Developing + management of nature quality

Small scale wind erosion

for the benefit of coastal dune grasslands
1. Introduction

Changes in the use and management of coastal sand dunes have led to a strong decline in aeolian (wind-driven) dynamics in many dune areas in the Netherlands, and other north-west European countries, over the past century.

Factors that have played an important role in this process include long-term fixation by planting marram grass, scrub and coniferous forest, the cessation of agricultural use and restriction of public access, high nitrogen deposition and a reduced rabbit population.

All these factors have accelerated vegetation succession and have had major consequences for the biodiversity of the EU Habitats Directive priority habitat type grey dunes (H2130) – also known as dune grasslands. Grey dunes occur in a large part of the coastal area. As a result of the factors mentioned above, these dune grasslands have a very unfavourable conservation status.

Several countries have responsibility for the preservation of the grey dunes within the European Union, among them the Netherlands. Almost all coastal dune areas in the Netherlands, including the dune habitat types and associated flora and fauna, have therefore been designated as protected sites in the context of the European Natura 2000 nature conservation programme, with the aim of preserving and expanding the area of grey dunes.

Small scale wind activity (blowouts) can contribute significantly to the quality of dune grasslands and thus to the conservation of the grey dunes habitat type. In 2014–2018, an extensive study into small-scale aeolian dynamics, commissioned by the OBN Expert Team for the Dune and Coastal Landscape and the dune water supply companies Dunea, PWN, Waternet and Evides, was carried out by a consortium comprising the KWR Water Research Institute, the Arens Bureau for Beach and Dune Research, the Bargerveen Foundation and the University of Amsterdam.

The research aimed to identify the most important factors responsible for small-scale aeolian dynamics in coastal sand dunes and factors that affect their sustainability. The effects on soil, vegetation and fauna were also studied. The results have been translated into recommendations about where, how much, what and when small-scale wind activity can contribute to the management and conservation of the grey dunes. These recommendations can be translated into best practice guidelines for grey dune management, where the application of large-scale and intensive measures could be counterproductive.

This brochure describes the most important results from the study, with the aim of contributing to appropriate management of the coastal dunes and sustainable conservation of the grey dunes.

Changes in the use and management of coastal sand dunes have led to a strong decline in aeolian (wind-driven) dynamics in many dune areas in the Netherlands, and other north-west European countries, over the past century. Factors that have played an important role in this process include long-term fixation by planting marram grass, scrub and coniferous forest, the cessation of agricultural use and restriction of public access, high nitrogen deposition and a reduced rabbit population. All these factors have accelerated vegetation succession and have had major consequences for the biodiversity of the EU Habitats Directive priority habitat type grey dunes (H2130) – also known as dune grasslands. Grey dunes occur in a large part of the coastal area. As a result of the factors mentioned above, these dune grasslands have a very unfavourable conservation status.

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2. Grey dunes

‘Grey dunes’ refers to habitat type H2130 of the EU Habitats Directive. Fixed coastal dunes with herbaceous vegetation (grey dunes). The habitat occurs mostly on dry, nutrient-poor sandy soils and includes species-rich vegetation of short grasses, herbs, mosses and lichens, and grasslands with burnet rose (Rosa pimpinellifolia). This habitat type consists of various plant communities with numerous characteristic plant species, such as wild pansy (Viola tricolor subsp. curtissii), early forget-me-not (Myosotis sylvestris), biting stonecrop (Sedum acre), rue-leaved saxifrage (Saxifraga tridactylites) and common restharrow (Ononis repens subsp. repens).

In addition, there are many butterfly species, such as brown argus (Aricia agestis), various fritillaries, grayling (Hesperia comma), various grasshopper species, such as the mot-tled grasshopper (Mymecotettix maculatus), breeding birds, such as the northern wheatear (Oenanthe oenanthe) and silver-spotted skipper (Hesperia comma), various blackcaps, birds, such as the blackcap (Sylvia atricapilla), biting stonecrop (Sedum curtissii subsp. repens), Viola tricolor, with numerous characteristic plant species, such as wild pansy (Viola tricolor subsp. curtissii), early forget-me-not (Myosotis sylvestris), biting stonecrop (Sedum acre), rue-leaved saxifrage (Saxifraga tridactylites) and common restharrow (Ononis repens subsp. repens).

In the Netherlands the following variants are distinguished: calcareous grey dunes (these mainly occur south of Bergen aan Zee, where lime-rich sand from the Rhine catchment has been deposited) and often the soil still has a calcareous top layer; acidic grey dunes (mainly north of Bergen aan Zee and on the Wadden islands, where sand from north-eastern Europe is found) which is naturally lime-poor and therefore most dune soils are de-calciﬁed; species-rich dune grasslands on soils that contain slightly more humus, have a higher moisture content and are often situated at the transition to wet dune slacks where a relatively high soil pH is buffered by seepage of lime-rich groundwater. In this brochure we present the outcome of research on the effects of small-scale aeolian dynamics on the first two, most wide-spread variants, those of the grey dunes on dry lime-rich and lime-poor soils.

The grey dunes habitat is very important in the Netherlands because in comparison with other European countries, the Netherlands has a relatively large area of grey dunes and is in the centre of the area of distribution (from Gibraltar to Scandinavia and from Ireland to the Baltic region). In the Netherlands, grey dunes occur along the entire coastline, from the Zwin nature reserve in the south-west at the border with Belgium to the island of Rottumerroog close to Germany in the north-east.

Conservation
Grey dunes are naturally maintained by a combination of factors, such as aeolian dynamics in the form of light sand deposition, water erosion and grazing by rabbits. Rabbits keep the above-ground biomass low and create bare patches of sand prone to wind erosion. Human influence, in the form of grazing livestock and the cutting of shrubs, also kept the vegetation short for a long time.

The conservation status of the grey dunes in the Netherlands and in other north-west European countries is (very) unfavourable due to strongly advanced acidification, encroachment of tall grasses and scrub and large-scale eutrophication resulting from high atmospheric nitrogen deposition. In addition, as a result of a reduction in aeolian activity, habitat rejuvenation has ceased in many dune grasslands.

In order to maintain a good conservation status of the grey dunes, the vegetation must be predominantly short with variation from open to closed swards, in which grazing (rabbits, and/or livestock) and aeolian activity play an important role. In a situation where grazing has declined and/or with high atmospheric nitrogen deposition, common grasses or shrubs may become dominant at the expense of herbs, mosses, lichens and fauna species that depend on an open structure. Additional management is then necessary. This could include introducing or restoring livestock grazing, mowing, burning, removing trees and scrub, and also increasing the aeolian dynamics.
3. The importance of small-scale aeolian dynamics

In the past, the coastal dune landscape was created by large-scale processes, such as those that resulted in parabolic dunes, migrating dunes and dunes with low hummocks. Within these, the landscape was further shaped by the formation of blowouts and other small-scale aeolian features.

