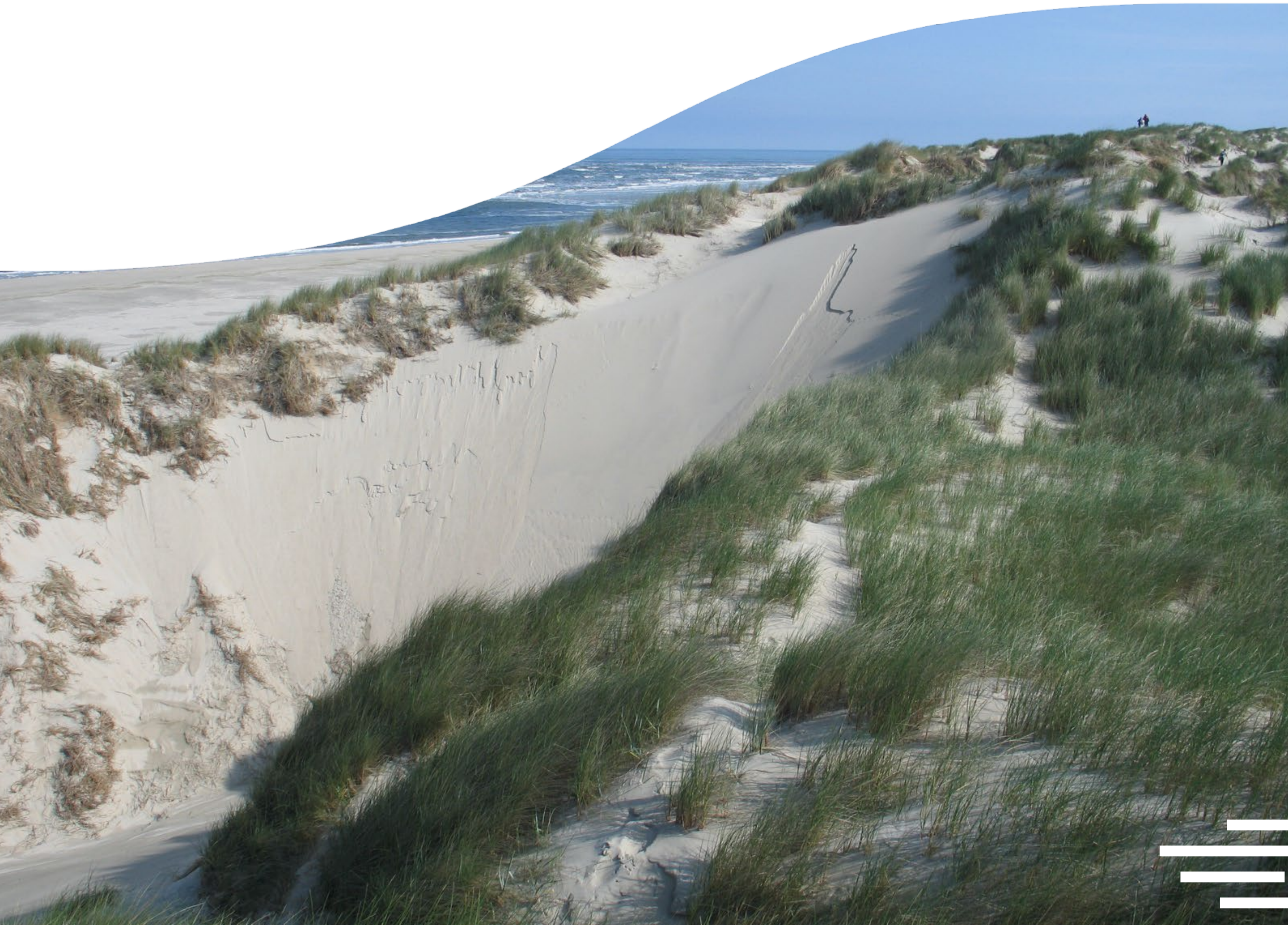
Foredune Dynamisation Manual



working together on nature restoration

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Foredune Dynamisation Manual

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Preface to English edition

This English translation of the *Foredune Dynamisation Manual* (original Dutch title *Handleiding dynamiseren zeereep*), arising from the Program for a Rich Wadden Sea, has been produced with the aim of making the Dutch experience of re-mobilisation interventions to create more dynamic sand dune landscapes available to a wider English-speaking audience. The original Manual was initiated by Albert Oost of the Dutch Forestry Department but is based on contributions from representatives of a wide range of public and private organisations in the Netherlands who have interests in the management and conservation of coastal dunes. It is intended both as a summary of Dutch experience since the 1990s and as a guide to the steps which need to be taken in undertaking such intervention works in the Netherlands and potentially elsewhere.

The translation into English has gone through a number of stages starting with a Google AI translation undertaken by Bas Arens, followed by editing to check meaning, grammar and spelling by John Houston and checking of the translation of geomorphological terms by Ken Pye. Following these editorial stages further checks have been made through consultation with Bas Arens and Albert Oost.

In editing the initial English translation we have tried to minimise alterations to the structure, format and technical content of the original, and our attention has focused on the clarity of the key ideas and methods. Some Dutch geomorphological and management terms have no direct equivalent in English, and in such cases an attempt has been made to explain the original meaning as closely as possible, and to provide the closest English terminology, summarised in a separate Glossary.

While this remains a 'quintessentially Dutch' publication we believe that it will provide a useful source of information and practical guidance to scientists and dune managers in the UK and other parts of the English-speaking world.

John Houston and Ken Pye

March 2024

Preface

The foredune along the Dutch coast before 1990 was an uninteresting element in the coastal landscape, when preservation of the dune as a sea defence was the main management purpose. The coast was eroding and therefore attempts were made to maintain the sand volume of the foredune with all kinds of measures. The most important of these were planting marram grass (*Ammophila arenaria*), installing sand trapping fences and continually stabilising blowouts. During storm surges the foredunes were eroded, causing the sand to be deposited on the beach and shoreface (below low water). This sand would then be available for onshore winds in the calmer months to contribute to the reconstruction of the foredune, with the help of management. In a number of places this was not sufficient to stop structural coastal degradation and the foredune dunes had to be regularly moved landward. Almost everywhere the foredune formed a massive barrier that captured almost all the drifting sand and also suppressed the dynamic processes of leeward sand transport. As a result, there was hardly any connection with or sand transfer between the beach and the hind dunes inland of the foredune.

Since 1990, the coastline has been successfully maintained through large-scale sand nourishments. As a result, strict foredune management is no longer necessary along a large part of the Dutch coast. Opportunities arose with nourishment for the stimulation of aeolian processes. From the nature management perspective, there was a need to increase aeolian (wind driven) processes to counter the negative effects of the fossilisation of the landscape, the blocking of sand movement, decalcification of the soil and increased nutrient levels due to Nitrogen deposition. Increasing aeolian processes by active stimulation became the new trend in the Netherlands. Thanks to nourishments, calcareous sand can now help rejuvenate the vegetation of the Natura 2000 habitats 'White dunes' and 'Grey dunes' through gentle sand burial. Sand mobility projects, collectively referred to as 'dynamisation' in the Netherlands, are now used in many places, spread along almost the entire Dutch coast.

Several things stand out when evaluating these projects:

- the goals are not always clearly formulated
- the preparation and implementation is often not optimal
- little has been learned from the interventions so far, because monitoring and evaluation is limited
- there is limited exchange between the various managers along the coast.

To improve this, the Program for a Rich Wadden Sea (PRW) supported the initiative to write a *Foredune dynamisation' checklist* to help managers achieve successful sand drift projects. The report is structured in such a way that it can be used as a guideline for all the steps needed to achieve a (hopefully) successful project. It offers tools for new projects and encourages you to get started with good courage and inspiration.

The checklist offers the option to jump to the relevant text in the manual per item. This way you can quickly access specific information without having to read the entire manual.

Structure of the manual

For the interested reader who would like to read the entire manual, the structure is explained below.

- Chapter 1 provides an introduction to the value of our coast, dynamic coastal management and a description of the different forms of dune dynamics.
- Chapter 2 is about the objectives. What do you want to achieve with your project?
- Chapters 3, 4 and 5 discuss the abiotic, biotic and anthropogenic preconditions that play a role in dynamic dunes and what you should consider for your project.
- Chapter 6 contains the steps to ultimately shape your plan for dune re-mobilisation, encouraging sand drift and creating bare sand and arrive at a (provisional) design.
- Chapter 7 then really focuses on the implementation: from preliminary design to final design to specifications to implementation. What permits do you need, how do you arrange financing?
- How to monitor the development of your area after the intervention is discussed in Chapter 8. Monitoring is important just to keep an eye on whether follow-up management is needed, often an essential, but sometimes a forgotten part, for a successful project. And monitoring is essential in order to be able to learn from the interventions.
- Post-management is discussed in Chapter 9.

PART I
Dunes and dynamics

1. Introduction

1 A general introduction to dune dynamics

Our dunes are special, formed by the dynamics of sand, wind, water and vegetation. In the past, most management attempts aimed at reducing these dynamics. But today we focus on how to utilise these natural processes. It is important to know how this system functions. Chapter 1 describes the system with specific attention to the hydrological elements and the different forms of dune dynamics.

There are varying reasons for the current interest in the restoration of aeolian processes. In the Netherlands for example, the aim can be to limit the negative effects of nitrogen deposition, or the goal can be the promoting of water safety (sea defence). Before intervening in the system, it is important to think carefully about which goals you want to achieve and to realise that not all goals are possible everywhere.

2 We have to learn how to work again with blowing sand

The beach has disappeared, is under water, waves are rolling against the dunes, eating away pieces of them. The wind pounds on the beach, fountains of sand spray high into the air and fall on the dunes behind them like a snow shower. A dune slope in the spring: grains of sand on the star moss *Syntrichia ruralis* still bear witness to last winter's storms. Plants come back to life, insects roam around. The first wheatear shows up again and the nightingale sings in the thickets. A dune valley in the summer: the groundwater has dropped. The grass-of-Parnassus is blooming. Beautiful orchids add further colour to the landscape. And while you walk around and marvel at all the beauty, a smell of mint fills the air and you hear a little ringed plover calling in the background.

The Dutch coast is that beautiful. It is, in part, a moving landscape, shaped by wind and water. The biodiversity is unprecedented and is among the best that Northwest Europe has to offer. In terms of nature, the dunes are undoubtedly unique and their value is enormous. The coast is also important for recreation, with the wide sandy beaches, the lively coastal towns and the extensive dune areas. In addition, the dunes protect us against flooding by the sea. And as if that weren't enough, they provide an important part of our drinking water supply. In addition, the freshwater lens offers protection against salinisation of the hinterland by providing a barrier to both the influx of saltwater and the outflow of fresh water. The high biodiversity is a result of the huge range of ecological gradients. Within the dune landscape there are all kinds of transitions: from dry to wet, warm to cold, calcareous to non-calcareous, young to old, bare sand to fully vegetated, close to the beach or further away, north or south facing, etc. All these factors determine the variation in the landscape and the associated specialised flora and fauna. Every place is different and has its own value. But there are many threats. One of the biggest is that,

Figure 1. Artist's impression of the intervention in the Northwest Nature Core on the right with the original situation on the left. (Copyright: U. Glimmerveen)

for various reasons, many dunes are in danger of becoming completely stabilised, which has put a large part of the characteristic flora and fauna at risk. Sand drift, the driving force behind dune formation, has come to a standstill in many places. Almost all managers are now looking for ways to restore the dynamics of aeolian processes. Coastal policy also looks for opportunities along the entire coast to make this restoration happen as naturally as possible, bearing in mind the existing qualities and functions. Anticipating natural processes, restoration of ecological values and less intensive forms of coastal maintenance have become increasingly important. The 3rd Coastal Memorandum from 2000 (Ministry of Transport, Public Works and Water Management, 2000) describes it as follows:

> **"Resilience, achieved through flexibility, buffer zones and dynamic processes is what it's all about. The result is a coast that can adapt to, for example, gradual consequences of climate change."**

We call this 'dynamic coastal management' and we define this as (Technical Advisory Committee for Flood Defences, 2002):

> **"Managing the coast in such a way that natural processes, whether stimulated or not, can proceed as undisturbed as possible, whereby the processes are managed in such a way that the safety of the area behind is guaranteed."**

An important precondition for dynamic coastal management in the Netherlands is that the coastline, where necessary, is kept in place with the help of nourishments. The need for the 'old-fashioned', intensive management of the foredune, characterized by planting of marram grass *Ammophila arenaria* (commonly just called marram), sand trapping fences and suppressing drift sand, has therefore ceased to exist. In fact, in recent decades there have been opportunities for the construction of notches and the implementation of other sand mobilisation measures in the

Figure 2. The monotonous sand drift dike along the Boschplaat, Terschelling, 2022. (Photo: A.P. Oost)

foredune zone. Initially, the desire for more dynamics came from nature management. A dynamic foredune forms a more gradual transition between beach and dunes and is home to all kinds of gradients. This is necessary to achieve rejuvenation in the landscape. It is also a means of counteracting the negative effects of acidification and nitrogen deposition, and it ensures greater biodiversity. Nowadays there is also increasing interest from coastal defence: sand can blow into the dune system via a dynamic foredune, causing it to grow in volume. A dynamic foredune therefore offers opportunities for the dunes to grow along with sea level rise. Please note that the Dutch definition of the 'foredune' is intrinsically linked to its sea defence function and includes several habitats such as the embryo dunes, foredunes, mobile dunes and semi-fixed dunes of ecological classifications.

When we talk about dynamisation in the Dutch context, we mean intervening to initiate the development of notches, blowouts, or a rolling foredune by stimulating the drift of sand by the wind. When reactivating the foredune, we are actually trying to restart the supply of fresh drifting sand. Sometimes a wider range of processes can be restored, for example on the Wadden Islands where water can also contribute to dynamic dunes through washovers, where sand is moved inland by water. However, this rarer process is not covered in this manual.

Intervening to create more dynamics occurs with varying degrees of success; re-mobilising the foredune dunes does not always go as well as desired. The goals, rate and desired form of sand movement are not always clear. Sand drift may not start, the new open surface may become vegetated again, the scale of sand drift gets too large or goes in the wrong direction. This leads to additional costs and is not efficient. The interventions also sometimes lead to unforeseen side effects, such as loss of ecological or cultural-historical values, or inconvenience to infrastructure.

Knowledge about working with dynamics is developing. At present there is a lot of attention being paid to the creation of notches. Various projects have been completed or are in progress. Practical experience is increasing, but more and more scientific facts are also emerging, both from national and international literature. In this manual we list the existing practical knowledge and scientific insights in order to provide managers with guidance and increase the chance of success for future interventions. This manual builds on previous work (including Löffler et al., 2011; Van der Valk et al.,, 2013) and on an evaluation of existing projects on notches (Nijenhuis, 2022).

1.1 The dune system

3 The important processes in dune formation

Although we are all working with dunes, it is still good to take a moment to consider the origin of our coastal area. How do our dunes form, what are the important processes and what is the role of dynamics in the system?

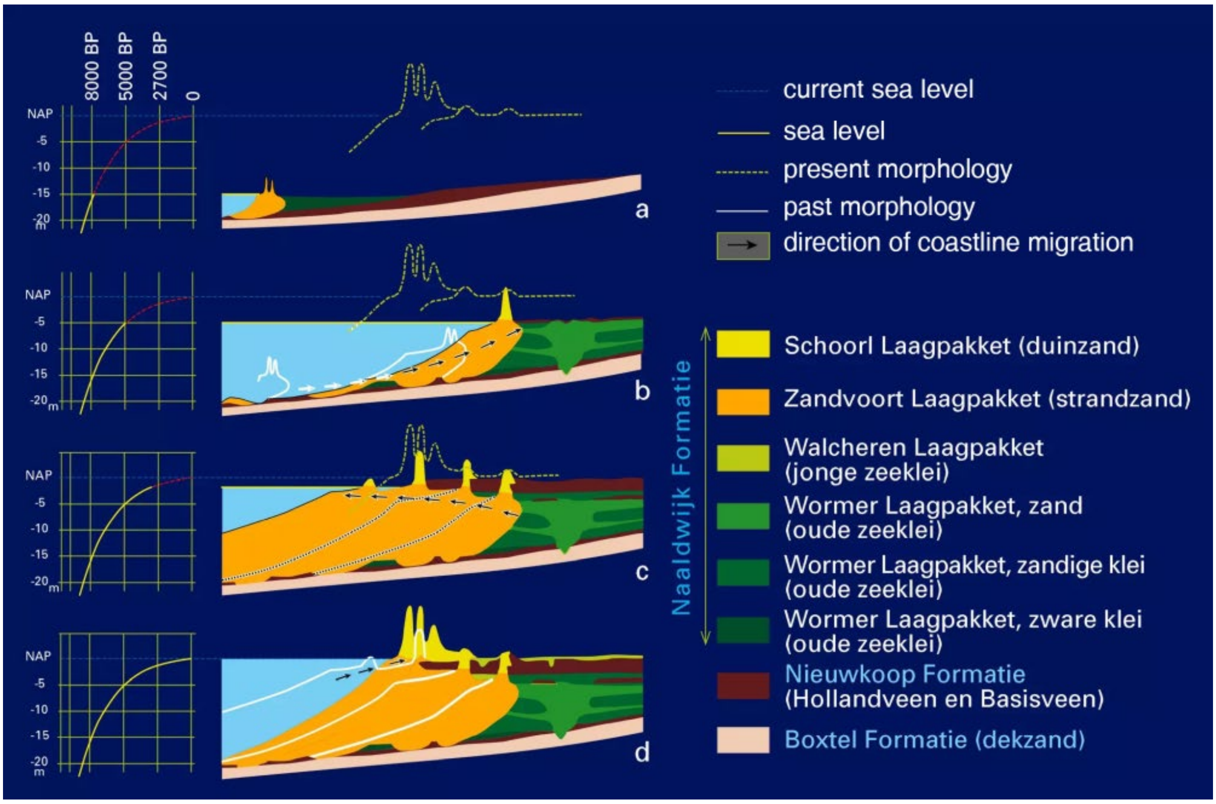

Figure 3. Sea level rise and the development and position of beach ridges and dunes. Shifting of the landscape with rising sea levels for different moments, a around 8000BP, b around 5000BP, c around 2700BP and d the current situation. The left diagrams show the position of the sea level in each situation and the degree of rise compared to the previous situation. (Source: Berendsen 2005, after Hageman, 1969)

1.1.1 Dune formation with rising sea levels

Dutch dunes consist of 'Old dunes' and 'Young dunes', two different geological units. After the last Ice Age, sea level started to rise due to ice melting. Figure 3shows different moments in a number of cross-sections. There was a period, roughly between 5000 and 3000BP (difference between b and c in Figure 3), when, despite the rising sea level, the coast expanded considerably. Beach ridges were formed, and on these beach ridges the Old dunes were formed, fairly low dunes with not too much relief. Around approximately 1000AD (difference between c and d in Figure 3), this beach ridge landscape began to erode. The erosion on the coast released a lot of sand that was blown inland, creating a transgressive dune system with higher and steeper dunes that slowly covered the Old dune landscape. These are the Young dunes. In the Young dunes all kinds of shapes, sometimes very large-scale, are visible, such as parabolic and transgressive dunes and extensive deflation valleys. The shapes are sometimes so large that you cannot even properly recognize them in the field; Digital Terrain Models give better insights (for a Dutch example, see https://www.ahn.nl/ahn-viewer , see also Figure 12 and section 1.2.7). Nowadays, the older beach and dune ridges have almost completely disappeared under the Young dunes. Only here and there do they still protrude from under the Young dune massif, mostly on the landward edge of the dunes. The Old dunes are low in lime and because of their age they are often deeply decalcified. The Young dunes south of Bergen are calcareous, but the surface, especially in the inner dunes, can also be decalcified.

The Old dunes were probably not very dynamic. We imagine a landscape like that of De Hors on Texel: a wide beach with new belts of fairly low dunes that grow quickly. The Young dunes, with their often enormous shapes, were extremely dynamic, with entire landscapes being buried under fresh drifting sand over a relatively short period of time. The dynamics in the lime-poor dunes were greater than in the calcareous dunes, the lack of nutrients making it more difficult for vegetation. There are stories of extreme sand drift ('an icy sand glacier') from the Schoorlse dunes, Vlieland and Terschelling. This is also visible in the morphology. In the calcareous dunes, the dominant, large-scale shapes are the parabolic dunes, where the shape is determined by an interaction between sand and vegetation. In the lime-poor dunes they are often wandering dunes (bare transgressive dunes); shapes that do not involve vegetation, i.e. pure desert dunes.

In the eventually stabilising and gradually decalcifying dune, a succession (aging) of vegetation towards scrub started. This process was partly counteracted by the fact that people collected marram and wood from the dunes and allowed their cattle to graze freely. However, at the end of the 18th century, the succession was accelerated by forest planting. Only more recently has vegetation been able to develop more naturally, but in recent decades this has been seriously disrupted by the impacts of nitrogen deposition.

Over the centuries, the dune area was used, sometimes intensively, sometimes extensively, for many purposes. Agriculture, hunting, rabbit farming, collecting wood, water extraction, tree

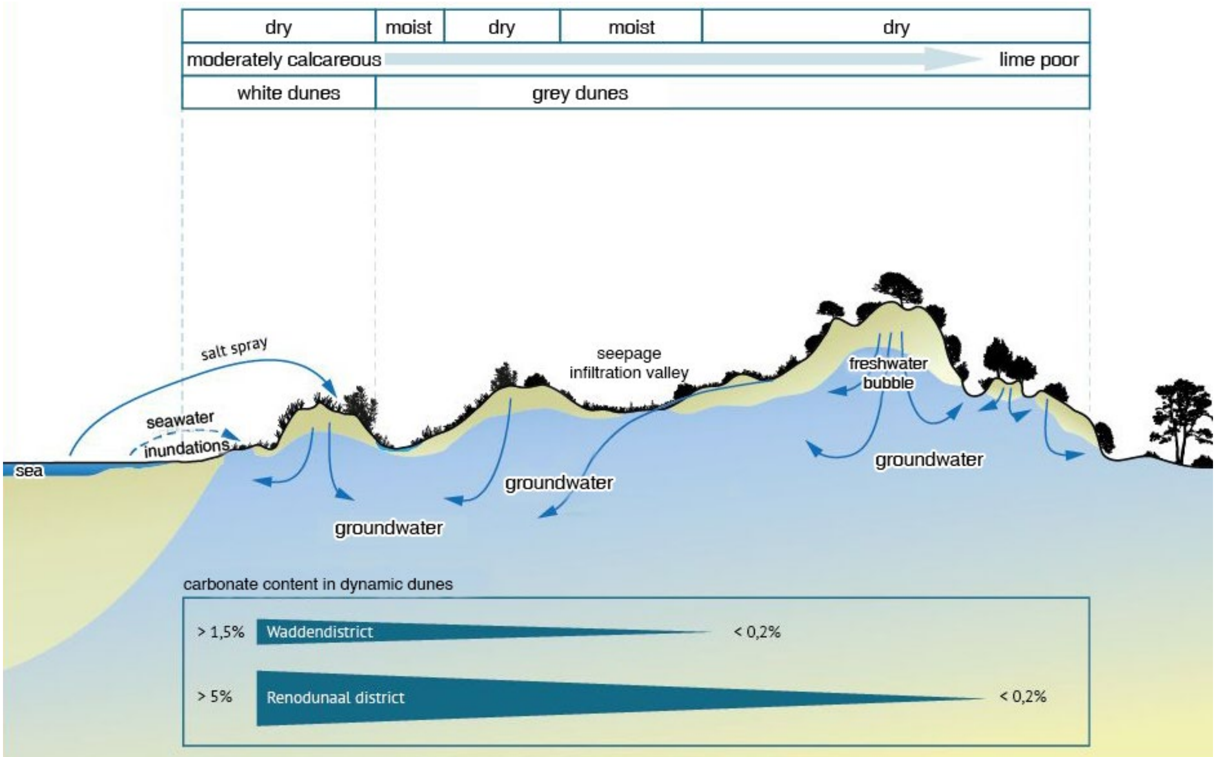

Figure 4. Cross section of the coastal dune landscape with location of habitats, hydrology and gradients (Copyright: Oscar Langevoord; OBN, w.d.). Important factors in the dune landscape are: wind and water dynamics, (presence of) groundwater/freshwater lens, lime content (different in Renodunal and more northern Wadden districts) and height differences.

planting , cleaning fishing nets, building holiday homes, planting marram, building defence structures, and recreation have all left their mark on the landscape to a greater or lesser extent.

1.1.2 Gradients within the dune landscape

With a stable or accreting coast, we expect the following sequence of landscape types: beach, embryonic dunes, white dunes, grey dunes and stabilised dunes, usually with an organic layer (also called brown dunes). The degree of soil formation and succession continues to increase from white to grey to stabilised dunes. Stable or expanding coasts with this sequence of elements still occur in various places.

The sequence differs in an eroding landscape: an eroding foredune has no embryonic dunes because they are continuously eroded by the sea. During (large-scale) coastal erosion, the foredune becomes dynamic and the white dunes move (partly) over grey and brown dunes under the influence of the wind, just as the Young dunes have buried almost the entire Old dune landscape. Figure 4 shows the abiotic factors that are important.

1.1.3 The hydrological system

Along the coast, seawater penetrates inland into the subsurface. Because of the precipitation surplus in The Netherlands (the amount of rainfall is greater than the amount of evaporation), a lens-shaped freshwater body is created above this salty groundwater. Because freshwater is lighter than saltwater, this freshwater lens floats on the saline groundwater (Figure 5). This freshwater lens is essential for all wet dune landscapes.

The size of the freshwater lens in a dune area is determined by the width of the dune massif, the amount of precipitation that infiltrates into the subsurface and the permeability of the soil (Bakker, 1981). Important causes of the decline in freshwater reserves in the Dutch dunes are: the excavation of the Old dunes, which has reduced the dune belt width and volume, the planting of dunes with coniferous forests, which reduces the infiltration of rainwater, the construction of ditches through which fresh groundwater is drained, the extraction of fresh groundwater for drinking water supply and drainage to lower the water level in adjacent plots.

In an accreting (growing) dune, the groundwater level will rise and thus the interface between fresh and saline groundwater will drop, causing the freshwater lens to become larger. In low lying areas, this will cause wetting (Figure 6) and wet dune valleys can change into dune lakes. With coastal erosion, the groundwater level will actually drop and the freshwater lens will become smaller. If the dunes become wider and/or higher due to sand accumulation this will result in an increase in the amount of freshwater held in the dunes (OBN, without data).

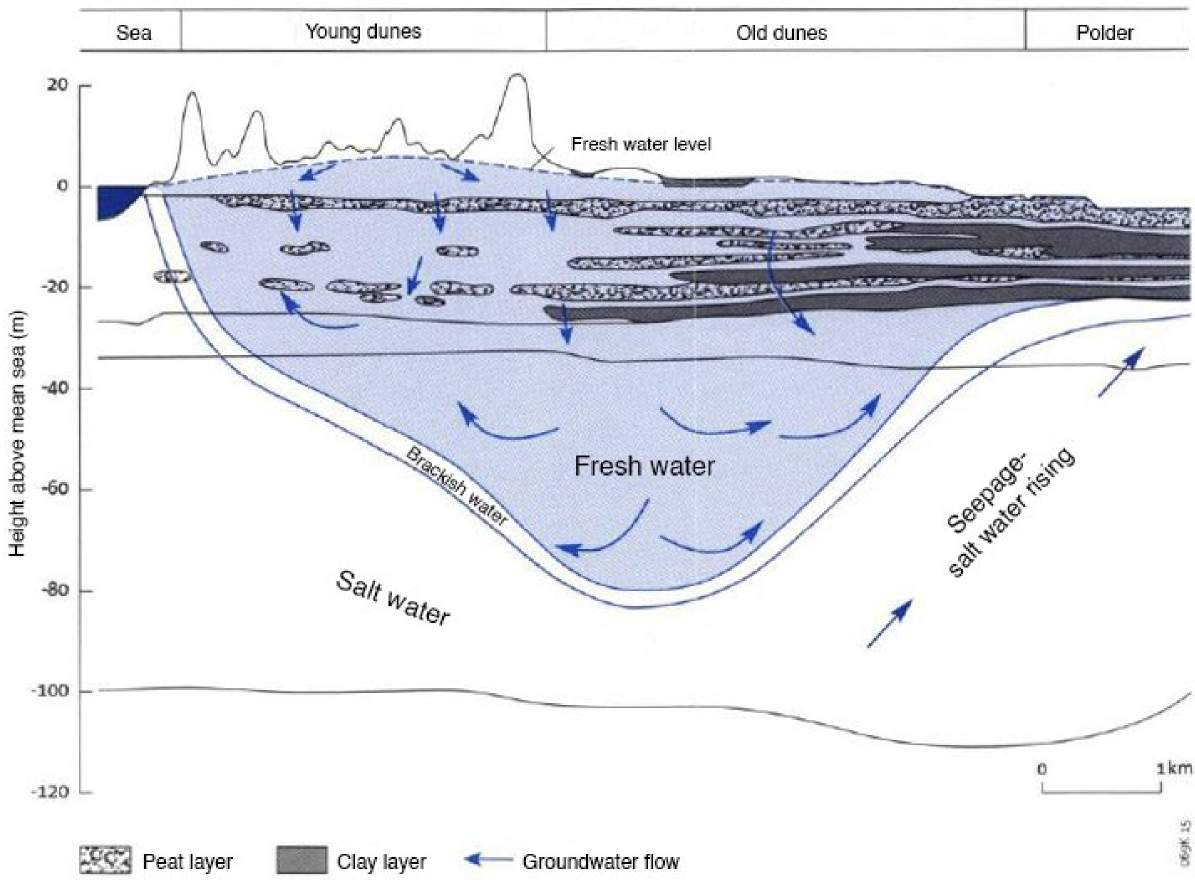

Figure 5. Cross section through the Berkheide dune area. Because the infiltrating rainwater is lighter than the salt water in the subsurface, a 'freshwater lens' is formed. (Source: Runhaar et al., 2000)

Figure 6. Wet dune valley at beach pole 13 on Terschelling. (Photo: M. Nijenhuis)

Rainwater infiltrating dry dunes flows through calcareous sand in the direction of lower wet dune slacks and carries dissolved lime from the dune sand. In the calcareous dunes of the Dutch Wadden Islands and the north of the mainland coast, north of Bergen, such calcareous water is essential for the maintenance of species-rich base-loving vegetation (Grootjans et al., 1995).

1.2 Different forms of dune dynamics

4 The range of dune types

Dynamics of blowing sand take many forms. Where the coast grows, new dunes are formed and dynamics are usually mild, light sand drift, some small scale wind erosion and a gradient of rapidly decreasing aeolian activity landward. Where the coast is stable or slightly eroding, sand drift can take on increasingly large-scale forms, from a small-scale, incidental blowout to a landscape of parabolic dunes or a landscape with washovers and/or channels.

The degree of burial by blowing sand is important for the final effect. After massive sand drift, the vegetation is completely buried. Climax vegetation can thus disappear under the sand, after which the establishment of new vegetation can start from scratch, a form of rejuvenation. At the other end of the spectrum we speak of over-powdering (the Dutch term) or sand rain, the burial with sand is so light that although it hardly leads to changes in height, it still has important ecological effects. Burial due to strong sand drift generally occurs immediately around notches or blowouts, but the sand rain can reach hundreds of metres inland. Due to turbulence, the sand is taken up high in the air, carried with the wind in a form of suspension and deposited again at

Figure 7. Dune field on De Hors, Texel. (Photo: B. Arens)

a great distance. Sand-rain is the process par excellence that can improve or maintain the quality of grey dunes (Aggenbach et al., 2018, 2020; Van Til et al., 2019).

There is a whole range of conditions between complete burial and sand-rain, from very extreme to very subtle. Below we describe different forms of wind dynamics, where the first three are characteristic of a growing coast, the others more of a stable or erosive coast.

1.2.1 Dune fields

Dune fields can only develop where wide sandbanks are present, where sand supply and dune formation can take place on a large scale. The dunes are often relatively low and grow slowly in height. Sand movement is slight and quite small-scale. Especially in the intervening dune slacks and lowlands, a highly diverse flora can develop due to the large variations in lime content, acidity, humidity, exposure, salinity and dynamics. Examples can be found on De Hors on Southwest Texel and Rottumerplaat. Wide sandbanks can also be created by human interventions, either directly, such as the Sand Motor, South Holland or indirectly, such as the Kennemerstrand as a result of the construction of the pier at IJmuiden. Also on such human-induced (artificial) sandbanks, dune fields with natural properties can develop.

1.2.2 Embryonic dunes

These are partly vegetated, low dunes on the beach and the outer edge of the foredune. They represent an early phase of dune formation and are characteristic of accreting coasts. These dunes are one type of ‘primary dunes’. Embryonic dunes form a buffer for sea defence and limit erosion of the outer slope of the foredune.

Figure 8. New dune formation in front of the foredune. Note that blowing in fresh sand leads to vigorous flowering marram in the foredune, which is therefore more stable. Schouwen. (Photo: A.P. Oost)

The formation of the dunes often begins by sand burial of strandline debris such as seaweed, shells and driftwood on Spring and early Summer strandlines. This is where salt-tolerant sand couch grass *Elytrigia juncea* germinates, a species that traps sand and is essential for the formation of dunes; As soon as the dune starts to retain small pockets of fresh water, marram can also establish. Depending on the dominant vegetation, embryonic dunes fall under either the EU habitat type Embryonic shifting dunes (H2110) with dominant *Elytrigia juncea* or Shifting dunes along the shoreline with *Ammophila arenaria* (white dunes) (H2120) with dominant marram. In the text reference to Natura 2000 habitat types are capitalised, e.g. White dunes, whereas reference to the broad habitat type, which may not all be Natura 2000, are lower-case, e.g. white dunes. The difference can be important in assessing the impact of a project.

Embryonic dunes often only exist for a short time because the sea floods and sweeps them away during a heavy storm or spring tide. Then the process of dune formation begins again. Sometimes, however, the dunes grow higher and join together to form a longer chain: a 'new foredune'. This new foredune is included in the white dunes habitat type. A dune valley, a primary dune slack, can develop on the original beach surface between this new and the old foredune. This is characterised by fresh, brackish to saline conditions. The supply of fresh water is largely determined by the size of the dunes further landward, and the supply of salt water through floods. The original foredune will become more sheltered and will eventually become less dynamic; it is expected that this will result in less sand transport to the dunes behind the original foredune. There is a good example of a recently spontaneously developed new foredune on Schiermonnikoog.

1.2.3 Foredune with accretion zone above the dune toe

Where beach plains are not as wide as the dune fields above, and space for development of embryonic dunes is insufficient, blowing sand can accumulate against the foredune. Ecological characteristics comparable to embryonic dunes may occur in these accumulation zones. The dynamics in this type of foredune are generally limited to the drift of sand. Wind erosion is limited and therefore there is little opportunity for the formation of secondary dune shapes (dune shapes that are created by wind erosion of existing shapes) such as a notched foredune or parabolic dunes.

1.2.4 Foredune promoting inland sand transport

This type of foredune is covered with open marram vegetation, interrupted by bare surfaces and blowouts. The foredune therefore varies in shape and height. Marram grass seeds profusely: the regular supply of fresh beach sand and salt spray gives fungi and nematodes less opportunity to attack the roots of the grass than in a densely vegetated foredune. Some sand is blown into the dunes directly behind the foredune, which therefore grow (to a limited extent). The type of foredune forms the habitat type white dunes. New approaches to foredune management (dynamic foredune management) have already led to this type of foredune in many places.

1.2.5 Dissected foredune

The dynamics in a dissected foredune are stronger than in a foredune, thus promoting inland sand transport. Natural notches usually arise from wind gaps and blowouts in the foredune. A notched foredune acts as a conduit, or corridor, for sand from the beach to the dunes behind it, which slowly grow higher. The drifting sand suffocates older dune vegetation, which then makes way again for pioneer species. Some degree of drifting sand is essential for the maintenance of the Grey dunes habitat type (EU habitat type H2130); these are dune grasslands that are rich in

Figure 9. Overview of different notches along the Dutch coast. The 'smaller' notches, 5-25m wide, are in the top row and the larger ones, 35-90m wide, are in the bottom row. Above from left to right: Vlieland, Terschelling beach pole 5, Schouwen, Schoorl. Below from left to right: Meijendel, Northwest Nature Core, Ameland, Terschelling beach poles 15-20. With the exception of Terschelling beach pole 5, all examples have been constructed artificially. (Photos: M. Nijenhuis)

flora and fauna. Beautiful examples of notched foredunes can be found along the coast of Terschelling, the North Holland Dune Reserve and the Meeuwenduinen on Schouwen. All the notches that have developed spontaneously to date show virtually no signs of stabilisation, unless large-scale embryonic dunes form seaward of them. The entrance is then often closed off, and the notch continues as a blowout.

