot or root fragments. Have an Ecological Clerk Of Works overseeing the work.

23.3.4 Disposal of plant material

The ideal is to remove arisings from the site altogether – if it is chipped first it can be used elsewhere as a mulch, although it can be costly and for inaccessible sites this is often not practical.

More common is to burn arisings in designated bonfire areas. Although volunteers love bonfires, the ash left behind can cause big nutrient spikes and become sources of colonisation of bramble and other ruderal species. Keep the burn sites to a minimum, and if possible try and remove the ash from site afterwards. Choose where to burn with care too – the temptation can be to burn in an already open unvegetated area or in a natural hollow, but these can be important sites for burrowing insects or rare plants.

If burning and removal are not possible, then scrub material can be stacked on the dunes in sacrificial areas. They will provide new habitat, but eventually rot down enriching the soil. This should be seen as a last resort.

Figure 38. Volunteers cutting scrub and burning it in controlled bonfires on site at Penhale, Cornwall, 2021. Photo, Ellie Chidgey.

23.3.5 Removal of enriched soils

Removing scrub alone is rarely enough to restore diverse dune grassland flora, even with grazing. If it has been established for years the actions of deeper rooting systems, accumulation of leaf litter will have changed soil properties and increased soil fertility. Some scrub species alter the soil in different ways: as Rhododendron leaf litter breaks down, for example, it acidifies soil and releases allelopathic chemicals that can impede the germination and growth of new plant species. If roots are still in the ground, they will slowly rot and continue to increase soil fertility for years.

If the goal is to set back succession enough to restore mobile or semi-fixed dune grasslands, then scrub clearance should be followed up with turf stripping to remove the surface organic-rich soils. The depth of soil to be stripped may vary from 10 – 30cm depending on the length of time the scrub has been growing. It is important to work this out beforehand, starting by digging a pit and looking - even on old dunes there tends to be a clear change in colour at a certain depth, below which the sand is paler and there is little organic content.

23.3.6 Public perception – key messages

Clearing vegetation, stripping soil and having bonfires go against most people's instincts for environmental protection, particularly when so much messaging is around the need for restoring soils and habitats that store carbon. Be clear that scrub removal on dunes is a response to the biodiversity crisis, not the climate crisis, and messaging should focus on the positive effects of this habitat restoration on many species that are under threat of extinction.

Historic photographs can be useful tools in this messaging: scrub is a relatively recent issue on most dune sites, and almost always old photographs of more open dunes help communicate the idea that its removal is an act of restoration, not destruction.

23.4 Things to watch out for

23.4.1 Regrowth

Areas where scrub has been cleared, and the immediate surroundings should be checked frequently for re-growth from roots, stumps, dropped plant fragments or the seedbank. Plant species dispersed by fruit via birds may seed some distance away, or be brought in again from sources off-site.

23.5 Nutrients

Some invasive plants are nitrogen-fixing (like Sea buckthorn [*Hippophae rhamnoides*]). 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.

23.6 Monitoring

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

- Checking the regrowth of scrub species
- That native or desirable dune species are recolonising the cleared areas

23.7 Cost

Removal of scrub ranges from cheap to medium, depending on the amount of large machinery used.

24 INVASIVE SPECIES CONTROL

This section covers issues around invasive species on sand dunes.

Other relevant sections: Scrub clearance

24.1 Goal/Target

24.1.1 Goal & benefits

The 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. These adverse impacts are discussed in more detail in the following paragraphs.

What makes species invasive?

In a globalised world species find many opportunities to spread beyond their natural range. Most don't survive, but some thrive. Away from natural competitors or other factors that would limit them, these species can become dominant in their new environments, often upsetting the fine balances and interactions between the native species they are coexisting with.

Most invasive species on our dunes originate outside the UK; many have arrived through horticulture, and have spread from people's gardens. Others are native to some parts of the UK, but have spread to new areas. Two of the species that most commonly cause management problems on UK dune systems because of their invasive tendencies – Sea buckthorn and Traveller's joy [*Clematis vitalba*]– are actually native to the East and South coasts respectively. Even native species like Gorse [*Ulex europaeus*] can take over if unmanaged. Most invasive species on dunes are plants – but there are animal invasives too: from carp in dune slack lakes to deer; from harlequin ladybirds to grey squirrels.

What problems do they cause ?

Shrubs such as Sea buckthorn and Japanese rose [*Rosa rugosa*], or Rhododendron [*Rhododendron ponticum*] in the wetter areas, form dense thickets they outcompete the native dune flora, shading out the bare sand and building up thick layers of organic litter. Within a few years areas become barely recognisable as dune habitats at all. Even smaller plants like Broad-leaved everlasting pea [*Lathyrus latifolius*], Red Valerian [*Centranthus ruber*] or Pirri-pirri burr [*Acaena novae-zelandiae*] can dominate patches of bare sand, squeezing out the native annual and perennial dune flowers.

Other species affect the ecological niches that native dune wildlife depends on. The heath star moss [*Campylopus introflexus*], for example, never grows taller than about 3cm, but it forms carpets over bare sand patches in dune heath, rendering them unusable for the burrowing bees, wasps and other invertebrates for which these habitats are so crucial.

