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Ecological effects of reactivation of artificially stabilized blowouts in coastal dunes

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Abstract. In an inner dune area in the Dutch coastal dunes several artificially stabilized blowouts were reactivated. The purpose was to investigate whether these reactivated blowouts could remain active despite the increased atmospheric deposition of nutrients, how much area would be affected by sand from the blowouts, whether the vegetation would respond to the deposition of sand, and whether the reactivation of blowouts could be a measure against the effects of acidification and eutrophication.

This paper presents the results of the first years of monitoring the changes in the blowout morphology and the response of the vegetation. In the monitoring period (1991-1994) the blowouts remained active and grew slowly in size and depth. The area which receives more than 1 cm of calcareous sand from the blowout in three years was up to six times the area of the blowouts. Moss vegetation responded to the accumulation of sand: *Campylopus introflexus* was sparse within the deposition area whereas *Tortula ruralis* was found near the contour of 1 cm deposition in 3 yr. No indications were found that shrubs or marram grass were adversely affected by the deposition of sand.

The experiment forms part of a programme to test measures aimed at mitigating the effects of air pollution on natural landscapes. From the viewpoint of the programme the experiment is a success.

Keywords: Aeolian process; Acidification; Eutrophication; Management; Vegetation type.

Introduction

Active blowouts are relatively rare in the Dutch coastal dunes, as a result of centuries of management practices directed at stabilization (Jungerius & van der Meulen 1988). Since the dunes in The Netherlands have an important function for protecting the low hinterland against the sea, blowouts are only tolerated as long as they are no threat to coastal safety. But even in areas where wind erosion is allowed, there has been a decrease in the number of blowouts during the last decades. Although the reduced grazing pressure by rabbits due to myxomatosis cannot be excluded as a possible factor, the reduction of blowout development has been attributed mainly to the increased input of nutrients by atmospheric deposition (eutrophication). The nutrients stimulate vegetation growth and are therefore thought to be responsible for the encroachment of grasses, shrubs and mosses. This encroachment leads to the stabilization of existing blowouts and prevents the formation of new blowouts. Another problem connected with the increased air pollution is the acidification of dune soils, which affects also the vegetation.

At present the character of coastal dune management changes under the influence of a growing appreciation for natural processes (Anon. 1993-1994; Anon. 1994; Anon. 1995) and legal obstacles against tolerating active blowouts are being removed. However, it takes many years before the dunes will be restored in their natural state.

Forced reactivation of blowouts can help to restore the natural dynamics of the coastal dunes. Around active blowouts there is a range of deposition rates, depending on the size of the blowout: from up to 50 cm/yr near the edge to some mm/yr at distances up to 100 m from the blowout. The calcareous and nutrient-poor sand deposited here can counteract the effects of acidification and eutrophication. Vegetation type and cover will react to the changes. The result is a very diverse landscape with different types of vegetation.

Within the framework of a programme sponsored by the government to test measures for counteracting the deteriorating influence of air pollution (van der Meulen et al. 1996), experiments were carried out to investigate whether it is possible to reactivate artificially stabilized blowouts, whether reactivated blowouts will remain active despite the increased atmospheric deposition, and whether the blowouts help to counteract the effects of acidification and eutrophication in the deposition area.

Location and Climate

The study area, Midden Heerenduin, is located in the coastal dunes near Haarlem, The Netherlands (Fig. 1). The distance of the experimental area to the coast is 1.5 km. There are several high dune ridges closer to the

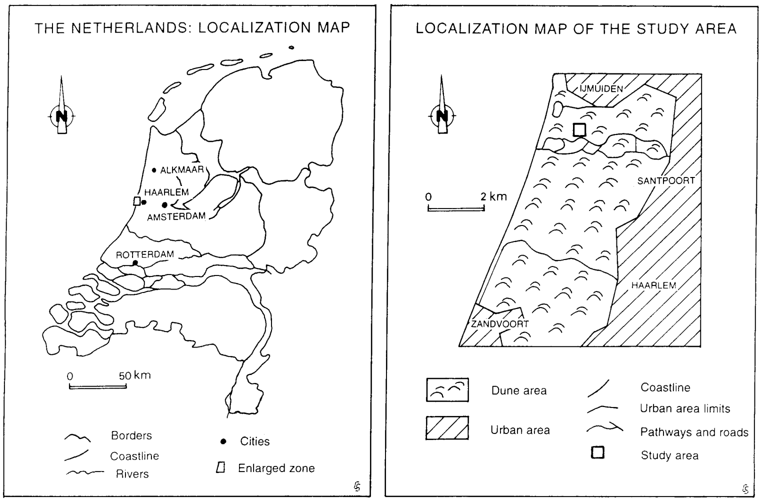

Fig. 1. Location of the study area.

coast so the area has no function in respect of the safety of the hinterland. The study area is located in the lime-rich zone of the Dutch coast, with the original sand containing 7 - 9 % calcium carbonate.