People often see notches as gaps or weak spots in the foredune and fear that the sea will flow in through those holes. But because most notches have a gradually increasing height from the beach landwards, this fear is unfounded. Notches ameliorate storm waves. During storms, erosion damage to the notches is therefore less than to the adjacent foredune. For the Springert dunes on Goeree, a model study has shown that during a major storm, which the flood defence would still have to withstand, little erosion takes place within the notches and sand from nearby dunes partly accumulates in the notches (de Ridder & Broers, 2020). For a coast with notches, the total erosion with an average storm is no greater than for a coast without notches.

Just like foredunes promoting inland sand transport, dissected foredunes can arise spontaneously by taking a more laissez-faire approach to foredune maintenance. A foredune where coastal erosion creates a steep cliff is an advantage but not a requirement. In the case of a (artificially constructed) notched foredune agreements are made in advance about the depth to which the notches 'may' erode. If the notch becomes too deep, the placement of, for example, sand trapping fences or bundles of reeds can ensure that the height increases again.

It is also possible to actively create a notch by excavation. Construction of artificial notches has varying degrees of success, but the notches that are 'not yet doing well' may need longer follow-up management to really get going.

Natural sand drift in the dunes behind the foredune, such as blowouts, are often small-scale and therefore have a limited local effect and often a limited lifespan. Sand drift from the foredune can then contribute to maintaining the dynamics of these blowouts. This increases the distance over which sand transport takes place and thus the spatial effects of sand drift. In some situations, especially on the Wadden Islands, sand drift from the foredune is virtually the only way to introduce some dynamics into the dune area and to bring in calcareous sand.

1.2.6 Transgressive foredune ridge

A series of larger notches can set an entire foredune in motion. If the foredune starts moving as a whole, it is called a transgressive foredune (a rolling foredune in Dutch). In principle, a rolling foredune can be constructed by making a large number of notches close together. In the past (around 1990), if the dune face became too steep and/or the beach became too narrow, this measure was also applied to allow the foredune to move inland in a controlled manner. An example of a rolling foredune was the Zandloper just south of Den Helder (Nieuwjaar, 1995). The foredune was set in motion here in its entirety. Not for nature conservation purposes, but

Figure 10. Natural notches, Schouwen. (Photo: M. Nijenhuis)

because the front of the foredune and the profile of the adjacent shoreface had become too steep due to years of erosion. There was therefore a risk that a large part of the foredune would be washed away in the event of an extreme storm. Notches were dug on top of the foredune in a south-westerly direction, which resulted in massive sand drift. On the lee side, the sand was trapped in a controlled manner with sand fences, so that a new ridge could build up here. It is surprising that at a time when reactivating aeolian processes in the foredune was still taboo, this kind of sand drift was applied to achieve a safety goal.

Another example can be found on Terschelling (Figure 11) where a series of notches were constructed and maintenance of the foredune was stopped (the area between km posts 15-20). The erosion of the dunes due to wind led to a lack of sand at the original location of the foredune, but a strong sand deposition further inland. When accretion at the front increased again, the total amount of sand in the system eventually increased considerably. This type of experiment is only possible in wide dune areas, where safety is guaranteed by a closed row of dunes of sufficient height/width behind the seaward dunes, or on the Wadden Islands in places where there is no safety risk. But even on Terschelling, where safety was no issue, the large-scale of the intervention still led to concern among residents.

The rolling foredune, like the foredune promoting inland sand transport and the notched foredune, belong to the habitat type White dunes. This process is important for the entire dune area. The deflation corridor functions as a conduit for sand from the beach to the dunes, which can grow with rising sea level. The drifting sand increases the landscape variation in the dune area behind it and ensures rejuvenation of the vegetation. If the deflation areas erode very

Figure 11. Rolling foredune, Terschelling, Paal 15-20 view to the east. (Photo: Archive Rijkswaterstaat)

deeply, the sea can occasionally flow into the dunes as in a slufter (see 1.2.8 Slufter). But because the flood defence is located landward, this does not pose any risk to safety.

1.2.7 Parabolised foredune

Parabolic dunes are mobile dunes that move inland from the foredune. These dune shapes arise from coastal erosion, when erosion of the foredune cliff mobilises large quantities of sand. In a parabolised foredune, the wind flow is accelerated through depressions in the ridge line and deep depressions may form through deflation. This can lead to a series of parabolic dunes that then slowly move inland. Parabolic dunes are among the largest dune shapes in the Dutch landscape and individual dunes may be up to several km wide. Figure 12 gives an example of a vast landscape in South Kennemerland, just south of the North Sea Canal, with several series of parabolic dunes.

Characteristic of parabolic dunes is the parabolic shape with arms that point in the direction of the wind (see also Klijn, 1981), a head that moves with the wind and the often extensive deflation valley on the windward side, where the surface has eroded down to the groundwater forming a humid dune slack (EU habitat H2190). The typical parabolic shape is created as a result of interaction with vegetation. Our hope is, that in the long term, with the development of a parabolised foredune, active parabolic dunes will again move inland from the foredune. This is currently happening on a small scale in the active notches on Terschelling and in the North Holland Dune Reserve.

1.2.8 Slufter

A slufter is a breakthrough through the foredune, with a channel where at high tide the sea can flow in, but flooding is controlled by surrounding dunes. The vegetation in the slufter plain is regularly rejuvenated and the slufter plain accretes vertically (to a limited extent) along with the rising sea level. Slufters can develop along both erosion and accretion coasts (Arens & van der Meulen, 1990).

Slufters are formed along erosion coasts after a breakthrough in the foredunes. Along accreting coasts, slufter-like situations can arise after the development of new dunes on the beach. Channels between the new dunes can fill with storm surges, creating a variety of fresh and brackish conditions.

A wide variety of habitats can often be found in slufters: salt marshes and saline grasslands on the lower parts, saline pioneer vegetation on the slightly higher parts, moist dune valleys at places where groundwater emerges, dry dune vegetation on the edges. The most dynamic places, on the beach and around the channel, will be bare. The development of embryonic dunes can cut off part of the beach from the sea. When the embryonic dunes form a closed row, the beach is completely separated from the sea; if not fully closed, a swale-like area may develop here, which is either flooded by the daily tide (northwest of Rottumerplaat), or only during storm

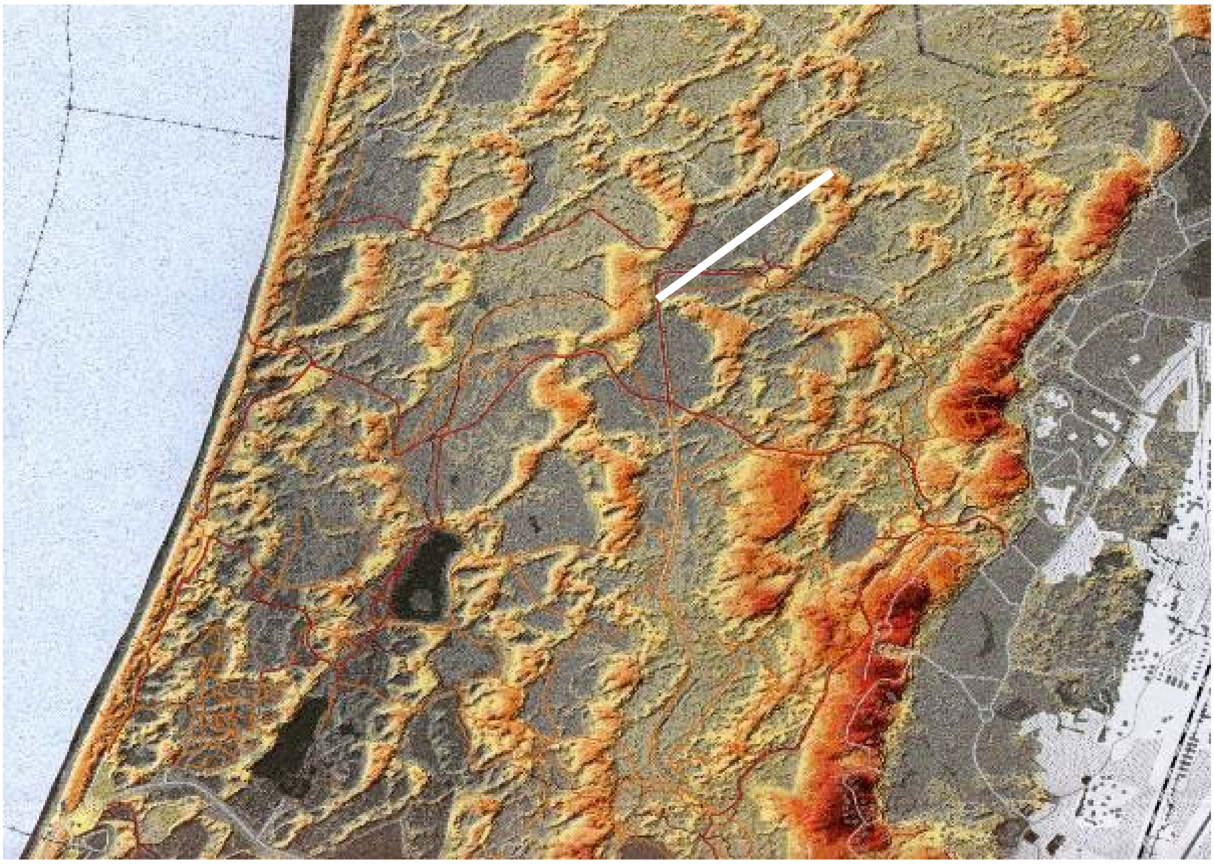

Figure 12. Series of parabolic dunes in South Kennemerland, as visualized with a Digital Terrain Model of the Netherlands (AHN). The parabolic dunes become increasingly larger from west to east. The length of the white bar is 1.2 km.

Figure 13. Slufter, Noordsvaarder Terschelling. (Photo: A.P. Oost)

surges (Kwade Hoek). Two well-known slufters are De Slufter on Texel and Het Zwin on the border of Zeeland and Flanders.

1.2.9 Washovers

A washover area consists of a breakthrough in the foredune and a depositional area behind it in open connection with the backbarrier lagoon or tidal flats. During storm surges the sea reaches the depositional area and deposits sand or silt. The vegetation is continually rejuvenated and overwash areas accrete vertically with rising sea level. Washover areas can occur in both eroding and accreting coasts.

Characteristic for washover areas are the transitions, for example from fresh to salty, from sandy to silty and from wet to dry. As a result, the diversity of habitats and species is relatively large. The exact species that occur depend on the frequency of flooding and the composition of the subsurface. In places with relatively little dynamics, algal mats can form, which capture the sand to some extent. In even more sheltered places, organic matter can accumulate and vegetation of salt-loving or salt-tolerant pioneer species such as shrubby marsh samphire (*Salicornia fruticosa*), common saltmarsh grass (*Puccinellia maritima*) and saltmarsh rush (*Juncus gerardii*) can establish themselves. Where the soil is brackish, succession starts with species such as seaside centaury (*Centaurium littorale*) and knotted pearlwort (*Sagina nodosa*). Even further from the influence of salt water, where fresh water from the underlying dune area seeps or where rainwater stagnates, wet dune valley vegetation can establish.

Figure 14. Washover at post 10 Schiermonnikoog. (Photo: Archive Rijkswaterstaat)

1.3 Dynamisation through intervention?

5 **How natural or unnatural are your actions?**

Clearly, where possible, it is preferable to allow dynamics to develop naturally. There are now many examples of places where, often after some coastal erosion, dynamics have started and led to interesting results. When you have the impression that the spontaneous development of dynamics is happening in a certain place: let nature take its course.

An important question, the subject of much discussion, is whether by encouraging aeolian processes we want to restore a self-sustaining process or artificially keep it going. Are the dunes stabilised forms, meaning they arise from processes that are no longer active today? Consider, for example, glacial moraines: the ice is gone, so these forms can no longer develop under the current conditions. Or have the dynamic processes been artificially suppressed and simply need to be restarted? An additional question is whether, perhaps, due to climate change (the most important factors being an increase in temperature and average precipitation, which have significantly lengthened the growing season) the conditions for sand drift deteriorated to such an extent that restoration of dynamics is an illusion (global greening , see for example Jackson et al., 2019). However, the observation at many places where aeolian dynamics have restarted naturally is that the processes of sand mobilisation are still working. The conditions around the foredune, with the influence of wind, seawater, salt and sandblasting, are apparently so intense that the sand can still 'beat' the vegetation here.

So, realise what you are doing. How natural or unnatural is your action? Are you trying to restore a natural situation or a natural process? Remember that it is often an illusion to achieve your aims in one go. A one-time operation does not reset the entire system, for example, because of the negative effects of remaining root material which can be at some depth. Sometimes years of follow-up management are required to get rid of this legacy. Sometimes long-term intervention is necessary to really bring a natural process back to life.

Practice will show how sustainable sand drift is under the current circumstances. With this manual we want to summarise current knowledge, but also provide an impetus for the collection of new knowledge about restoration projects in a structured way and to bring together experiences from different managers and areas. By looking at each other and learning from each other, the chance that a restoration project will be successful can be significantly increased.

For many foredunes along the coast, the intensity of management has declined considerably since 1990 when the policy of Dynamic Coastal Management was introduced. Since 1990, the percentage of foredunes along the Dutch coast that are dynamically managed (i.e. where dynamics are allowed) has increased from 11% in 1990 to 51% in 2017. In 2017, an inventory was made of the dynamic conditions of foredunes (https://www.openearth.nl/coastviewer-static/). Despite reducing the intensity of management, data show that stable foredunes often retain their character for a long time (IJff et al., 2019). This is probably related to the lack of extreme storm conditions. In that case, the desired development can be initiated with targeted interventions such as removing vegetation.

There are now several interesting examples of restoration projects. Positive results so far mainly relate to the development of sand drift and morphological changes. The projects are not old enough to draw conclusions about ecological development. Some examples of well-documented projects are highlighted here, with reference to available literature for further information.

De Kerf near Schoorl was created in 1997 as an opening in the dunes that was so low that during storm surges the sea could penetrate into the dune valley behind it. So a small slufter arose. Later, the gap in the foredune dunes partly closed and a notch formed. The intervention has been extensively monitored for the development of geomorphology, vegetation, fungi and ground beetles. The project was evaluated after five years (Vertegaal et al., 2003). As a direct result of the increased marine influence, strandline vegetation, salt marsh vegetation and (fresh or brackish) water vegetation emerged. Many tidal marsh and salt marsh species appeared in the area, including species such as frosted orache (*Atriplex laciniata*), sea beet (*Beta vulgaris* subsp. *maritima*) and parsley water-dropwort (*Oenanthe lachenalii*). Some new species also colonised the wet dune valleys, such as marsh helleborine (*Epipactis palustris*). As with the higher plants, fungi responded surprisingly quickly to the new habitat. In the years after creation of De Kerf, many new fungi species were found, including some very rare ones. In particular, the number of species and habitats of foredune species and strandline species increased sharply, including rare species such as dune brittlestem (*Psathyrella ammophila*), dune stinkhorn (*Phallus hadriani*) and the little ink cap (*Coprinellus xanthothrix*). Almost all ground beetle (*Carabidae*) species showed a more or less spectacular increase after 1997. In particular, species characteristic of humid conditions and coastal areas increased sharply. Before construction these species groups were almost completely absent from the study area. Perhaps the most important development in De Kerf was the establishment of ringed plover (*Charadrius hiaticula*), a valuable coastal species, which began breeding with 1-2 pairs in the vicinity of the turf-stripped valley.

The changes in the occurrence of indicator species and ecological groups reveal a clear and consistent picture that indicates an increase in the dynamics and gradient richness in the study area. Despite extensive monitoring and attention to design and implementation, there were a few omissions in the monitoring, especially for breeding birds, amphibians and reptiles.
For created notches on Ameland east, a review (Riksen et al., 2016) concluded that the effect on the more inland grey dunes was limited. The effect on the white dunes was greater (more sand drift compared to the adjacent foredune without notches), but according to the authors, the positive effects were disproportionate to the effort required to create the notches.

The Noordvoort project, between the villages of Noordwijk and Zandvoort, was evaluated five years after construction. The creation of 17 blowouts in the foredune led to an enormous increase in landscape diversity, with a much greater variety of aeolian forms. From an ecological point of view, the research period was still too short to observe any differences. The foredune in the dune landscape has traditionally been species-poor, so expectations should not be too high for biodiversity of flora here (Kruijsen et al., 2018).

The interventions in the Northwest Nature Core, north of Zandvoort, have resulted in a large-scale dynamic landscape. For geomorphology, the development is spectacular, with deposition lobes that now extend more than 400 m landward and parabolic dunes that seem to be slowly moving. Ground beetles of dune species such as *Calathus ambiguus*, *Calathus mollis*, *Amara curta* and *Amara lucida* have increased considerably. As expected, the dune chafer (*Anomala dubia*) also responded with a significant increase. On the other hand, seventeen beetle species are no longer found, but these are (very) common species nationally. The interventions also had a positive effect on populations of wild bees, such as the willow specialist, the vernal mining bee (*Colletes cunicularius*) and the yellow composite specialist hairy-saddled colletes (*Colletes fodiens*). The endangered coastal leafcutter bee (*Megachile maritima*), the critically endangered large sharp-tail bee (*Coelioxys conoidea*) and the more common square-jawed sharp-tail bee (*Coelioxys mandibularis*) benefited, as did thread-waisted wasps (*Podalonia*). The sand wasp (*Bembix rostrata*) an easy-to-inventory species from open sandy areas, increased in numbers.

2 Goals of the dynamisation project

2.1 Introduction

6 **Draw up realistic goals and express them clearly**

An inventory of Dutch projects to increase dune dynamics (Nijenhuis, 2022) shows that the aims of projects creating notches are not always specifically stated. Clear long-term goals are crucial for a successful project. It is smart to link the goals as much as possible to the Natura 2000 management plans and the nature management plans of the site management organisations, because these are an important driving force behind these types of projects. The nature management plans often contain much broader objectives, for example with regard to fauna, than the Natura 2000 management plans (which tend to focus on the habitats and species listed in the EU Habitats Directive).

The first step in the process is to think about what goals you want to achieve and whether they are realistic. That starts with looking at the parameters you cannot change yourself. These are the preconditions for what you can or cannot achieve. Within these preconditions, you and other managers and possibly clients (including funders) must think carefully about: i) what you want to achieve? ii) is this feasible at that specific location? and iii) can combinations be made with other goals within the area?

2.1.1 The importance of drawing up clear goals

A clear goal makes more concrete what exactly you want to achieve and what is needed for the intervention (and what is not needed). It is important to keep both feet on the ground. Re-mobilisation and sand drift unleashes natural forces that you cannot entirely predict. A dry or wet year or a few heavy storms or storm surges can make a world of difference. So be aware that you should not formulate goals down to the last square centimetre, because that is doomed to failure. Try to overcome that by guessing what could happen under various scenarios and include those guesses in your goals. So not: 'in two years after construction of the notch, 25 hectares of the underlying area must again be a qualifying grey dune', but 'we aim for between 15 and 35 hectares of the underlying area to become a qualifying grey dune again in the coming decade, depending on the development of the project.'

It is also important to be aware that choices are subjective. Goals, if not clearly stated give room for different interpretations. And that gives all kinds of different opinions about whether or not the project was successful. You can test specific goals afterwards. Research shows that even within the same organisation, different opinions can arise about the success of created notches. What one manager considers successful, another manager may consider bad. By asking yourself: '

Figure 15. De Kerf near Schoorl in 2004, 7 years after the intervention. (Photo: F. Erinkveld)

Why do I want this?' and also by asking other managers and possibly clients, you can avoid this pitfall.

The example of De Kerf at Schoorl (kerf is a Dutch word meaning notch) shows that some goals sometimes take on a life of their own. When planning the project, the aim was to enhance all kinds of gradients, such as dry-wet, freshwater-saltwater, high-low, mobile-stable. One of the processes by which this had to be achieved was the inflow of seawater into the dune valley behind the notch. De Kerf was the first of its kind on the Dutch Mainland coast. Creating a break through the first dune ridge to let the sea in was even international news at the time. This made such an impression that it remained in the collective memory as the main objective. When the entrance became too high over time due to sand accumulation, the sea could no longer reach the dune valley behind. So the project was considered a failure in the eyes of many, although even nowadays, dynamic processes are still at work and the flora and fauna is special.

2.1.2 Feasibility

The feasibility of a goal and its objectives depends on many factors. Your choice of how to intervene to achieve your goals depends on how much space the coastal landscape offers and what kind of dune mobilisation is possible. Climatic parameters, water safety (i.e. flood safety), current coastal development, freshwater supply or recreation can all influence the feasibility of your goal. From a water safety point of view, a narrow foredune and a small dune area to landward offer little prospect for sand drift, at most on a small scale. In a wide dune area, safety problems are less likely to arise and connections are possible between processes in the foredunes and active parabolic dunes or transgressive sand sheets allowing the dynamics to penetrate further inland. In the Netherlands the presence of infrastructure for drinking water extraction can limit the degree of dynamism that can be permitted. Other infrastructure or, for example, archaeological values in the subsurface and even other natural values (e.g. a well-developed species-rich wet dune valley) can also 'get in the way'. There are now several examples of large-scale burial of cycle paths, causing conflicts with other interest groups. If remnants of ammunition are present in the soil, removal of explosives before initiating sand drift can be a major expense. At the start of a project it is therefore necessary to make a thorough inventory of which factors in your area are relevant with regard to initiating dynamics. Chapters 3, 4 and 5 discuss in detail the various preconditions and how to deal with them. Together, these preconditions determine the feasibility of restoration projects.

2.2 Possible targets

7 **Use an integrated assessment to develop your goals**

This manual deals with the restoration of sand drift by giving free rein to the sea, sand and wind. This can be done on a large to small scale, to achieve a more specific goal (for example a notched foredune or a light 'sand rain' on landward grey dunes). To determine your specific goal, there is first a need for an integrated assessment of water safety, climate adaptation, nature, conservation of freshwater supplies, recreation, etc. Such an assessment (sometimes even a policy choice) should normally be incorporated in management plans that are intended for managers as a guideline. Managers should not have to make this choice alone; it is very important to coordinate this with other stakeholders.

2.2.1 Goal: system restoration

One of the larger-scale goals, currently receiving more and more attention is system restoration. By system restoration we mean restoring dynamics on a landscape scale by allowing free-rein to natural, geomorphological processes that shape the landscape. In this way, the landscape-forming processes can once again play an active role in the development of the landscape. The resulting gradients can produce a habitat mosaic with a wide range of ecological conditions (see Figure 4). The evolution of the landscape is spontaneous; patterns arise automatically through the operation of processes, now here, now there. After restoration, the system can ideally continue to develop through natural dynamics with little or no management. We do not pursue an original reference landscape (the landscape before human influence), as this reference situation is often unknown. Sufficient space is required for system recovery measures, or where there is a great social need (for example, new high-quality nature for nitrogen compensation).

An example of system recovery can be found in the Northwest Nature Core in South Kennemerland (managers PWN and Natuurmonumenten). Here, the original sea defence foredune has been notched on a large scale and several landward parabolic dunes have been stripped of vegetation. The aim is to create a living landscape. Dunes are allowed to move through the landscape, burying climax vegetation. At the same time, new dune valleys are created by wind erosion (deflation plains) with space for the establishment of pioneer dune slack vegetation. Before setting such large-scale goals, it is recommended to ask for expert advice about the complexity of large-scale interventions and the approach, feasibility and expected changes in the landscape, for example from the Dune and Coastal Landscape expert team of OBN (The Dutch OBN Knowledge Network for Nature Restoration and Management: https://www.natuurkennis.nl/english/).

2.2.2 Goal: restoration of gradients

Restoring landscape gradients takes place on a somewhat smaller scale than system restoration. Gradients in terms of, among other things, the degree of sand drift, salt, moisture, lime content and nutrient richness are essential for biodiversity in the dunes, because they provide a variety of conditions for plant growth. Both large-scale and small-scale dynamics in the dune landscape are important for producing and maintaining these types of gradients. Due to sand burial or flooding, gradients and their species communities are periodically 'reset'. The result is a dynamic landscape with a 'shifting mosaic' of microclimates, habitats and species. Rising sea level can threaten gradients if the available space decreases due to erosion. A naturally dynamic landscape will shrink on the seaward side as the sea level rises, but could expand again on the landward side if there is free space, with the existing gradients shifting along with it. In this way, the habitats continue to exist in their mutual morphological coherence.

Coastal breeding birds, various insects and plant species and fungi, among others, benefit from the increase in dynamics. Reintroducing dynamics is therefore also seen as the most promising measure for preserving biodiversity in the long term (Löffler, Spek & Gelder-Maas, 2011).

2.2.3 Goal: landscape diversity

Your goal may also be to strive for greater landscape diversity. The stuifdykes, which were constructed on the Wadden Islands mainly in the last century and were reinforced in the 1950s, result in a monotonous landscape. A stuifdyke is an artificially created foredune, shaped by the placement of sand trapping fences, traditionally of brushwood or reeds, and maintained as a barrier between the beach and the hinterland. Similar structures are found in all Atlantic dune coasts. On a stuifdyke the natural dynamics have disappeared and the relief has become uniform. The same applies to large parts of the foredunes along the Dutch coast and in the Delta, which have been intensively managed for centuries, have been planted with marram grass and have been given the character of an unnatural sand dike. Dynamic management can allow the monotonous relief to become more natural over time through sand drift. The shape of the foredunes becomes more irregular due to the development of notches and blowouts. In addition, the landward dunes and dune valleys also change shape due to the import of sand through sand drift. Over time, the foredunes lose their sand dyke character and, in terms of geomorphology, they form more of a whole with the landscape behind.

Figure 16. Excavated elongate notches near Noordvoort. (Photo: ESRI images)

It is not only sand drift which provides greater diversity. Slufters (tidal breakthroughs) and washovers (sand carried by sea water over low dunes) especially on the eastern ends, the 'tails', of the Wadden islands also increase the naturalness of the landscape. This makes the landscape more varied, which is also more attractive for visitors (Arens, Löffler & Nuijen, 2007). Improving the way the public can experience the landscape is therefore important for many managers. Making a notch accessible (such as with the Northwest Nature Core) can help to increase support for an intervention among residents and municipalities.

A good example of a project where landscape diversity was an important objective is Noordvoort, between Zandvoort and Noordwijk, initiated by Waternet, in the Rijnland foredune (see Arens, 2018, Figure 16). A number of artificial elongate notches have been dug here, which in a relatively short time (less than 5 years) resulted in an enormous revival of aeolian dynamics and spectacular changes in height, which has thoroughly changed the image of the foredune.

2.2.4 Goal: to rejuvenate or reset succession

Perhaps the most frequently pursued goal is to reset succession and rejuvenate vegetation through aeolian dynamics. This is also a secondary goal of all the goals mentioned above. Dune and habitat rejuvenation can be achieved at different scales. A 'sand rain' of calcareous sand from even small scale mobility gives the existing vegetation a boost without significant change of the habitat type or vegetation type. With large-scale sand drift, vegetation may disappear completely, either through erosion or because the vegetation is completely buried. In such a scenario a bare sand surface is created where vegetation can start from scratch, resetting succession. Grey dune habitat types may change to white dune habitat types. In the short term, this may mean a loss of grey dune habitats, but when the process eases down in the longer term, grey dunes may develop again. Although loss of priority habitat Grey dunes is not simply permitted in the Natura 2000 system (see also Chapter 4) there are strong arguments for a dynamic approach to the conservation of dune habitats. And this is the case in several areas.

2.2.5 Goal: to combat the effects of nitrogen deposition

Nitrogen deposition in the Netherlands is still too high; and also the case in the dunes. There are two ways in which action can be taken for nature goals: on one hand by reducing the supply of nitrogen and on the other hand by actively improving the conditions for the threatened habitats, through restoration strategies. Nitrogen deposition in the dunes has indeed fallen from approximately 25 kg/ha/year in 1990 to 15 kg/ha/year in 2020 (https://www.clo.nl/indicatoren/nl0189-stikstofdepositie). This appears to have resulted in a decrease in the above-ground biomass of the herb layer in un-grazed grey dunes and an increase in the number of vascular plant species (Figure 17). That indicates we are on the right track, even if we are not there yet. In addition to nitrogen deposition, the acidity of the soil and the amount of organic matter are also important: the more acidic the soil and the higher the organic matter content, the higher the biomass production of the herbaceous layer.

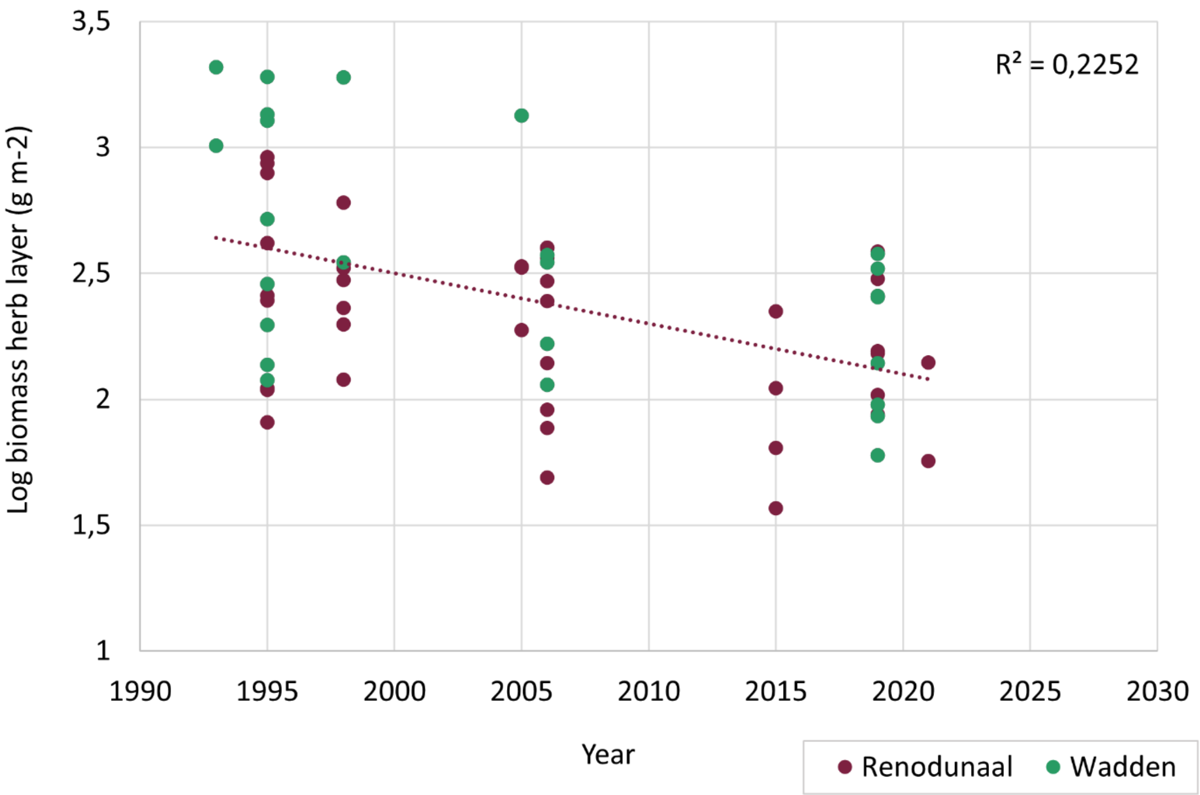

Figure 17. Decrease in above-ground biomass of the herb layer in un-grazed grey dunes between 1992 and 2021. The points are average values of multiple measurements per area: orange = Wadden district; blue = Renodunal district. (Source: A.M. Kooijman & M. van Til, unpublished results)

Dynamic coastal management is an important part of the recovery strategies for grey dune habitats. By promoting sand drift, the influx of calcareous sand will make the soil less acidic and the effects of nitrogen deposition will be partly counteracted. Lime also has an effect on the fixation of phosphate. In calcareous soils phosphate is bound to lime, making it unavailable to plants, but in acidic soils phosphate becomes mobile. Kooijman et al. (2021) provide a nice overview of the relationship between lime, pH, phosphate availability and nitrogen deposition. In calcareous dunes, sand drift keeps the pH high, even if the soil contains a lot of organic material. One caveat is that you should not aim for pioneer vegetation everywhere. After all, older calcareous dune grasslands are also important, because they are characterised by special species such as bastard toadflax (*Thesium humifusum*) and cross gentian (*Gentiana cruciata*). Lime-poor dunes are even more sensitive to acidification, because there is only a little lime in the sand, and sand drift generally becomes inactive more quickly. But in lime-poor dunes, sand drift can be extra important, because the soil locally becomes less acidic and contains less organic matter, increasing the species diversity in the vegetation.

2.2.6 Goal: water safety (flood defence)

Sand drift in combination with an additional supply of sand can make the flood defence more robust. Flood safety can be strengthened by specifically targeting a 'weaker' spot in the underlying flood defence to be blown over with sand so that it becomes higher. You can also create direct reinforcement by mechanically placing the sand that is released from digging a notch on the 'weaker' spot. The Dutch water boards (including HHNK in North Holland) are experimenting by using sand drift to strengthen the flood defence and thereby improving flood safety. There is increasing awareness that net sand drift strengthens the dunes and can therefore contribute to flood safety. Light burial by sand also ensures that the vitality of marram plants increases. In zones of accretion marram grass grows in clumps, which alternate with bare sand, whereas marram grass that is no longer trapping sand grows much more in dense, monotonous mats that cover the entire dune and therefore slow down dynamic processes. With dynamic foredunes, a dune area can grow and keep pace with sea level rise, because wind has room to deposit extra sediment. A densely vegetated and stable foredune hinders this process.

Recent research shows that dune areas with notches can resist sea level rise better than areas without notches. If sufficient sand is present, a lot of sand can be deposited through a notch in a short time. In the direct vicinity of a notch this can result in an increase in height of up to one metre per year or even more, at greater distances this can range from centimetres to decimetres. It should be noted that the sand will not be perfectly distributed over the surrounding area; within the notch, depressions can also be carved out by wind erosion (deflation). However, the movement of sand can be easily controlled with, for example, sand fences, so that lower areas can be raised with specific measures. There is therefore sufficient reason to conclude that notches can make a significant contribution to adapting to sea level rise (Wegman, Leenders & Arens, 2022).

2.2.7 Goal: freshwater security

By increasing the freshwater groundwater reservoir in the dunes, long-term drought periods due to climate change can be better handled. This is not only important for nature but also for the environment, because more groundwater from the dune massif flows into the surrounding area. A dune area has more options than a polder to absorb the precipitation surplus in winter and to discharge it more slowly. Surrounding polders benefit from this delayed flow of fresh water from the dune area during periods of rainfall shortage.

Fresh water is also needed to flush out brackish water. The greater the groundwater reservoir in the dune area, the longer it can fulfil this function. Particularly in the Zeeland Delta and on the Wadden Islands, dune water run-off is the only source of fresh water during dry periods, because no supply from elsewhere is possible. As also indicated in section 3.4, the root of the freshwater lens will respond very slowly to changes, on the order of centuries, while the groundwater level can respond quite quickly, on the order of months.

Climate change will probably result in an average precipitation surplus increasing over the year. This also causes the groundwater level in the dune massif to rise, especially if this extra water is prevented from draining, for example by filling in ditches in the dunes (Caljé , 2022, see Figure 18). This creates new opportunities for wet nature in the dunes.

With rising sea levels, the freshwater lens in the dune massif will be pushed upwards (it floats on the heavier sea water). As a result, in future it will become increasingly common for dune valleys directly behind the foredunes to first become wet and then drown. Rapid runoff (for example through ditches, etc.) may prevent this, but consequently the freshwater lens in the dunes will decrease in volume.