24.1.2 When to use

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.

24.2 Design considerations

24.2.1 How to

Manual and mechanical control. For woody plants some general techniques are described in the section on scrub management – but it is always worth researching the best practice for your particular species. It is important to understand the reproductive biology of the plants you are removing. Pine trees, for example, can be simply cut at the base and they normally won't regrow. Sea buckthorn and Japanese rose, on the other hand, will quickly re-sprout from the base and need either chemical treatment or for roots to be fully removed in order to be effective.

Smaller invasive plants like Pirri-pirri burr or Heath star-moss can be ripped out by hand or with simple hand tools – but beware that if you leave them on the ground they are likely to re-root. Burn the arisings or take them off site with you.

For annual and short-lived flowering plants like Evening primrose [*Oenothera* spp.] or Canadian fleabane [*Conyza canadensis*], remember that they will soon build up a seedbank in the sandy soil: removing them all one year does not mean they won't return in similar numbers the next – and there is little point in removing them after they have flowered and set seed.

Chemical treatment. In many cases it is unrealistic to try and eradicate an invasive species without the use of herbicides. For low lying leafy species, spot spraying plants in situ is easy but should always be done with great care to spray only the species you are targeting. For taller and woodier species the normal practice is to cut first a few cm above the ground, and then treat the exposed stumps soon after. Dune slack invasives, such as New Zealand pigmy-weed [*Crassula helmsii*], can be extremely pervasive and need herbicide treatment to remove them; but use of herbicides in damp environments brings high risk of wider environmental damage and should only be done with consent from the relevant bodies.

24.2.2 Should I try and get rid of all invasive species ?

Invasive plants are hard to get rid of: they are effective at spreading and recolonising – that's what made them a problem in the first place. In many cases, by the time the problem is detected it is time-consuming to solve it. Managing invasive species on dunes is often about keeping them from becoming dominant, and making sure the dune ecology can still function around them.

It is essential for dune managers to take a realistic and pragmatic approach. Pick the most important battles, and the ones you can win – and don't give up half way through!

There are three factors to think about when deciding how to manage an invasive species:

What impact is it having and where? Some invasive species are worse than others, and some dune features are more important to conserve than others. Map the extent of the invasive, and understand which site features are threatened by it, before deciding it is a priority to remove. Look at the literature available about these species and research the ecology of the habitats you are trying to protect; try and understand how important an issue it is before acting.

How well established is it – can I remove it altogether? Monitor your site regularly against a checklist of common invasive species. In the early years of establishment it may be possible to remove every plant, saving years of future expense and problems. But if you have inherited an older problem, focus your efforts. It's often better to clear all invasive plants from 30% of the site than 30% of invasive plants spread over the whole site.

What are the impacts of dealing with it? As well as financial costs and staff time, eliminating invasive plants normally involves chemical herbicides. Even highly selective, professionally applied sprays will have some wider impact on the dune ecology, and in wetter dune slacks in particular the collateral damage can be significant. If you are using herbicides, make sure they are going to work and that the end justifies the means.

There are many examples of where dune managers have spent thousands of pounds and hundreds of hours fighting a losing battle with invasive plants. There will always be another site or another dune manager who has experience of the same problem; learn from their experiences.

24.3 Other considerations

24.3.1 Contractors

Work closely with contractors to ensure they are fully aware of access routes, and the need for bio-security when removing material, especially for material which is able to re-grow from shoot or root fragments.

24.3.2 Disposal of material

As with scrub management, it is important to remove cut vegetation from the dunes or burn on site, in order to reduce nutrient enrichment. In the case of some invasive species it is even more important in order to prevent regrowth: many of the most rapid colonisers are able to re-root from just small sections of root or stem material that are left on the sand. Burying cut material at depth can also be effective. If you do this it is essential to bury deep enough (at least 0.5m, ideally deeper for some species) in order to both prevent its survival but also to avoid enriching the surface sand layers as material rots down.

In some cases, it will be necessary to remove root mass and some soil, also off-site, to prevent regrowth of invasives.

24.3.3 Public perception – key messages

Digging up plants from sand dunes (especially pretty species like Japanese rose), having bonfires and using chemical sprays can all be misinterpreted by visitors, and to most people doesn't feel like looking after wildlife. Communications of the reasons why some plants are good and others are problematic is essential on any dune site with lots of visitors. If animal species are being controlled, for example through deer culls, this is even more sensitive.

Two messages should be central to communications about invasive species management:

1. The emphasis is on looking after dune wildlife by restoring dune habitats. We only remove invasive species because the wildlife that we all love in the dunes is threatened by them.
2. This is not a minor issue! Invasive species are a significant problem in many habitats, driving an estimated 20% of biodiversity loss worldwide.

It always helps to talk about a particular species of plant or animal that is declining on the dunes and which will benefit from removal of the invasive competitors.

24.4 Things to watch out for

Return of invasives. Areas where invasive species have been cleared, and the immediate surroundings should be checked frequently for re-growth from roots, stumps, dropped plant fragments or the seedbank. Plant species dispersed by birds via fruit may seed some distance away, or be brought in again from sources off-site. The same principles to monitoring of invasive animal species.

24.5 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.

24.6 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

24.7 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