The climate in The Netherlands is humid temperate, and precipitation exceeds potential evaporation (Wartena et al. 1991). The major aeolian events take place during storms in the winter and spring (Arens et al. 1995). Summer storms do occur occasionally, and although their frequency is low (Wieringa & Rijkoort 1981), they can be very effective because the sand is dry (Jungerius et al. 1981). Wind speed and direction are highly variable and there is no prevailing wind (Wartena et al. 1991), although there is a slightly higher frequency of southwesterly winds (35 - 40 % of the time between 180 ° and 270 °) compared to the other directions. However, winds strong enough to move sand (> 6 m/s) do have a prevalence for southwesterly directions (Pluis & van Boxel 1993). The effects of the southwesterly winds are therefore reflected in the geomorphology of the dunes along the Dutch mainland coast.

The study area has been divided into two geomorphological units: flat terrain, consisting of abandoned agricultural fields and undulating terrain with height differences of several m.

The soil profile in the area surrounding the reactivated blowouts consists of freshly deposited yellow sand on top, followed by a thin grey band, then a second layer of yellow sand, followed by a clearly visible buried soil. The grey band is the start of a soil profile formed between the artificial stabilization of the blowouts in the early 1970s and the reactivation in 1991. The second layer of yellow sand was formed by accumulation of sand issuing from the blowouts before their stabilization. The clear soil profile at its base was present before the formation of the blowouts.

Methods

In the flat terrain two types of blowouts have been reactivated: small patches with an area of 1 to 5 m^2 (F3 and F4 in Fig. 2) and medium-sized blowouts of 50 to 500 m^2 (F1, F2, F5). The undulating terrain also contained small (U9 and U10) and medium-sized blowouts (U1 through U8). Blowout F5 (Fig. 2) was the only blowout which was still active at the beginning of the experiment. All other medium-sized blowouts had been artificially stabilized with branches cut from trees in the surroundings. For the small patches the reason for stabilization was not obvious. They might have been stabilized in a more or less natural way.

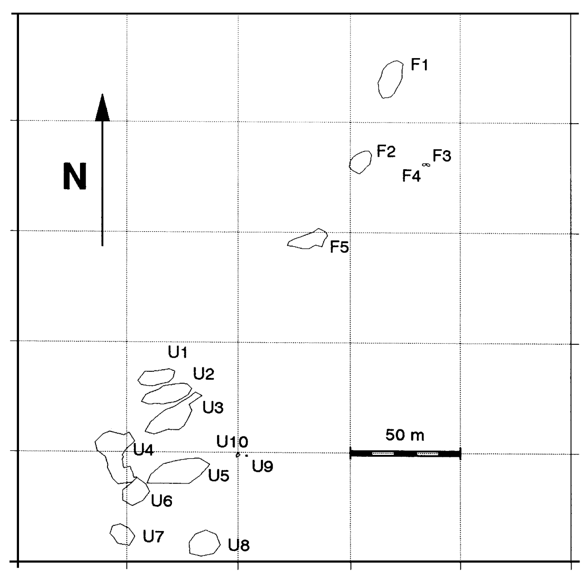

Fig. 2. Relative locations of the reactivated blowouts in the flat terrain (F1-F5) and undulating terrain (U1-U10).

In order to reactivate the blowouts, first of all the remains of the branches used for stabilization, along with the vegetation that had established since then, had to be removed. Furthermore it is essential to remove all soil material until the original yellow dune sand is exposed at the surface, because sand mixed with organic matter is cohesive and not easily eroded by wind (Jungerius & de Jong 1989). By means of a gauge auger the depth of the organic sand layer was established in most blowouts to be 30 to 50 cm. In blowout U4 of the undulating terrain the layer of grey sand was considered too thick (more than 50 cm) for a successful reactivation, but it was decided to reactivate this blowout anyway.