Dune building and re-mobilisation, especially if it is large-scale, can have an effect on the freshwater supply in the dunes. When new rows of dunes are created on beach plains due to large-scale sand supply and coastal expansion (Kwade Hoek, Sand Motor), the dune massif becomes wider, causing the freshwater lens to increase in size. This increases the freshwater

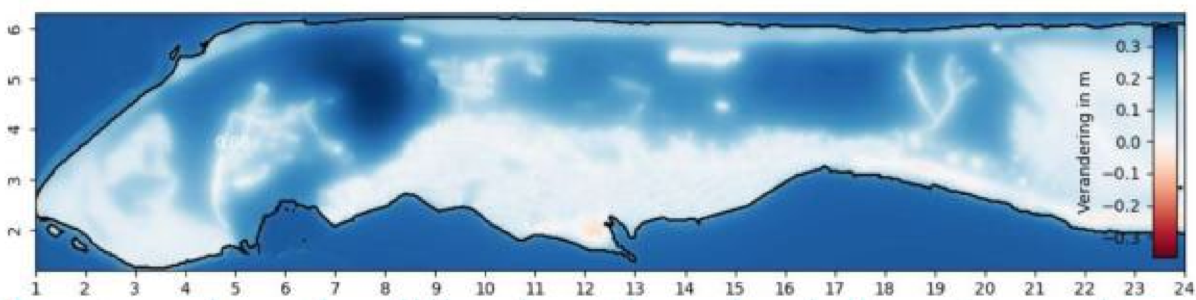

Figure 18. Expected increase in the groundwater level in the dunes of Terschelling by 2050 due to an increase in the total annual precipitation. Left and X_axis: distance in km; right axis: Evaporation in m. (Source: Caljé, 2022)

supply in the dunes and increases the groundwater in the dune massif. The opposite happens with coastal erosion. The dune massif will become narrower and the groundwater level in the dunes will drop and in the long run the freshwater lens will become smaller.

Primary dune slacks develop parallel to the dunes and can increase the dune water table. Large-scale drift creates new dune valleys (secondary dune slacks) that can reach groundwater level. New vegetation of wet dune valleys is establishing itself here. Wandering dunes also cause the formation of new wet dune valleys on the windward side (where the wind comes from) (Geelen et al., 2022; Geelen, 2022). Injection of sand can then cause the soil to be raised to such an extent that its position in relation to the groundwater remains relatively the same and lake formation is prevented. Raising the dunes and dune valleys can also contribute to maintaining or increasing groundwater volumes.

Dynamics can also be used in parched landscapes where, for whatever reason, groundwater has fallen sharply. New wet dune valleys can be created by erosion down to the groundwater.

2.2.8 Goal: recreational zoning

Zoning of recreation can concentrate more intensive forms of recreation in certain parts of the area and thus ensure sufficient peace and quiet in other areas. This helps protect valuable and/or vulnerable plant and animal species which are sensitive to disturbance. Zoning is often combined with re-mobilisation projects by managers. An example is the Northwest Nature Core in South Kennemerland (Bloemendaal aan Zee), where the first notch, closest to the parking lot, is open to the public, while the other four are not accessible.

2.2.9 Goal: to increase knowledge

Rarely, if ever, will restoration projects be carried out with the sole aim of increasing knowledge. But almost all projects will provide new information about the possibilities (and impossibilities) of reactivation of aeolian processes and can therefore have the secondary aim of increasing knowledge. Furthermore, monitoring is necessary to ultimately determine whether goals have been achieved or not. It is therefore good to check to what extent your project can generate new knowledge. Maybe your area is home to unique geological forms? Is the sediment abnormal? Does the foredune have an exposure or orientation that is unusual? Remember that every area has a unique set of characteristics and from that point of view could by definition yield new knowledge.

Type of dynamic processes	**Dune field** Irregular dune field developed on wide beach plain	**Embryonic dunes** Young dunes developed on the beach	**Foredunes with accretion on the seaward side** Mostly irregular shaped dune ridges	**Foredunes with transfer of sand to the hinterland** Foredunes with bare surfaces/ small blowouts and sand rain	**Carved foredunes** Foredunes with blowouts/ notches	**Parabolising or rolling foredunes** Irregular dune ridge with blowouts/ notches	**Slufter** Breakthrough through foredunes with tidal influence	**Washover** Breakththrough through foredunes, active during storm surges
Coastal development	seaward	seaward	seaward	stable	stable/landward	stable/landward	stable/landward	stable/landward
Scale	large	middle	small	small	middle/large	large	large	very large
Natural	sandbank	accreting coastline	accreting coastline	erosive foredune	erosive foredune	very erosive foredune	natural break through	natural island tail
Artificial	mega nourishment	nourishment	nourishment	remove marram grass	create notches	create different scale of notches	breaking through stuifdyke	large scale breaking through stuifdyke
System-restoration	large	moderate	limited	limited	large	very large	very large	very large
Restoration of gradients	very large	large	limited	moderate	large	very large	very large	very large
Landcape quality	large	moderate	limited	moderate	large	very large	very large	very large
Rejuvenation	large	large	limited	moderate	large	very large	very large	very large
Combating the effects of nitrogen deposition	limited	limited	limited	moderate	large	very large	very large	very large
Water safety (flood safety)	very large	large	moderate	limited	large	large	no	no
Freshwater-security	large	moderate	limited	very small	moderate	large	small to negative	small to negative
Chances for zonation	very large	large	moderate	moderate	large	large	very large	very large

Figure 19. Overview of the different goals that are achievable with different forms of dynamisation. For an explanation see section 2.3.

2.3 Give direction to your goals

8 Is your goal achievable?

Figure 19 gives an initial idea of what goals can be pursued with certain forms of dynamics. The colours give an indication of the feasibility of a certain goal. What goal can you set, depending on the local situation? For example, it is not useful to develop a parabolic foredune for rejuvenation of the landscape when the coast is developing seaward. The heading 'Natural' indicates which form of aeolian activity suits a particular natural development. The heading 'Artificial' indicates how you can achieve this form of aeolian activity through intervention. 'Scale' refers to both the scale of the measures and the spatial scale of the landscape or landscape element to be pursued. 'Water safety' (flood defence) is mainly based on sand volumes: how can certain types of aeolian processes contribute to an increase in the sand volume.

2.4 Other targets in the re-mobilisation area

9 Include other goals and try to come up with smart combinations

There are more stakeholders in every area. Make an inventory of whether there are any wishes among other stakeholders and to what extent these wishes can align with your own goals. Sometimes goals can be contradictory, but there are also many situations where different goals can reinforce each other. There are many examples.

The goal of a water board to make the dunes more robust through sand drift for (future) water safety (flood risk management), combined with the wish of the nature manager in the landward area to prevent acidification through sand drift (example: Springer dunes, Goeree, Hollandse Delta Water Board and Natuurmonumenten).

The goal of increasing water safety around an infiltration area and the desire to reactivate the foredune in front of it (example: Kieftenvlak, PWN and Hoogheemraadschap Hollands Noorderkwartier).

The desire to initiate sand drift on a large scale and the need from the public to experience this 'wild' nature (example: Northwest Nature Core, PWN, Rijnland Water Board and Municipality of Bloemendaal).

Talk to other stakeholders and managers of adjacent areas to investigate whether different goals can be combined. It can increase support for your desired intervention, but it can also increase the financial resources for your project. It is important to determine who you need for what, how you can work together and which agreements you need to make.

2.5 Dealing with changes

10 How may trends in development influence the goals set for the next 20-50 years?

Given the relatively long term that re-mobilisation and subsequent re-vegetation takes, at least one to several decades it is important to think about the feasibility of goals for changes that take place beyond this period.

This concerns abiotic, biotic and anthropogenic changes:

- Due to rising temperatures, the growing season is becoming longer, giving vegetation more chance to grow and stabilise sand drifts.
- More precipitation could also increase the vigour of vegetation, which makes sand drift more difficult. On the other hand, more extreme drought can limit growth, which actually stimulates sand drift.
- Construction plans around a project location can increase nitrogen deposition, making desired vegetation development impossible.
- Recreational development can increase pressure on an area, causing increased disturbance, with negative consequences for breeding birds, for example.
- Changes in recreational pressure and use of the landscape by people can be anticipated in advance, but cannot be completely predicted. The effects of this can sometimes be unexpected, and can be both positive (trampling can help limit the overgrowth of dynamic places) and negative (groups of cyclists who access a notch from the beach and use it as a training area, thus having a disruptive effect). Changes in recreational use may only occur after a longer period of time.
- Due to accelerated sea level rise, certain infrastructure could prove unsustainable in the longer term. Projects that are currently unthinkable due to, for example, the presence of such infrastructure could prove realistic in the longer term if the infrastructure itself is removed.
- Structural changes in coastal policy, such as the construction of sand motors (large artificial deposits of dredged sand designed to feed the dunes by longshore drift) around coastal villages to cope with increasing sea level rise, could drastically change the character of the coast. Large scale sand drift would therefore become increasingly problematic, unless parts of the coast (between the coastal villages) were also completely abandoned.

A reasonably up-to-date picture of the current climate changes can be obtained via most of the national meteorological websites. For other matters, good information can often be found from various managing organisations and their management plans and surveys.

PART II
Preconditions and preliminary research

3 Abiotic conditions

11 **Check carefully what restrictions apply in your area.**

When reintroducing dynamics to the foredune, it is important to know which factors influence the feasibility of your goals. You should look at abiotic, biotic and anthropogenic factors. Here we follow the ranking model of Bakker, Klijn & van Zadelhoff (1979), from large to small scale, with some adjustments. In general, the larger the scale, the less influence we can have on it (i.e. we cannot influence climate but we can influence vegetation). You must therefore regard these as hard preconditions within which any re-mobilisation takes place. They largely determine your choice for the type and method of introducing or reintroducing dynamics. The smaller-scale factors (e.g. presence of sea buckthorn or development of embryonic dunes) can be influenced if necessary and can be targeted to achieve project goals.

The preconditions within which mobilisation and re-mobilisation must take place are discussed in this chapter. Local factors that play a role in the preparation and realisation are diverse and location-specific. They can hinder or promote dynamism. Most of these conditions are known in advance. But you do have to check them systematically to arrive at a good assessment of the possibilities and impossibilities (Arens & Janssen, 2009). This way, nasty surprises can be avoided, such as delays due to the presence of ammunition or archaeological artefacts, or not being able to fully utilise the possibilities, for example in the Dutch situation when there is no excavation permit, and consequently no more than a maximum of two metres can be excavated.

In the ranking model, climate, (geo)morphology, hydrology and soil form the abiotic preconditions. The abiotic preconditions determine the biotic preconditions.

3.1 Climate

12 **Assess the impact of wind climate, drought and precipitation in your area**

The temperate climate zone in which the Netherlands is located (the Atlantic Biogeographical Region) has an important impact on dune and coastal development (Arens et al., 2007). The most important factors are wind climate (direction and speed), precipitation and evaporation. The wind climate determines the number of sand transport events and the average direction in which the sand moves. Precipitation generally has a limiting influence on sand transport by the wind (the sand grains become ‘sticky’). Evaporation can lead to desiccation, making it easier for sand to be taken up by the wind. The 'most active' wind direction (the dominant wind direction), although this concerns a limited percentage of the wind rose, can often be found in the large-scale dune shapes in the landscape. Along the Dutch coast this direction is almost everywhere west-southwest to east-northeast. On the Wadden Islands, where the coast is oriented more to the north, northwest-southeast directions can also be found. Keep in mind that these directions are a reflection of the time when these types of large-scale dune forms arose, often more than 100 years ago, and that wind patterns may change over such long periods. Around blowouts, areas of sand deposition are often directed to the east-northeast (due to the west-southwest wind) and to the southwest (due to the dry, north-easterly winds that often blow in winter and can then cause quite a bit of sand transport). Plumes in other directions can also occur around blowouts, because the surrounding relief can force different directions of sand transport. Where the beach/foredune runs east-west, the amount of onshore wind is much smaller than where a foredune runs north-south and there is even a chance of offshore transport. But this also implies that you must always pay close attention to the orientation to the main wind direction(s) to decide whether it is useful to create notches. Dominant wind direction is a factor in the development of all dune systems in the Atlantic region.

It is helpful to consider the wind rose for your area for the exact design of notches. The wind rose gives a graphical illustration of the annual, seasonal or monthly wind patterns for a given location. Wind data for a number of stations may be requested via the national meteorological services. Because the wind direction distribution can also vary from year to year, it is best to look over a longer period of 30 years. You can view the long-term average wind roses for the main stations in the Netherlands at https://www.knmi.nl/klimaat-viewer/grafieken-tabellen/windrozen.

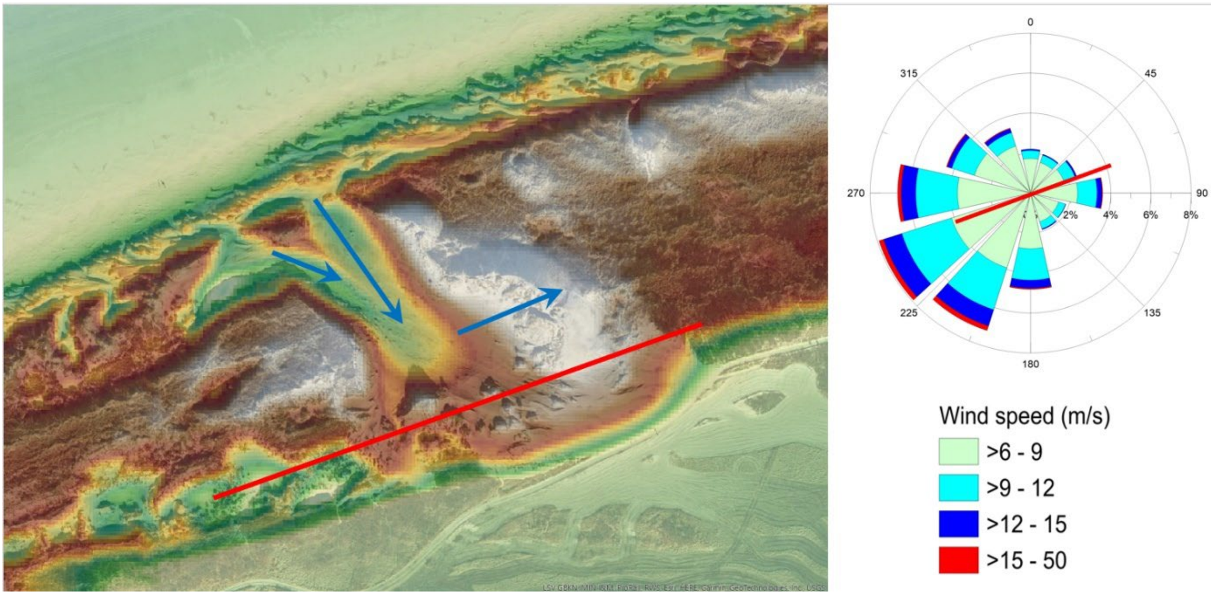

Figure 20. Long-term average wind direction at Hoorn, Terschelling and the spontaneous sand drift at pole 20 on Terschelling (AHN north is top; white is high, blue-yellow is low). Red line is the coastal orientation. The main wind directions from west to southwest do not influence the entrance direction. The direction of the first entrance from the west is west-northwest-east-southeast, which is a fairly strong wind direction but not the dominant wind direction. The direction of the 2nd entrance is northwest-southeast, not a dominant wind direction, but almost perpendicular to the coast. Construction of the dune on the east side of the notch appears to be driven by west to southwest winds. The wind is probably also controlled to a significant extent by the relief; wind from the west will deflect to the southeast due to the orientation of the notch. The notch influences its own development with its shape and if a wind rose is measured in the notch itself, it will differ considerably from the wind rose at Hoorn.

Figure 21. New growth of marram four months after construction of Terschelling notch. (Photo: AP Oost)

The important thing is to place the foredune orientation on the wind rose to find out which main directions you can expect wind from the sea through the dunes. Check which station is closest to your area. Please note that the local wind climate, depending on aspects such as relief and extent of vegetation, can deviate considerably from what is recorded at the meteorological stations. Remember that only the wind directions that come from the seaward side (roughly a semicircle) bring sand in. The movement of sand is partly determined by the orientation of the dominant wind directions. This is evident, for example, from the difference between the sand drift at the notches of the Northwest Nature Core (west orientation, 100 metres wide and sand drift up to hundreds of metres landward) and that of east Ameland (north orientation, tens of metres wide and only local sand drift). The orientation of the notch on the dominant wind direction therefore ensures as much sand drift towards the hinterland as possible.

If spontaneous notches have developed in your area, it is useful to observe the directions of the entrance and the depositional lobe. The development of the local notches can be traced with the help of AHN (https://www.ahn.nl/ahn-viewer). This is illustrated for the situation of Terschelling (beach pole 20) in Figure 20. The large-scale coastal orientation of the island is given by the red line. The most frequent winds come from west to southwest. The directions we see in the notch are (west) northwest (the blue arrows pointing southeast and east-southeast) and northeast (the blue arrow pointing northeast, in the direction of the high sand depositional lobe). Northwest and northeast winds occur only to a limited extent, but leave their mark on the landscape. Because of the exposure of the coastline, the southwest wind, although very frequent, apparently has little influence on the development of the notches themselves, but does have an influence on the adjacent dune on the east side. The height of this dune will mainly increase under the influence of west and southwest winds.

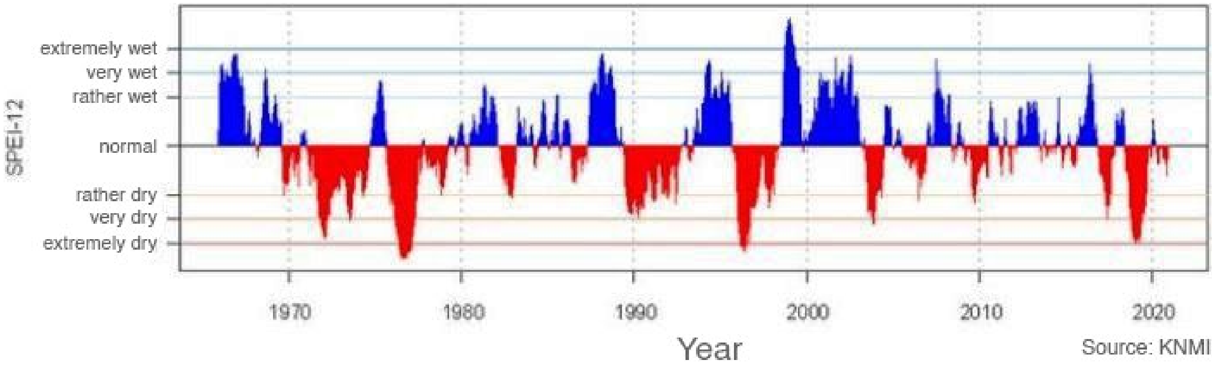

Figure 22. Standardized precipitation- evaporation index as a running average over 12 months in the period 1965-2020 based on monthly average precipitation and potential evaporation data from 13 stations spread across the Netherlands. (Source: https://www.knmi.nl)

It is good to understand that climate is changing rapidly. The increase in air temperature gives a longer growing season. This implies more plant growth and faster stabilisation of bare soil. The annual average precipitation is also increasing, which also has an average positive effect on vegetation growth. Meanwhile, extremely dry periods are also increasing in frequency, sometimes even causing vegetation to die back and the soil to be exposed. Intervention procedures are often performed in the autumn when the bird breeding season has ended, vegetation growth has stopped and the storm season has begun: a lot of wind, but often also a lot of rain. If you create notches during the growing season, there is a good chance that any roots left behind will quickly grow again and cover the surface (Figure 21). It can be beneficial to plan a project in such a way that dry conditions occur after completion. The chance of this is greatest in April, the month with the least rainfall on average. Furthermore, luck plays a role; after all, our climate is quite variable. Extremely wet and dry years alternate (Figure 22). If you are unlucky enough to have a number of very wet years following notch creation, there is a good chance that the sand drift will be difficult or impossible to get going. Obviously, this cannot be taken into account when planning interventions; long-term weather is unpredictable. So, looking at Figure 22, it may be a good idea not to plan all your sand drift projects at once to reduce the chance of precipitation spoiling everything. Another option is to carry out your interventions on such a large scale and so thoroughly that they cannot stabilise in a few years.

In the Netherlands, despite its small size climate differences can already be observed from south to north. This can be also important for your flora and fauna goals.

3.2 Sea level rise

13 The worst case sea level rise scenario leaves us with less time and options for measures

Since 1901, the rate of sea level rise along the Dutch coast has been more than 1.8 mm/year, a quarter of which is due to land subsidence[1]. Recently it became clear that sea level rise along the Dutch coast has accelerated (Steffelbauer et al., 2022), something that is also observed on average worldwide. If greenhouse gas emissions are not reduced, sea levels along the Dutch coast could rise by about 0.82 m (0.59-1.21 m) by 2100[2]. With current climate policy, it seems more likely that we will end up with the IPCC middle scenario SSP2-4.5 of about 60 cm sea level rise (Figure 23). In the worst case of an unstable Antarctic ice sheet, a rise of 2.50 m in 2100 cannot be ruled out, according to KNMI (The Royal Dutch Meteorological Office, which forces us to take it into account. Even after 2100, sea level rise will continue for centuries .

In a more unfavourable scenario, the acceleration may be so rapid that there is less and less time to take measures to keep up with the increase. This implies that some measures can be ignored because they simply do not lead to results quickly enough within the available time. Or they require intervention too often, for example sand nourishments everywhere every year. Coastline maintenance may be forced to frequently switch to mega-nourishments that will also influence the dunes, for example via wide beaches that lead to embryonic dune formation and reduced success in re-mobilising the foredune. Another example is that the Water Boards will ensure that the primary water defence in the dunes grows significantly in volume for the benefit of flood risk management. Nature will also have less time to adapt to such drastic measures.

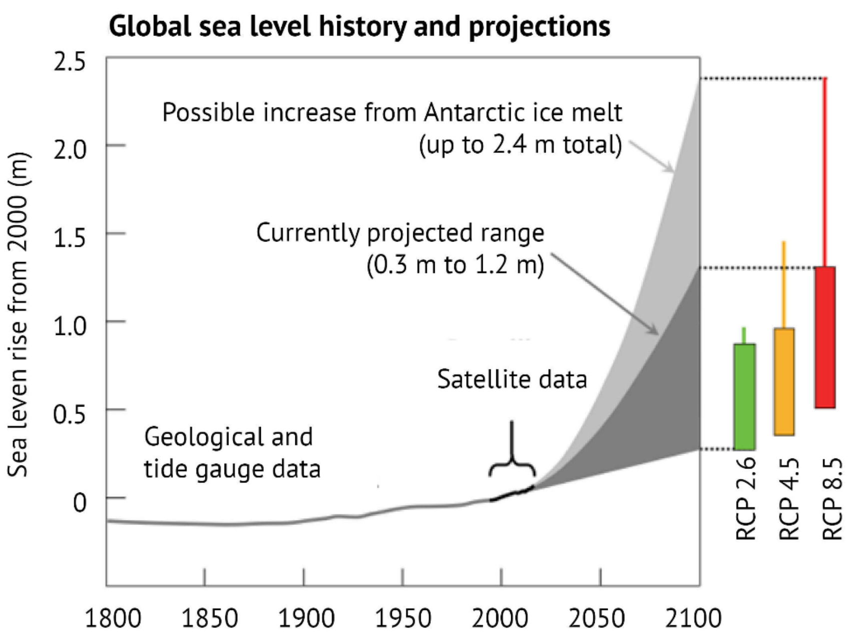

Figure 23.
Historical sea level reconstruction and projections up to 2100 published in 2017 by the U.S. Global Change Research Program. RCPs are different scenarios for future concentrations of greenhouse gases.
(https://tidesandcurrents.noaa.gov/publications/techrpt83_Global_and_Regional_SLR_Scenarios_for_the_US_final.pdf)

1 https://www.knmi.nl/kennis-en-datacentrum/ achtergrond/knmi-klimaatsignaal-21
2 https://cdn.knmi.nl/system/ckeditor/attachment_files/data/000/000/357/original/KNMI23_klimaatscenarios_gebruikersrapport_23-03.pdf

Fortunately, things may not be as bad as they first appear: for example, a large part of the Dutch dunes and the primary flood defences are massive and high, so that even a few metres of sea level rise is not a problem. In places with a small dune volume, interventions will eventually be necessary for flood protection. In addition, there are lower parts in every area where rising seawater can eventually push the groundwater level up, to above the surface. Any deflation will enhance this wetting process whereas natural or artificial sand deposition will reduce it.

3.3 Morphology

14 Which part of the coast are you dealing with and how has it developed over time?

3.3.1 Deltaic, open barrier coast or closed barrier coast?

A sandy coast can have many forms. Here we discuss deltaic, open barrier and closed barrier coast with examples from the Netherlands which exists of three completely different regions: the open barrier Wadden coast with its islands, the closed barrier coast of Holland and the deltaic coast of South Holland and Zeeland.

Due to the growth and then connection of sandbanks to the islands, the Wadden coast has a 'wavy' pattern of accretion alternating with erosion, which usually moves from both the heads (western part) and the tails (eastern part) towards the centre of each island. During a growth phase, the beach can become so wide that green beach (vegetated foreshore) formation occurs, which can turn into new dune formation or even a completely new foredune ridge. As a result, the old foredune is increasingly cut off from the beach, which reduces its dynamics. Most of the coast of Ameland and Schiermonnikoog has a northern exposure. Terschelling and Vlieland have a north to northwest exposure. In terms of exposure, Texel is comparable to the mainland coast. The common southwest wind is often offshore on the Frisian Wadden Islands. The Wadden belongs to the low-lime district, but there are differences between the islands: Texel, Ameland and Schiermonnikoog are still somewhat calcareous, whereas Vlieland and Terschelling are extremely low in carbonates. The foredune is calcareous everywhere due to the proximity of a beach with shells and in some cases also due to the influence of the aeolian influx of calcareous sand from beach nourishments (dredged sand is always calcareous).

The Holland coast, a closed barrier coast, is predominantly an accreting coast with embryonic dune formation, mainly due to nourishments. Despite the (often mild) growth, sand mobilisation within the foredune is possible, but the presence of embryonic dunes forms an additional constraint. Here too, 'waves' of erosion and accretion occur on the beach, but these are less strong and clear than on the Wadden Islands. The orientation of the coast is predominantly south-west, shifting more to the west when going north. The northern part of the Dutch coast, north of Bergen, belongs geologically to the Wadden district, with low levels of carbonates, comparable to Vlieland and Terschelling. The part from Callantsoog to Den Helder consisted of islands in historic times. These islands were connected to each other and to the mainland coast by stimulating the growth of sand dykes. South of Bergen the sand is calcareous.

The Southwest Delta is still strongly dominated by the large tidal channels that run from the (former) inlets towards the North Sea and are often located very near the coastline. This makes the relief steep and the dunes and coast predominantly narrow. The foredunes often are the primary flood defences in this region. Very little room for aeolian processes is allowed there; preservation of the existing dune massif is usually the main goal. Sand drift cannot develop spontaneously, also because there is little dune behind the flood defence to receive the drifting sand. Exceptions are the Kop van Schouwen with an extensive dune area and Kwade Hoek on Goeree with extensive new dune formation. The orientation of the coast in the Delta region varies. Walcheren is an extreme example, with a southwest orientation south of Westkapelle, a northwest orientation to the north, and a north orientation at the most northern part Oranjezon. Also on Schouwen, Goeree and Voorne the coast turns from southwest exposure on the southern side to north exposure on the northern side. Just like on the Wadden, the islands in the Delta vary in lime content, with Walcheren as the lime-poor extreme.

It is important to look at the entire morpho-ecological system on various temporal/spatial scales. Are you in a deltaic coast, or a closed barrier coast, or an open barrier coast? And in more detail: are you on the head, middle or tail of a barrier island? Or where are you exactly in the delta? A system analysis provides insight into the history of the dune area and recent changes in morphology, properties of the subsurface such as the occurrence of calcareous sediments, the morphology and dynamics of the dunes, and processes that determine the occurrence of plants and fauna. (Bakker et al., 1979; Grootjans et al., 1995; Runhaar et al., 2000).

3.3.2 Coastal development, long and short term

It is important to understand the age of the landscape behind the foredunes. Coastal erosion in the Netherlands was largely stopped after the 1953 flood disaster, through investments in the flood defence dunes and intensive management of the foredunes. Due to intensive management, the foredunes are often obsolete and fossilized, with grey dunes or forest behind them. Coastal policy changed from 1990; from now on, the coastline was held in place with sand nourishments, either on the beach or on the shoreface (below mean low water). Since 1990, there has been a gradual transition on a large scale from an eroding to a slightly accreting or stable coast. Beaches have become wider and in many places embryonic dunes can now grow and persist.

On a larger time scale there are locations with different phases of accretion and erosion. Figure 24 shows this for the southern tip of Texel. The orientation of the coast has rotated during these phases. What is special is that within this long-term erosional development there is a shorter cycle of accretion and erosion. Such a cycle often lasts from half a century to more than a century, where sometimes channels cause the coast to erode and other times large sandbanks reverse this loss and dunes can be built up and eroded again.

Fortunately, relatively much is known about the development of the Dutch coast. For example, in the management libraries of Rijkswaterstaat (Ministry of Infrastructure and Water Management), a lot of information can be found per coastal section about long-term development, the functioning of the coastal system (morphology, ecology and socio-economic situation) and effects of nourishments.[3]

What does this mean for your choices for encouraging sand drift? The local coastal situation strongly determines what development is possible (Löffler et al., 2011). Is the coast growing rapidly or eroding? Do you have a lot of space or little? Figure 26 shows what is possible. The first thing you should look at is whether you are dealing with an accreting coast. In that case, seaward developments are particularly promising. Re-mobilising a foredune where embryonic dunes develop at the dune front on a large scale is usually not useful, unless part of the plan is to remove the embryonic dunes (and ensure that they do not return). Are you dealing with a stable or eroding coast with a preference for landward developments? Then there are more

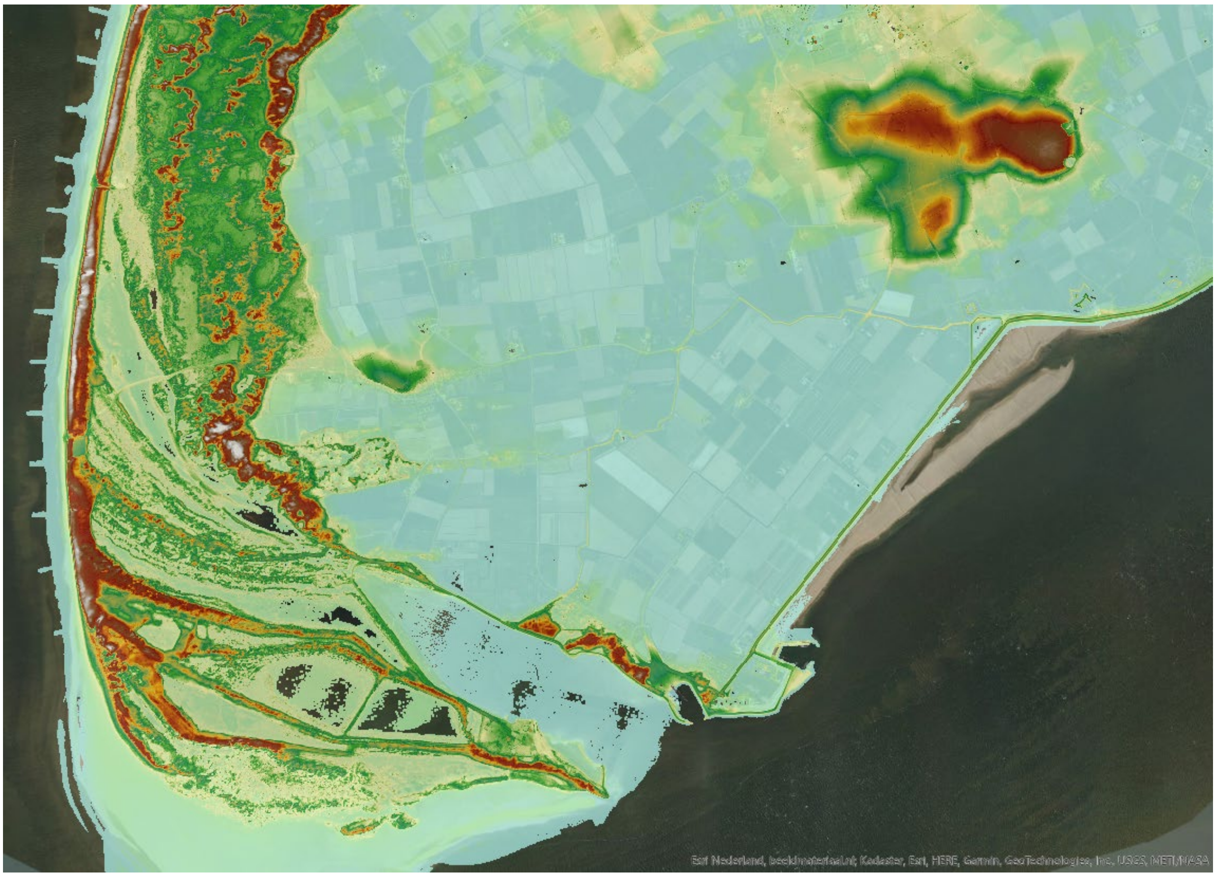

Figure 24. Dune valleys and dune ridges have been created at an angle to the foredunes on SW Texel due to rotating coastal erosion in the period 1870-1990.

3 https://publicwiki.deltares.nl/pages/viewpage.action?pageId=131142282

Figure 25. Narrow beach and narrow dunes: few opportunities for reintroducing dynamics, East Vlieland. (Photo: A.P. Oost)

options for notching and blowouts. Since the cessation of intensive foredune management by water management bodies, there are several examples of notches having formed spontaneously, and still being active. On eroding coasts, aeolian dynamics can more easily start spontaneously when the eroding cliff provides places where the wind takes hold. Obviously, the locations where spontaneous notches develop are less predictable than the locations you choose for notch creation.

In general, it is preferable to 'let nature take its course' on an accreting coast, unless other preconditions make this impossible. This does mean that you accept that the dunes landward of this new nature will stabilise and age. This can partly be counteracted with specific management measures. Because the new dunes, dune valleys and possibly slufters naturally develop into white and grey dunes and thus take over the role of the original dunes, a choice can also be made for shrub development and, in the long term, natural coastal woodland formation.
It is therefore important that you map current coastal development. Is a wave of coastal accretion coming? Then embryonic dune development must be expected in the long term. What do you see in dune erosion/accretion in recent years? What do you expect for coast and dune development in the coming years? The way to quickly check how the coast is developing is through the coastline maps, which for the Netherlands are released every year by Rijkswaterstaat. These maps show, at the level of transects taken every 200-250 m, what the expected coastline trend is for the coming year and what the position of the coastline is in relation to the Basic Coastline (BKL). The BKL is maintained with sand nourishments (see section 5.2.2). The presence of sand is therefore guaranteed (Valk et al., 2013; Arens et al., 2007).

The coastline maps provide four options.

1. The trend is seaward (so the coast is growing) and the location of the coastline relative to the BKL is seaward (so there is spare space). In that case you are dealing with growth and you can expect embryonic dunes to develop (for some time). There will be no nourishments here for the time being.
2. The trend is seaward and the location of the coastline relative to BKL is landward. Although the BKL has been exceeded, nourishment will probably not take place in the short term due to the seaward trend in the movement of the coastline. Depending on how long the seaward trend will continue (or how long there has been a seaward trend), embryonic dunes may develop.
3. The trend is landward and the location of the coastline relative to the BKL is seaward. The BKL has not been exceeded, so there is no reason for nourishment yet, but that may change in the future, given the landward movement of the coastline.
4. The trend is landward (so the coastline is eroding) and the location of the coastline relative to the BKL is also landward (so there is no room anymore). In that case, it is likely that nourishment will take place in the short term.

If you are dealing with situation 1 or 2, you probably have to take embryonic dune development into account. If this development is strong, it may hinder any foredune re-mobilisation interventions. If re-mobilisation is the management choice, for example, embryonic dunes will have to be removed during the intervention, and/or follow-up management will have to be taken into account to prevent the development of new embryonic dunes. If you are dealing with situation 3 or 4, the conditions for re-mobilisation are more favourable, because you can probably take advantage of some erosion that will occur and automatically stimulate aeolian processes. The coastline maps provide a quick insight into what you can expect for your part of the coast in the coming years.