In the case of large-scale processes, strong wind (aeolian dynamics) initially created white dunes, where marram grass (Ammophila arenaria) dominates and conditions are too dynamic for dune grassland species to establish. Grey dunes developed further inland, where the dynamics were lower (spatial gradient) or slowly decreased over time (temporal gradient). In a more strongly stabilised dune landscape, small-scale aeolian activity can create blowouts. A blowout is considered as the whole of the erosional depression (deflation zone) and the surrounding area affected by sand deposition (accumulation zone). Blowouts contribute to large variation in the decalcification depth and humus profile, and in the vegetation, which results in high spatial and temporal variation and considerable biodiversity of flora and fauna in the grey dunes.

On the one hand, aeolian dynamics rejuvenate the soil in places where the sand is being blown away or where a layer of sand is being deposited. This leads to conditions being lower in humus content and relatively lime-rich (less acidic) – an environment from which characteristic pioneer species can benefit. Stabilisation in a blowout and in the accumulation zone enables rejuvenation of the vegetation, followed by succession towards species-rich dune grassland within a few decades. On the other hand, an important effect of small-scale wind erosion is sand rain, where a thin layer of sand is deposited on existing vegetation growing on an old soil. If this sand is lime-rich, the calcium level of an acidified soil is raised and the topsoil pH increases.

Until the 1990s, in the Netherlands wind erosion both in and behind the foredunes declined sharply as a result of long and very intensive management to stabilise the dunes for coastal security in order to protect the hinterland from flooding. In the distant past, active foredunes alternated between coastal accretion and coastal erosion, making it possible for sand to move inland from the beach via the foredunes. Today, dynamism is often limited to the front of the foredunes.

Large-scale dynamics only can benefit dune grasslands on longer time scales, when erosional and depositional processes come to an end. Only then, the vegetation of the grey dunes can develop. In the short term (up to a few decades), small-scale aeolian activity offers the best prospects for restoring dune grasslands. In an ideal situation, however, large-scale and small-scale aeolian activity will both occur. Large-scale wind dynamics supply lime- and base-rich sand to the acidified and decalcified dunes behind the foredunes. Besides, this contributes to more robust dunes that can better resist the rising sea level. The mild dynamics of periodic small-scale deposition of wind-blown sand (sand rain) to a thickness of no more than a few centimetres will then be an important condition for the maintenance of the grey dunes.
4. Soil and vegetation

The grey dunes habitat type occurs on sandy soils that, depending on their lime content, have a low to high capacity to neutralise acids. Lime-rich soils have a higher pH than lime-poor or acid soils. Many dry dune grasslands are superficially decalcified, which gives them a very distinct stratification of the upper decimeters of their soil: a relatively low pH in the topsoil and a higher pH deeper down. For this reason, baasophilous and acidophilous plant species (preferring a relatively lime-rich or acid soil) can be found growing together.

Young dune grassland soils are characterised by pioneer vegetation with thin grass, herbs and mosses. In the course of succession, humus accumulates, increasing the availability of water and nutrients. The more humus is present, the more rainwater is retained in the topsoil. Humus decomposition releases nutrients. On stabilised soils, species-rich dune grasslands can develop over a period of about 20 to 40 years.

The vegetation growth of dune grasslands is generally limited by drought stress in summer and often also by low nutrient availability. The species diversity is strongly determined by the acidity of the topsoil: the lower the pH of the topsoil, the lower the species diversity. In soil with a high lime content, species-rich dune grasslands can persist for many decades. These calcareous grey dunes are often very rich in flowers and herbs. Light sand deposition (sand rain) can maintain a high base status in old soils for a long period. Soil-dwelling ants and rabbits can also play an important role in maintaining a high lime content in the topsoil of old soils by moving deeper soil to the surface. The growing marram plants keep up with the deposition of the sand and thus help to bind the sand and to form the relief. Behind the marram grass vegetation, sand deposition is less, allowing smaller pioneer plants such as dune fescue (Festuca arenaria) and sticky stork’s bill (Erodium cicutarium) to establish (3). They benefit from the calcareous sand that has been blown in and initiate the vegetation succession towards fixed dune grassland. Here, most of the soil surface consists of humus poor sand. In the calmer zone behind this lies the accumulation zone with little sand deposition (sand rain; W) on an older, relatively lime-rich soil (4). Rainwater washes the deposited sand into the moss layer and into the topsoil, which is then supplemented with lime from the deposited sand. This allows species-rich dune grassland to develop. In the area beyond, where no sand is deposited (N), the species diversity of the vegetation is relatively low because of the acidified topsoil. Much aeolian activity and a very large density of dynamics or grazing they easily suffer from grass encroachment.

The effects of an active blowout

Active blowouts have a strong effect on the soil and vegetation in the deflation zone and their surroundings. This is shown schematically in the figure ‘The spatial effects of an active blowout’.

In an active blowout, the sand from the bottom of the blowout (the deflation zone D in the figure) is blown over the edges, thereby creating a sandy soil that is low in humus and in which few, if any, plants grow (1). The abrasive effect of the drifting sand makes it impossible for seedlings to establish. On the edges of the blowout and just behind them lies the accumulation zone, where much sand is deposited (5). Almost the only plant that can establish here is marram grass (2), because hardly any humus is present and the dynamics are too great for other plants. The growing marram plants keep up with the deposition of the sand and thus help to bind the sand and to form the relief. Behind the marram grass vegetation, sand deposition is less, allowing smaller pioneer plants such as dune fescue (Festuca arenaria) and sticky stork’s bill (Erodium cicutarium) to establish (3). They benefit from the calcareous sand that has been blown in and initiate the vegetation succession towards fixed dune grassland. Here, most of the soil surface consists of humus poor sand. The amount of sand blown out of the deflation zone and the size of the area where sand is deposited depends on factors such as the wind force, the size of the blowout and its position in the topography, and the vegetation. This is described in more detail in section 6. Around an active blowout, as distance from the deflation zone increases there is a clear decline in the topsoil in terms of thickness of sand deposition, lime content and pH. The zone of influence with an elevated pH is smaller for stabilised blowouts than for active blowouts.

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An active blowout in the Haasvelderduinen (Amsterdamse Waterleidingduinen), positioned on a southwestern slope, with the accumulation zone on the northeast side (to the right).

The vegetation of a stabilised blowout

Blowouts often stabilise over time. The soil and vegetation of a stabilised blowout differ from those of an active blowout: less bare sand is present in the deflation zone because herbs and mosses gradually establish. Pioneer species appear here when the immediate stress of drifting sand has stopped but a very open vegetation structure with good light conditions is still present. In the accumulation zone where much sand has been deposited (S) there is less bare sand and more moss cover than in the case of an active blowout. In the next zone, where less sand was deposited (W), stabilised blowouts have on average less moss cover and more herb cover.

Calcareous grey dunes naturally have a high pH due to the presence of lime in the soil, with the result that there are relatively more basophilous pioneer and dune grassland species in and around stabilised blowouts. The greatest diversity of pioneer species in the deflation hollow is achieved around 10 to 20 years after the blowout has stabilised. For fixed dune grasslands, it takes approximately 40 years for species diversity to peak.