In narrow dune areas, not much sand mobility is usually possible, except through seaward expansion of the coast (Löffler et al., 2011 see also Figure 22). The foredunes often form the *primary flood defence* (for definition see Appendix 2) and the space for sand drift processes is limited, especially if there is little dune area landward to receive the drifting sand. If the dunes are wide, re-mobilisation for sand drift is easier.

Coastline development	**Dune field** Irregular dune field developed on wide beach plain	**Embryonic dunes** Young dunes developed on the beach	**Foredunes with accretion on the seaward side** Mostly irregular shaped dune ridges	**Foredunes with transfer of sand to the hinterland** Foredunes with bare surfaces/ small blowouts and sand rain	**Carved foredunes** Foredunes with blowouts/ notches	**Parabolising or rolling foredunes** Irregular dune ridge with blowouts/ notches	**Slufter** Breakthrough through foredunes with tidal influence	**Washover** Breakthtrough through foredunes, active during storm surges
	+	+	+	±	-	-	-	-
	+	+	+	±	-	-	-	-
	-	±	±	+	±	±	±	±
	-	-	-	+	+	±	±	±
	-	-	-	+	+	+	+	+
	-	-	-	+	+	+	+	+
	-	-	-	+	+	+	+	+

Figure 26. Possibilities for development dynamics related to the available space (extended based on Löffler et al., 2011). + = possible, ± = possible depending on local conditions, - = not possible. Light green arrows show coastal expansion, dark green arrows coastal erosion. The larger the arrow, the greater the displacement of the coastline.

Figure 26 indicates the possibilities for promoting dune dynamics, depending on local coastal development. There are two possibilities:

1. With an expanding growing coast, the dynamics mainly arise on the seaward side, new nature is partly created and it is more difficult to achieve sand mobility in the foredune, because processes on the beach (exposure, more wind, more sand) do not cooperate. The embryonic dunes limit sand drift by reducing wind speeds and building up sand in front of notches. The greater the seaward growth, the larger the scale of the new nature. This can vary from a completely new dune field (such as that developed on the Sandmotor and on De Hors on Texel) with different gradients (and possibilities for the development of a variety of habitat types) to a limited strip of embryonic dunes against the foredune (with only development of embryonic and/or white dunes parallel to the foredune).
2. With an eroding coast, aeolian processes naturally affect the foredune which grows landward through deposition of sand on the leeward side. Aeolian processes on the beach, with no obstruction from embryonic dunes help to maintain the dynamics. The greater the erosion, the greater the sand drift and the further its influence will reach landward. Here too, the scale can vary from very small-scale, in the form of bare, erosive patches and small blowouts, to very large-scale, in the form of parabolic dunes forming from eroded foredunes. The range of habitat types that are influenced or benefit from the dynamic processes is more extensive than in case of the seaward forms of dynamics.

However, it is not necessarily the case that larger-scale dynamics always go hand in hand with larger-scale erosion of the coast. Figure 26 shows that the different forms of landward dynamics can all be associated with different degrees of coastal erosion. Slufters and washovers represent a special form of landward dynamics, in which water also plays an important role. With a slufter, the system of inland channels and creeks in the embryonic dune valley must be low enough to guarantee that it regularly fills with seawater. In the Netherlands a washover involves a connection between the North Sea and the Wadden Sea, and by definition are limited to the Wadden coast.

3.3.3 Morphological features, geological heritage

The landscape you manage is part of our geological heritage. Remember that nature is more than just plants and animals, the underlying landscape also has an important value. Some elements may have originated centuries ago. For instance, all Dutch dunes are classified as Geological Monuments. Therefore, be careful when digging. You can irreparably damage unique shapes. If there are special morphological elements in your area, such as fossilized medieval parabolic dunes or (as in Texel) very old dune valleys that are at an angle to the coast, or an extremely high dune that is a landmark in the landscape, then you should be careful before intervening. This is either because you may directly affect the shape by excavation, or because it can disappear under sand from large-scale drift. It is also important to know how old these elements are and to what extent they represent ecological and cultural values. It's not just digging that disrupts the landscape. If the removal of sand and/or sods (e.g. from turf stripping)

Figure 27. Geological heritage: Peat profile in the Nieuwe Westerse Laagte, Schouwen with teeth/molars of a young brown bear, 2018. (Photo: Bert van der Valk)

out of the area is not possible, it is often decided to dispose of the material locally. This should only be a solution if there really isn't a better one available. Spoil heaps (dumps) are rarely neatly integrated into the landscape. Remember that such a spoil-heap will remain visible for a long time, even long after the work has been completed. Due to the disturbed soil, such a site usually also becomes overgrown with ruderal (weedy and disturbance adapted) vegetation, which makes it recognisable as an enriched spoil-heap. There are ways to hide excavated material in such a way that it is no longer visible in the landscape, for example by (partially) filling in adjacent blowouts. Think carefully about how the advantages of the intervention you want to carry out outweigh the disadvantages, for example as a result of the construction of a spoil-heap or other disruptions. Weigh the two against each other and, if the balance is not clearly positive, consider not going ahead. A geomorphologist could help propose solutions to accommodating a spoil-heap within the dune landscape.

With Digital Terrain Models such as available for the Netherlands (AHN) you get a detailed picture of the height (https://www.ahn.nl/ahn-viewer) and of the different shapes in the landscape. In addition, a lot of information can be found in the nature management plans about geomorphology, geology and soil, altitude, geohydrology and surface waters (e.g. https://www.bij12.nl/onderwerp/natuurinformatie/natura-2000-beheerplannen/). If in doubt, consult an expert in morphology, soil or hydrology.

3.4 Hydrology: large-scale groundwater and surface water patterns

15 Do your intended measures have an effect on groundwater and surface water patterns?

In the preparation of your dune re-mobilisation project, it is important to know whether the intended measures have an influence on the hydrology. Even if your project does not have a hydrological objective, the measures can change the hydrological system. In general, the influence will only become really important if you start mobilising dunes on a large scale.

This is because the freshwater lens 'floats', as it were, on the heavier seawater that is deeper in the subsurface. In the Netherlands, the bottom of the freshwater lens is on average approximately 12 times as deep below average sea level as the top rises above it. That's a huge mass of freshwater; the growth or shrinkage of the freshwater reservoir in the subsurface is therefore a slow process, lasting many tens or hundreds of years. Although the size of the freshwater lens is constantly changing, this process is so slow that we notice little of it in daily practice. In practice, nowhere in the Dutch dunes is there a balance between the doming of the groundwater and the size of the freshwater lens in the subsurface (Bakker, 1981).

The groundwater level rises or falls very quickly, within a period of weeks or months. Interventions, especially in combination with measures that influence drainage, can have a rapid impact on the height of the groundwater table. For example, wet dune valleys can turn into lakes or dry up. It is therefore important that you try to estimate the influence of your measures on the groundwater level.

In the past, dune valleys in the dune area were flooded for many months during a year. But from the beginning of the 20th Century, drinking water companies started pumping out fresh water for drinking water. Polder levels behind the dunes were lowered. As a result, groundwater levels in the dunes have fallen sharply and the freshwater supply in the dune massif has continued to decline. That is why Dutch water companies have started infiltrating fresh surface water into the dunes to achieve a balance where the freshwater supply does not decrease further, but groundwater levels are still lower than before. If you can combine the intervention measures with an increase in local groundwater levels, this can provide an ecological plus. Whether this is desirable for human shared use must be considered.

For example, converting coniferous forest in the dunes to deciduous forest or open dune is an effective measure to increase the freshwater supply. Because less water evaporates, more rainwater infiltrates and the groundwater level in the dune rises. It is also important to fill in ditches in the dunes and prevent groundwater drainage. In many coniferous forests in the dunes, ditches have been constructed that drain fresh groundwater. Filling in these ditches is an important measure to increase the freshwater supply. Climate change is likely to increase annual

Figure 28. Conversion and clearing of 7.6 hectares of forest near Schoorl. (Photo: Staatsbosbeheer)

average precipitation. This also leads to more infiltration of rainwater and an increase in the doming of the groundwater.

Furthermore, it is important, especially in the case of large-scale measures such as mobile foredunes or formation of parabolic dunes, to consider whether this could influence groundwater flows. Examples of questions that help to gain insight into the system are: does tidal action play a role? Where does the gradient from freshwater to saltwater occur? Where is freshwater located near the surface? What is the base richness of the groundwater? How does groundwater flow from the dune massif to the surrounding area, and where are the wet dune valleys fed by calcareous groundwater? You will often need to consult a specialist to answer these questions.

3.5 Soil: lime and mineral content and acidity

16 Where do you have calcareous sand and where has the soil been decalcified?

Important processes in dune soil are: accumulation of organic matter and mineralisation, acidification, enrichment, weathering, and leaching of nutrients such as lime. As shown in Figure 4, there is a difference in lime content between the dunes of the Wadden and the Renodunal district with the Renodunal district more calcareous than the Wadden district. This is due to the supply of mineral-rich sand from the Rhine system and because there is a richer shell fauna with shells that are easy to crush. The border between these two areas is approximately near Bergen in North Holland. This has important consequences for sand drift. Due to higher lime content plants in the Renodunal dunes often have smaller root networks and this makes sand drift easier to initiate (Kooijman et al., 2021). The erodibility of the soil is greater, which means that the soil is more sensitive to wind erosion. This mainly occurs in the dunes behind the foredune (hind dunes); much less in the marram-dominated foredune. If you look purely at the sand, low-lime sand is actually easier to be transported by the wind than high-lime sand. In calcareous sand, the lime particles provide greater internal cohesion and therefore greater resistance to sand drift. Vegetation grows less easily on a bare, lime-poor soil. As we saw in section 1.1.1, this had consequences in the past for the degree of sand drift which was more extreme in the lime-poor than in the calcareous dune.

In addition, there is a limestone gradient from the coast inland. The white dunes in the foredune are logically more calcareous than the grey dunes further landward, because they are younger, closer to the sea, and are therefore covered with calcareous sand from the beach (see also Figure 29). In some areas, the Young dunes on the landward side merge into Old dunes, which are much older and therefore often decalcified. Due to the difference in lime and mineral content, different species occur and the vegetation structure is different. It therefore also influences succession. This is reflected in the development of shrubs. This occurs much faster in calcareous dunes than in lime-poor dunes. All this obviously also has a major influence on the composition of the fauna.

The influence of this on the habitats is discussed in the next chapter. In soils without sand drift, decalcification and acidification is a normal process, because there is a precipitation surplus in the Netherlands and the precipitation dissolves lime when it seeps through the soil. This process is further enhanced by the high deposition of nitrogen. The 'sand rain' by calcareous sand is therefore an important process for increasing the base richness of the soil (preventing acidification). Since the lime content in the Wadden district is lower anyway, this process is even more important for base loving vegetation there (OBN, 2016).

4 Biotic boundary conditions

17 Consider the various scales of the ecological system to inform your intervention

As with the abiotic factors, different scales can also be distinguished for the biotic factors. The largest scale, the eco-morphological landscape, determines which habitat types are present and, to some extent, their quality. The medium scale shows which habitat types are present and what quality they have at the location you want to re-mobilise. This determines where exactly intervention is most desirable. This also determines the extent and method of intervention (for example excavation and turf-stripping / sod-cutting). At the smallest scale, of species and individuals, your interventions may create more favourable conditions for establishment. Also take into account any extreme vulnerability of species, for example regarding the hen harrier (*Circus cyaneus*). This is further elaborated in this chapter.

It is also recommended to think on different time scales. For example, your intervention may have a negative impact in the short term for the priority Natura 2000 Grey dunes habitat type (H2130), because the sand drift is too extreme and vegetation is buried. But in the longer term, when the dynamics have decreased, there will be good preconditions for the development of new grey dunes. Any loss of grey dune habitat due to interventions is a problem in the Natura 2000 system. In the Netherlands this requires coordination with policy makers at the Province level.

4.1 Largest scale: the eco -morphological landscape

18 Consider how the coastal landscape is eco -morphologically structured and how it has developed over the past millennia and centuries

As discussed in Chapter 3, the Dutch coastal landscape was created by a phase of coastal expansion in which small dunes formed on beach ridges; the so-called phase of the Old dunes. Due to their age, the dunes that were formed at that time have now almost completely decalcified. From about 1000 AD there was a phase of coastal retreat that resulted in the formation of predominantly parabolic and transgressive dunes, with rows of more coast-parallel dunes and isolated mobile dunes in the South-western Delta and the Wadden. This is the so-called phase of the Young dunes. The younger parts near the coast are richer in carbonates than the older dunes located further inland. As a result, the major trend in these dunes is one of plant cover succession in a landward direction: from beach to Embryonic dunes, (H2110) to White dunes (H2120) with local sea buckthorn (*Hippophae rhamnoides*) (H2160), and Grey calcareous dunes (H2130A) to Grey decalcified dunes (H2130B) with their associated dune valleys (H2190) and a subtype of Grey dunes (H2130C) (lichen-rich decalcified dunes with species such as grey hair-grass *Corynephorus canescens*), to Dune heaths with crowberry (*Empetrum nigrum*) (H2140) and Dune heaths with heather (*Calluna vulgaris*) (H2150) and Creeping willow thickets (H2170) to Dune woodlands (H2180). Due to coastal erosion the habitats nearer the coast are close together and do not represent such wide zones. On the one hand, this is simply because the coast is being rolled up. As a result, the original habitats are being overrun by White dunes and Grey dunes that are fed with calcareous sand from the coast. On the other hand, succession continues as usual and dune scrub and dune woodland will expand seawards until the influence of the sea (including salt spray, wind, sand supply) makes conditions too extreme and the expansion comes to a halt.

As mentioned, that is the general story, but it turns out to be slightly different for every specific coastal landscape. On the one hand, it is because the coast has not been constantly eroded over the past millennium, but has also gone through phases of stagnation and even growth. This sometimes causes habitats in a coastal section to be 'stretched' or even repeated. In addition, coastal development can also vary in orientation and erosion and accretion manifest themselves at different angles with respect to the coast, with all the consequences for the habitat sequences. This mainly happens near tidal inlets.

For example: in the early 16th Century, the fishing hamlet of Borkamer was located on the beach on southwest Texel. Due to the 'landing' of several large sandbanks (the process where a large offshore sand bank becomes connected to the coast), the coast expanded over more than 2.5 kilometres, with the foredune orientation (i.e. the coastline) rotating counter-clockwise. Subsequently, erosion occurred again from 1880 onwards over approximately 1 kilometre, with the coastline retreating at an angle to the dunes that had been formed in the previous phase. Rijkswaterstaat and the Water Board curbed this erosion by first forming a massive sand dike in the foredune, which had to be regularly moved backwards because these measures were not sufficient to stop erosion. From 1990 onwards, the coastline could be maintained through nourishments, which brought the coastline erosion to a permanent halt. The result of the erosion is that there are virtually no grey dunes on large parts of southwest Texel, but dune heath occurs close to the coast. Due to reduction in dune mobility and planting, the drift dike is now a dense marram-covered landscape with sea buckthorn fields here and there (see also Figure 2).

The message here is that you need to carefully consider how your coastal landscape is eco-morphologically structured and what the development has been, in order to make an optimal choice for reintroducing dynamics. Where can the most benefits be achieved for sand mobility projects and where do you quickly end up with undesirable effects? Can you allow large-scale dynamic processes to shape the landscape again, so that the coherence and connectivity of the landscape can be restored? Or are you forced to opt for more modest sand drift and bare sand such as local notching or blowout development?

4.2 The middle scale: habitat types and effects of dynamics

19 Assess the effect of re-mobilisation on habitat types

The dunes are known for their high biodiversity and internationally. The nature in the Dutch dunes is of enormous value. It is the largest, almost contiguous, dune area in Northwest Europe. Over the centuries, many dune areas have been lost due to urbanisation and construction. However, a relatively large part has been spared thanks to a number of very large private estates, which prevented development, followed later by legislation in the field of nature and spatial planning. Water extraction has also played an important role, because large areas of the dunes are used for drinking water production. It is not surprising that much of the area of Dutch dunes has been designated as Natura 2000. An important part of this consists of Grey dunes (H2130). However, the ecosystem, and many of the species that live in it, is under great pressure, due to, among other things, nitrogen deposition, recreation, climate change and coastal management (Martens & ten Holt 2020). This ensures that continuous management and restoration measures are required (Geelen et al., 2022). Sand re-mobilisation projects in the dunes are part of this.

The biotic local factors that you need to take into account are primarily set by the presence of a series of habitats. With the help of habitat maps you can determine which habitat types occur in your area. For the Netherlands, such maps can often be found in the management plans for Natura 2000 (prepared by policy makers) as well as the tasks for nature restoration (https://www.bij12.nl/onderwerp/natuurinformatie/natura-2000-beheerplannen/). For a spatial overview of the vegetation of a dune area and the relationships within a landscape, it is better to view a vegetation map. In the Netherlands managers need vegetation maps in the context of the Nature and Landscape Subsidy System (SNL) and have them updated on a regular basis. For the Wadden Islands, the eco-hydrology of the dune valleys is well described in Grootjans et al. (1975). Much interesting information can be found for the Southwest Delta in van Haperen (2009). There are many interesting studies dealing with different dune areas. A good start is the OBN website www.natuurkennis.nl .

Listed below are the effects of some important interventions at the habitat level:

1. Removal of vegetation (grazing, mowing, scrub removal and sod cutting/turf-stripping). This often resets the succession completely. This creates opportunities for the new formation of white and - in the slightly longer term - grey dunes. This may mean that flora and fauna elements disappear and it is at the expense of existing habitat, usually habitat type H2160 (sea buckthorn) or non-qualifying (i.e. not Habitat Directive) habitat.
2. Sand rain with/without local burial by tongues (lobes) of calcareous sand. Nitrogen precipitates through the air from the sea and from the land, which promotes the succession of vegetation. Grass and shrub development are taking hold. Where calcareous sands migrate inland in the form of a lobe, White dunes (H2120) will form. Sand rain with more calcareous sand, can change carbonate-poor habitats into more calcareous habitats and the

effect of acidification is reduced. The habitat type Grey dunes (H2130) can be improved in quality in this way (Aggenbach et al., 2018, 2020; Van Til et al., 2019). The supply of calcareous sand is always beneficial in the carbonate-poor grey dunes and is in fact essential for the preservation of the calcareous grey dune. This creates a natural gradient (Figure 29). In the zone with calcareous sand drift you will see more species appear: star moss (*Syntrichia ruralis*), dune pansy (*Viola tricolor subsp. curtisii*), heath dog-violet (*Viola canina*), rue-leaved saxifrage (*Saxifraga tridactylites*), etc. In these zones, you will also see open short vegetation: phosphate is fixed and organic matter decomposes quickly or does not have a chance to accumulate.

The rate of sand drift is an issue. For grey dunes, sand rain, whether or not in combination with prior sod cutting or (repeated) mowing or grazing, gives better results than complete burial by migration of sand lobes from a deep notch. Sand rain can be subtle, with a very slow increase in height, but with the deposition of calcareous sand. Excessive sand drift mainly leads to new formation of white dunes locally and only to sand rain at a greater distance. Generally, you do not want to see places, with well-developed grey dunes with high natural values disappear under the sand, such as those where the queen of Spain fritillary (*Issoria lathonia*) is present. It should be noticed that existing dune heaths, shrubs, and even woodlands, with qualifying Natura 2000 habitats, have been observed to be covered by migrating sand, causing them to disappear.

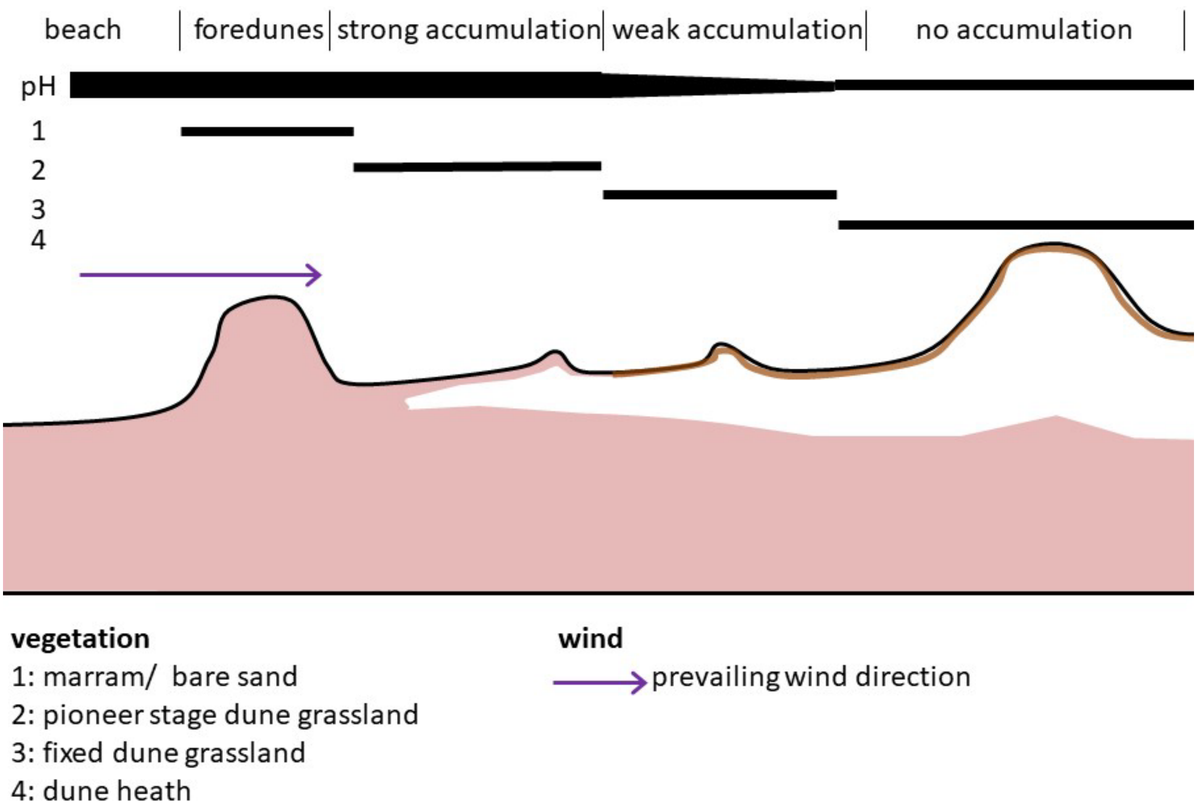

Figure 29. Degree of sand drift, soil and vegetation during sand drift from the beach in a deeply decalcified and nutrient-poor dune area. (OBN, 2016)

3. Infilling of lower parts. Due to the supply of sand, especially through sand lobes, lower parts such as dune valleys are filled up, allowing them to dry out. This leads to a transition from the habitat type wet dune valleys (H2190 humid dune slacks) to a possible grey dune habitat type. A large supply of sand over a broad front can also lead to a dune valley further landward becoming drier. However, when a parabolic dune starts to migrate through the landscape (i.e. it breaks away from the foredune), new dune valleys can be created through deflation down to the groundwater.

It is important to check, on the basis of the vegetation and/or habitat map and terrain data:

1. Which vegetation and/or habitat types are possible as a result of the restoration projects;
2. In which vegetation and/or habitat types significant sand drift is undesirable or unnecessary;
3. Whether the negative effects of sand drift are greater than the positive ones. If more negative, the planned intervention is not recommended or another form of bare sand creation or specific management measures should be considered.

4.3 Smallest scale: species

20 Make conscious choices based on available inventory data.

4.3.1 Introduction

In general, the dunes are rich in species; wheatear (*Oenanthe oenanthe*), sand lizard (*Lacerta agilis*), rabbit (*Oryctolagus cuniculus*), dune pansy (*Viola tricolor* subsp. *curtisii*), niobe fritillary (*Fabriciana niobe*), grey bush-cricket (*Platycleis albopunctata*), moonwort (*Botrychium lunaria*), common milkwort (*Polygala vulgaris*) and many other species find their place there.

It would be virtually impossible for an intervention not to have a direct effect on the species present. Given the vulnerability and value of the flora and fauna, sand re-mobilisation (sand drift) projects must therefore take into account the impact on existing species. This may impose restrictions if these species have a protected status or are classified as Habitats Directive species (examples are: fen orchid (*Liparis loeselii*), narrow-mouthed whorl snail (*Vertigo angustior*), sand lizard (*Lacerta agilis*), natterjack toad (*Epidalea calamita*) and pond bat (*Myotis dasycneme*) or as Bird Directive species (such as wheatear, hen harrier, short-eared owl (*Asio flammeus*) and Eurasian curlew (*Numenius arquata*)). It is therefore important to make conscious choices based on available inventory data (for example, in the Netherlands, via the National Database of Flora and Fauna NDFF).

Figure 30. Grey dune on Terschelling. Here the low-carbonates type (H2130C) gradually changes into the low-carbonates type (H2130B). (Photo: M. Nijenhuis)

4.3.2 Flora elements that deserve attention

In recent years, many characteristic plant species of the dunes have increased in distribution. This is due to measures taken by dune managers. Re-mobilisation projects often go hand in hand with other rejuvenation actions such as scrub clearing, flailing, sod-cutting, mowing or grazing. It is important to carefully check where any special vegetation is present. Consider marking these areas and excluding them from any disruptions. Protection of the habitat is mandatory for Habitats Directive species such as the fen orchid. In addition to well developed, species-rich wet dune valleys with autumn gentian (*Gentianella amarella*), bog pimpernel (*Anagallis tenella*) and grass of Parnassus (*Parnassia palustris*), vegetation worthy of protection can also be less remarkable, such as dune slopes with special moss species, moonwort and lesser wintergreen (*Pyrola minor*).

Not all plant species that need to be protected can be helped with re-mobilisation. A number of species such as the fen orchid, grass of Parnassus and black bog-rush (*Schoenus nigricans*), mainly rely on development of new dune habitat, where young new dune slacks can form and space is created for these species. For example, the fen orchid mainly occurs in calcareous wet dune slacks. With sufficient carbonates, for example through the supply of carbonate-rich groundwater, the species can exist in a dune valley for decades. When vegetation ages and acidifies, the species disappears. The desired carbonate richness can be achieved by burial with calcareous sand, but then the valley actually dries out, for example when a lobe of sand migrates into it. The creation of new bare surfaces by deflation can be a solution. Reactivation of sand drift is therefore only a partial solution to preserve the species. Wet dune slack species do

Figure 31. Common milkwort (Polygala vulgaris) (left), Moonwort (Botrychium lunaria) (right). Both found on Terschelling. (Photo: M. Nijenhuis)

benefit from re-mobilisation, especially when, due to deflation down to the groundwater level, new wet dune slacks are also created landward from the foredune. This has already proven successful in several projects.

4.3.3 Fauna elements that deserve attention

Typical fauna species of the Dutch dunes, especially populations of breeding birds, butterflies and reptiles, have declined since 1990 (Environmental Compendium, undated).

As discussed above, there are special species that receive extra protection. If monitoring results show that they occur at the site of the intended measure, special permits (exemptions) are required. Therefore, always check in advance and, if there are indications of the presence of a population of protected species, also carry out an extensive inventory. There are examples where small faunal elements have been successfully moved from the intended sand drift areas to other areas.

Re-mobilisation often goes hand in hand with creation of bare sand and small-scale sand drift in the landward area through, for example, scrub removal and sod cutting. It is important to carefully determine where any special faunal concentrations are present. Consider marking these and excluding them from any disruptions. Below is a brief overview of a number of animal groups that should be taken into account when undertaking projects to re-mobilise the foredune.

4.3.3.1 Molluscs

We regularly see fairly large concentrations of snails in the dunes. With 20-50 to more than 100 eggs per clutch and sometimes several clutches per year, snails are an important food source for predators (predatory snails, beetle larvae, birds, shrews, hedgehogs and some rodents) and parasites and are therefore an important link in the food web. Many snail populations are declining in the Netherlands. As a habitat guideline species, the narrow-mouthed whorl snail (*Vertigo angustior*) is present in many dune areas and is therefore an important species to be aware of in the implementation of sand drift projects

Most small snail species live close to the surface in the litter layer. Some species climb plants or live on tree trunks where they usually feed on lichens or algae. Many species can be found dormant in cool shady places hidden under wood, the litter layer, dense vegetation or slightly below the surface. The black slug (*Arion ater*) prefers to hide deeper underground or in crevices in wood. During dune management interventions, the vegetation and the litter layer are often removed by clearing, flailing, mowing and sod cutting, and thus the habitat for snails disappears.

Zoning by habitat occurs in land snails. The garden snail (*Cornu aspersum)* and the fairly rare vineyard snail (*Cernuella virgata)* can occur in the marram dunes on the sea side although this is not always necessarily the case (https://edepot.wur.nl/546655). More species are found on the lee side of the foredune between dune thickets: in addition to generalists such as *Cepaea nemoralis*, *Cernuella virgata*, *Cornu aspersum* and *Candidula intersecta*, also *Clausilia bidentata*, *Succinella oblonga* and *Vitrina pellucida* and such can be expected. Larger snails such as *Helix pomatia* can also occur en masse around wet dune valleys. A number of these species are currently under considerable pressure and it may be wise to spare places here and there to facilitate re-colonisation.

Many larger land snails can travel about a kilometre per week. Even after very large-scale disturbance, the area can be colonized again quite quickly from the edges, if the conditions (plant growth and litter layer) in the sand drift area are right again. Other species are less mobile and are so endangered that it is advisable to transplant these species from the drift area (e.g. transplant *Vertigo angustior*) and perhaps even bring them back later, or spare some areas where they live so that they can spread more easily when the environment becomes suited again.

Freshwater molluscs may also occur in dune lakes and wet valleys, which have probably 'flown in' with birds. Although there are only a few species, many Dutch freshwater molluscs are endangered. From that point of view, it is important to think carefully about the extent to which you want a dune lake to be filled in by dynamics, or whether your sand drift should be directed to a different direction.

4.3.3.1 Insects

Insects may have a limited habitat. Many species spend their entire lives on 10 m^2. Non-flying insects in particular are likely to have difficulty re-establishing populations in an area after disturbance from re-mobilisation. To conserve insect populations it is important not to clear all habitats in the area when you start reintroducing dynamics (analogous to the Dutch technique of sinus mowing designed to create butterfly-friendly meandering paths). Is that possible? Are there special insects that depend on the foredune and underlying White and Grey dunes? A number of specialist species will also benefit from sand drift projects. Below are some examples by insect group.

Beetles

True foredune species are adapted to a dynamic environment. For example, in vegetation in dynamic areas there are not only many more larvae of the dune chafer (*Anomala dubia*), but they can also be fully grown after one instead of two years. This means more beetles, which is beneficial to their predators. The disappearance of the red-backed shrike (*Lanius collurio*) as a breeding bird in the Dutch dunes is linked to the decline of the dune chafer due to a stabilised foredune.

Bees and wasps

Most species of solitary bees nest in the ground. Sandy open landscapes are of great importance; dense growth of vegetation reduces opportunities for nesting. It is also important that food plants are not far away. When nesting opportunities are the limiting factor and there is sufficient food, reintroducing dynamics can cause a rapid increase in these populations.

Butterflies

A dynamic foredune and similar sites with open sand form the habitat of the vulnerable grayling (*Hipparchia semele*). Other characteristic dune butterflies benefit more indirectly from dynamics including the queen of Spain fritillary (Red List status: Vulnerable), the niobe fritillary (Endangered), dark green fritillary (*Argynnis aglaja*) (Critically Endangered), grizzled skipper (*Pyrgus malvae*) (Endangered) and the silver-spotted skipper (*Hesperia comma*) (Endangered). Light sand drift makes the grey dune, with the food plants important for their caterpillars, such as dune pansy, dog-violet, dewberry (*Rubus caesius*) and grey hair-grass, (*Corynephorus canescens*), more productive.

Grasshoppers

In the habitat types H2110 - Embryonic dunes, H2120 - White dunes and H2130 - Grey dunes, three grasshoppers are mentioned as typical species: blue-winged grasshopper (*Oedipoda caerulescens*), mottled grasshopper (*Myrmeleotettix maculates*) and the grey bush-cricket (*Platycleis albopunctata*). These species are all dependent on a bare, rapidly warming soil and/or disturbed places in the environment, with the blue-winged grasshopper mainly benefiting from small-scale dynamics further from the foredune. The same applies to the grey bush-cricket. A

Figure 32. Burrows of digging bees, Schoorl. (Photo: A.P. Oost)

varied dune area with open areas alternating with marram or other grass vegetation is ideal for these species that occur almost exclusively in the dunes.

Hoverflies

There are currently only two known locations of the hoverfly *Eumerus sabulonum* in the Netherlands, both in the dunes. The species is dependent on the sheep's-bit (*Jasione montana*) for its reproduction. Where this occurs, it is with very sparse vegetation.

4.3.3.2 Amphibians and Reptiles

These species are generally having a difficult time in the Netherlands. It is therefore good to consider what re-mobilisation and creating more bare sand can mean for these species. For example, natterjack toads occur en masse in a many kilometres long primary dune slack behind the foredune on northwest Terschelling. It was concluded, however, that it was not a problem if this wet dune valley was cut in half by expected sand drift from re-mobilisation of the foredune to create a migrating lobe of sand.

The dunes are important as a habitat for the sand lizard. Some increase in bare sand and local mobility can contribute to improving the habitat of the sand lizard, but large-scale sand drift can have negative consequences. The species benefits from mosaics of White dune with Grey dune and dune heath alternated with, for example, open scrub and burnet rose (*Rosa spinosissima*) vegetation. Any creation of more mobile conditions must be carried out in such a way that these vegetation types remain present in mosaics with reasonable surface areas. Here too, you should always ask yourself whether you can locally spare the best part of a habitat of an amphibian or reptile species such as the sand lizard in a re-mobilisation project.

Figure 33. Just behind the foredune an earlier dynamic with sand martin nests, North Texel. (Photo: A.P. Oost)

4.3.3.3 Birds

The first thing to consider is the presence of breeding colonies. It is better not to intervene in such places because it could affect the success of the colony and also if there is a large amount of nutrients in the soil this could stimulate the development of vegetation. Obviously, implementation must also be planned outside of the breeding season. However, there are examples (Schouwen) where re-mobilisation activity did not appear to have a negative impact on a nearby large seagull colony and possibly even a positive one. The dune area, which was dense with scrub, had become less and less suitable for this species and the increase in sand drift helped to counteract this. It certainly depends on the species involved and the development of the dune area.

Steep sand slopes may provide opportunities for nest holes of sand martins (*Riparia riparia*). The periodic formation of these temporarily stable steep cliffs is of crucial importance for a sand martin (or bee-eater (*Merops apiaster*)) as a breeding opportunity. Such places with nesting sites should be avoided, just like rabbit holes in which the wheatear breeds. Lack of dynamics in the dunes ensures that these species do not get a chance. Some degree of dynamics is also necessary for the wheatear, especially light sand rain over grey dunes. This creates small-scale open spaces, calcareous, high-quality (flowering) species rich grassland and associated insect fauna from which the wheatear can benefit (van Oosten, 2015).

Furthermore, breeding birds such as stonechat (*Saxicola rubicola*) and sometimes short-eared owl (*Asio flammeus*), hen harrier, and curlew also occur in dune systems. These species breed in grey dunes or dune heath. For these species it is important that re-mobilisation is not carried out at too large a scale, as this could result in the loss of breeding area. A large-scale

Figure 34. Rabbit hole with Heath dog violet in the foreground – Terschelling. (Photo: M. Nijenhuis)

intervention should be carried out at a sufficient distance from their habitat. For these species too, slight sand rain over grey dunes contributes to the quality of habitat.

Naturally, the removal of shrubs and/or woodlands in favour of more open sand areas will have negative effects on certain species. For example, nightingale (*Luscinia megarhynchos*) and grasshopper warbler (*Locustella naevia*) can lose habitat as a result. A careful assessment of the pros and cons of any project must be made in advance.

4.3.3.4 Mammals

The rabbit is a very important species in the dunes, not so much because of its rarity, but because of its contribution to 'management'. The rabbit, with its digging and grazing activities, plays a key role in keeping the dune open and the maintenance and restoration of the grey dunes habitat type. Due to a lack of rabbits in many dune systems, there is a relatively large amount of grass and shrub growth and the dunes are covered with dense vegetation in many places. This is disadvantageous for many species that depend on relatively open dune systems. Species that benefit from the presence of rabbits in the dunes include the shelduck (*Tadorna tadorna*), the wheatear and dune violets. Unfortunately, the rabbit is suffering in many places from viral diseases. Attempts are currently being made in places to strengthen the population by introducing vaccinated rabbits (see the work protocol Releasing Rabbits for Population Recovery). Research has also recently been conducted into the possibility of recovery of populations in the coastal dunes (Dekker *et al.*, 2022).

Increasing dynamics in the foredune can contribute to the creation and/or maintenance of habitat for rabbits. Find out what the state of the rabbit population is in the area. If there is already a good population present, there is probably already a dynamic situation. If not, but rabbits are found nearby, some additional measures may help to facilitate the rabbit in the re-mobilisation area.

The Netherlands has a few endemic mouse species - species that only occur in our country. The (subspecies of the) northern vole (*Lexandromys oeconomus arenicola*) is one. The species is a relic of the last ice age that lingered here and developed further and is currently under great pressure. Competition with other species such as the field vole (*Microtus agrestis*) is a particular threat to its survival. The dunes are not the most important habitat for the northern vole in the Netherlands,
but the species is still quite numerous, especially on Texel and also in the northern part of the Southwest Delta. The species can sometimes be found, especially in the more rugged dune valleys, and is therefore a factor to take into account. Sand disturbance initially seems to have a negative effect on this species and it is therefore a good idea to examine whether the Northern Vole occurs in the plan area and whether the habitat can be spared.

5 Anthropogenic conditions

21 **Human land use set limitations**

In addition to abiotic and biotic factors, anthropogenic factors, human influences, are also of enormous importance for the possibilities (and impossibilities) for re-mobilisation projects in the dunes. You can only reintroduce large scale dynamics, in consultation with stakeholders, where it does not affect water safety (coast defence), buildings and infrastructure and, in the Netherlands, drinking water extraction. Locally, you also have to take cultural-historical values and remains of ammunition (unexploded ordnance UXO) into account. You also have to be careful about causing inconvenience to the existing infrastructure. For example, if a cycle path becomes completely overwhelmed by blowing sand, an alternative route could be sought, but then alternatives must be available.

In the current circumstances, with a rapidly changing climate and an acceleration of sea level rise, discussions will be held about the sustainability of certain infrastructure. Dune management interests could respond to these discussions or perhaps join in. This could lead to more, new or different opportunities for dynamic dune projects in the longer term.

5.1 Buildings

22 **Sand drift and built-up areas do not go together well**

In built-up areas such as coastal villages, campsites and recreational parks, and houses or farms located behind the foreshore, sand drift can cause a lot of nuisance. Buildings near or in the foredunes such as beach establishments and summer houses can reduce the boundary and scope for reintroducing dynamics in the foredune. Behind beach pavilions that are not on stilts, or behind a closed row of beach huts, less sand will be deposited and the morphological development of the foredune will clearly be different (less natural) than without buildings. (Löffler, 2010 a, b).

Where buildings are present, it is often virtually impossible to initiate sand drift, although it may be desirable. However, there may be a possibility of having plans ready in case the buildings are demolished or replaced so that an intervention project can be quickly carried out before any new buildings appear. With buildings built on high piles, there are more opportunities to allow sand drift, if there is sufficient space between buildings and the base of the dune. Coastal management policy differs for locations with and without buildings.

Because interventions creating large sand drift areas or notches will often attract the public, it is best to carry out this work some distance away from recreational facilities. Otherwise there may be too much trampling with all the negative consequences. But you may consider making part of the intervention area (for example one of the notches) accessible to give the public an experience. This may be an option if it can deflect the (recreational) pressure away from the rest of the site. Communication and information can help to dissuade visitors from entering active mobilisation areas. You could also consider installing a fence with signs saying '*resting area for animals*' or similar.

It is important to discuss your re-mobilisation project with the beach manager, often the municipality / local authority.

5.2 Water safety (sea defence) and management

23 Check with the flood defence manager to determine which requirements must be met and what possible gains can be achieved

The so-called *primary flood defence* is present in front of most dunes in the Netherlands in populated areas. The permissible probability of flooding may not be exceeded here. Thus, for the implementation of projects, where the foredune is part of a flood defence system, coordination with the flood defence manager is therefore a precondition. Foredunes re-mobilisation can also be used to strengthen a landward primary flood defence, as discussed in Chapter 3 because it can provide sand and therefore strengthen the flood defence.

Important questions to consider are: What is the location of the flood defence in your area? Is it just the foredune or do the dunes behind it also count for the water safety calculation? What requirements does the responsible water safety management authority impose on the site for proposed dynamic interventions? Usually a permit is required. Discuss the requirements and wishes regarding the primary flood defence with the flood defence managers.

5.2.1 Current management and development foreshore

Before 1990, in the Netherlands in order to keep the coast in place, as much sand as possible had to be captured in the foredunes by means of sand fences and planting marram. By law, one was obliged to plant each blowout with marram grass, reed fences or branches of sea buckthorn. When the foredune was strongly eroded, a new foredune (dune dike) could be pushed up from the beach with the help of bulldozers and planted with marram. This served as a buffer to have some spare room for erosion in the event of a storm. In this way managers tried to prevent the landward movement of the coastline. Since 1990 and especially since 1995, coastal erosion in the Netherlands has been counteracted by systematic application of sand nourishments. This was at first mainly with beach nourishments (on the beach and near the low-waterline), but from the late 1990s onwards also with shoreface nourishments (below mean low water). This eliminated the need to strictly maintain the foredune position in many places. Where there are special values behind the foredune or where the foredune position coincides with the primary flood defence, strict management to stabilise the foredunes may still be necessary. As the nourishment volume increased, the dune volume in the foredune along the Dutch coast also increased (IJff et al., 2019).

Information about Dutch beach management can be found in the management libraries commissioned by Rijkswaterstaat, which are regularly updated. A management library contains knowledge for each coastal section about the functioning of the coastal system (morphology, ecology and socio-economic) and the effects of nourishments. This contains information about the (long-term) developments of the dunes. All management libraries can be found at: https://publicwiki.deltares.nl/pages/viewpage.action?pageId=131142282

5.2.2 Beach and shoreface nourishments

In principle, the Dutch basic coastline is kept in place, where necessary, with nourishments. Coastal evolution is measured annually and reported in the coastline maps: (see section 3.3.2). This is the basis, on which Rijkswaterstaat decides where and when nourishments should take place. In general, the spatial planning of nourishments is known for the coming years. Nourishing the coast implies that coastal erosion is usually suppressed or limited. Because there is much more sand in the system, erosion has turned into (light) dune growth in many places.

Nourishments provide an extra source of sand, which can be moved by aeolian processes. But dune formation on the seaward side of the foredunes, as a result of an excess of sand on the beach, can actually reduce the success of foredune re-mobilisation. The enormous increase in the development of embryonic dunes along the Dutch coast is most likely also the result of nourishments. It is therefore important to determine: 1) where and when nourishments will take place; 2) what shape they will have (shoreface or beach, beach profile); 3) how large they are and 4) whether the planning and design of either the nourishment and/or the dune re-mobilisation project must and can be adjusted, in order to achieve the goals for both nature and nourishment more effectively or cheaper.

Important factors with regard to beach nourishments are:

- The maximum height of the nourishment. Construction above 2.5m NAP (Normaal Amsterdams Peil = Dutch Ordnance Datum) implies that the beach will almost never be flooded by waves, the sand will not be sorted and shells will cover the surface rapidly (desert pavement), which greatly hinders sand drift.
- The grain size: shells (too coarse) and clay (too fine) both have a negative influence on sand drift. Note that the average grain size or median of the sand to be applied is not a meaningful parameter; the grain size distribution is important, and therefore also the content of shells and clay.

Figure 35. Beach nourishment at the Hoornderslag, Texel, 2021. (Photo: AP Oost)

5.2.3 Historical use and former design measures

Is there any historical land use or form of management (e.g. historical ditches or dikes that must be retained or removed), coastal defence structures, drinking water extraction and nature management? Have there been any dune strengthening measures, such as the building or strengthening of foredunes or sand dikes? Be aware that unorthodox means have been used in the past to stimulate dune growth, such as fences with branches of young pine trees and Christmas trees. There is also a known case where a number of car wrecks were placed in a blowout (now cleaned up) on Texel. There may also be structures underneath the dunes, such as small dikes, paved paths, bunkers etc.

Have dunes been constructed or strengthened in the past? This happened regularly with coarser, angular and shell-rich sand, sometimes even containing clay or gravel. Information on this has been available from Rijkswaterstaat since 1965. Water boards, water extraction companies, nature managers and municipalities may also have intervened in the dunes. This must be checked on site.

It is also good to check what management has already been carried out in the past, in and near the target area. This helps to provide direction to needed measures, but perhaps things can also be combined: for example, it may be more interesting to stimulate sand rain over an area where sods were removed or that is intensively grazed.

5.3 Water extraction and hydrological situation

24 Is there water extraction in the underlying dune area, or soil pollution? See how sand drift could change the hydrological situation.

Due to the availability of freshwater in the Dutch dune areas, drinking water production takes place in several places. Dune re-mobilisation at a large scale could have an effect on drinking water extraction. At an erosion coast, the width of the dune massif decreases, causing the freshwater lens to become smaller. Large scale sand movement could exacerbate this process and further reduce the possibilities for extraction of fresh groundwater. But widening the dune massif can also have unexpected consequences. Due to the construction of the Sand Motor, the watershed in the dune massif shifted towards the sea and contaminated groundwater flowed from a dumping site towards the drinking water wells (Lackin & Stuurman, 2014). Pumps had to be installed to capture the contaminated groundwater, which is a very expensive measure.

When excavating notches, saltwater might flow into the dune area if the entrance is dug too deep or if it blows out too quickly. This can cause the fresh groundwater to become locally salinised and unusable for drinking water (Province of Zeeland, 2019). At all natural and constructed notches along the Dutch coast, the height is still such that the sea cannot flow in. The exception was that inflow of sea water was the explicit intention at De Kerf near Schoorl, but there the minimum height in the notch quickly increased due to sedimentation, after which the sea no longer had access to the dune slack behind it. Infiltration ponds in drinking water areas are sensitive to sand being blown in; this must be prevented as much as possible or additional management measures must be taken to maintain infiltration ponds (Arens et al., 2007).

A subject that has so far been neglected is the availability of freshwater in and around dune areas. The expectation is that this soon will require a lot of attention. As described in section 2.2.7, compared to for example a polder, a dune area has more options to absorb a precipitation surplus in the winter six months (October- March) and discharge it more slowly. Surrounding polders benefit from this delayed flow of fresh water from the dune area during periods of precipitation shortage. This provides possibilities for maintaining water levels during dry periods, or to flush out salinised water. Larger, higher and less drained dune areas provide better opportunities to fulfil this function.

Particularly in very dry periods in the growing season, polders behind the dunes of the Zeeland delta and the Wadden Islands are dependent on this additional fresh water supply. These areas hardly have any alternatives; they cannot be fed with freshwater from the major rivers. It is expected that freshwater availability from the dune area will decrease further in the future as a result of sea level rise. Sea level rise causes the size of the freshwater lens to decrease and salinisation in the underlying polders to increase. Such drought problems are more likely to

Figure 36. Water well in the dunes of Schouwen. Water extraction is an important factor in many places along the Dutch coast. (Photo: M. Nijenhuis)

occur in small dune massifs. One of the ways to store sufficient freshwater in the dunes for drought periods is to allow them to grow in width and/or height. The insight that notches and sand drift can provide a solution for this is beginning to develop.

In the Netherlands PFAS/PFOS (man-made chemicals) are present in the foredune in many places in the dunes. No policy has yet been developed about this, except that such 'contaminated' sand may not be removed from dunes, or else it must be treated as contaminated soil. However, if it remains in the area, it may be moved somewhat. This is in line with the wishes of the water safety managers (Water Boards and Rijkswaterstaat), who generally require that the sand remains within the coastal sections from where it is removed.

5.4 Infrastructure

25 Above and below ground infrastructure needs to be taken into account

Infrastructure mainly concerns roads and paths that have been constructed just behind the foredune dune: beach crossings, parking lots, electricity cables and gas pipelines. It is important that these things are not buried (bicycle path) or uncovered (cables, pipes). If pipes become buried by sand, contact the pipe manager and discuss whether additional burial could cause a problem (extra weight or periodic checks). For Dutch underground infrastructure: check Cables and Pipelines Information Center (KLIC) (https://www.kadaster.nl/zakelijk/registraties/landelijke-voorzieningen/klic). Sometimes an alternative is possible, for example relocation of infrastructure or acceptance of nuisance of roads and paths. But infrastructure will often be a hard precondition that determines what is possible in terms of sand drift. It is best to consider

Figure 37. At Schouwen, a beach entrance is no longer passable due to drifting. (Photo: M. Nijenhuis)

this in advance. An alternative is to see how big the problem becomes and then, if necessary, make an adjustment.

5.5 Archaeological values and ammunition

26 Consider in advance how you will deal with historical remains and ammunition that may be revealed by sand movement

When implementing measures, the presence of archaeological values and ammunition must also be taken into account. Both mean that additional measures must be taken.

5.5.1 Ammunition remains

In many places, explosive remnants of war (formerly conventional explosives or non-exploded explosives) are present, such as ammunition, aircraft bombs, grenades and land mines. If present, additional safety measures may be required during the work (for example using an armoured excavator) and one must be aware of the possibility of ammunition being uncovered due to erosion from sand drift. Information for ammunition and the like in the Netherlands can be obtained from the environmental services https://www.Omgevingsdienst.nl/ and municipalities. Clearing ammunition can mean considerable additional costs.

5.5.2 Archaeological values

For interventions for nature development, where archaeological values are involved, state procedures are to be taken into account. In the Netherlands, the Archaeological Monuments Map (AMK) procedure must be followed. This starts with desk research to determine whether any

Figure 38. On Vlieland the cycle path was located shortly behind the foredune. This has been moved so that there is no nuisance due to drift. (Photo: M. Nijenhuis)

archaeology can be expected, and this may lead to a further process that can lead to exploratory drilling research, digging test trenches or even a complete excavation. It is not always necessary to go through the entire cycle, because each subsequent stage depends on the findings of the previous stage. Discovered archaeological values may therefore mean that further archaeological research must be carried out and that a Monument Permit must be applied for. In exceptional cases this may cause delays, but with some planning and joint consultation, the archaeological work can usually be properly integrated into the nature development work. An example is the dune dynamics project of the Meeuwenduinen on the Kop van Schouwen. There, archaeological volunteer research showed that prehistoric to medieval material was present in various dune valleys. This material was recovered and documented during various monitoring campaigns. To make re-mobilisation possible, additional archaeological desk research was carried out to estimate the chance of finding archaeological values. After the start of the project, a five-year monitoring program was established. Additional permits turned out to be necessary, which led to a delay of two years (Province of Zeeland, 2019). Due to the possible presence of archaeological values, digging was not allowed to be deeper than 0.2 m.

There have now been numerous interventions in the Dutch dune area that have affected archaeological values. In most cases, work could ultimately be carried out.

The presence of bunkers (mainly remains of the WWII Atlantic Wall) can also hinder the execution of projects aiming to reintroduce dynamics. These are often protected monuments and sometimes they host a bat population. When bunkers become accessible again because of erosion, they can also pose a safety problem because this attracts public interest. For

Figure 39. Volunteers from the AWN Dutch Archaeology Association document finds in one of the drifting valleys in the Meeuwenduinen, Kop van Schouwen. The dark bump in the centre of attention is a water/waste pit from the late Iron Age, uncovered by the wind. (Photo: T. van Brummelen)

archaeological values (including landscape) in the Netherlands see https://www.cultureelerfgoed.nl/onderwerpen/bronnen-en-kaarten/overzicht and check with the municipality.

5.6 Nitrogen deposition

27 Estimate the influence of nitrogen deposition

Nitrogen deposition is still too high along the Dutch coast. Although N-deposition has been declining for decades, it is often still too high to maintain and improve the quality of nitrogen-sensitive habitats. The carbonate-poor grey dunes are particularly sensitive to high nitrogen deposition, which leads to grass encroachment, further acidification and loss of biodiversity. Of all dune habitat types, Grey dunes (H2130) have by far the lowest critical deposition value (KDW Kritische Depositie Waarde). And since the Netherlands is home to a relatively large share of the Grey dunes in Europe, this indicates how serious the nitrogen problem is. To determine whether the local nitrogen deposition exceeds the current critical deposition values, the values in Figure 41 can be compared with the results of the AERIUS model (Aerius Monitor or Aerius Calculator) to determine the nitrogen deposition in the current situation and in the coming decades.

Figure 40. In several places in the dunes there may still be remains of ammunition or grenades from the Second World War, or even, as at De Geul on Texel, from the First World War. This also applies to places where the army has been active, such as the Noordsvaarder on Terschelling. (Photo: M. Nijenhuis)

5.7 Support base

28 Communication involves listening to and involving parties to make them proud of the project

Löffler (2010) indicates that communication in dune re-mobilisation projects is an important factor. For example, support can increase enormously by clearly explaining that safety (from flooding) is not at stake (and in fact may benefit from it) and what the purpose of the project is. Always tell the true, correct story. All parties involved, stakeholders and local residents, must be kept informed during the development process.

The point is not only to inform stakeholders, but also to actively involve them in the design if possible. Consider communication via local media and messages via social media such as Facebook and X, but also an excursion at a time that suits you (for example a quiet period outside the tourist season). It can also work very well to take stakeholders to another place where something similar has already been done.

5.7.1 Preconditions and agreements with residents

Sand mobilisation measures in the (sea) dunes regularly evoke a feeling of insecurity among residents, because these measures go against traditional coastal management, in which dunes had to remain in place. In practice, it has been shown that agreeing on concrete preconditions, such as minimum heights, helps in getting measures accepted. These are often not even preconditions that require adjustments to the design, but when they are on paper, they do

Code subtype	Habitat type	Subtype	kdw (mol n/ha/year)
H2110	Embryonic dunes		1429
H2120	White dunes		1429
H2130A	Grey dunes	Calcareous	1071
H2130B	Grey dunes	Low in lime	714
H2130C	Grey dunes	Nardus grassland	714
H2140A	Dune heaths with crowberry heath	Damp	1071
H2140B	Dune heaths with crowberry heath	Dry	1071
H2150	Dune heaths with shrub heather		1071
H2160	Sea buckthorn thickets		2000
H2170	Creeping willow thickets		2286
H2180Abe	Dune woodlands	Dry birch oak forest	1071
H2180Ao	Dune woodlands	Dry other	1429
H2180B	Dune woodlands	Damp	2214
H2180C	Dune woodlands	Inner dune edge	1786
H2190A0m	Damp dune valleys	Open water oligo- to mesotrophic variant	1000
H2190Ae	Damp dune valleys	Open water moderately eutrophic variant	2143
H2190B	Damp dune valleys	Calcareous	1429
H2190C	Damp dune valleys	Decalcified	1071
H2190D	Damp dune valleys	Tall swamp plants	>2400

Figure 41. Relevant critical deposition values of the habitat types and habitat of species. (Source: Van Dobben, Bobbink, Bal & Van Hinsberg, 2012)

provide certainty (i.e. guarantees) for residents. It is also valuable to be aware of historical developments in the area, so that you are also aware of any local sensitivities to be taken into account.

The idea that nature is being lost because existing natural values disappear under the sand can also lead to resistance. And, as tastes are different, please be aware that some residents or site users think a highly dynamic foredune looks neglected.

5.7.2 Examples in the field during excursions

Nature management is a profession in itself and therefore as a manager you do not always speak the same language as other stakeholders. Therefore, work with concrete examples that people can imagine and use terms that people understand. Make visible/tangible what the intention is.

A few examples:
- Plot heights in the field and compare them with, for example, the beach. What initially looks like a hole in the dune landscape can also be seen as a low dune that still has more than sufficient height.
- A jagged row of dunes looks unmanaged to many people, while this actually provides a wider and therefore safer dune area. A dune does not have to be 16 metres high, it is better to use that sand to widen the dune area: a half-height but thick wall is sturdier than a high narrow wall.
- Take stakeholders to projects already completed. Experiencing the project is a good way to create or increase support.

5.7.3 Communication within and between organisations

In addition, good (internal) communication is important, because there are sometimes barriers within and between organisations that hinder cooperation. In addition to communicating with those involved, it is also good to identify the most important parties and their interests. Local knowledge (knowing what is going on) is essential to gain sufficient support. On this basis, plans can also be developed jointly, with understanding for each other's goals. And communicate as joint authorities/administrators; the story from nature often fits seamlessly with the story from safety. Make sure that in addition to the nature manager, the coastal manager is also present at public meetings.

5.8 Recreation

29 Keep recreation on track

Notches are attractive for recreational users to enter, especially from the beach. Access causes disruption, but if the dynamics are high compared to the trampling intensity, traces of visitors are quickly erased. However, if there is too much foot traffic, the geomorphological development will be disturbed. This does not necessarily have to be a problem for the supply of sand to the hinterland, but it can pose a problem for optimal geomorphological development (Arens, 2022a). As already indicated in the goals (Paragraph 2.2.8 Objective of recreational zoning), creating or improving options to experience (part of) the project can ensure that the rest of the project can develop undisturbed.

5.9 Laws and regulations

30 Check well in advance which laws and regulations apply and what you must deliver on time to avoid delays or rejection.

When digging notches in the foredune, it is necessary to check in advance where what is possible and under what conditions. In the Dutch situation, in addition to the water safety discussed earlier, the Nature Conservation Act and the Excavation Act must also be taken into account. Dune re-mobilisation projects often aim to improve the quality of habitats. Based on Natura 2000 and the Nature Conservation Act, interventions will usually not cause any problems but this must always be checked with the environmental department. Especially if existing habitat types (H2160 Sea Buckthorn) are converted into other types (usually H2120 White Dunes and H2130 Grey Dunes) or if the Embryonic Dunes habitat type H2110 is removed for the purpose of encouraging sand drift. Granting permits becomes a lot easier if the dynamism of the foredune is included in the nature management plan. Think about this in time.

The following permits are usually required for projects in the Netherlands:
- Consent in connection with water safety (coast defence, Water Boards and Rijkswaterstaat)
- Exemption from the Nature Conservation Act (also Natura 2000 issues)
- Permission for excavations deeper than 2 metres under Excavation Act (also archaeological issues)
- AERIUS calculation (for N deposition and critical loads)
- Municipal exemptions (planning permissions etc)

5.10 Project Manager

31 **Get your project manager, or land affairs expert involved from the start; who knows what regulations apply to the land where you want to encourage sand drift and bare sand**

From the start of a project, it is important to involve a 'steward' or land affairs expert. Stewards, in the Dutch context, often work more in the business domain and less in the nature domain. This implies that they are often aware of many business aspects that may be important, which a nature manager will never think about from a professional perspective. If a steward is involved at the beginning of a process, this can prevent unpleasant surprises during or after completion of the project.

A steward looks in particular at the private law aspects in the project area. Both the private law relationships in the area and the value and development value of the objects involved (land/buildings).

Consider, among other things:
- Ownership and real rights of the land ownership plots involved in the project and resulting private law agreements that may be necessary to implement a project with the consent of all landowners or rights holders involved. Make the project 'obstacles free'. Consider also leaseholders and tenants. If you overlook this, you may be committing an unlawful act with possible claims for damages.
- Insight into financial aspects of the project and the any economic value developed as a result of the project. This will not be so relevant in nature reserves, but it may possibly be at the

edges, where there is a transition to economic activities or at a commercial operation (e.g. a beach pavilion) in the nature reserve.

- Gaining insight into other (not landowners) users with a contract or permit in the areas concerned. If these exist, it may be necessary to communicate about the temporary inability to make use of the right of use or permit.
- Re-mobilisation of the foredune may lead to consequences for recalibrating 'logical' property boundaries. For example: in the Netherlands from the beach to the foot of the dunes the property may belong to Rijkswaterstaat, from the foot of the dunes landward the property belongs to a nature manager. But due to coastal change, the location of the dune foot changes over the years and boundary corrections (or exchanges) are necessary to continue logical ownership relationships. This is desirable from the Nature and Landscape Grant Scheme (SNL – a grant scheme administered by provincial authorities for the development and management of the National Ecological Network), but also for clarity about management and supervision, liability, etc. An adjustment in the location of a dune (cycle) path is also a common example of a consequence of a sand drift project. If the owner of the nature reserve and the owner of the path are different, an extensive legal exercise is required to make property boundaries appropriate again.
- Problems related to cables and pipes through and under nature reserves. Monitoring is important. Projects in the foredune offer an opportunity (now that we are here working on it…) and a threat (cables/pipes being exposed due to erosion) for the construction, management and maintenance of cables and pipelines.

PART III Implementation

6 Planning and design

32 Putting the plan into action

Now that you are aware of all relevant preconditions and factors, it is time to start developing your plan. What do you need to achieve your goals? Which scale of measures do you choose? How will you design the final intervention? And how are you going to organise it? Various elements are discussed in this chapter that may be less obvious at first, but that are crucial for the success of your project.

6.1 Introduction

33 Before you start planning and design, check once again whether you want to carry out dune re-mobilisation in a seaward or landward direction

The design of the project to restore dune dynamics is determined by what goals you are pursuing (Chapter 2) and what is possible in view of your preconditions (Chapters 3, 4 and 5). You can design interventions to induce sand drift both seaward and landward. This is strongly determined by the natural situation and the space that the coast offers. Seaward developments require different types of interventions than landward developments (figure 43).

A form of seaward dynamism on a large scale is, for example, the Sand Motor. The Solleveld dune area, in front of which the Sand Motor was constructed, is narrow and therefore there is little room for dynamics in the foredune, even though it was reinforced just before the construction of the Sand Motor. Over the years, a large area of embryonic dunes has developed on the wide, landscaped beach of the Sand Motor, considerably more dynamic than the original foredune. The formation is very similar to the development on a naturally 'landed' sandbank, such as De Hors on Texel. The dunes are often relatively low and grow slowly in height. Especially in the intermediate dune valleys and depressions, a diverse flora can develop due to the large variations in lime content, acidity, humidity, exposure, salinity and dynamics.

Another large-scale seaward project is the construction of the Hondsbossche Dunes, in front of the former Hondsbossche and Pettemer sea defences. A completely new dune landscape was created here in one go, in a place where there were no longer any dunes. A natural parallel can be found on Schiermonnikoog, where a completely new strip of dunes has emerged over the years on the beach in front of a sand dike that forms the flood defence.

Development of embryonic dunes on a smaller scale is now found along large parts of the coast. Embryonic dunes form a buffer for flood defence and limit erosion of the outer slope of the *primary flood defence* and the transport of sand to the area behind it. Due to the smaller scale, the variation in gradients is smaller than in a dune field. The variation in flora and fauna is

Figure 42. Dune formation on the Sand Motor, 08-12-2020. (Photo: B. Arens)

therefore also more limited and mainly concerns the habitat types White (H2120) and Embryonic dunes (H2110).

On an even smaller scale, sand drift against the foredune can develop in a narrow strip of dunes that show characteristics of embryonic and white dunes. In many places with a totally stabilised foredune this is the only form of aeolian dynamics: small-scale and limited exclusively to the zone around the foot of the dunes.
In the remainder of the text we will only deal with wind-driven, landward dynamics, that is to say measures in the foredune for sand drift, sand rain, creating notches, parabolizing the foredune, etc. This often requires specific construction, but sometimes application of management measures is sufficient.

6.2 Scale of your measures

34 The goals you pursue determine the scale and type of re-mobilisation project

Based on the above considerations, you have identified a number of areas where the intended interventions are most feasible.

The first question is to what scale dynamic processes are needed to achieve your goals. How far should the effects of the measures reach inland? Is an extreme burial with sand required, or just a light sand shower? With sand rain, a thin layer of calcareous sand is deposited over a large part of the area. During storms it has been observed that sand is deposited more than 1 km from the fore-dunes. The layer is sometimes only a few grains thick and therefore cannot be measured in height changes. Sand rain over long distances requires a dynamic foredune, for example notched or with a bare front.

The desired degree of sand drift can be easily controlled. In the case of Vlieland, for example, very small-scale drift was chosen, imposed by the presence of a cycle path and the presence of valuable Grey dunes just behind the foredune. At Schouwen and the Northwest Nature Core in Zuid-Kennemerland, there is room for a much larger-scale sand drift, due to the opportunity offered by the wide dunes there.

In the case of large-scale sand drift, such as in a foredune with large notches, there will be a gradient from very strong sand burial around the notches to a very slight sand rain up to a great distance. This will manifest itself mostly in a gradient from White dunes around the notches to Grey dunes in the area behind. A gradient in decreasing sand burial can also create zoning within the grey dunes with vegetation that can better withstand sand burial close behind the foredune, and vegetation that can tolerate only little deposition at a greater distance. In the event of large-scale sand drift, the development of White dunes can be at the expense of Grey dune area and/or dune valleys. The sand lobes from notches can migrate inland up to many tens and even hundreds of metres, which sometimes mean that infrastructure will have to be relocated or kept sand-free.

Instead of one large-scale sand drift with effects of hundreds of metres downwind, another option is to design a chain of smaller-scale measures, for example by constructing a series of blowouts in the direction of the dominant wind.

6.3 Encouraging sand drift

35 Sand drift can be grains that roll or bounce and do not travel far or grains carried in the wind more than a kilometre inland

Simply by stopping the more intensive management of the foredune, it may transform into a dynamic/transgressive foredune. The marram vegetation becomes less dense and dune erosion, due to wind and water and, for example, digging by rabbits, can lead to sand drift. However, there are also many densely vegetated foredunes where the sand is captured directly in the dense marram. Some help is then needed by locally removing vegetation (usually marram grass, lyme grass (*Leymus arenarius*) and sea buckthorn). By removing beach houses and other obstacles (especially removing seasonal structures in the winter season) as much as possible to minimise the obstruction of wind and sand transport from the beach, sand drifting can be promoted.

To encourage sand transport over long distances, it may be a good idea to remove vegetation mainly around the top of the dunes, where the wind speed is greatest. It is important to provide a 'run-up' on the sea side, so that sufficient sand can be picked up. In addition, you must be

Form of dynamics	**Dune field** Irregular dune field developed on wide beach plain	**Embryonic dunes** Young dunes developed on the beach	**Foredunes with accretion on the seaward side** Mostly irregular shaped dune ridges	**Foredunes with transfer of sand to the hinterland** Foredunes with bare surfaces/ small blowouts and sand rain	**Carved foredunes** Foredunes with blowouts/ notches	**Parabolising or rolling foredunes** Irregular dune ridge with blowouts/ notches	**Slufter** Breakthrough through foredunes with tidal influence	**Washover** Breakthtrough through foredunes, active during storm surges
Artificial development	Spontaneous on an artificially constructed coastal expansion	Spontaneous after beach expansion due to nourishments	Same as embryonic dunes; possibly stimulated by foredune construction	Remove marram grass Remove shrubs to enhance sand drift	Construction by digging	Construction of several notches	Remove stuifdyke in a situation with a foredune behind it or in a dune field	Remove stuifdyke in a situation with a foredune behind it
Rate of coastline movement with respect to the present foredunes Seaward ↓ Landward ↑	↑	↑	↑		↓	↓	↓	↓
Conservation and/or expansion of	Embryonic dunes White dunes	Embryonic dunes White dunes	Embryonic dunes White dunes	White dunes Grey dunes	White dunes Grey dunes	White dunes Grey dunes		White dunes/ pioneer-vegetation
Management measures	Limit/prevent driving and/or trampling Protection beach breeders	Leave flood marks behind Limit/prevent driving and/or trampit obstacles such as beach houses	Leave flood marks behind Limit/prevent driving and/or trampling protection beach breeders	Extend foredune management Remove vegetation Limit obstacles such as beach houses	Extend foredune management Make notches or blowouts Make agreements about supplements Remove vegetation	Extend foredune management Make notches or blowouts Make agreements about nourishments Remove vegetation Define contiguous boundary profile Temporarily allow coast erosion	Remove foredunes Make agreements about nourishments Define contiguous water defence Remove dune formation in the entrance	Remove foredunes Remove vegetation

Figure 43. Dynamics and management measures (partly based on Löffler et al., 2011).

aware that a significant part of the sand is deposited just behind the top and often gives rise to marram growth there. This sand often moves rolling and bouncing (by saltation and creep) and often forms the lobes that can be seen at the landward side of a notch.

Due to turbulence, the finer fraction of the sand can be carried high into the air and can therefore travel greater distances (sand rain). This effect is probably stronger for high and steep foredunes than for low and gentle ones. Recent research in the Northwest Nature Core in National Park Zuid-Kennemerland (Arens, 2022b) has shown that sand transported floating

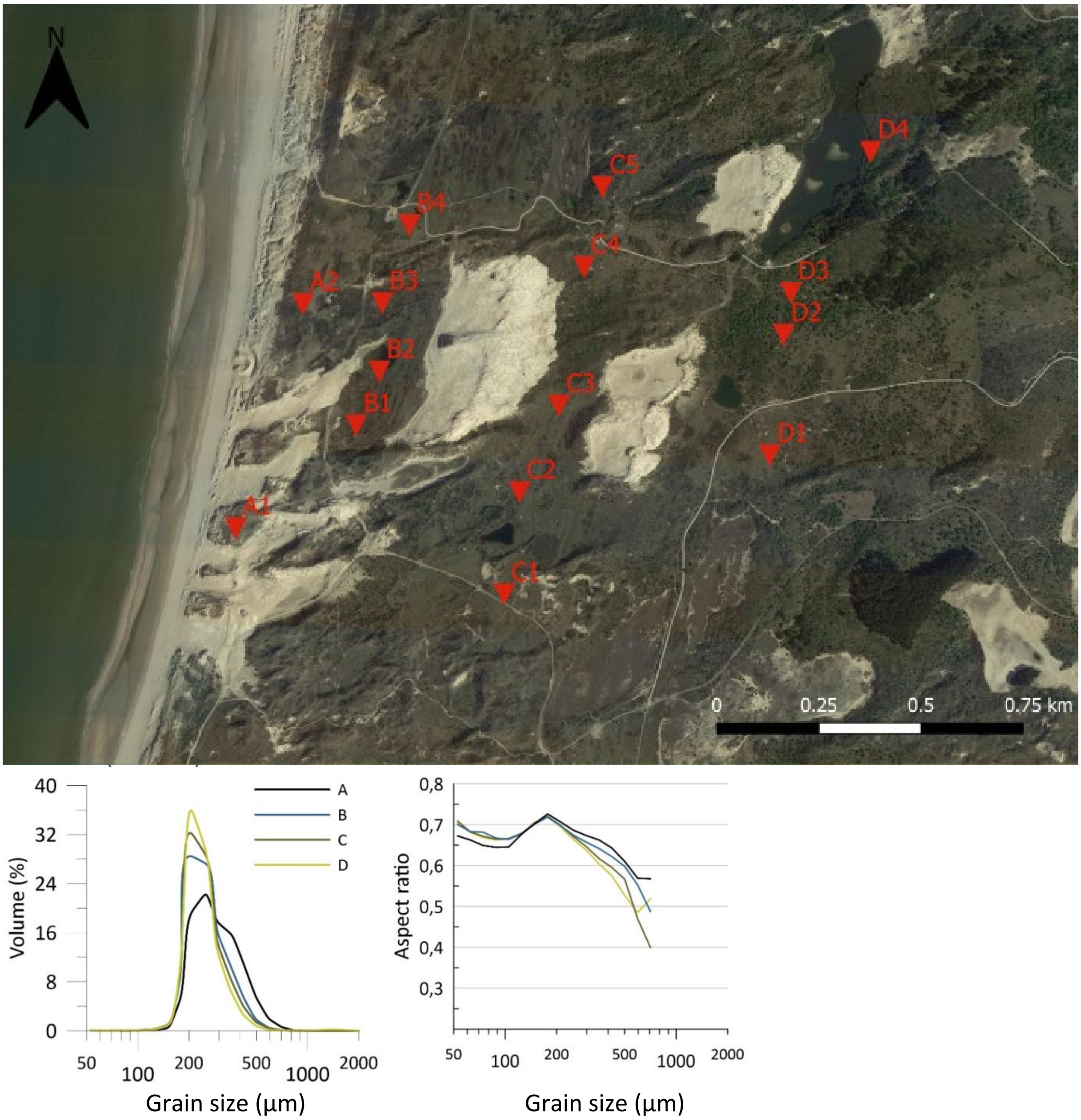

Figure 44. Comparison of the grain size and grain shape distributions of sand captured close behind the foredune with sand traps A (A1 and A2) to the grains captured with sand traps D at a distance of ~1500 metres from the foredune at the Northwest Nature Core sand drift project (Van Buuren et al, 2021). The distributions shown concern the composition of the sand captured during a storm in February 2017.

through the air can be carried more than a kilometre inland. It has a different composition than the sand that is transported rolling and bouncing on the beach and in the notches (Van Hateren et al, 2020). First of all, selection on grain size occurs: the smaller grains travel the furthest. But selection on shape also occurs: the rounded grains (with a so-called high aspect ratio), usually quartz grains, do not travel as far as the flatter / elongated sand grains (with a low aspect ratio). The latter is precisely the shape that shell fragments and feldspar grains have. The result is that the percentage of lime and feldspar increases with increasing distance from the foredune. The amount of sand deposited is less than near the foredune, but it is richer in lime and feldspar. Feldspar and lime will both disintegrate over time due to chemical weathering during soil formation, thus providing the area with nutrients (Van Buuren et al, 2021; Prins, unpublished data). The average grain size and grain shape distributions of the sand captured along transects of sand traps A to D are shown in Figure 44. The spatial patterns in sediment flux, grain size and lime content can be seen in Figure 45.