In the deflation zone of stabilised blowouts in strongly decalcified grey dunes, and also further away in the deposition zone, there are more acidophilous plant species of lime-poor dune grasslands – mainly mosses and lichens. Nevertheless, basophilous species may persist here in the former deflation zone for several decades after stabilisation.

(Re)activating blowouts

When dune grasslands have become acidified and/or degraded (as a result of succession and nitrogen deposition), the restoration of small-scale aeolian dynamics can be considered. This may involve reactivating a stabilised blowout or making a new one where previously there was none. If the wind can pick up the sand, a similar outcome results as with natural, active blowouts. In calcareous and decalcified grey dunes areas, aeolian activity will result in more bare sand, an increase in the pH, less organic matter in the topsoil, less above-ground biomass of the vegetation and less cover of tall grasses. Numbers of lichens and pioneer and desirable species around active or reactivated blowouts are much higher than in non-active areas, even if the blowouts stabilise relatively quickly.

Reactivation is therefore important, especially in coastal dune areas with deeper decalcified, lime-poor and strongly acidified soils and where spontaneous reactivation rarely occurs. In those dune areas, poorly calcareous soils, also low in iron content, are very susceptible to grass encroachment in response to high nitrogen deposition. Such soils are very common in the northern part of the Netherlands (Wadden district; north of Bergen aan Zee). In areas with abundant crowberry (Emetrum nigrum), reactivation seems less useful, because crowberry tolerates light sand deposition and hence no development towards dune grassland occurs. Crowberry can even recolonise areas with much accumulation of lime-poor sand. In that case, the increase in pH brought about by the aeolian activity will have disappeared completely within 25 years.

Number of species in the vegetation of a stabilised blowout in the superficially decalcified inner dunes of the Luchterduinen (the southern part of the Amsterdamse Waterleidingduinen).

Source: Aggenbach et al., 2018
Food quality
The food quality of herbs and grasses such as lady’s bedstraw (Galium verum), grey hairgrass (Corynephorus canescens) and crested hairgrass (Koeleria macrantha) varies between species and between areas. The effect of aeolian activity on a plant’s nutrient content also differs. In general, aeolian activity hardly affects the nitrogen, carbon and phosphorus contents in the plant, but active sand deposition increases the calcium and iron contents, especially in calcareous dunes where these minerals are abundant in the soil. In contrast, the magnesium, manganese and silica contents decrease as a result of active sand deposition. Silica makes plants sturdy and protects them from being consumed. If the silica content is reduced by sand deposition, plants can be eaten and digested more easily, which is an advantage for herbivores. In lime-poor areas, the food quality of the plants increases less as a result of sand deposition. When very active sand deposition leads to soils that are low in organic matter and susceptible to desiccation, the food quality of plants can decrease significantly in the summer.

Abundance of food
Active sand deposition changes not only the food quality of plants, but also their quantity (and therefore the abundance of food). It accelerates plant growth and improves soil conditions, thus increasing the amount of digestible plant material. There is a strong correlation between aeolian activity, the occurrence of fresh mar- ram grass roots and high densities of root-feeding beetle larvae of, for example, the dune chafer (Anomala dubia) and the garden chafer (Phyllopertha hortitola). When these larvae emerge as adult beetles, they are bulk food for bird species such as the red-backed shrike and the northern wheatear.

Effect on invertebrates
There is a strong correlation between plant food quality and quantity and the biomass of herbivorous invertebrates (herbivorous grazers, such as caterpillars and grasshoppers), especially in active blowouts in the calcareous dunes, such as occur in the Meijendel nature reserve near The Hague. This also applies to their predators, including omnivores such as bush crickets and ground beetles, and other heterotrophic generalists. In Meijendel, the high food quality leads to a high density and high biomass of large invertebrates. This increases the food supply for insectivorous birds such as the northern wheatear, the woodlark (Lullula arborea) and the European stonechat (Saxicola rubicola). For grasshoppers, such as the mottled grasshopper, it has been proven that the presence of both stable and dy- namic patches in a landscape results in a greater species diversity on a small scale. This effect is less obvious in lime-poor areas; here are fewer omnivores and insects that eat dead organic matter (detritivores), probably because less litter accumulates in places with active sand deposition.

Effect over time
Clearly, active sand deposition has a positive effect on the food quality of plants and thus on the number of herbivorous insects and insectivorous birds in the cal- careous dunes. The deposition of a layer of calcareous sand can have a long-term effect (from 50 to 100 years) on the soil base status and vegetation. In contrast the effects on the plant food quality and small fauna seem to last no longer than 10 to 15 years after blowouts have stabilised. To achieve a continuous effect on the fauna, there should be a permanent presence of active blowouts in a dune area.

Other animals
Other animal species also benefit from the effects of small-scale wind dynamics, both in areas with calcar- eous and acidic grey dunes. For example, digger bees and sand lizards need bare patches of sand in which they can make nests or lay eggs. Bees and butterflies benefit from an alternation of open to more closed species-rich and flowery dune grassland. This makes the dunes one of the most species-rich landscapes in the Netherlands.

Small-scale aeolian activity creates various gradients in the landscape in terms of vegetation composition and structure, microclimate and soil chemistry. This provides a suitable habitat for many animal species, includ- ing insects characteristic of coastal dunes, and their predators such as various breeding birds (red-backed shrike (Lanius collurio), northern wheatear (Oenanthe oenanthe), tree pipit (Anthus trivialis) and the sand liz- ard (Lacerta agilis). In addition, sand deposition changes the amount and composition of nutrients in the soil. This can improve the food quality of plants, from which small animal species benefit.

Red-backed shrike (Lanius collurio)
Dune chafer (Anomala dubia)
Northern wheatear

Northern wheatears are migratory birds; their summer habitat is in open areas where short vegetation and open, sandy patches alternate. In the Netherlands they nest mainly in old rabbit burrows and benefit greatly from the grazing and digging activities of rabbits in dune grasslands. The northern wheatear feeds on insects, preferably larger ones found in and on the soil. Over time, its numbers have declined sharply in recent years. The remaining core populations of northern wheatears occur in the open dunes with short-grazed fixed dune grassland, where the birds forage preferentially around the accumulation zones of active blowouts. Each northern wheatear needs about 1 hectare of open dune within its territory in order to gather enough food. Not surprisingly, besides a large population of rabbits, a large area with much small-scale aeolian dynamics ensures the survival of the northern wheatear.

Small-scale aeolian activity is influenced and driven by many different factors. No single factor is decisive, but the interaction of several factors determines whether aeolian activity will occur. To stimulate wind dynamics for the benefit of the grey dunes, it is useful to know the drivers of small-scale aeolian activity. These are described below and their interdependence is depicted in the two figures at the end of this section.

**Weather**

Wind is the driving force of aeolian activity. Wind force 6-7 Beaufort (strong breeze to near gale) is particularly important, since it is at this wind force that most of the effective aeolian activity takes place. Severe storm winds can move a great deal of sand, but heavy precipitation often accompanies such storms and that results in little aeolian activity.