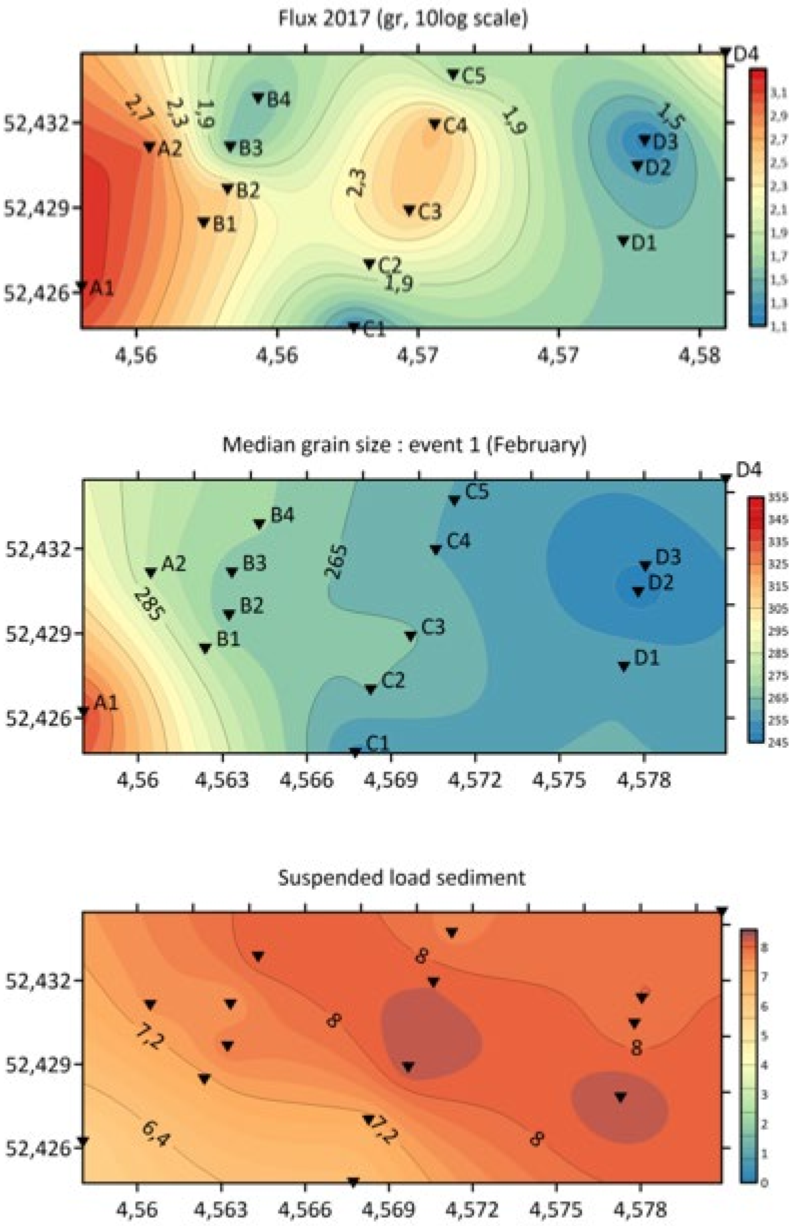

Figure 45.
Spatial change in (A) sediment flux (total weight captured in 2017); (B) grain size (captured during a storm in February 2017), and (C) lime content (average captured in 2017) with increasing distance from the coast of the sand transported floating through the air and captured in sand traps (N=15) in the Northwest Nature Core sand drift project.
(Source: Van Buuren et al, 2021)

6.4 Dune crest flattening (topping)

36 Topping is a small-scale measure that allows sand showers over a large area

Topping, the removal of the top of the foredune by pushing it landward, is the most small-scale measure that can be taken in a foredune to provide a relatively large area with fresh sand by sand rain. The simplest form is to slide the top of a high and steep foredune backwards, creating a bare spot high on the foredune from which sand can be blown out. To enable sand transport from the beach, vegetation from the frontal part of the foredune could be removed. The acceleration of the wind is strongest at the top of the windward side of the foredune. During strong winds, the sand taken up ends up high in the air due to turbulence and will then be carried with the wind over the underlying landscape, whereby a relatively large area can be covered with a minuscule thin layer of sand. This will not lead to changes in the relief, but the thin cover with (calcareous) sand does have an ecological impact and will have a rejuvenating effect on the underlying grey dunes. A bare spot can develop into a blowout due to wind erosion and this could also develop further into a notch in the long term. Depending on the rooting depth of the marram, the bare spot can, however, also stabilise again. Consideration may then be given to counteracting this with follow-up management. Alternatively, you can repeat topping in a large number of places and then let those develop freely. Some will grow, some will stabilise, which benefits landscape diversity. If necessary, this procedure can be repeated after a number of years (5-10). In this way, a large area can be covered in the long term.

6.5 Notching

37 Things to consider when constructing notches

Natural notches usually arise from gaps and blowouts in the foredune. The accumulation zone and supply from the beach only really develop when the landward edge of the blowout is 'broken through' by wind erosion creating the corridor.

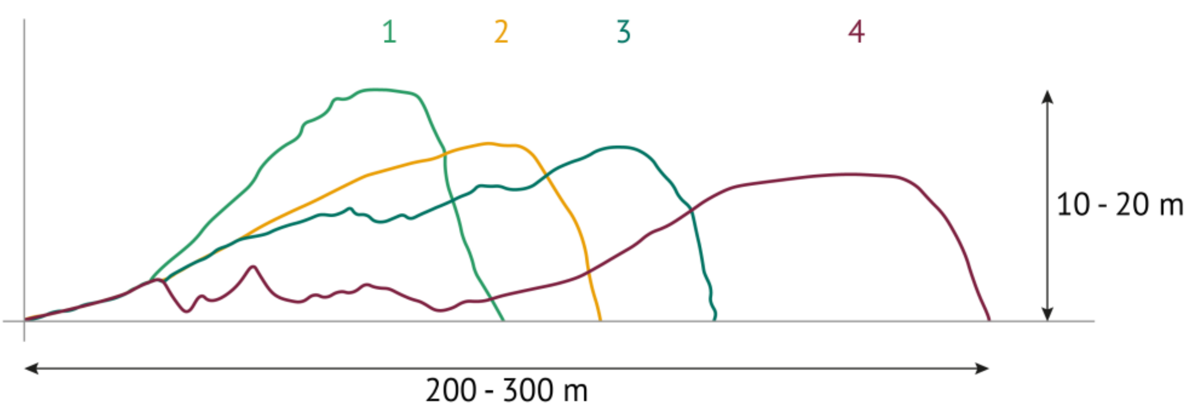

Figure 46. The development of a notch through time. Sea is to the left. Extend of the longest profile order 200-300m, height 10-20 m. (B. Arens)

For a natural notch, it begins with a blowout at the top of, or in the slope of the foredune. The blowout grows, eats into the slope of the foredune and in the meantime a depositional lobe is built up on the landward side. The blowout grows further and comes into contact with the beach: it becomes a notch. There is an erosive and an accumulative part. The axis of the erosive part is often not the same as the axis of the accumulative part. The notch grows. The moment the former wall of the blowout breaks through on the landward side, the notch can grow considerably further. If the process continues, the lobe may at some point become detached from the foredune and migrate further landward as an independent parabolic dune. That takes a lot of time. At the moment we don't see this happening anywhere: the oldest notches have been in development for about 25-30 years.

Many aspects are discussed in the (preliminary) design of notches. To date, active sand mobility has been induced in many different ways and spontaneous reactivations of dynamic processes have also occurred. To find out whether spontaneous formation is possible, you can look at the extent to which this already occurs in nearby foredune areas where maintenance has already ceased (for management, see: https://www.openearth.nl/coastviewer-static/).

Little is known about which key factors are decisive, what the ecological effects are and what defines a successful intervention. An inventory (Nijenhuis, 2022) of the notches constructed in the Netherlands shows that there is still a lot of uncertainty about the optimal shape of the notch. However, the matters described below are already clear.

6.5.1 Orientation

The notch openings should be positioned so that the wind can blow through them properly. For example, in the Netherlands, on coasts with a southwest to northwest exposure, west-southwest is optimal, because wind in the quarter from south to west often occurs with sufficient speed. On coasts that are more north-oriented, such as on the Wadden and in parts of the Delta, south to westerly winds contribute little to the development of the notch. Natural blowouts here usually form by wind from the northwest direction. Although northwest winds are less common than south to west winds, their frequency is apparently sufficient to develop notches. Northeast winds can also contribute to development here in the winter months. These winds are often accompanied by dry conditions and are therefore often able to transport sand. When a notch is constructed with an approximately northerly wind direction, the wind will probably further shape the notch in the correct direction, but only if the direction of the excavated notch is approximately correct. The notches at the Noordsvaarder on the barrier island of Terschelling show that two directly adjacent notches can have different directions, the northernmost lies due west-east, the southernmost lies northwest-southeast. Research in New Zealand (Nguyen et al., 2022) has shown that with small notches (width <10m), as soon as the angle between incident wind and the longitudinal axis of the notch is less than 27° , the wind accelerates through the notch. If the angle is greater than 27°, the wind actually slows down. Larger notches probably have a much more extreme influence on the direction of the wind. Based on the existing, autonomous notches in the Netherlands, it appears that all notches with a wind direction between north (on the north-exposed coasts of the Wadden) and southwest (along the rest of the coast) catch sufficient wind for their development. No autonomous notches can be found on the north-exposed coast in the Delta.

6.5.2 Shape in plan view

A trapezoid or funnel shape in viewed from above, where the notch is wide on the beach side and narrow at the top (towards the top of the foredune), encourages the funnelling of the wind. Figure 47 gives some examples of the contours of constructed notches, Figure 48 for autonomous notches in the Netherlands. Due to the trapezoidal shape the width of the notch reduces down wind, which accelerates the air flow in the notch and greatly increases sand transport. Beyond the dune ridge, the speeds decrease again and the sand is deposited. With less strong winds, the sand accumulates in front of the notch, with stronger winds it blows through the notch. De Kerf near Schoorl (top left Figure 47) is being closed by the development of embryonic dunes. What is striking about both figures is that the contours partly have a west-east orientation and partly a southwest-northeast orientation. The exception is Terschelling 2 (top right Figure 48) with a northwest-southeast orientation.

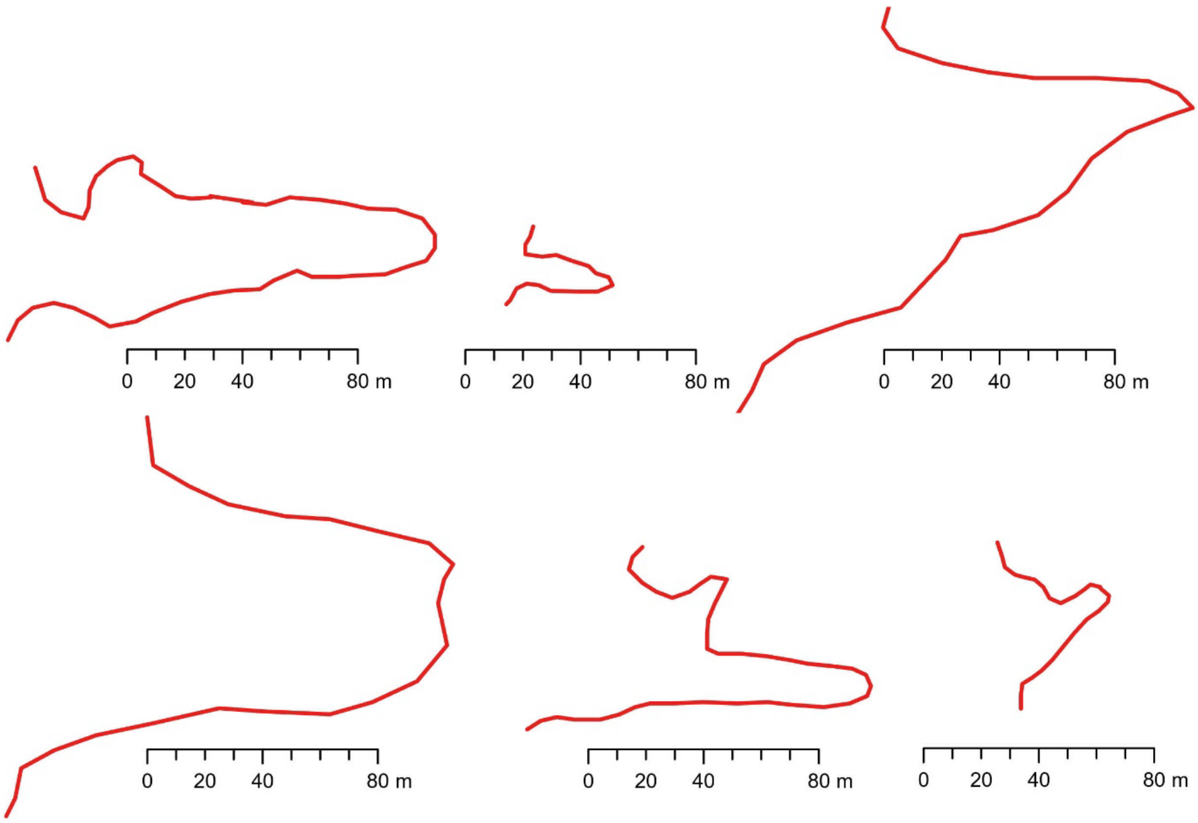

Figure 47. Contours in plan view of some constructed notches. From top left to bottom right: De Kerf Schoorl, Noordvoort, Northwest Nature Core 1 and 2, Meijendel, Schouwen. (Source: partly from Arens, 2022)

6.5.3 Width

The opening in the foredune, width, length and angle of inclination, vary considerably in practice. Basically, a larger notch allows more sand to pass through than a smaller one (Fortuijn, 2020). It is also expected that a large notch will be active longer than a small notch. The minimum width of the notch should be around 30 – 50 metres at the entrance. With notches with a width of less than 30 metres there is a risk that there is insufficient sand drift or that the notch will close again too quickly. In that case, new notches would have to be created repeatedly to achieve a permanent influence. In existing, constructed notches, the width varies from 5 metres to very large notches with a width of more than 100 metres. In the Netherlands, examples of areas with large notches are Schouwen and Terschelling (spontaneous) and the Northwest Nature Core (constructed) where the wide dunes offer good opportunities for large-scale sand drift.

It is not yet clear whether too large can also be unfavourable. If the opening is too large, the funnelling effect disappears, so that the wind no longer accelerates in the opening. It is not known at what size the effect of funnelling decreases (Wegman, Leenders & Arens, 2022).

6.5.4 Slope angles

In conversations with managers, it was stated several times that when excavation is limited, steep edges are important, so that the wind impacts directly on the steep wall and can therefore

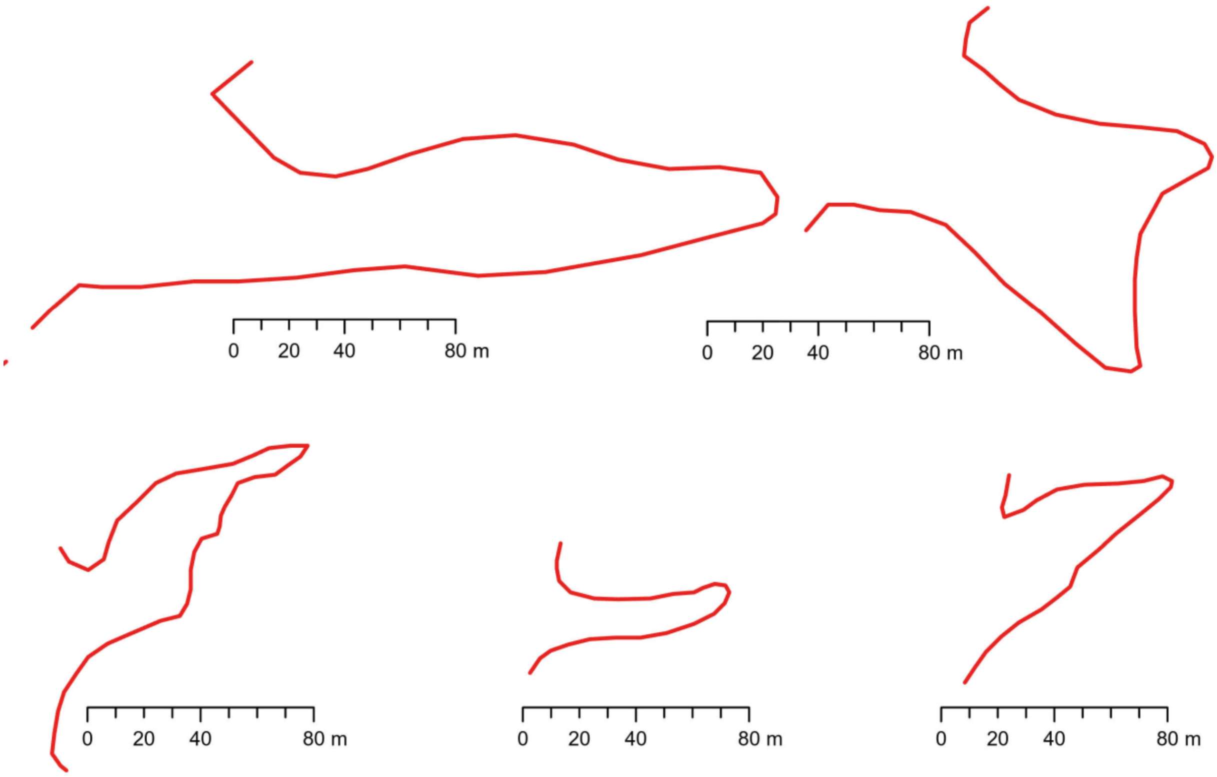

Figure 48. Contours in plan view of some autonomous notches. From top left to bottom right: Terschelling 1 and 2, NHD 1 and 2, Schouwen.

develop a greater erosive force. This has been applied, for example, to the notches in Meijendel and the blowouts at Noordvoort, where a maximum of 1-2 m has been excavated (Figure 49). In larger interventions such as in the Northwest Nature Core, the notches are constructed in a V-shaped (and ascending) profile (Figure 49). After construction, the V-shape was quickly transformed into a U-shape by wind erosion, with the steepness naturally increasing. The steepness of slopes within a notch is often determined by slumping; the bottom of the slope is then undermined by wind erosion, after which parts of the top regularly collapse. This is easily recognisable by the slumps of marram or other vegetation that are spread over the slope (Figure 50).

Figure 49 shows the difference in excavation depth and the ultimate effect on development for Noordvoort and the Northwest Nature Core. At Noordvoort the excavation depth was limited, but was enough to initiate blowout development. The wind then did most of the excavation work, lowering the surface by approximately 7m in 8 years and in some cases the blowouts have grown all the way to the beach. A deep trench was immediately created in the Northwest Nature Core, with approximately 14 metres excavated, also with the aim to eradicate vital marram roots.

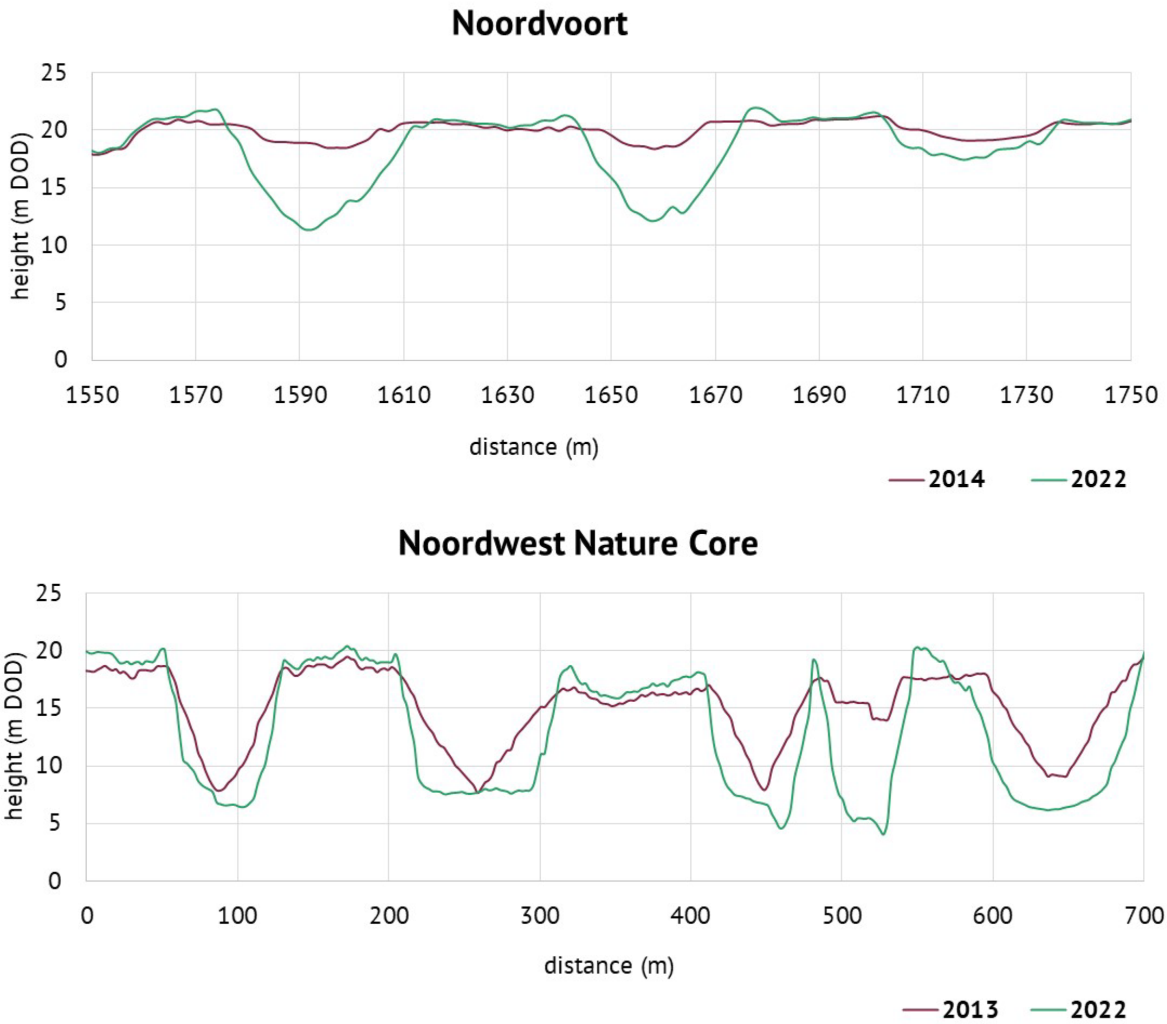

Figure 49. Difference in excavation depth at Noordvoort and the Northwest Nature Core. 2013/2014 immediately after the procedure, 2022 current situation. Y-axis: height (m NAP), X-axis: distance from reference point (m.)

Figure 50. Deposition on a slope that is undermined by wind erosion. NHD, March 2022. (Photo: B. Arens)

Even then, some marram roots were still present in the bottom of some of the notches. Note that two completely different approaches were followed at Noordvoort and the Northwest Nature Core, with not significantly different results. It makes quite a difference to your intervention: deep excavations, or just a little.
If you create a notch in one go, a deep V-shaped profile releases considerably less sand than a U-shaped profile (Figure 49).

Figure 51 shows some examples of cross-sections of different notches in the Dutch coast. The width varies from about 15 metres at the Seven Sisters (3 years after the intervention) to more than 60 metres on Terschelling. The angles of inclination are similar. All 'large' notches show steady growth along the longitudinal axis, sometimes linear, sometimes increasingly rapid. There is no constant growth, sometimes it shrinks, sometimes it expands, but the trends are clear (Figure 52).

6.5.5 Connection to the beach

The connection with the beach is an essential factor, because it determines the accessibility of the notch for sand supply from the beach. If dune formation occurs in front of the foredune or if the threshold height is too high, or if there are other obstacles, large-scale sand transport through the notch towards the hinterland will not occur. An eroding coast therefore provides a better starting position than an accreting coast (Arens, Geelen, Hagen & Slings, 2007), because the entrance to the notch is always kept free through erosion and the chance of embryonic dunes being formed is small. A gradual upward slope from the beach to the dune ridge is desirable. An important aspect in many places is the maximum depth compared to the original profile to which a notch may extend as part of the conditions imposed by the flood defence

manager. Discuss this carefully, when this applies to your coast. The interpretation must be unambiguous. An agreement could, for example, be that in the dune ridges around the notch the height will not be lower than +7m MSL anywhere so that there is closed 7m MSL elevation line around the notch. It must be especially clear where the minimum height may be reached. At the entrance the height may be much lower, but if further landward in the profile the height increases to above 7m MSL then this does not have to be a problem.
Figure 53 shows a longitudinal height profile of a number of notches. Using the most recent height maps, lines have been drawn in ArcGIS from beach to back dune, through the centre of the notch. In all cases the longitudinal profile is a continuous profile, with a maximum height in the notch above +10m NAP. For comparison, a reference profile is also indicated for all situations of a closed part of the foredune, adjacent to the notch. The longitudinal profile of the notch on Schouwen is from one of the two constructed notches. What is striking is the threshold at the entrance here, which can be seen in the figure by the increasing height to almost +10m NAP at the beginning of the profile, followed by a reduction downwind. This threshold causes stagnation in the development of the notch. There is probably a harder layer here, possibly a remnant of an older reinforcement.

6.5.6 Deposition zones

A large quantity (up to at least 30m^3/m per year and probably more) of sand can reach the hinterland through the notches. This will partly take the form of the deposition of a sand lobe with relatively calcareous fresh sand, where vegetation can be completely buried. This implies

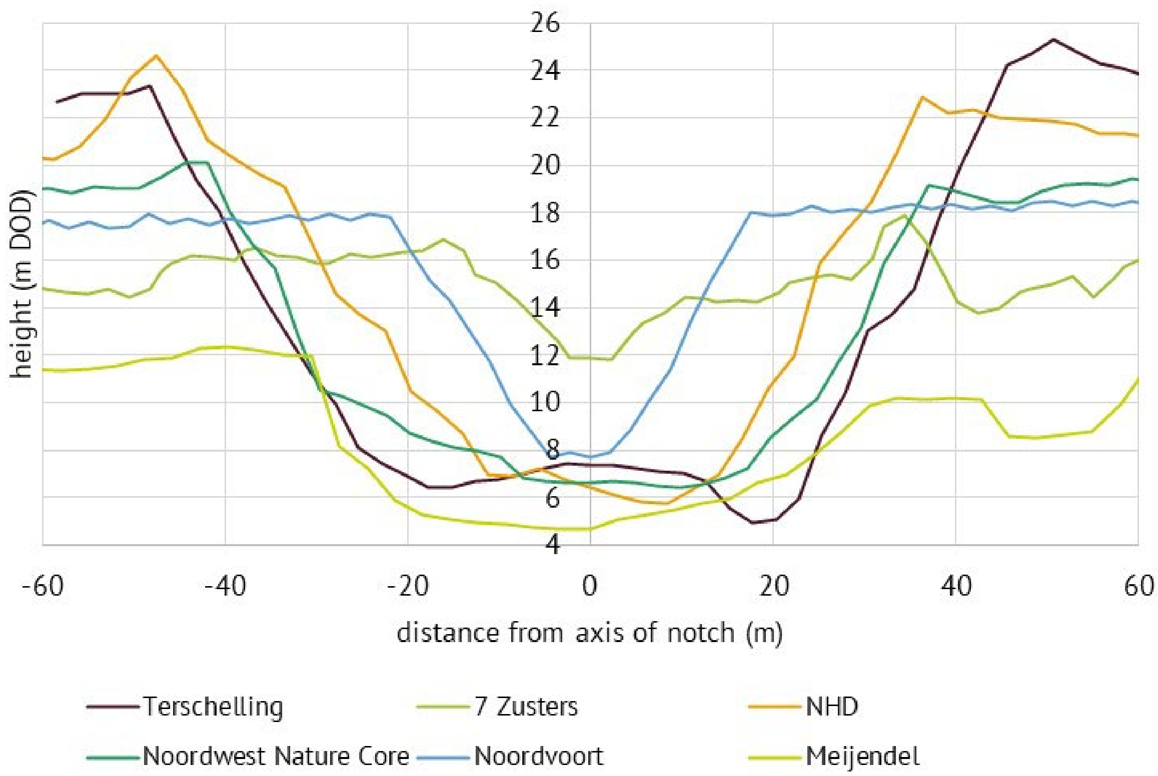

Figure 51. Cross profiles through different notches. Y-axis: altitude (m NAP)

that existing white dunes are given a rejuvenation treatment. Also, new white dunes are formed slightly inland where a different habitat existed. Sand drift within the foredune can lead to a significant increase in height. In the notch in Figure 20, winds from the southwest blow some of the sand from the notch against the slope and deposit it on the top, which has therefore grown enormously. The difference in height between this dune top and the sand dike is clearly visible in Figure 54. Deposition behind the top usually creates a slope that adopts the natural angle of repose of sand (approximately 33°). A dense growth of marram can then develop on this.

When blown from the foredune, a large part of the sand is further spread through the air and is deposited over the area as a thin layer of calcareous sand (sand rain). During severe storms, sand can be transported far into the hinterland. In general, this zone is approximately one kilometre wide, but there is evidence that it can go much further, especially if there are no major obstacles such as trees or buildings in the way. This is not only something concerning natural values

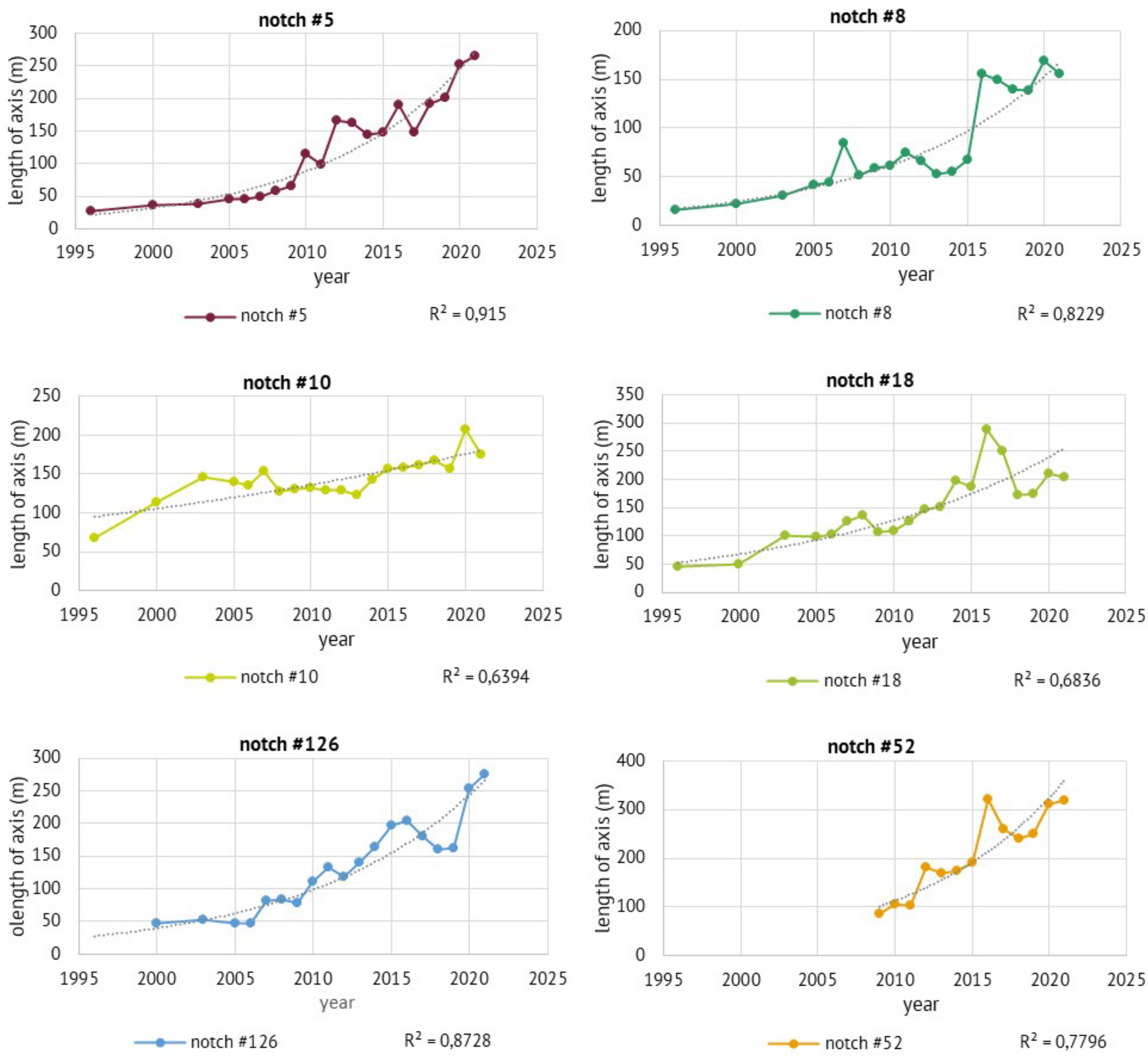

Figure 52. Examples of how the longitudinal axes of the notches in the North Holland Dune Reserve develop over time. The Y-axis gives the length of the axis through the middle of a notch, the X-axis gives the year, starting with the first year of existence of the specific notch. (Source: partly from Arens, 2022a)

(rejuvenation of grey dunes), but also concerning sand nuisance. For example, at the Sand Motor sand ended up on the balconies of flats in Kijkduin, 1.5 km away. Up to now, our knowledge is insufficient to accurately estimate the volume of sand that ends up at greater distances. The surface area served by sand rain can cover ten hectares, but because the average sand cover is much less than 1mm, the total volume is limited. Compared to the amount of sand that is deposited directly around a notch, this will be negligible.

6.5.7 Sand supply

A notch is intended to provide a conduit for sand; the place where sand from the beach can drift inwards. Sand must therefore be available. In the Netherlands the supply of sand on the beach is strongly influenced by nourishments, but on the Wadden Islands and in the Delta, for example, also by the connection to sandbanks (when a bridge forms between the coast and an offshore

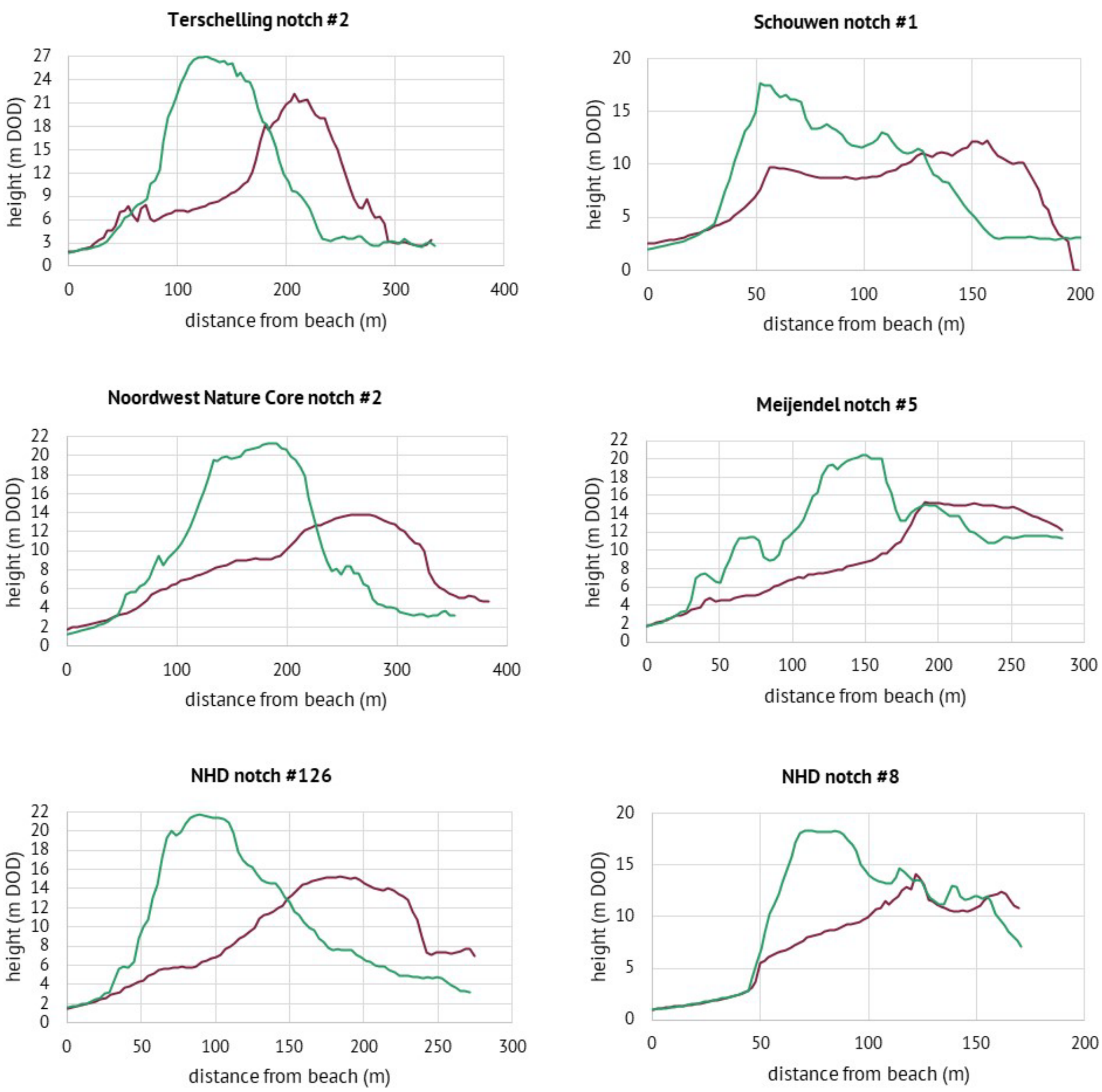

Figure 53. Longitudinal profiles through some notches (blue) and adjacent reference foredune (red). Y-axis: height (m NAP), X-axis: distance from reference point (m). (Source: partly from Arens, B., 2022a, b, c)

Figure 54. Strong increase in height of the dune at the blowout at post 20 Terschelling; compare the original height of the drift dike at the top left. (Photo: A.P. Oost)

sand bank it allows a vast volume of sand to reach the beach). A subtle balance is needed, which is not yet well understood. When do embryonic dunes form that hinder the development of the notch? When does this sand drift through the notch in large quantities? We know little about that yet. In any case, it is a good idea to consult with the local authorities about plans for nourishments (see also section 5.2.2). If the sand transport through a constructed notch is disappointing, the situation could perhaps be improved with a small supply of sand via nourishment.

6.5.8 Remove roots

Living and dead roots of vegetation can seriously hinder sand drift. Remaining living roots of, among others, marram, dune reed (*Calamagrostis epigejos*), sea buckthorn, dewberry and dune fescue (*Festuca rubra*) can lead to rapid regrowth and stabilisation. But dead root material left behind, or exposed by wind blow, can also lead to local stabilisation of drifting sand.

Marram is able to form wide horizontal root mats, but also to keep up with a metre of sand burial a year by growing vertically and then expanding horizontally again. The deeper roots can still be vital. To find out whether you need to take multiple root layers into account, it is wise to look at how the foredune has developed. Where no sand formation has occurred for a long time, the root layer will become lignified and it is not necessary to take into account deeper root layers that can come back to life. Where the foredune has been raised by ongoing sand accumulation, several still viable root mats may occur at different depths. In the Netherlands, Rijkswaterstaat has data on height changes in the foredune since 1965. Until 1997, this was done at with coast-normal transects every 200-250m (the Jarkusraaien). Since 1997, the information is full-coverage (Lidar). You can check whether there are still root mats at greater depths by drilling or digging a test trench. Vegetation recordings and aerial photographs can be used to determine whether there is long-term vegetation with sea buckthorn or marram.

There are many types of grass whose viable roots can break apart into smaller pieces and come back to life. Non-living roots can also hinder sand drift. It is important to remove these roots during notch construction and also when they are exposed by wind erosion and cover the surface or when they re-grow from fragments. Old roots of shrubs often still emerge, especially at former erosive coasts. Reed normally grows in wet conditions, but can grow considerably taller due to sand drift and can thus keep up with burial. That is why you sometimes find reed vegetation on a strongly drifting dune (Figure 56). The roots will then be present deep into the soil.

In places where shrubs are removed, but where drifting does not start properly, marram grass can appear en masse (Dune Conservation Foundation, 2020). Shrubs such as sea buckthorn can keep pace with sand burial. Roots of shrubs are often still viable and must be removed as much

Figure 5547. Terschelling: two months after removing and loosening the roots, the marram is growing again. (Photo: M. Nijenhuis)

Figure 56. Reeds on the dune. March 2021, Terschelling pole 15-20. (Photo: B. Arens)

as possible, but during any intervention some of the roots usually remain in the soil. When removing sea buckthorn and dewberry, (a lot of) follow-up management is required to keep the sand drift going. This usually implies an annual task to remove re-sprouted or exposed roots. Coverage of 10-15% of roots can be enough to stop sand transport.

Ideally, you look for locations where the amount of roots at depth is limited. In practice, this could mean that locations that are suitable from other points of view are discarded. If root depth proves to be aproblem, intensive aftercare must be taken into account. Sometimes this can be solved by involving local volunteers.

Removing roots during excavation is an important measure. This can be done in various ways, but specifically for sand drift projects, so-called 'grizzling' is often used. This involves scraping the soil with a large rake (called a grizzle in Dutch), with tines of 1 metre depth, to remove as many roots as possible from the soil. Research at Meijendel showed that this is indeed an effective method for removing roots. This is especially the case with sea buckthorn. In marram it appears to be highly dependent on the density of the root system (Arens, 2021). In addition, marram often roots vertically and the tines of the grizzle may pass between the roots. On Ameland, experiments were therefore carried out with a rake with cutting blades, which also cuts through the vertical roots. This seems to have a positive effect (F. Zwart, personal communication, June 9, 2022). Removal of plant roots is also an important aspect of follow-up management.

Figure 57. Leeward side of an artificial notch in the Springertduinen, Goeree, where the sand from the notch has been pushed backwards. The sand pushed back assumes a natural slope angle. (Photo: B. Arens)

In addition to roots, blowout debris and ammunition remains can hinder deflation and sand transport. This will also have to be removed during subsequent management. It is not always easy to estimate whether debris remains are present in the soil. Keep in mind that this can sometimes lead to nasty surprises. For details on follow-up management, see Chapter 9.

6.5.9 Other design aspects

A relatively simple way of creating a notch is to push the sand back at the location of the intended notch. The landward side of the foredune is usually quite steep. If you push the sand down here, it will fall down like a landfill. As the notch develops, the deposition lobe will expand along this slope and gradually bury the artificial slope, transforming it into a natural slope. The procedure can therefore be performed relatively simply. No sand needs to be removed and the impact on the landscape in the sense of the construction of artificial elements is limited to the erosive form of the notch, where sand is pushed away. This approach has recently been applied in the Springert dunes on Goeree (Figure 57) and previously on a smaller scale on Ameland.

6.6 Rolling foredune

38 If you want a rolling dune, make enough notches next to each other, and take into account a relatively long period of momentum

Extreme measures must be applied to create a rolling foredune which is one type of transgressive dune where the sand is mostly contained within the original ridge as it moves landwards, though sometimes growing or reducing in size. We know from the past that a large

Figure 58. Rolling foredune at the Zandloper, North-Holland, October 15, 1990. A large number of notches have been dug on the foredune in a south-westerly direction. At the top and back (middle and bottom of the photo) the sand fences are visible that capture the sand in a controlled manner to guarantee a closed row of dunes. (Photo: Rijkswaterstaat)

number of notches next to each other can set the foredune as a whole in motion. As we already saw in section 1.2.7, this was applied in the past, among other sites, in the north of North Holland (Figure 58). A large number of trenches were dug here in a south-westerly direction and close together. The deposition of wind-blown sand was controlled with sand fences. A similar intervention was carried out on Terschelling between beach poles 15 and 20. Here the deposition was not controlled, causing a completely new dune landscape to develop over the years. The inner dune edge of this new landscape is situated approximately 400m landward from the original dune base. Also new dunes formed in the deflated zone, thus increasing the sand mass significantly. New relief has been formed up to this point. Further landward the surface has been covered by sand rain, but this has not led to new relief here. This fairly limited distance is probably related to the orientation of the coast, west-southwest to east-northeast, as a result of which the frequent west and south-west winds did not blow sand inward, but rather seaward. The landward expansion had to come from northwest to northeast winds that blow much less frequently (see also section 3.1 and Figure 20).

Figure 59. Parabolizing foredune in the Northwest Nature Core, South Kennemerland. The reactivated parabolas of Houtglop and Wieringen are also visible in the background on the left. The lobes from the notches are partly already in contact with the reactivated The lobes from the notches are partly already in contact with the reactivated parabolas. (Photo: Beeldmateriaal Nederland)

6.7 Foredune with parabolic dunes

39 If you want a foredune with migrating parabolic dunes you need a lot of space and a lot of patience

Such a development takes a lot of time, estimated to be at least 25 years. To create a parabolic foredune, several large notches must be constructed next to each other, and then time will tell whether the notches develop in such a way that they indeed grow into parabolic dunes. There is no experience with the construction yet, because the development time of various projects is not yet long enough. At the Northwest Nature Core, the hope is that the notches will develop into a series of parabolic dunes. The notches are so active that the deposition lobes have sometimes already reached a considerable height of more than 15 m NAP and extend far into the underlying dune valleys (Figure 59).

7 Implementation

40 **Involve the people and arrange information you need to implement the project in a timely manner**

7.1 Introduction

After all the previous steps, it should be clear how you want to shape sand drift in your area. Objectives are clear, the location has been found suitable and you have a plan that you want to realise. It is time for the next phase, where the intervention will be worked out in concrete terms; from preliminary design to final design to actual implementation. Take a good look within your organisation for possible supporting documents about project management. And do that at an early stage; Good preparation reduces the chance that you will forget things. Make sure you do not start performing too quickly and forget steps in the preparation.

The steps described below are all based on the current situation in the Netherlands (2022). This will change in the future, especially when a new environmental law comes into effect. The intention is to update this chapter regularly for the Netherlands. Although similar steps and procedures will be necessary in other countries it may be useful to see the Dutch approach in some detail.

7.2 Do it yourself or outsource it

41 **Choose what to do yourself and what to outsource. Good outsourcing takes time, but this way you avoid problems during implementation**

The first question is what you do yourself and what you will outsource. In many organisations, various steps in the project, such as making a preliminary design or developing specifications, are awarded to consultancies. Sometimes they also supervise the entire implementation, including management and permit applications. The choice of what you keep in your own hands or outsource to an engineering firm depends on the available capacity and finances, but also how confident you are of the successful outcome if you outsource it or how confident you feel about carrying it out yourself.

Various organisations are in the habit of drawing up a tender strategy in preparation, together with a purchasing advisor. What do you want to make, which type of contract (specifications is only one form) is appropriate, what can and cannot be recorded in it and which tender procedure form do you choose (also depending on the procurement laws)? If you work this out well in advance, which does take time, you are less likely to have problems later. Good planning is therefore crucial.

7.3 Financing

42 When considering financing consider all the necessary steps from preliminary research to post-management

One of the preconditions for getting started is financing. In many cases this is also necessary for the entire preparation; just think of all the preliminary research. It is wise not to start a project if there is no clear overview of implementation funds. And not to start implementation if there is no prospect of management money if necessary. It is extremely important not to forget about the costs of monitoring and after-management. In summary, this concerns the following points:

- preliminary investigation
- preliminary design, final design and specifications
- the actual intervention
- staffing preparation and implementation including communication
- monitoring and evaluation
- follow-up management

It is good to see whether combinations with other objectives are possible (making work with work) to reduce costs, such as re-using released material. Released soil can, for example, be used for the restoration of management/walking paths in the area. And it is important to see whether you can realise an integrated approach with a combination of objectives with other sources of financing.

The costs of deploying a steward (project manager) and the legal consequences of a project can be considerable. Particularly in the case of externally financed projects, it is desirable to identify these costs at an early stage and include them in a budget and financing application. Experience has shown that these costs are often not budgeted and the organisation often bears the significant costs itself.

7.4 Permits

43 Carry out a permit scan at an early stage, i.e. prior to the implementation phase itself

A lot can go wrong, especially when applying for permits and permissions too late or not applying for enough permits. In your preparation it is very important to do a permit scan; carefully check which permits are required and from which authorities they must be applied for. It is wise to organise preliminary consultations with the various competent authorities so that they know what you plan to do. They can indicate how they interpret the work in relation to their competence and what is required (including which investigations you must have carried out) to obtain permission for this.

If you only take this step in the implementation phase, you will be too late. You need to know which documents (detailed to what level) you need to apply for the various permits and exemptions. Some permits take a lot of time and it can (probably) be different in every municipality, province, water board or national government. If you do the scan early, you will also know what research you need and what your planning phase will look like.

Consultation with the water board in particular is very important in the planning process. As a nature manager, explain your goals carefully and, together with the flood defence manager, look at how the goals can be achieved and adjusted if necessary. The water board cannot simply grant a permit for projects that promote sand drift, but must first formulate policy about it itself. Sometimes it is necessary for them to become the initiator of the project in order to obtain permission for the measures. The preconditions are set by the flood defence manager, for example with regard to the minimum depth. Is it the lowest point within a notch? Or the lowest point within a continuous profile from the beach through the notch to the depositional lobe? Or around the lowest point in a closed dune ridge that borders the notch? These are completely different views on minimal depth. To avoid misunderstandings, it is essential that your vision matches that of the water board. The permitted depth often varies per location depending on expected storm surge heights and wave conditions.

A Nature Management Exemption Act is not necessary if the measure in a Natura 2000 area is included in the existing Natura 2000 management plan. However, this does not absolve you from the duty of care under the Nature Conservation Act. The existing natural values (species and habitats) will therefore have to be identified, as well as the possible effects that the measures have on these natural values. Any measures to mitigate these effects therefore remain in force. By drawing up a Nature Assessment you gain insight into possible effects and mitigating measures. What exactly the contractor should do with this must then be translated into an ecological work protocol. This protocol is indispensable for careful implementation.

How you deal with natural values and how you record them may differ per province. In North Holland, for example, they make an activity plan and conduct nature research to demonstrate that they do not cause significant damage. This has been agreed with the environmental agency and the province. At the same time, it is very important that you coordinate well with the municipality and that you already have the information when you apply for an environmental permit. Because otherwise the municipality (one-stop shop principle) will start working on the Nature Conservation Act itself. Many municipalities do not know enough about this and would therefore rather not do so.

Possible other studies that may be relevant:

- Archaeological research. The zoning plan includes sites for the various areas in the municipalities where archaeological values may be present in the subsurface. Planning rules include conditions at which excavation depth a preliminary archaeological investigation is required in order to grant an environmental permit.
- Preliminary investigation into explosive remnants of war. Under the Working Conditions Act, the client has a responsibility to ensure that the executing party can carry out the work safely. If there are indications of military activity, and this is often the case in dune areas, a preliminary investigation into explosive remains must be carried out. If the excavation locations are classified as suspicious areas, the actual detection and approach can be included in the contract and carried out via the contractor. There are options to obtain a subsidy for this through the municipality. It is good to discuss this with the municipality in the preliminary stages.
- Nature and landscape values. Some municipalities have included separate zoning in their adopted spatial plan (bestemmingsplan in Dutch), which requires advice on the damage to nature and landscape values in order to issue a permit.

7.5 From sketch to specifications and contract

44 Start early to go through all these different steps

In most cases we work from a sketch design to a preliminary design. The preliminary design is translated into a final design, which serves as the basis for the specifications.

In the specifications phase, consideration must be given to, for example, the type of machines that will be used and the access routes through the site. How you structure a specification and how much room you leave for solutions chosen by the contractor is very important. Too little attention is often paid to this phase and complaints arise during the actual implementation that things should be done differently. That causes a lot of tension and additional costs. The specifications are the contract with the contractor and any changes will have financial consequences.

Depending on the scope of the work, a choice must be made for the form of contract. You have different options.

- A work description with a compact description of the activities. This form of contract is suitable for small-scale work that can be calculated on an hourly basis.
- A RAW specification in which the measures are detailed in specification items. RAW is a system of legal, administrative and technical conditions used in the Netherlands for drawing up contracts in the civil engineering sector. This form of contract is suitable if it is clear exactly what actions the contractor must carry out to achieve the desired result. If a multiple

private or public tender procedure is to be followed, this contract form is preferred. It also facilitates easy comparison of the offers.

- For very large projects, a design and build contract form can be chosen (UAV-GC 2005 in the Netherlands). Part of the development of the design and possibly part of conditioning studies can be added to the contract. This contract form is suitable for large-scale projects where the implementation risks are estimated as high, or where possible reuse of released materials could result in significant cost savings. At an early stage, the implementing party, which has a better view of the market for reuse of these materials, is at the table.

When choosing the tendering method, it is also important to take into account the tendering policy of the subsidising parties. Sometimes subsidy conditions are included regarding the method of tendering. In summary, there are the following phases:

- Design sketch (measures and first cost estimate).
- Convert design sketch into final design
- Translate final design into specifications
- Outsourcing
- Award work to contractors through tender process

7.6 Role of contractor

45 The role of the contractor is important and good project management is essential

The role of the contractor is quite large. The flexibility and ability for a contractor to deviate from the specifications or original plan is of great importance. Several project managers indicate that adjustments need to be made during the work, because practice sometimes turns out differently (for example, a location turns out to be inaccessible). Failure to make adjustments can then hinder the success of the project. But as mentioned, adjustments may be associated with additional costs.

It is essential that good project management is also guaranteed during this process and that agreements have been made in advance about roles (i.e. who manages and supervises and if you take a role you must also be available). In all cases, it is important that on days when earth moving is taking place, someone on behalf of the project manager is present or at least available for consultation. Field managers can play a good role in the quality control of outdoor work. However, when adjustments have financial consequences, this must always be done via the project manager (i.e. the person with overall responsibility). What works well is to include an explanation of the ecological work protocol in the contract. The managers and the ecologist can then provide an explanation of what the contractor must take into account during implementation. At the same time, agreements can be made about the roles and responsibilities of the people involved. Close cooperation usually makes it easier to find a good solution to the problems that arise.

Figure 60. Construction of one of the Seven Brothers, Noordvoort. (Photo: M. Wiltink , Waternet)

Given the nature of the work and the work area, contractors who are familiar with carrying out nature management work are preferred. One contractor has much more feeling for working in nature than the other. Some people can effortlessly imitate natural shapes, while others prefer to work with more engineered forms. Two strategies are possible for managing the contractor:

1. A flexible contractor who, in consultation with the manager, seeks solutions to problems on site;
2. A well-thought-out specification in advance in which the exact earthworks are recorded in GIS and are followed by the contractor.

Furthermore, it is important to stipulate that machines which are used are not contaminated by work at another site, with, for instance, seeds of invasive species. Make an agreement in advance with the contractor that additional work will only be paid if agreement has been reached in advance.

7.7 Support base

46 Continue communicating during implementation

Continue to communicate well with stakeholders, residents and visitors during implementation. Inform them, because only at the moment the 'shovel hits the ground' do people become alert. Surprises may also occur during the works that need communication (e.g. taking longer than expected, beach crossing temporarily unusable). Suggestions for promoting support include organising information meetings and/or excursions and informing local press and use of other (social) media.

7.8 Climate-neutral and nitrogen-neutral implementation

47 Pursue climate and nitrogen neutrality

In these times it is no longer defensible for implementation of a nature improvement process not to be climate and nitrogen neutral, even if this is not necessary. Many contractors are already working to offer such services. Unfortunately, practice shows that working with electric vehicles, for example, is not easy. Often sites are quite far away from any electric charging point. That being said, more and more efficient electric vehicles are becoming available.

Perhaps climate-neutral work can also be ensured in one's own management area, for example through tree planting, as long as this does not take place in naturally open landscapes. After all, dynamism is intended to maintain open landscapes and it would be contradictory to undertake tree planting as compensation. You must carefully investigate whether locations do not already fall within other compensation tasks. Nature managers are frequently asked for locations for carbon compensation.

7.9 Timing

48 Choose the work dates wisely

When do you carry out the work? First of all, look at the seasons. Work should preferably not be carried out during the breeding season. So work will often start after September 1. Please note that work may be delayed due to bad weather during the storm season. Anticipate this by making agreements about delays and discussing all possible delay scenarios. You must also look, as mentioned earlier, at the relationship with sand nourishment plans; you don't want your new expensive notch to be stabilised again by a new growth of embryo dunes.

7.10 Removing roots

49 Please note that removing remaining roots can be a significant expense

The measures taken or work carried out may differ. It is often a combination of removing vegetation, sods (organic turf), excavating and removing roots. As described earlier, sufficient removal or damage of roots appears to determine the level of sand drift that occurs and the degree of aftercare required. If more sand has been excavated (so fewer roots are present) or the soil has been sufficiently prepared (by loosening the soil when looking for ammunition and then harrowing), roots of existing vegetation have less chance of sprouting again. Removing roots is expensive and may need to be adjusted during the job because there are fewer or more roots than originally expected. In practice, however, it usually turns out to be more. So, it is therefore good to reserve sufficient budget for this.

Figure 61. During the interventions on Vlieland, a wheatear box was installed for compensation of damage due to the work. (Photo: M. Nijenhuis)

7.10.1 What to do with excavated sods and sand

50 **Dealing with excavated material**

During work, sods (vegetated upper layer with organic enriched sand), and sand usually become available and the question is where to put it. Agreements about this must be made with the flood defence manager. Leaving it up to the contractor is the first choice. They then have to come up with a solution for the material. If they see market value in it, this could have a positive effect on the registration price.

Sometimes removal is not an option because the water board wants to maintain the sand volume in the dune area and requires that the released material remains within the same zoning of the flood defence. It is good to look at this in the preliminary phase with the water board and to include this as a requirement in the design. If the soil is contaminated, you need to know this in advance and also know what you can do with the material. In the Netherlands the risk of contamination with PFAS (per- and poly-fluorinated substances) in the foredunes is high. Consideration must be given in advance about what to do with soil contaminated by PFAS. Subsidy regulations may also state that the subsidy given may not be used for contaminated soil. So it is important to check in advance whether you can carry out your project with the available project money if there is pollution.

In practice, it may prove more difficult to place the remaining plant material or sand exactly at the planned location, for example because the distance is greater than expected or the access route to it turns out to be impassable or too steep for the machines.

Finally, it is also important to ensure that the relief is affected as little as possible when processing the material locally. You can plan processing locations in such a way that they will be overblown by sand after implementation and thus become less noticeable in the landscape.

7.11 Taking mitigating measures

51 Sometimes mitigating measures are necessary

Sometimes mitigating measures must be taken because the project can also have negative effects on certain species or habitat types. An example of this is the installation of breeding boxes for wheatears after work in its habitat (see Figure 61). On Vlieland, it preferred old rabbit holes close to the installed nest boxes. In the Vogelduin (PWN area), it successfully nested in nest boxes installed in 2022.

8 Monitoring and evaluation

52 What do you want to know and what are you going to measure?

Monitoring serves two purposes. On the one hand, monitoring is done to determine whether you have achieved your goals. The response of the dynamics to the intervention usually becomes visible within a number of years. Effects on ecological development can be much slower. Effects of sand rain with calcareous sand on grey dunes are usually only visible after a longer period. Monitoring of ecological effects will therefore usually cover a period of at least 5-10 years. Since the effects of aeolian processes also have an effect on longer time scales, evaluation milestones after even longer periods, of the order of 25-50 years, must also be taken into account.

On the other hand, monitoring serves to make interim adjustments if necessary and to see whether follow-up management is necessary. If sprouting roots are going to hinder sand drift, you want to know this as soon as the problem starts to occur, not just after 5 years. Only then can you respond adequately and prevent stabilisation from having already started.

8.1 Monitoring abiotic, biotic and anthropogenic parameters

53 Start measuring before the project is carried out

Research into existing sand drift projects shows that relatively little has been learned from the interventions, because it has not always been considered in advance how the project should be evaluated and what kind of monitoring is required for this. That is a shame, because you want to be able to learn from one intervention to make the next one even better. It is also valuable for other managers to learn from projects carried out in other areas. What you monitor naturally depends primarily on your goals, but a standard part of any monitoring should be whether the implementation has been effective.

A clear monitoring program must be drawn up in advance, based on the objectives and evaluation questions. With good monitoring, baseline measurements are taken before the intervention to record the starting situation as it existed before the intervention (this should also include areas expected to be influenced by sand rain). For the morphology and monitoring of dynamics, the zero situation point T0 is the situation immediately after completion of the project in the areas directly affected by interventions. But for flora and fauna, the starting situation must be recorded before the intervention. This is necessary because during execution, sand drift can already start and the vegetated periphery can become covered with sand. In full monitoring, in addition to the project area, any changes in nearby reference areas are also examined to determine whether changes observed in the project area are also observed in the reference areas and are then probably not related to the interventions.

Ideally, monitoring is based on the BACI concept:

- Before : the situation before intervention
- After : the situation after intervention
- Control: the situation in the reference areas
- Impact: the situation in the project area

Good monitoring is complex. Which parameters do you have to measure? Do you also measure process variables? How often and for how long should you measure? Ideally, all these questions are already worked out in a monitoring plan when designing your interventions. In any case, the more you measure, the better you can understand changes and link them to the intervention. For example, you can only measure the vegetation type and see how that changes, but you can also measure the degree of sand drift and investigate whether the differences you measure can explain the differences in the vegetation. In general, the more you want to explain, the more expensive and complex the monitoring becomes. If it mainly concerns just noting a desired development, it is simpler and cheaper (but also less interesting). So here too, think carefully about what you want to know and learn.

Thanks to monitoring, undesirable developments can be responded to at an early stage. Confidence in the project can also be increased because information about the process and developments can be shared with the public. Finally, it provides insight into the extent to which the project objectives are being achieved. This also provides insight into any success and failure factors, which can be taken into account in the future for follow-up measures in adjacent areas.

The monitoring of already implemented projects is very diverse. There are various projects where monitoring is an important part of the entire project. Both abiotic factors (usually the degree of sand drift and height changes, sometimes also hydrology) and the development of the biotic factors are examined. Good examples of this are Schoorl (see Figure 62), Schouwen, Noordvoort and the Northwest Nature Core. In addition, there is often reactive monitoring of anthropogenic factors, such as burial of cycle paths or nuisance caused of sand drift near buildings. However, it is important that you also think about these factors in advance. What are the possible effects for stakeholders in the area and how will you monitor dangerous developments (e.g. high steep sand walls, new exposure of ammunition) or nuisance situations?

Points of attention are:

- What should I monitor to investigate whether my goals are being achieved?
- How extensively do I want to/can I monitor?
- What detail can I go into?
- Do I also want to measure changes in the preconditions?
- Do I also want to measure process variables?
- Do I want to point out or also explain?
- How many T0 moments should I measure before the procedure?

- What should I monitor to determine whether follow-up management is necessary?
- What are possible effects for stakeholders in the area and how will you monitor dangerous or nuisance situations?
- What can be managed in-house and what must be outsourced?
- How do I ensure that long-term monitoring is carried out consistently (i.e. not agency A recording the vegetation in such a way in 2026 and agency B doing it the other way in 2030)?

It is important to carefully consider the following matters in advance during all this monitoring. What is the purpose of your monitoring? What are you going to monitor? How often is useful? How far in advance do you start measuring? Who will interpret the results? What and where will you report? Can you co-finance the costs of monitoring for a number of years in your project? Compared to the costs of the intervention, the cost for monitoring is small and adds little to the total project costs. But although the costs for monitoring are limited, it is often very difficult to find the budget after finishing the intervention part of the project.

The abiotic, biotic and anthropogenic factors are further elaborated in the following paragraphs.

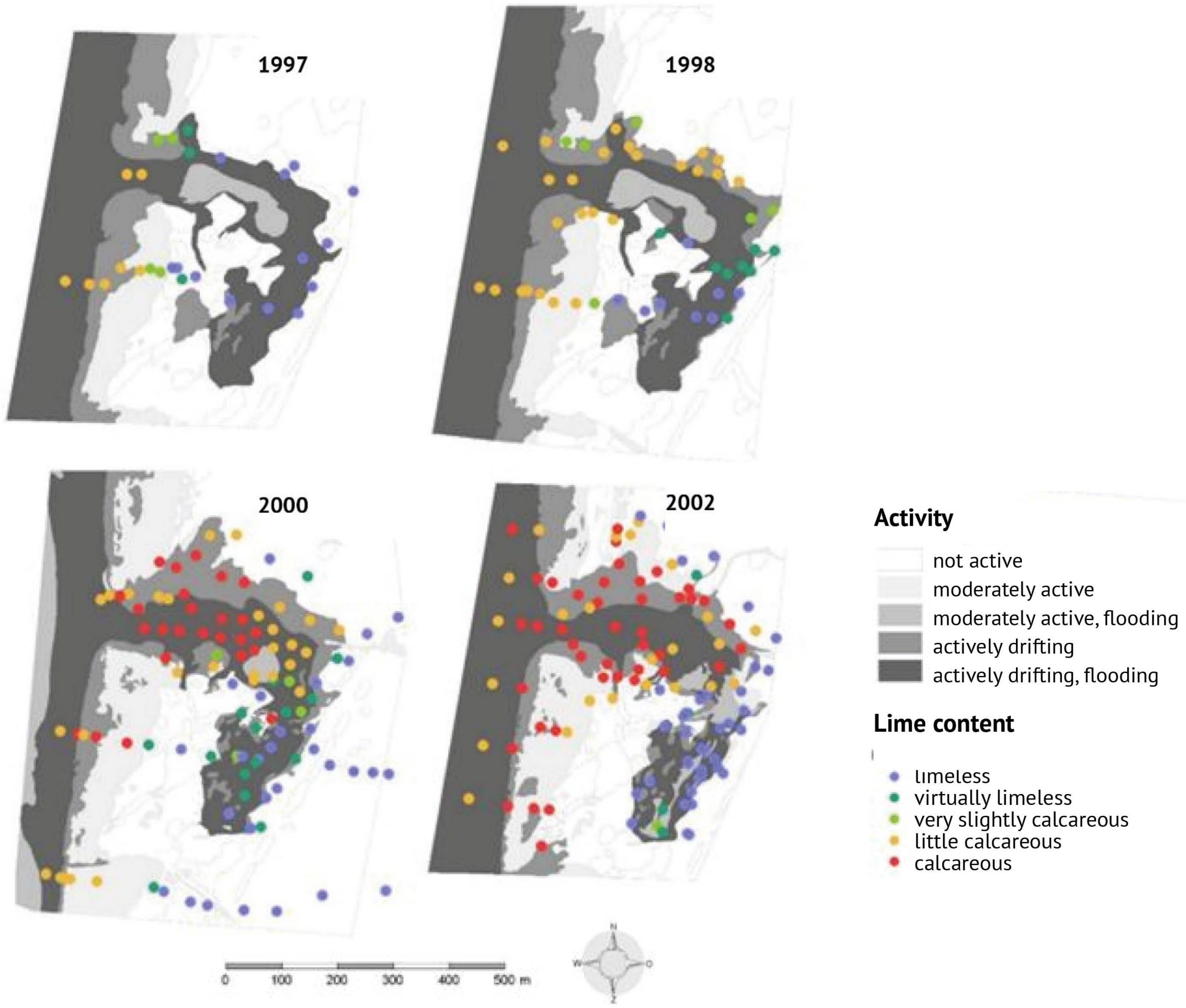

Figure 62. Changes in carbonate content in De Kerf near Schoorl. (Source: Arens, 2003)

8.1.1 Abiotic factors

Developments on the beach, such as embryonic dune formation, sand nourishments, shell floors (desert pavements). In the Netherlands, the beach is included in the annual coastal measurements (JARKUS) of Rijkswaterstaat which provide the input for research and assessment of the basic coastline position.
For these measurements, the height of the beach (ideally to the low-water line) and foredunes is measured every year, preferably with area covering techniques such as Lidar. Changes in height and therefore volume changes can be determined with these measurements.

Often the coastal development is monitored by authorities. In the Netherlands, Rijkswaterstaat keeps a file of nourishments, where and when nourishments were ever carried out. Inquire at coastal authorities about the measurements of shoreface and beach nourishments.

Make sure the whole dynamic area is covered for topographic measurements. By example, the foredune is also included in the Dutch Jarkus measurements, but the landward boundary is not always optimal. Thus, in the Netherlands, if your dune re-mobilisation interventions extend far inland, they are probably outside the reach of the Jarkus measurements. Sometimes it is possible to expand the measurements for a location, in consultation with Rijkswaterstaat.

Development of the sediment transport behind the foredune. If this part is not covered by coastal measurements, a manual measurement of the sand lobes is probably the quickest to monitor their development. Nowadays there are many drone companies that can measure heights. To measure sand rain this is less suitable, due to the limited accuracy of several centimetres.

To measure sand rain, measurements with sand traps will do. Measuring inland from the foredune in a gradient gives a good idea of the amount of sand that drifts landward from the foredune. During onshore winds and good conditions for sand drift, sand can be trapped more than 1 km behind the foredune, thus your sand traps should be spread over a large area, behind the intervention.
Development of ground and surface water. Larger interventions can affect wet dune valleys or areas where water extraction is still active. Depending on the situation, monitoring wells (simple dip wells or data loggers) are necessary or simple observations are sufficient.

Whether sand drift is initiated and continues is also influenced by, among other things, the presence of inhibiting factors in the terrain, such as the development of shell floors or the exposure of roots. This ensures that the sand drift is blocked and must therefore be monitored so that reactivation measures can be implemented in a timely manner. This is best measured in the field, but it can often also be combined with height measurements with drones (based on the photos taken).

8.1.2 Biotic factors

Vegetation mapping. Whether vegetation mapping is desirable partly depends on the size of the intervention and the area expected to be affected. Based on the most recent vegetation mapping and the observed terrain development, it is important that you have vegetation information as close as possible before the intervention. Thereafter, periodic vegetation mapping is desirable, for example every three to approximately nine years after the intervention. After that, the regular SNL monitoring (subsidy system nature and landscape) as part of EU Habitats Directive reporting every six years applies. A vegetation map provides a strong spatial impression.

Consider also monitoring at multiple reference locations: locations that are ecologically comparable and that are not affected by your project. This will give you a better impression of whether changes are the result of your project or caused by other factors.

Plant species (transects). Some plants are strong indicators of success (e.g. dune violet) or failure of the intervention (e.g. return of marram, sea buckthorn or dune reed). This can vary from year to year and can be observed quite easily. It may be sufficient to count a number of indicator species instead of carrying out a complete vegetation mapping. Transects to monitor change can be based on the expected abiotic development. The distance between monitoring spots can increase with increasing distance from the intervention (depending on terrain and objectives).