Precipitation is an important factor. It wets the ground, so that a greater wind speed is needed to get sand moving. Continuous rain makes the surface so wet that aeolian activity is no longer possible. At the beginning of a shower, aeolian activity can increase, because raindrops can loosen grains of sand on a surface that is still dry. The effect of precipitation cannot be quantified, but it is clear that under wet conditions aeolian activity is much less than under dry conditions.

Another aspect of precipitation is that it can lead to water erosion on dune slopes during heavy rainfall, especially after a dry period. Drought and solar radiation create a hydrophobic (water-repellent) sandy soil, which makes the surface particularly susceptible to water run-off and erosion. A combination of a dry period followed by a period of heavy rainfall leads to extensive water erosion, after which the wind is able to pick up the underlying exposed sand. Water erosion is therefore an important trigger for small-scale wind erosion.

Location relative to the coast

Most active blowouts occur close to the coastline. As the distance from the coast increases, the number of active blowouts decreases. Dynamic foredunes are also a source of drift sand. In the poor dunes of the Wadden district (north of Bergen aan Zee) in particular, sand blown inland from the foredunes is often the only source of lime for the dune grasslands behind. The closer to the coast, the greater is the effect of the in-blowing sand. If the dunes behind the foredunes are high, wind will have a stronger effect there, because it is accelerated when it hits the dune slopes. This promotes the formation of blowouts.

Height of the dune

There are significantly more blowouts higher up the dune slopes than lower down. Many of the blowouts lie on or near the top of the larger parabolic dunes and favour slopes facing south-west, south or south-east. These high locations catch the most wind, which is why there are more blowouts here than lower down. Another reason is that higher dunes often have steeper and longer slopes and are therefore even more susceptible to water erosion.

Aspect

Although wind and precipitation tend to come from the west, blowouts tend to occur on south-facing slopes instead of west-facing slopes. Southern slopes receive the most solar radiation and so are hotter and drier. Drought stress makes a slope more susceptible to water and wind erosion because drought stress often results in short and sparse vegetation with a slow accumulation of humus and more friable soil.

**Soil conditions**

The lime content influences the development of both soil and vegetation. In the past, aeolian activity was
much more extreme in acidic dunes, as was known from the dunes near Schoorl and on the island of Terschelling. This was because the vegetation cover in these dune areas was sparse due to the very poor soil. Now, nitrogen deposition that still exceeds the critical deposition values for acidic dune grasslands, particularly on the Wadden islands, appears to be the reason that fewer blowouts currently occur in these lime-poor areas than in calcareous areas.

In many places in the Wadden district, high nitrogen deposition results in vegetation being dominated by species with dense root systems, such as marram grass, sand sedge (Carex arenaria) and crowberry. In addition, the high biomass production in combination with the lime-poor and rapidly acidified soil boosts the development of the humus layer. A dense, coarse vegetation, thick litter layer, higher organic matter content and a deeper humus profile make the soil less susceptible to water erosion and wind dynamics. In calcareous dune areas, the vegetation has remained more open and shorter and the humus layer is often shallow. Nowadays, soils of calcareous dunes are much more susceptible to water and wind erosion than those of lime-poor dune areas.

Vegetation cover and type
The vegetation cover, rooting depth and density, the thickness of the humus layer and the roughness of the vegetation are important factors for aeolian activity. The sparser the vegetation cover, the more likely it is that sand can be picked up by the wind. And with more roots in the soil, the better it can withstand wind erosion, while the thicker the humus layer, the less susceptible the soil is to water and wind erosion. Thicker vegetation provides more shelter to the surrounding dunes.

Dune grasslands with a short vegetation structure, a sparse cover of grasses and herbs and more open sandy spots are also more sensitive to aeolian activity because they are attractive to rabbits. The current state of the vegetation is therefore a strong driver of aeolian activity. Dune grasslands with a short vegetation structure and high biomass production make the soil more susceptible to drought and water erosion. After extremely dry periods, the vegetation may even die off, giving wind erosion another chance.

Nitrogen deposition
In many places, atmospheric nitrogen deposition still exceeds the critical load values for protected habitat types such as the grey dunes. Nitrogen deposition has a direct influence on vegetation, which in turn influences the soil’s susceptibility to wind erosion. Nitrogen deposition is still too high, particularly in the lime- and iron-poor dunes of the Wadden district and also in the decalcified parts of the Delta area and the middle and inner mainland dunes of Noord-Holland and Zuid-Holland. A dense-rooted species such as marram can benefit from this, with the result that more sand is fixed. High nitrogen deposition also leads to increased growth of algae that can fix bare sand. When nitrogen deposition is reduced, existing grass mats and thick layers of litter do not disappear quickly, so the susceptibility to sand drift does not immediately increase.

Trampling and grazing
In some cases, trampling – whether by people or grazing animals – is an important factor. In some areas, trampling can result in sparse vegetation or even bare sand, thereby initiating aeolian activity or keeping the blowouts active for a long time. Blowouts may appear in paths or can remain active because paths run through them. However, we do not suggest to stimulate trampling in dune areas. More often it leads to uncontrolled erosion and landscape destruction.

Animals can initiate aeolian activity by their grazing and path-making, especially at high stocking densities (high grazing pressure). Such high grazing pressure has occurred in a limited number of areas: for example, on the Landserumer heide on Terschelling and to the west of the Prins Bernhardweg on Schiermonnikoog, where it has led to an increase in aeolian activity. Certain behaviour, such as bulls pawing the ground, can also create patches of bare sand. For example, the sand-bathing sites of wisents (European bison, Bison bonasus) in the Kraansvlak (near the Kennemerduinen) have started to deflate and are growing bigger.
Rabbits are herbivores that maintain short vegetation. They also dig up the soil to eat plant roots and they burrow. All these activities can increase susceptibility to water and wind erosion. The development of blowouts often goes hand in hand with the development of the rabbit population. For example, after the rabbit population in Zwanenwater collapsed, the dynamics of blowouts started to decline. In the Eierlandsche Duinen on Texel and in the Amsterdamse Waterleidingduinen, a significant increase in rabbit numbers was followed by a similarly sharp rise in the number of blowouts. But in other areas with relatively high rabbit numbers, such as the lime-poor parts of the Wadden district, the aeolian activity did not increase. This suggests that rabbits mainly promote wind erosion if they are present in very high densities and if the terrain is already sufficiently susceptible to small-scale aeolian activity.