Consider to map the areal extent of these types with Differential Global Positioning System (DGPS).
It is also possible to set up a monitoring network of Permanent Quadrats. This can record in great detail what changes occur in the vegetation composition. This provides the most information at the level of vegetation communities, but it does not provide a good picture of spatial development and there is a chance that the chosen quadrat ultimately turns out to be in an unfavourable location.

Furthermore, combining Permanent Quadrats with exclosures may help you to distinguish between the effects of the sand drift and other effects such as grazing by cattle. For instance you might exclude a Permanent Quadrat from grazing, from sand drift, or both and compare their development with that of an open Permanent Quadrat.

Animal species. It can also be interesting to look at the occurrence of animal species. For example, insects are sensitive to changes in microclimate and quality of vegetation. Birds provide a stronger picture of the overall structure of the area and partly of the quality (determination of breeding success says even more about the quality). The occurrence of rabbits (maintenance/return/densities) is also interesting to monitor because this species can be an important factor in keeping the area open.

8.1.3 Anthropogenic factors

The abiotic and biotic developments can also lead to effects on humans. You often see it coming: if a sand lobe slowly approaches a path, you can intervene in time and, for example, move the path in consultation with the municipality. Or if the sand lobe really moves out of the project area, creating an undesired development you can fix it by planting marram. If the walls of a notch become very steep, you can place warning signs.

Blowing sand can sometimes also lead to unexpected effects, such as the sudden covering of infrastructure, nuisance from sand near homes, or higher water levels that hinder the use of paths or agriculture. By checking regularly, especially after extreme weather (drought, downpours and strong storm winds), most developments can be closely monitored and intervention can be taken where necessary.

Conversely, humans will also interact with a sand drift project. People are drawn to it, enter the area and recreate in it. On the one hand, this can lead to dangerous situations (dune collapse, ammunition) and on the other hand to unwanted disturbance (impact on mining bees, breeding birds, sand martins, etc.). Some can be solved through closure and supervision. Another option is to open one notch for visitors and close the others.

Also keep in mind that fences can get buried. This can make an area accessible to people, but above all it will often result in grazing livestock being able to escape from the area. Consider in advance whether it is necessary to move a fence to outside the expected sand drift zone, or ensure that the fence is regularly checked and, if necessary, raised/adjusted.

8.1.4 Who does the monitoring?

This can often be done by your own people, whether or not in combination with volunteers or students from universities/colleges (good agreements required). Check whether some activities are so specialised that they can only be carried out by specialists. Monitoring to determine required follow-up management is best done by your own people.

8.2 Evaluation

54 **Evaluating is part of monitoring**

8.2.1 Need for evaluation

Good monitoring is necessary, but monitoring without good interpretation or proper evaluation is pointless. When drawing up a monitoring plan, it is therefore also necessary to plan (and budget) for the evaluation of the monitoring data. The questions underlying the monitoring carried out must be answered.

8.2.2 Who evaluates the results?

It can be very tempting to do the evaluation yourself, but then we get a case of what the Dutch call 'the butcher inspecting his own meat'. In general, it is better to have this done by an external party. This may be a specialised agency or a university/college. Interpretation of the monitoring results to determine the need for follow-up management can of course be carried out by your own people.

8.3 Financing monitoring and evaluation

55 **Reserve money for adjustments when monitoring results give reason to do so**

The financing of monitoring and evaluation should be determined at the start of the project, so that the costs of monitoring and the evaluation of the monitoring data are covered at least for a sufficient number of years. This is where things have often gone wrong in the past. In practice, it appears that the abiotic and biotic monitoring of developments before and after implementation of a measure is often not properly arranged. Many projects have been carried out for millions of Euros, with financing arranged through subsidies. In the years that followed, the financing of monitoring and evaluation had to come from internal resources, which were usually insufficient. So include the costs for monitoring and evaluation in the financing of your project.

It is very important to think carefully about monitoring and evaluation in advance, because all monitoring, evaluation and supervision and management measures that you have to take cost money and must be included in the financing. Most projects to stimulate sand drift last at least a decade. It may therefore be smart to make monitoring (interim evaluation) and additional management part of the budget for 10 years. Also clearly state who the client is for the monitoring and evaluation and which questions need to be answered. Ten years is a long time and there is a good chance that evaluation of the monitoring will be carried out by employees who were not actively involved in the plan preparation and implementation. Such employees need to be brought up to speed by the original employees.

Funding for monitoring and evaluation is essential. But it is at least as important to also reserve money for adjusting the project when the results of monitoring and evaluation give reason to do so.

8.4 Research

56 Additional research may be necessary: this is not the same as monitoring and evaluation, but is sometimes important

Monitoring is a suitable instrument to visualise the actual results of a project: the amount of sand deposited, changes in plant and animal populations, nuisance to the environment. Monitoring does not necessarily provide new insights into the causes of effects and success factors for new projects. This requires research that is set up and carried out by specialists with experience in scientifically sound research. It is good to think about possibilities for scientific research when preparing a project to stimulate bare sand and sand drift.

Remember that many things are not or hardly known yet. This makes the interventions in the coast interesting for researchers from universities and colleges. We often involve them in projects too late for the important T0 measurements. That's a missed opportunity. A research application will also often have to be set up well in advance (sometimes with the participation of your organisation). Drawing attention to the possibility of research in time can help to answer some of your questions (for future projects) and to obtain good research results for little (often technical support) or no money. Organisations involved in coastal research in the Netherlands include: Utrecht University, TU Delft, University of Twente, NIOZ, Deltares , Rijkswaterstaat, Wageningen University, TNO, IHE, Zeeland University of Applied Sciences, Van Hall Larenstein (see also: https://www.nck -web.org/repositories).

9 Follow-up management

9.1 Introduction

57 Follow-up management comes after implementation and also concerns abiotic, biotic and anthropogenic factors

After the work has been carried out, follow-up management must be carried out for a while. Depending on the size of the intervention, this could be a decade or several decades. The experience with several projects shows that a period of 3-5 years is usually sufficient to get rid of the legacy of residual roots. In general, the follow-up management will be most intense shortly after the intervention, because the sand drift then develops quite quickly, after a start-up period.

Over time, your sand drift will lose momentum and vegetation will return; this does depend on the size of your intervention, because with various large-scale projects and also with natural notches, it is clear that the process does not simply stop. If stabilisation is too rapid, targeted specific management measures may be necessary to maintain the desired dynamics. In general, you can expect that the more you go into system restoration, i.e. on a landscape scale, the less follow-up management is likely to be needed, because nature can take care of itself. However, because this concerns large-scale areas, any follow-up management measures you take will probably also be larger-scale.

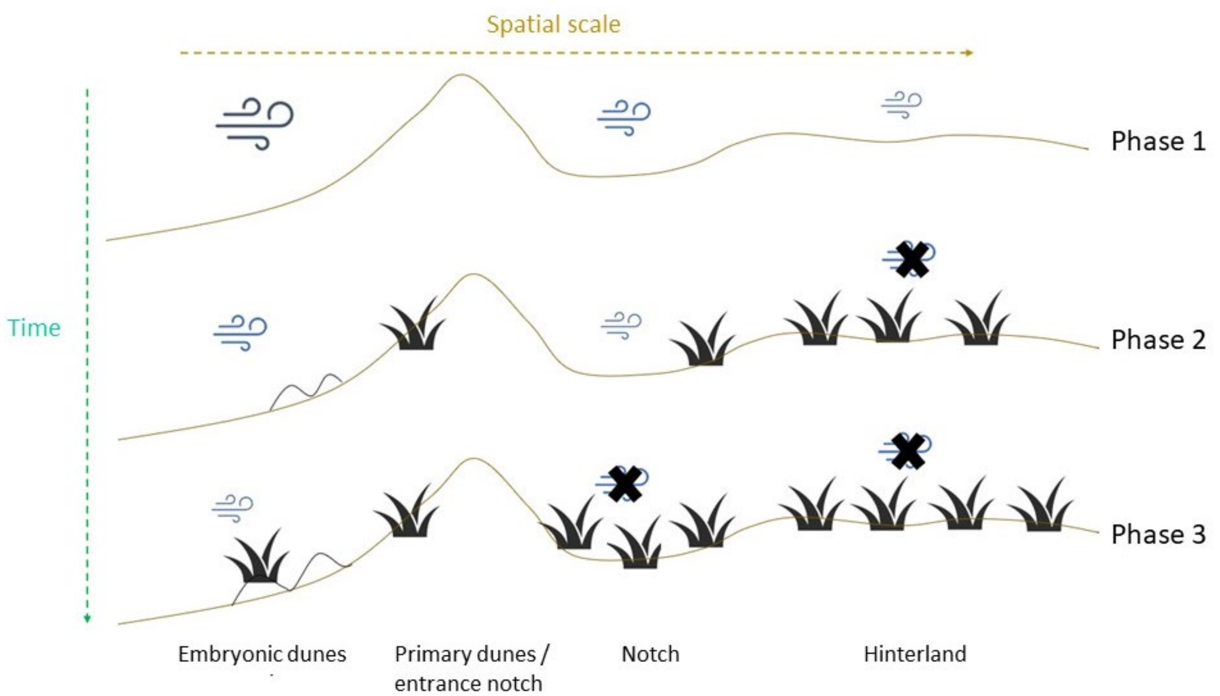

Figure 63. The life cycle of a re-mobilisation project in the dunes. (Source: Wegman, Leenders & Arens, 2022)

What aftercare is required, either management, or maintenance, is discussed below in the sections abiotic, biotic and infrastructure, after a discussion of the life cycle of re-mobilised and dynamic dunes in section 9.2. In all cases, it is important to arrange the implementation of the various follow-up management activities in a timely manner.

An important question regarding follow-up management is how long it should be continued. When are you restoring dynamics and at what point will you decide that you are trying to artificially maintain a situation with follow-up management? As long as roots are still present, it is clear that subsequent management is aimed at removing an old legacy. But what if after removing the last root the system still tends towards stabilisation? Do you have to accept that the process apparently cannot be restored here and now? Or, just like when mowing dune valleys, are you willing to keep removing vegetation endlessly to keep things moving? The latter is quite contrary to the idea of mobility: initiating sand drift, after which the system is left to nature's forces to maintain it. It is good to realise that aeolian processes in a completely natural dune system also fluctuate (see below). There are years when the processes on a larger scale revive (extreme droughts, many storms, recovery of the rabbit population) or decline (extreme precipitation, succession of wet years, collapse of rabbit populations). You may need to make additional adjustments to bridge a period of unfavourable weather conditions. A concrete answer cannot be given and will differ by situation.

9.2 Life cycle of dynamic dunes

58 Take account in your planning that dynamic systems go through a cycle of beginning, growth, stagnation and end

Theoretically you could say that dynamic systems have a life cycle, from beginning, growth, stagnation and end. This is very clearly the case with blowouts; blowouts arise and die out on a time scale ranging from a few years to sometimes several decades. For large-scale sand drift it is not yet clear on what time scale stagnation can be expected. The large, autonomous notches on Terschelling, in the North Holland Dune Reserve and on the Kop van Schouwen, all show no sign of stabilisation, while some have been in development for more than 30 years. The same applies to large-scale reactivations such as the Buizerdvlak between Bergen and Schoorl and the Northwest Nature Core, although these projects were carried out not so long ago, 12 and 9 years respectively (in 2022). Much also depends on external circumstances. For example, the foredunes in front of the Buizerdvlak showed an autonomous development of notches, but the development has stagnated because over time an extensive embryo dune field has developed in front of the foredunes. Please note that in general, the larger the scale of the re-mobilisation, the greater the chance of a long life cycle (>10 years).

In addition to the logical, predictable cause-and-effect development of your project, there are also so-called 'stochastic developments'. These are developments that are largely determined by coincidental processes, so that you cannot predict them in advance (for example the succession of weather conditions or the succession of extremely dry or wet years). Below is a brief discussion of a few important stochastic processes:

- Droughts lead to an increase in bare sand and dune mobility because the sand becomes drier and therefore more susceptible to wind transport, while at the same time the vegetation can fill the open spaces less easily.
- Windy years will lead to an increase in dynamics, whereby sand transport can also reach further inland and may cause nuisance there ("Staatsbosbeheer makes your teeth grind" was once a slogan on Terschelling). At the same time, embryonic dune formation can be promoted in the summer months (April – September), which counteracts sand transport via notches, rolling foredunes, slufters and washovers.
- Severe storm surges can seriously affect the foredune at the coastline and wash away embryonic dunes. The coast may change to such an extent that stakeholders will question the restoration project. The penetration of storm surges into areas behind the foredune can also lead to feelings of uncertainty about flood defence. Management measures may then be necessary, even when there is no direct risk for water safety. In Terschelling, for example, pine branches and Christmas trees have been placed in some gaps to somewhat curb the process of notch development.
- In extremely humid years, the stabilisation of a re-mobilisation project may happen more quickly, which may require additional management measures, such as heavy grazing and/or manual or mechanical removal of emerging vegetation.

Continue to communicate well with your stakeholders, visitors and residents throughout the life cycle. Inform them, because surprises may occur during this phase that need to be communicated (hazards, positive developments, infrastructure that is temporarily unusable). Continue to consistently tell the true story, even if the message is equally unpleasant. Deliberately providing incorrect information always comes out and puts you at a huge disadvantage. Communication often lies in the power of repetition. This can be done via:

- Leaflets
- Online informative films (example Terschelling: https://vimeo.com/649382122)
- Articles in local media and tourist newspapers
- Tie in with the (storm) season
- Actively take media into the field

9.3 Follow-up abiotic management

59 If embryonic dune growth starts blocking the entrance to the notch consider removal

It is essential for a notch to function properly that the opening remains open and the notch and beach are connected. Embryonic dunes around the opening may not be a problem as long as they are dynamic enough to capture only a limited amount of sand. However, if they become an obstacle for sand blowing into the notch, it is advisable to remove them. However, this must be carefully considered. Embryonic dunes also have an ecological value. An argument for removing them in the Dutch context is that the development of most embryonic dunes is a direct or indirect consequence of sand nourishments. After all, development can only come about, because there is an excess of sand, as a result of nourishment. This effect of nourishment goes against the natural erosion of the coast and thus hinders the process of notch development and sand drift. Other arguments can be that the expendability of embryonic dunes is high and the rarity is small. This is the situation for the Dutch coast where they now arise in many places.

If nourishing is taking place in your area, skipping a planned nourishment event can be a good way to prevent the development of embryonic dunes. Erosion can then occur to some extent, which benefits the development of notches. This procedure has been applied to Schouwen. Alternatively nourishment may be done in the shoreface zone instead of the beach, which has less influence on the dune formation. Try to make agreements about this with beach management authorities.

9.4 Follow up biotic management

60 **Removing roots is an important action which you may have to continue**

Without exception, the removal of vegetation and (living and dead) roots is mentioned by all managers as one of the most important factors determining the success of the notch. Dead roots hinder sand drift and must be cleared regularly, in any case frequently enough so that the reduction in sand drift does not lead to stabilisation. Dead roots can go extremely deep (several metres or even more in some cases) or be very dense, making them a persistent and long-lasting problem. Subsequent management may therefore be required for much longer than expected and therefore be more expensive. Even a small cover of roots (10-15%) can considerably limit sand drift.

The majority of follow-up management therefore consists of the regular removal of exposed roots and vegetation that is (re)establishing itself. The extent to which this is necessary varies greatly. This is a major point of attention at the Seven Sisters south of Egmond. The marram here has roots metres deep and roots have already been removed several times, but continue to be exposed again and again. Persistence is the motto here. At Meijendel and the Northwest Nature Core the problem with residual roots is much less. It is important that it is carefully considered in advance how and to what extent the vegetation and roots will be removed during follow-up management. But you cannot always know in advance with 100% certainty about the root penetration in the project area, unless you dig test trenches on a large scale.

We know that sufficient removal or damage to roots appears to determine the level of sand drift that occurs and the degree of follow-up management that is required. The more sand has been

Figure 64. Radiographically controlled follow-up management at Noordvoort. (Photo: M. Wiltink, Waternet)

excavated (so fewer roots are present, as in the Northwest Nature Core) or the more the soil has been sufficiently prepared (by loosening the soil when searching for ammunition), roots of existing vegetation have less chance of sprouting again.

Exposed roots and root fragments are often removed manually (often by volunteers). It is also done mechanically. At Noordvoort a horse and plough was used and recently with a radio-controlled cutter (Figure 64). So-called grizzling (with a large mechanical rake) is often used specifically for sand drift projects . This involves raking the soil with a kind of large rake, with large tines of 1 metre (Figure 65), to remove as many roots as possible from the soil. Research at Meijendel showed that this was an effective method for removing roots. This is especially the case with sea buckthorn. In marram it appears to be highly dependent on the density of the root system (Arens, 2021). In addition, the marram usually roots vertically and the teeth of the grizzle pass along this. On Ameland, experiments were therefore carried out with a grizzle with added cutting blades to cut through the vertical roots. This seems to have a positive effect.

What also works well is a remotely operated tracked vehicle with an attached rotary cultivator. The driver walks along with the machine at a safe distance, which also makes it possible to work on fairly steep slopes. Marram roots are chopped by it and the top layer of sand is loosened. Repetition (2 to 3 times a year) is necessary for several years. The advantage of this machine is that you can get to many hard-to-reach places, virtually without having to worry.

9.5 Follow-up management of anthropogenic matters

61 Follow-up management is also important for matters that concern people

9.5.1 Removal of debris

A similar problem to exposed dead roots is exposed debris or other coarse material. In many places there are wartime remains in the soil, which may appear on the surface after the intervention. Remains of cleared bunkers are also present, sometimes remarkably dark layers or compact horizons. Sometimes there has been a lot of disturbance in the foredune in the past (see section 5.2.3). So be aware that rubbish can be exposed and if in large quantities, it will need to be cleared away. This is not only advisable from an aesthetic point of view, it is also necessary so as not to hinder the sand drift.

Figure 65. The grizzle. (Photo: B. Arens)

9.5.2 Water safety

Wind erosion can endanger water safety (flood defence), or the height of the notch can fall below the established threshold level. How this will be resolved must be decided in consultation with the flood defence manager. One option is to install sand trapping fences (e.g. reed stakes) in the opening of the notch to promote sand deposition. This allows the height to increase again to a desired level. Depending on the degree of impact and further development, removing the fences may be considered over time. Reed stakes will decompose and disappear in the long term. If it is desired that the notch continues to function as a conduit for sand transport in a landward direction, it is important that the zone with reed stakes or sand fences does not stabilise and remove any emerging vegetation.

9.5.3 Freshwater security

Changes in the hydrology of a dune area can lead to effects on the extraction of fresh groundwater for drinking water supply. Two important effects are flooding with salt water during storm surges and changing groundwater flows.

Flooding with saltwater can lead to salinisation of the shallow groundwater, making the extraction of freshwater for drinking water impossible. In drinking water areas it will be necessary to take measures to prevent inundation by the sea. This can be done by reinforcing the current coastline with sand or by expanding the coast through nourishments. Such nourishments break the waves and prevent flooding. For example, Schouwen has intervened with nourishments to protect drinking water extraction. By keeping a close eye on how the dune area and the beaches in front of it develop, you can ensure that flooding of a water extraction area with seawater is prevented.

Even after careful and extensive research in the preparation of restoration measures, you can still encounter surprises. Measures to initiate aeolian processes sometimes lead to unpredictable changes in morphology. These morphological changes can in turn cause changes in the direction of groundwater flow. Areas with groundwater extraction are particularly vulnerable, because groundwater extraction often draws groundwater from a large area. A change in flow direction can cause an extraction to attract polluted or saline groundwater. Especially in the case of larger interventions that can lead to widening or narrowing of the dune area, monitoring groundwater provides valuable information about changes.

9.5.4 Recreational safety

People like to visit sand drift projects.

Figure 66. On Terschelling (beach pole 13), in the design of the project, a bridleway has been taken into account to prevent burial with sand. (Photo: M. Nijenhuis)

There are several possible risks that must be taken into account:

1. Quicksand can occur in the deeper part of the project on the beach (also consider flooded blowouts). Consider warning signs and (temporal) closure.
2. The steep walls of active notches can collapse. Consider signs with warnings and closure and/or zoning, for example keep the slopes gentler at one notch and make this one accessible to the public.
3. Release of ammunition residues and phosphorus. Closure and warning signs.
4. Also remember to remove the signs when 'the danger' has passed

9.5.5 Nuisance

The shifting sand can end up on infrastructure and buildings. Regularly (perhaps monthly) cleaning of paths can become a significant expense. Check whether relocating the infrastructure or locally capturing the shifting sand is not a better option. It may also be possible to direct the sand drift in such a way that most of the sand no longer ends up on a path. Place signs like "Caution: crossing dunes" to prepare visitors for possible burial of a path. For buildings, residents/users will have to roll up their sleeves themselves. Communication about the nuisance and what will be done about it is essential. What you don't want is an action like the one on the barrier island of Vlieland, where residents called on each other to put their Christmas trees in blowouts to close them.

9.5.6 Miscellaneous

Don't forget to be accountable to the subsidy provider.

10 Finally

62 Let something beautiful arise!

Now that you've reached the end of this guide, you may be thinking about not starting it; so many things to take into account and then you also have to seek expert advice from time to time. Do it! Take a good look at where it is possible and get started. Visit great projects and talk to colleagues who have experience. If done properly, it is not only good for nature, but it also provides an attractive landscape, increases freshwater safety and the collaboration between sea, sand, wind, flora and fauna can make a substantial contribution to our water safety.

The sand moves uphill,
as if helped by an invisible hand.
Where it gets stuck in vigorous marram,
a foredune forms, large and proud.

With a finger of wonder
we quietly open this green wall.
As children we watch breathlessly
how the landscape resumes its course.

Spraying high in the storm,
creeping slowly in the gentle breeze,
rolling quickly down the slope.
And then the plants and animals...

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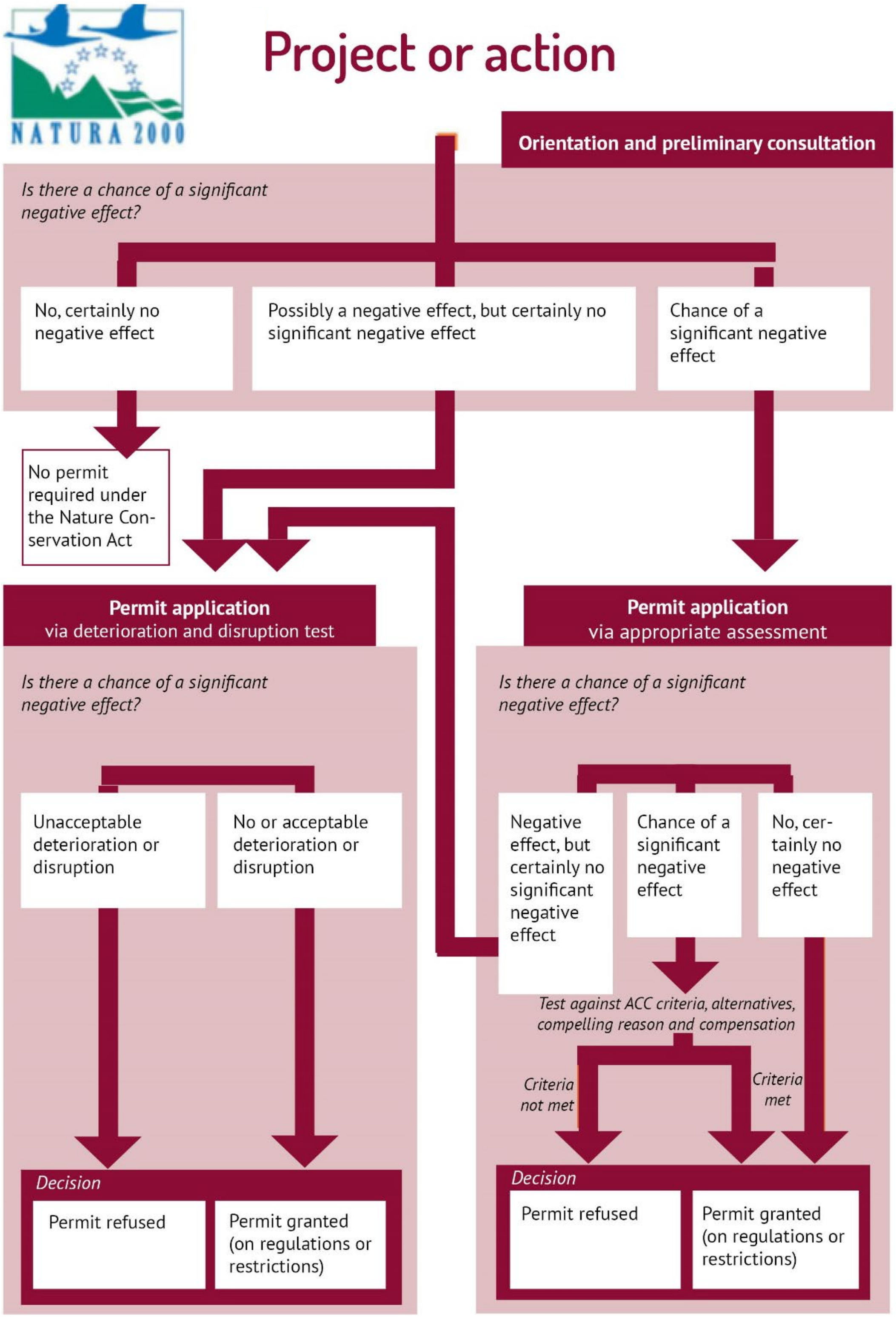
Appendices

APPENDIX 1 – Schematic representation of the N2000 permit process



APPENDIX 2 – Glossary

Accreting coast: A prograding (seaward-moving) coastline, often with new embryonic dune formation.

Aeolian processes: the movement of wind and wind-blown sediments (mainly sand and dust).

Basic Coastline (Dutch): The reference coastline (or coastal baseline) as defined in the context of coastal defence policy. Generally it is the position of the 'average' coastline on January 1, 1990.

Blowout: Clearly isolated, saucer-shaped wind erosion form in the dunes which, if sand is blown out to the level of the groundwater, will create a secondary dune slack.

Decalcification: The process by which initially calcareous sand is leached of calcium over time, reducing the pH and leading to the formation of de-calcified and more acidic dune soils.

Drift (Dutch): Accumulation of drifting sand against an existing row of dunes, causing the foredune to expand seaward. In the past drift was often controlled / enhanced by sand-trapping fences.

Dune crest flattening (topping): Relatively small scale interventions to stimulate the formation of blowouts and sand movement on dune ridges by removing marram grass, creating small hollows and pushing the top of the dune landwards. Where it works it is an economical way to get sand drift started.

Dune foot (Dune toe): Lower edge of the dune where the beach turns into the foredune. The NAP +3 metre contour line is often used to define the dune foot.

Dune slacks: Dune slacks are the natural freshwater component of the dune system, including primary dune slacks formed by new dune ridges creation on the foreshore and secondary dune slacks formed by wind erosion in the white and grey dunes. These morphological components include the EU habitat type H2190 'humid dune slacks'

Dutch coast: The Dutch coast is broadly divided into the Delta area in the south, the Mainland coast and the Wadden area in the north.

Dynamic coastal management (Dutch): Managing the coast in such a way that natural processes, whether stimulated or not, can proceed as undisturbed as possible. Maintenance of the Basic Coastline is by dynamic enforcement, whereby processes are managed in such a way that safety is guaranteed.

Dynamics: Movement (drifting) of windblown sand, whether or not combined with wind erosion.

Dynamisation: Dynamisation is used in the Dutch context to include all actions and interventions to initiate the development of notches, blowouts, or a rolling foredune by stimulating the movement of wind-blown sand. The English translation prefers the term 're-mobilisation' to cover the same set of actions.

Embryonic Dunes: Small dunes which most frequently form by windblown sand accumulation at the foot of the foredune; may or may not be vegetated and including the EU habitat type H2110 'embryonic shifting dunes'.

Eroding coast: Where the trend is erosion (landward movement of the dune foot)' and where under natural conditions there would be no embryonic dune formation. In the Dutch situation sand nourishment has in some cases halted or even reversed natural erosion.

EU Habitat type: Natura 2000 habitat types described in the EU Habitats Directive include dune habitats embryonic dunes H2110, yellow dune H2120s, grey dunes H2130

Flailing: The felling/ chopping of small trees and shrubs by means of a quickly rotating blade

Flood defence (water safety): The Dutch term 'water safety' translates to broader 'flood defence' and means any national or regional policy for public safety in relation to the standard of dune condition and repair.

Foredune (Dutch): The 'foredune' in the Dutch context (zeereep) is a zone behind the beach that includes the embryo dune, foredune and mobile dunes formed from them. This zone may coincide with, or be located seaward of the primary flood defence. The Dutch zeereep often provides the height and depth to meet the requirements of flood defence.

Foreshore: (English definition): In a general (non-legal) sense that part of the beach located between the mean high and low water levels of spring tides. In Dutch the terms 'foreshore' and 'shoreface' are used to refer to the part of the coast below the low water line. To avoid confusion the term shoreface is used to refer to the zone below low water in this document.

Freshwater lens: Underlying the dune system is a large lens-shaped reservoir of freshwater which overlies a wedge of brackish or saline groundwater. Its volume changes only slowly in response to the width and height of the dune system, long-term changes in precipitation and any artificial drainage or extraction (e.g. for drinking water).

Freshwater security (Dutch): In the Dutch situation the protection of drinking water supplies drawn from the dunes by water companies is paramount and this can be a constraint on the location and scale of sand-drift projects.

Grey Dunes: Fixed dunes including the EU habit type H2130 'fixed coastal dunes with herbaceous vegetation (grey dunes)'. The broad species-rich habitat generally includes a mosaic of dune sub-habitat types including decalcified dunes and dune scrub.

Humid dune slack: Where the dune groundwater table lies close to the surface or seasonally above the surface the EU habitat type H2190 'humid dune slacks' may occur. Dune slacks are formed both in the valleys created by dune ridges on an accreting coast and by wind deflation inland from the coast. Dune slacks may show stages of succession through to dry slacks over time due to accumulation of sand rain and/ or organic matter.

Inner dune edge: The edge where the dunes merge into the landward polder, the most landward edge of the dunes.

Kerf (Dutch): A 'kerf' is a notch, whether natural or artificial.

Marram grass: Marram *Ammophila arenaria* is the main dune building grass responsible for the formation and growth of the white dunes.

NAP: Normaal Amsterdams Peil is the Dutch Ordnance Datum

Notch: The term 'notch' as used in the manual includes 'natural notches' and 'artificial notches'. A notch is generally a U-shaped or V-shaped corridor breaking through a dune ridge to allow sand transport from windward to leeward.

Notching: The term notching is used for the artificial creation of a notch, to form a wind corridor to transport sand from the beach inland.

Notched foredune (dissected foredune): Where several natural or artificial notches are positioned along a dune ridge the combined effect can increase the amount of sand drift to the hinterland.

Over-powdering (sand rain): Diffuse transport of sand in suspension by the wind and deposition over a wide area as a thin layer of calcareous sand.

Parabolised foredune: A foredune ridge or group of ridges which have been dissected by blowouts, some of which have evolved into parabolic dune forms (which can have very large dimensions and cover many square kilometres).

Parabolic dunes: Dunes which have a U-shaped or V-shaped form in plan and whose seaward end is open to the prevailing or resultant wind direction.

Polder (Dutch): The low-lying, generally agricultural land behind the dunes, often at or below sea level, which is protected from saline water incursion by the dunes and the lens of freshwater underlying them. Over-extraction of fresh water from the dunes can lead to saline groundwater water rising in the polders.

Primary dunes: dunes developing on the beach .

Primary Flood Defence (Dutch): Flood defence that provides protection against flooding by sea water.

Rejuvenation: More generally applied to the rejuvenation of dune habitats, such as putting the process of succession back to the start (e.g. by sand drift overwhelming a fixed dune area), or by the more subtle process of sand rain helping to maintain the diversity of grey dune habitats.

Re-mobilisation: The translation of the Dutch term 'dynamisation' used for any artificial action taken to re-start dynamic processes by turf-stripping, creating notches or more ambitious projects to kick-start new transgressive dunes and parabolic dunes.

Rijkswaterstaat: Dutch Ministry of Infrastructure and Water Management with overall responsibility for water safety (sea defence).

Rolling foredune: A foredune that moves or extends inland either through diffuse sand drifting or avalanching on the landward slope of the dune. The seaward side of the foredune may also move landward due to wind erosion and transport of sand over the dune crest. This can happen spontaneously or be stimulated by placing sufficient notches to set the entire foredune in motion.

Salt spray: The blowing of salt onto land from the North Sea side.

Sand drift: Sand drift, or drifting, is the movement of wind-blown sand and may take the form of diffuse transport of individual sand grains, ripples, sand sheets, lobes or better defined dune forms. Sand drift from the beach leads to the formation of embryonic dunes and foredunes; sand may also spill over the crest of a foredune ridge or move further inland through gaps and notches.

Sand nourishment: The Dutch coastal policy to maintain the Basic Coastline involves sand nourishment to supplement existing sand stocks. The nourishment sand is sources from the subtidal offshore zone or from dredging of channels and harbours. If an extra amount of sand is provided to the beach it can help to feed the inland movement of drifting sand through notches.

Sand rain (over-powdering): Strong winds can carry sand high into the air and carry it up to 2 km inland where it falls as a very thin layer over the more inland dunes. This can give enough fresh calcareous sand to maintain species-rich grey dunes.

Sand trapping fences (drift screens): Drift sand can be trapped by any suitable fence which slows down the wind and allows sand to accumulate in front or behind the fence. Traditional Dutch drift screens are of materials such as reed stakes, willow branches and brushwood but fences can be made of hard or softwood palings, plastic mesh or coir matting

Shoreface (Dutch definition): Generally defined as the part of the shore below the low water line. In Netherlands also referred to as the foreshore.

Slufter (Dutch): An opening in the foredune dunes to the sea that is bordered on all sides by dunes and/or dikes and that is regularly flooded by the sea.

Stuifdijk (Dutch): An artificial sand dike (embankment) created on the beach by bulldozing or trapping sand to make an engineered foredune which acts as a flood defence. The form is frequently monitored and managed to maintain its integrity.

Succession: Progressive replacement of the species composition of a plant community by the next stage. If natural conditions do not prevent this, this stage will also gradually transition into the next, from the pioneer plants to the climax vegetation from, for example, bare ground to forest.

Topping (dune crest flattening): The Dutch term 'topping' can be described as 'dune crest flattening', smaller scale interventions to stimulate sand drift.

Transgressive foredune / rolling foredune: A landward-migrating foredune ridge or zone with sand deposition covering all vegetation; may occur naturally or as a result of the creation of numerous notches and gaps in the foredune.

Transgressive sand sheets: Areas of mostly bare sand which move inland from the beach covering all vegetation, generally having low to moderate relief and absence of pronounced dune forms.

Turf-stripping (sod-cutting): Removing the well-rooted top layer of the soil, which removes both the plants of the later successional stages and the nutrient accumulation.

Wadden area*:* The area of the Wadden Sea, including the adjacent mainland, the *Wadden Islands* and the adjacent North Sea area (up to approximately -20m NAP line).

Wadden Island: A mostly sand island, often with a blunt western 'head' and an elongate eastern 'tail'. The 'heads' are usually characterised by mobile dunes, long-shore drift is from west to east, and the 'tails' taper to a salt-marsh and bare sand beach plain. Features such as 'washovers' are usually found towards the 'tails' of the islands.

Washover: An opening in the dunes, where seawater and sediment can move into relatively low areas of ground (including dune slacks) behind. Washover events normally only happen during high spring tides with storm surges accompanied by high waves. Wind transport of sand also plays an important role in the development of a washover area.

Water Boards: Regional authorities responsible for coordinating water management including flood defence. Water Boards are independent of provinces and municipalities.

Water Companies: Dutch water companies produce and supply drinking water. Large areas of the dunes are used as drinking water catchments and water companies such as Dunea (South Holland), Waternet (Amsterdam) and PWN (North Holland) support dynamisation projects.

Water safety (Dutch meaning): Flood defence in the Netherlands is coordinated by the national Rijkswaterstaat and district Water Boards.

White Dunes: Mobile dunes including the EU habitat type H2110 'Shifting dunes along the shoreline with *Ammophila arenaria* (white dunes)'.

Colophon

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