Viral diseases caused the rabbit population in the entire Dutch coastal dune area to decline sharply from the 1980s; it began increasing again after 2003, but in recent years it has again fallen considerably. In some areas, however, the rabbit population has continued to increase until recently.
The relationships between the drivers for the erodibility of the soil

- Drivers for susceptibility to aeolian activity:
  - 100% vegetated
  - 100% vegetated
  - + N-deposition
  - + litter layer
  - + grass encroachment

- Drivers that trigger aeolian activity:
  - low altitude
  - + wind force
  - - drought periods

Legend:
- Brown: drivers for susceptibility to aeolian activity
- Red: drivers that trigger aeolian activity

Source: Aggenbach et al., 2018.
7. Small scale wind erosion in North West Europe

Decline in small scale aeolian dynamics

In many countries in the Atlantic biogeographical region in North West Europe coastal dune mobility has decreased dramatically since the middle of the 20th Century. This reduction is reflected in a severe decline in area of bare sand and increased large scale stabilisation. This resulted in a decrease of small scale wind activity, and also affected large mobile dune systems. 

The area of bare sand along the western part of the Belgian coast has declined since 1948 by about 80%. A large (> 80 ha) mobile dune in the Westhoek almost completely stabilized after 2000. In the coastal dunes of the Boulonnais in North West France, large parts nowadays are dominated by scrub of sea buckthorn (Hippophae rhamnoides) and common privet (Ligustrum vulgare), as near Merlimont. The coastal dunes in Normandy are much more open with a low coverage of scrub vegetation, but most areas do not show small scale wind dynamics. In South West France, in the Vendee, blowouts are found in the frontal dunes of some coastal dune areas of Pays-des-Monts, but have become stabilized in the dunes behind. In the predominantly afforested coastal dunes of Aquitaine aeolian dynamics can be very strong, especially in the white dunes, but in the grey dunes blowouts are not very common.

In Wales an 81% decline in bare sand was averaged from 12 coastal dune sites between the 1940s/50s and 2009. Blowouts are restricted to only a few dune areas, such as Morfa Dyffryn in North Wales. A similar reduction of 75% between 1945 and 2015 was measured on the Sefton Coast in North West England. In Ireland, an average reduction of 68% in bare sand was calculated from 12 sites, over a 10 year period between 1995 and 2005.

In Denmark aeolian dynamics in coastal dune systems have reduced dramatically over recent decades. Aerial photographs from Jutland illustrate that there

Maps with area of bare sand in the Belgium dunes in 1948 (left) and 2010 (right) (MSc thesis Verbestel, 2009)
were considerably more blowouts in the 1950s than today. The coastal dunes gradually have become more and more fixed. Apart from the large mobile dune at Råbjerg Mile today there are only a few areas left with blowouts, which are almost entirely restricted to the frontal dunes. On the Wadden Islands of Lower Saxony (Germany) at least since 1950 coastal dunes also have become more and more stabilized. The area of pioneer stages has declined in favour of older succession stages. In rabbit grazed dunes, aeolian dynamics are higher. As a consequence of large scale stabilisation the development of thick grass swards and scrub is an increasing problem. Dense dune grasslands have become dominant at the expense of open grey dunes, for example in Jutland, on the Wadden Islands of Lower Saxony, in Wales and also in some dune areas in Pays-des-Monts (Vendée). In other regions scrub (especially sea buckthorn) has expanded as in the Westhoek, the Boulonnais, and South Wales. Another problem in, for example the Vendée and Aquitaine, is coastal squeeze, where a narrow fringe of grey dunes suffers from coastal erosion causing landward displacement of white dunes at the seaward side, and expansion of coniferous forest at the landward side.

Aerial photographs (source: GeoDanmark) of National Park Thy in Jutland from 1954 and 2019, showing a strong decline in the area of bare sand and blowouts.
Isolated remnants of small scale wind dynamics

Nevertheless, there are still coastal dune areas with blowout activity, although not as much as it used to be. In Denmark in some areas sand is transported from the beach through notches in the frontal dunes, for example in Thy National Park. On the other hand, active blowouts can hardly be found in the stabilized dunes behind. In Lower Saxony, areas with blowouts are almost restricted to Wadden Islands with a healthy rabbit population, such as Norderney. Also, dynamic grey (and white) dunes locally occur in areas without coastal defence measures. Morfa Dyffryn in Wales and the Dunes d’Écault in the North of France are situated along an eroding coast and have several active blowouts (see figure 8). In both areas rabbits help to keep the vegetation open. In Normandy small scale wind dynamics is functioning well in the Dunes d’Hattainville which is grazed by cattle. In other areas along the Belgian coast (Schipgatduinen near Kokkijde), in the Boulonnais (Fort Mahon, Merlimont) and in Wales (Morfa Harlech) small scale wind erosion is mainly restricted to the frontal dunes and is related to recreational activities. In North West England (Ainsdale Sand Dunes National Nature Reserve on the Sefton Coast) some blowouts have spontaneously developed after the removal of coniferous forest. This phenomenon is also seen in the dunes of Aquitaine in South West France. The main landscape-scale drivers for this spontaneous sand mobility are being studied.

Causes for the decline of small scale aeolian dynamics

Several factors are thought to have contributed to the gradual (but locally sometimes rapid) stabilisation of coastal sand dunes across the Atlantic biogeographical region. Human activities in the past, such as planting of marram grass (coastal defence) and coniferous as well as broadleaved forest (defence of villages behind the dunes; wood production), together with urbanisation and industrialisation have played an important role for example on the Wadden Islands of Lower Saxony, in the Vendée and Aquitaine, the Sefton Coast, Wales and in Belgium. Decreased grazing has probably driven a reduction in small scale wind erosion as well. In many coastal dune areas the historically widespread use of livestock has almost disappeared (some German Wadden Islands, Danish dunes). Rabbit populations have been decimated by rabbit diseases (Welsh dunes, French dunes) or are absent (Danish dunes). Several studies mention unfavourable climate conditions as an important reason. The amount of rainfall has increased considerably in Irish, Welsh and Belgian coastal areas since 1970, whilst the mean wind velocity has decreased. The longer growing season also plays a role. Finally, nitrogen deposition has also exceeded critical loads of grey dunes and has probably favoured stabilisation in the coastal dunes of Western Jutland, the Wadden Islands, Belgium and parts of Aquitaine.

Coastal dune management

In most countries of the Atlantic biogeographical region coastal dune management does not specifically focus on promoting aeolian dynamics in the way it is done in
In the last decade, examples of restoring dynamic processes can be found in different countries. In Wales, reactivation of aeolian activity has recently been advised for several dune areas. Some large-scale intervention measures have been executed by Natural Resources Wales (NRW) in order to promote a more self-sustaining solution. At Merthyr Mawr and Kenfig National Nature Reserve (NNR) in South Wales and Newborough Warren NNR in North Wales reactivation measures in the period between 2012 and 2015 included scrub clearance, stripping turf off areas of fixed grassland vegetation, the initiation of artificial trough blowouts in the frontal dunes (notches), and the excavation of artificial blowouts further inland, on stabilized parabolic dunes. In many dune areas notches are required in the frontal ridge for the transport of sand from the beach into the grey dunes behind. This could be further promoted by adding sand to the system by means of beach or dune nourishment. More measures are following as part of the Sands of LIFE project in Welsh dunes and a range of sites in England are expected to undergo rejuvenation measures (Dynamic Dune- capes project). In the Westhoek in Belgium reactivation measures will be executed on both a large and small scale. On the Sefton Coast in North West England the removal of coniferous forest will be investigated as an opportunity to enhance small scale wind dynamics, and in order to address coastal squeeze. In some dune areas in North West France the recent translocation of rabbits can help reactivation of small scale dynamics in grey dunes, while an increase in grazing pressure of livestock is considered a prerequisite for the success of some restoration management, for example in Wales. Finally, the restoration of wind dynamics in the frontal dunes is now considered indispensable to improve the resilience of coastal sand dunes to future sea level rise.

Aerial photographs showing spontaneous blowout development after the removal of coniferous woodland in the early 1990s at Ainsdale Sand Dunes Natural nature reserve (Wales).
8. Small-scale wind erosion in the Netherlands

Small-scale sand drift from blowouts occurs everywhere along the Dutch coast, but the density of these coastal blowouts varies greatly from area to area. The intensity of blowout activity and their development in recent decades also vary greatly. However, most of the dune area is still stable.

Differences in blowout density per region in 2014

On the Wadden islands there are relatively few active blowouts and their density is low: on average, 30 blowouts per km². Vlieland has by far the lowest density; it has large areas where active blowouts no longer occur. The most numerous active blowouts on the Wadden islands occur on Texel and the western part of Terschelling.

The density is highest along the coast of Noord-Holland and Zuid-Holland: an average of 50 blowouts per km² and even as many as 120 to 600 or more blowouts per km², especially in Zuid-Holland. However, the differences between areas are considerable: for example, south of Bergen aan Zee, local densities even exceeding 600 blowouts per km² have been recorded, which is extremely high. In the Amsterdamse Waterleidingduinen, the density in the calcareous foredunes is much higher than in the calcareous middle and inner dunes, where large parts even lack small-scale wind dynamics.

In the Delta area, the density of active blowouts is 15 blowouts per km², which is extremely low. Active blowouts only occur on the islands of Goeree and Schouwen.

Changes over time

It is striking that over time there are large differences in wind dynamics between, but also within regions. Before 1980, the dunes had been fixed for decades, so there was hardly any aeolian activity. Between 1980 and 1990, aeolian activity in the calcareous dunes slowly increased, probably because during that period, measures to actively promote stabilisation were terminated, the rabbit population was still relatively high and there were some severe storm events. Nitrogen deposition was high at the time, but this was compensated by high numbers of rabbits, which kept vegetation growth under control. Between 1990 and 2003, however, rabbit numbers dramatically declined due to rabbit viral haemorrhagic disease, yet nitrogen deposition remained very high. All this led to large-scale stabilisation, with the proportion of bare sand shrinking enormously even though wind speeds were similar to those in the preceding period.

After 2003, the aeolian activity in the calcareous dunes recovered spontaneously, especially in rabbit-rich areas, although the average wind speed was lower than in the 1980s and 1990s. This increase in wind dynamics resulted from an increase in rabbit numbers, combined with a significant decrease in nitrogen deposition to values around the critical load for grey dunes. Lime-rich dune areas with abundant short vegetation are still able to reactivate spontaneously under current climate and soil conditions. A climate factor boosting this is the higher frequency of heavy showers along the Dutch coast, which promotes water erosion.

Since the stabilisation phase of 1990–2003, there has been hardly any recovery of the aeolian activity in the lime-poor Wadden district, probably because of the previously noted development of the vegetation and soil in response to the strong fertilising effect of the high nitrogen deposition. The number of active blowouts therefore declined on many Wadden islands between 2000 and 2014. On Texel (near De Slufter and De Hors) and in many places along the calcareous mainland coast of Noord-Holland and Zuid-Holland, blowout numbers have remained low.
Mainland coast of Noord-Holland and Zuid-Holland:

In the predominantly lime-rich dunes of the mainland coast, and especially in the foredunes, closest to the coast, conditions are much more favourable than on the Wadden islands because of a combination of the following more favourable factors:

1. Nitrogen deposition that approaches the critical load value for calcareous grey dunes and is dominated by nitrate, which leaches to groundwater more easily than ammonium and is therefore no longer available to the vegetation.
2. More rabbits.
3. Less advanced soil development and vegetation succession, areas dominated by herb- and moss-rich dune grassland with little grass encroachment – all this increases the soil erodibility.
4. Higher lime and iron content and pH of the soil, making it less susceptible to eutrophication from high nitrogen deposition.
5. More days with heavy rainfall, which is conducive to water erosion.
6. A west-north-west orientation of the coast, which is more favourable in terms of the prevailing winds.

Another advantage is that many calcareous dune areas were stabilised only recently. In the 1990s, so locally the humus layer was not very developed and the vegetation around 2000 still possibly consisted mainly of pioneer species and mosses. It is easier to reactive aeolian activity in this vegetation than it is in dense, tall vegetation with deep-rooting plants on soil with a thick humus layer.

Delta area:

In the Delta area, the state of the current vegetation is a major disadvantage. Here it consists mainly of thickets of sea buckthorn (Hippophae rhamnoides) and tall scrub or woodland. In addition, there are old dune grasslands with a short vegetation structure, where the susceptibility to wind erosion is poor because of the centuries-old soils with relatively deep humus profiles. In many places, the dune grasslands are situated on deeply decalcified soils which are very susceptible to the effects of nitrogen deposition and therefore have suffered from grass encroachment. In addition, the dunes in various parts of the Delta area (Voorne, Geer- ee and Walcheren) are relatively low and therefore less exposed to the wind.

Stimulating factors:

Given the patterns found in the Dutch coastal zone and the regional differences between them, it is difficult to find individual explanatory factors. It seems that the main driver of aeolian activity is a combination of the following factors:

1. Low nitrogen deposition.
2. High rabbit density.
3. Low soil organic matter content and shallow humus profile.
4. High lime content and a high pH, partly because these reduce the availability of phosphate and thus the susceptibility to eutrophication when nitrogen deposition is high.
5. Short, open vegetation.

A combination of factors

Wadden district:

In the lime-poor dunes of the Wadden district, conditions for small-scale aeolian activity are relatively unfavourable due to a combination of factors that reinforce each other:

1. Nitrogen deposition that still exceeds the critical load value for acidic grey dunes, with an excess of ammonium, which leads to eutrophication and accelerated accumulation of organic matter.
2. Relatively few rabbits.
3. Relatively advanced soil development and vegetation succession due to a high degree of encroachment, especially with marram grass, sand sedge and crowberry, with dense rooting and therefore low soil erodibility.
4. Lower lime content and low soil pH, which enhances humus formation (reduces decomposition).
5. Less precipitation and fewer wet days, which could mean less water erosion.
6. On northern exposed coasts in some dune areas, a less favourable orientation of the North Sea coast towards the prevailing west-south-west winds.
7. Lower dune massifs (on average 3.5 metres lower than the calcareous mainland dunes).

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3. Less advanced soil development and vegetation succession, areas dominated by herb- and moss-rich dune grassland with little grass encroachment – all this increases the soil erodibility.
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Another advantage is that many calcareous dune areas were stabilised only recently. In the 1990s, so locally the humus layer was not very developed and the vegetation around 2000 still probably consisted mainly of pioneer species and mosses. It is easier to reactive aeolian activity in this vegetation than it is in dense, tall vegetation with deep-rooting plants on soil with a thick humus layer.
9. Stimulating small-scale aeolian activity

Maintaining or restoring the dry dune grasslands of the grey dunes habitat type (H2130) by means of small-scale wind dynamics may require a proactive approach. What, where and when this can best be tackled depends on various factors. Before intervention measures can be planned, it is necessary to first look at the area to be managed at a longer time and space scale and to develop a long-term strategy at the landscape scale. This is necessary because the effects of aeolian activity after stabilisation can affect the soil and vegetation for a long time—50 to 100 years—whereas the effects on small fauna level out after 30 to 15 years and active blowouts are needed continuously.

Long-term strategy

The following steps can be taken to obtain an overview and to draw up a long-term plan, (see also the flow chart for assessing long-term strategy):

- collect information on the history of the area (concerning soil, vegetation, fauna, relief, management plans);
- collect information on the current state and the nature conservation objectives of the area;
- analyse the feasibility of increasing the area or improving the quality of the grey dunes present;
- assess the ecological need to implement measures to achieve the nature conservation objectives;
- assess the costs against the benefits (financially, but also in terms of nature conservation gains and, for example, geological values);
- estimate the chances of success of the measures for aeolian activity (based on the factors that determine the area’s susceptibility to aeolian activity);
- define a strategy over time and space for implementing the measures;
- implement the measures and monitor.

Specific measures

When implementing measures to promote small-scale aeolian activity, it is important to take account of the factors that influence the desired objectives in the short term. These factors, described in detail in the previous sections, determine why the measures are needed, where they can be implemented, how many are needed and when they should be implemented.

Why are measures needed?

- the area of dune grassland is small;
- the area and quality of dune grasslands are declining;
- dune grasslands are becoming species-poor and have a superficially calcified soil with a moderately to strongly acidified topsoil, which makes them also vulnerable to nitrogen deposition;
- aeolian activity is absent or occurs only to a limited extent;
- the drivers for aeolian activity are favourable (e.g. high elevation, favourable aspect, short distance from the coast, short and open vegetation, little humus, numerous rabbits) or can be improved with management;
- calcarious sand drift can be effective for 50 to 100 years;
- small-scale wind dynamics generally benefit grey dune fauna much more than equivalent large-scale aeolian activity because it results in much less disturbance and creates much more small-scale variation.

Where?

- the best locations for blowouts are near (but not on) the tops of high dunes, with low vegetation behind them;
- preferably on the south-east, south and south-west slopes (possibly on slopes facing west or north-west); note this applies to the Netherlands, elsewhere in Europe this can be different;
- in places where there is sufficient space for the accumulation zones, preferably in existing dune grassland (these can be twice as much as 10

Information

- current situation in terms of aeolian dynamics, relief, soil, vegetation and fauna
- trends in aeolian dynamics and vegetation
- lime content
- management plans
- PAS (the Dutch integrated approach to nitrogen)
- coastal defence

considerations

- ecological necessity:
  - is aeolian activity sufficient?
  - is aeolian activity desirable for vegetation?
  - is aeolian activity desirable for the fauna?
  - is more aeolian activity needed?
- socio-economic:
  - sustainability to aeolian activity is high or can be increased?
  - potential locations for creating blowouts?
  - where the potential for small-scale aeolian activity is best

short-term strategy

- increase the vegetation’s susceptibility to aeolian activity; other spontaneous aeolian activation?
- opt to (re)activate blowouts?
- encourage sand to blow in from the beach foredunes and combine this with activation of blowouts?
- in addition, enhance the vegetation’s susceptibility to aeolian activity?
- because there are limited opportunities for small-scale aeolian activity, opt not to proceed, even though small-scale aeolian activity is desirable?

measures

- stop encroachment by scrub/woods
- greater management to achieve dune grassland with a short vegetation structure
- regular management (e.g. grazing)
- potential locations for creating blowouts
- interventions in the foredunes / coastal defences
- phasing over time

monitoring

- aeolian activity
- soil
- vegetation
- fauna

Source Aggenbach et al., 2018
times larger than the deflation zone, and are often located downwind of the prevailing wind direc-
tion; • preferably in places with dune grassland of poor or moderate quality (where, for example, tall grasses or the alien invasive species heath star moss (Callune pusilla) dominate) or scrub, so that well-developed dune grasslands can be spared; • preferably in places where the soil is decalcified to a depth of less than 50 cm; • aeolian activity can still be useful in dune areas where the soil is deeply decalcified (50 to 100 cm of time-poor or non-calcareous sand); • if possible, just behind the foredunes, or connect-
ted to small fauna.

and aeolian activity is absent but would be benefi-
tial; • the favourable density of blowouts ranges from 25 to 60 active blowouts per km² for areas with calcareous sand; this is also a suitable target range in deeply decalcified dune areas; • too many blowouts (> 100 per km²) close to each other may be undesirable, because then the remaining well-developed dune grasslands (which are important as propagule source areas) may be completely buried and may even start to develop into white dunes; • only few blowouts – if any – should be created in deeply decalcified areas (where, for example, tall grasses would be a huge intervention; • the magnitude of the reactivation depends on the space available for the deflation and accumulation zones; this in turn depends on the surrounding in-
frastucture, the relief, the pattern of the dunes and dune slacks and the size of the surrounding dune grassland to be influenced; • plan on having an accumulation zone no more than 200 m from the blowout.

Which measures? • remove the humus layer and most of the root layer under the vegetation in the area intended to be the deflation zone; • remove shrubs and trees growing immediately downwind from the deflation zone as well as on the windward side, in order to encourage wind penetration as much as possible; • dispose of the removed soil and vegetation but do not create permanent dumps; • there are no general recommendations about the size of the sites to be reactivated. The average size of a blowout in the Dutch coastal dunes is approx-
imately 400 m² (larger in the foredunes, smaller in the middle and inner dunes), but appropriate vari-
ation in size is desirable because different stages of stabilisation then occur.

The distribution of aspect in four dune areas. Left-hand column: the aspects present in the entire dune area. Right-hand column: the aspects of the blowouts. In most areas, blowout aspect is south-
east, south, south-west, while in the dune areas as a whole the distribution of aspect is much more even.

Luchterduinen = Amsterdams Waterleidingduinen (southern part); Meeuwenduinen = Schouwen Source Arens Bureau for Beach and Dune Research

Axiallin activity from the foredunes on Ameland
Aerial photos of the Haasvelderduinen in 2013 (left, before intervention) and in 2015 (right, after intervention). Source of aerial photos: www.beeldmateriaal.nl.

In 2013, the soil in the areas outlined in yellow was stripped off to a depth of 30 to 50 cm and three blowouts (two small and one large) were made. In the area outlined in green, shrubs and trees were removed and the vegetation mowed. The right-hand aerial photo (2015) shows that significant sand deposition has occurred on the north/northeast side of the blowouts. It has resulted in calcareous sand being spread over the vegetation of lime-poor dune grassland.

Species such as wild pansy, the host plant for the caterpillars of the Queen of Spain fritillary (Issoria lathonia), grow in the deposition zone.

Amsterdamse Waterleidingduinen

In the south-western part of the Amsterdamse Waterleidingduinen, as in many other dune areas in the provinces of Noord-Holland and – especially – Zuid-Holland, many blowouts have developed naturally in the foredunes or have been activated by small-scale wind dynamics. Within a period of 15 years the number of active blowouts has increased enormously.

Haasvelderduinen

In large parts of the middle and inner dunes, such as in the Haasvelderduinen, blowouts have been stabilised for decades. Under the influence of nitrogen deposition and a declining rabbit population, a closed vegetation cover including wood small-reed (Calamagrostis epigejos) developed on this shallowly decalcified part of the Amsterdamse Waterleidingduinen. Restoration management carried out as part of an EU LIFE+ project and the national nitrogen program entailed digging out blowouts from 2013 onwards and removing some thickets (e.g. of sea buckthorn and black cherry) from the potential accumulation zones.

Grazing can keep the vegetation short and open.

When?

- create any blowouts or notches in the foredunes in order to profit from calcareous beach sand (possibly in combination with sand nourishment / beach-feeding);
- take account of the presence of any old ordnance, bunkers and waste dumps;
- dig a new blowout if the local factors are favourable but as yet there is no spontaneous aeolian activity;
- perhaps combine the activation of aeolian processes with the removal of exotic species such as black cherry (Prunus serotina) or Japanese rose (Rosa rugosa);
- balance the positive effects of the (re)activation measures against the negative effects of the work, such as the soil compaction and damage to the vegetation caused by the heavy excavating machinery and the removal of the stripped material.

The Importance of follow-up management

It is often necessary to carry out further management for at least a few years after measures have been implemented, in order to ensure the aeolian activity keeps going. This should be anticipated in the planning and budgeting. Post-management may consist of:

- removing remnants of roots that have sprouted (especially of deep-rooting species such as marram grass and dewberry (Rubus coeius));
- removing exposed dead roots (such as those of sea buckthorn);
- loosening sand compacted during the stripping of the topsoil;
- grazing (if the vegetation is dominated by tall grasses);
- removing sprouts of shrubs;
- monitoring development, so that it becomes clear whether or not post-management is necessary;
- adopting a laissez-faire approach in a few places.

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When?

- plan the activation/reactivation of the blowouts to take place over a timescale of decades, and spread the activities over time and/or vary the size of the blowouts (larger blowouts remain active longer than small ones), so that all stages of blowouts are present for a longer period of time (active, declining and stabilised);
- species-rich dune grasslands develop in 20 to 40 years after the sand has stabilised; therefore blowouts do not necessarily have to persist for a very long time and it is not a problem if they stabilise after a while;
- as the effects of aeolian activity on the food quality of plant species for small fauna disappear relatively quickly (within 15 years after stabilisation), for greater diversity and biomass of small fauna it can be important to activate blowouts periodically (for example, every 25 to 30 years).

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- plan the activation/reactivation of the blowouts to take place over a timescale of decades, and spread the activities over time and/or vary the size of the blowouts (larger blowouts remain active longer than small ones), so that all stages of blowouts are present for a longer period of time (active, declining and stabilised);
- species-rich dune grasslands develop in 20 to 40 years after the sand has stabilised; therefore blowouts do not necessarily have to persist for a very long time and it is not a problem if they stabilise after a while;
- as the effects of aeolian activity on the food quality of plant species for small fauna disappear relatively quickly (within 15 years after stabilisation), for greater diversity and biomass of small fauna it can be important to activate blowouts periodically (for example, every 25 to 30 years).

The Importance of follow-up management

It is often necessary to carry out further management for at least a few years after measures have been implemented, in order to ensure the aeolian activity keeps going. This should be anticipated in the planning and budgeting. Post-management may consist of:

- removing remnants of roots that have sprouted (especially of deep-rooting species such as marram grass and dewberry (Rubus coeius));
- removing exposed dead roots (such as those of sea buckthorn);
- loosening sand compacted during the stripping of the topsoil;
- grazing (if the vegetation is dominated by tall grasses);
- removing sprouts of shrubs;
- monitoring development, so that it becomes clear whether or not post-management is necessary;
- adopting a laissez-faire approach in a few places.

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Customised management

The implementation of measures will always have to be assessed for each area. Local factors are particularly important in this, but there are also differences per region. Over a large part of the Wadden district, the probability of spontaneous small-scale aeolian activity is low because the dune grasslands have low susceptibility to aeolian activity, so here, measures are very important. The opportunities for restoration and conservation are greatest in:

- the dune zones with calcareous sand which have only been decalcified to a shallow depth (these have the greatest spatial impact);
- in high dune masses (here, activation is more likely to succeed);
- in the areas behind the foredunes (where calcareous sand can accumulate).

In the deeply decalcified dune areas, the blowouts will result in young, new dune grasslands in the deflation zones only after these have stabilised again. They therefore have a smaller spatial effect but do contribute to the restoration of biodiversity.

Along the coast of Noord-Holland and Zuid-Holland there are relatively more blowouts and spontaneous reactivation of blowouts is also more frequent, because here many determining factors are favourable. However, there are exceptions, for example, in the shallowly decalcified middle and inner dunes. Here, long periods without aeolian activity result in deterioration of dune grasslands. There is then an increase in tall grasses, thickets (especially of sea buckthorn) and even woodland, which leads to a major distinction between active, open areas and ever more densely vegetated areas. It is also desirable to introduce more variation here to create transitions between bare sand, short dune grassland and tall vegetation. This can be achieved by:

- in the outer (seaward) zone of the dune area: reactivating old, stabilised blowouts, in order to provide a permanent habitat for small fauna as well;
- in the middle and inner (landward) dune zone: activating wind dynamics on a larger scale and removing scrub, especially in areas that are superficially decalcified, and have suffered from grass and shrub encroachment (e.g. sea buckthorn and the exotic black cherry).

In the Delta region, susceptibility to aeolian activity is generally low, because here vegetation succession is at an advanced stage, with scrub and woodland and afforestation. However, in the young dune areas there is good potential for aeolian activity, as soil development here is not yet as advanced. This can be achieved by:

- the large-scale removal of sea buckthorn and black cherry;
- sometimes this needs to be followed by turf-stripping;
- after scrub has been cleared, grazing is effective.

There is also potential for activating blowouts in order to improve the quality of the dune grassland in Zeeland. It is difficult to activate the centuries-old dune areas such as the Vroongronden nature reserve because here the soil is too well developed and the dunes are low. Furthermore, these areas have no history of much small-scale aeolian activity.
10. Further reading


OBN publications


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