The small patches were reactivated with a spade and barrow, but for the medium-sized blowouts a mechanical shovel was used. The use of this heavy equipment in a natural area and the amount of sand (in this small scale experiment already over 600 m^3) that had to be displaced pose a number of problems. The amount of movements in the area has to be minimized, because the tracks will be visible in the terrain for many years. Therefore the sand cannot be removed by trucks and has to be stocked as closely as possible. Suitable stocks have to be found and previously removed vegetation should be placed on top of the stock for regrowth.

Monitoring techniques

Increasingly precise measuring techniques have been applied throughout the years to record the dimensions of the changes caused by wind activity: measuring tape in 1991, theodolite in 1992 and tachymeter in 1992 and 1994. The results of the measurements of the reactivated blowouts of the flat and undulating terrain were sufficiently systematic to warrant a first assessment of the success of the reactivation measures. The data set is still too limited for effective statistical analysis.

The theodolite and tachymeter data were processed by means of a spreadsheet where the perimeters could be rotated and translated in order to fit the same coordinate system. This made it possible to draw maps (Figs. 2, 5 and 6), compare the measurements of different years and calculate the area of the blowouts and deposition area.

From the perimeter measurements the area of the blowouts and the deposition area could be determined with (Stolk & Ettersbank 1987):

$$area = 0.5 \cdot \left| \sum_{k=1}^{n} \left(X_{k-1}\, Y_k - X_k\, Y_{k-1} \right) \right| \quad (1)$$

where n is the number of points, (X_k,Y_k) are the coordinates of the perimeter, and the point (X_0,Y_0) is equal to the point (X_n,Y_n). For the tape measurements the area was calculated with the formula for an ellipse (Area = $\pi \cdot l \cdot w/4$, with l = length and w = width of the blowout). These results were corrected with a shape correction factor, which was calculated for each blowout from the results of the perimeter measurements.

In November 1994 a more detailed study was carried out in the undulating terrain (blowouts U1-U6). In addition to the size measurements, a gauge auger was used on a 1.5 m × 1.5 m grid to map the thickness of the new sand layer in the deposition area. The deposition area is defined as the area where the accumulation of sand is > 1 cm.

The vegetation map produced in 1994 includes five types with three types subdivided on the basis of the amount of sand accumulation: 'Marram grass' (*Ammophila arenaria*) with subtypes Stable (1), Semi-stable (2) and Active (3); 'Short grass' (mainly *Festuca rubra*) with subtypes 'Sand with short grass' (4) and 'Short grass with sand' (5); 'Moss' (mainly *Campylopus introflexus*, *Hypnum cupressiforme* and *Tortula ruralis*), with subtypes 'Active' (6), dominated by *C. introflexus* and *H. cupressiforme*, and 'Stable' (7), dominated by *T. ruralis*; 'Bushes' (of sea buckthorn, *Hippophae rhamnoides*), with subtypes 'Semi-stable' (8) and 'Stable' (9); and 'Bare sand' (10).

For the determination of the lime content, four soil samples were taken from 0 - 5 cm depth within each vegetation type. Depending on the reaction to a drop of 2N HCl, five classes were recognized, from 4 (strong reaction) for calcareous soils to 0 (no reaction) for fully decalcified soils. The results were averaged per vegetation type and multiplied by 25 (to obtain a scale of 0 to 100 %).

Results

Fig. 3 shows the depth of the separate blowouts in the flat terrain (top) and the undulating terrain (bottom). Despite the different measuring techniques, the general trend is clear: the medium-sized blowouts gradually increase in depth with ca. 5 - 10 cm/yr. The increase seems to be larger in the undulating terrain.

The area of individual blowouts in the undulating terrain is shown in Fig. 4 (top), as well as the total area (bottom) of the blowouts in the flat terrain and the undulating terrain (only blowouts U1-U6). Although there is some scatter, mainly because it was sometimes difficult to define the upwind edge of the blowout, the general trend is a slow increase of the blowout area of ca. 5 %/yr.

The perimeters of the deposition areas in the flat terrain in 1994 are shown in Fig. 5, as well as the perimeters of the blowouts and two transects for each blowout. In this terrain unit the blowouts cover 319 m^2 whereas the deposition area is 1822 m^2, so the deposition area is roughly 5.7 × the area of the blowouts. The

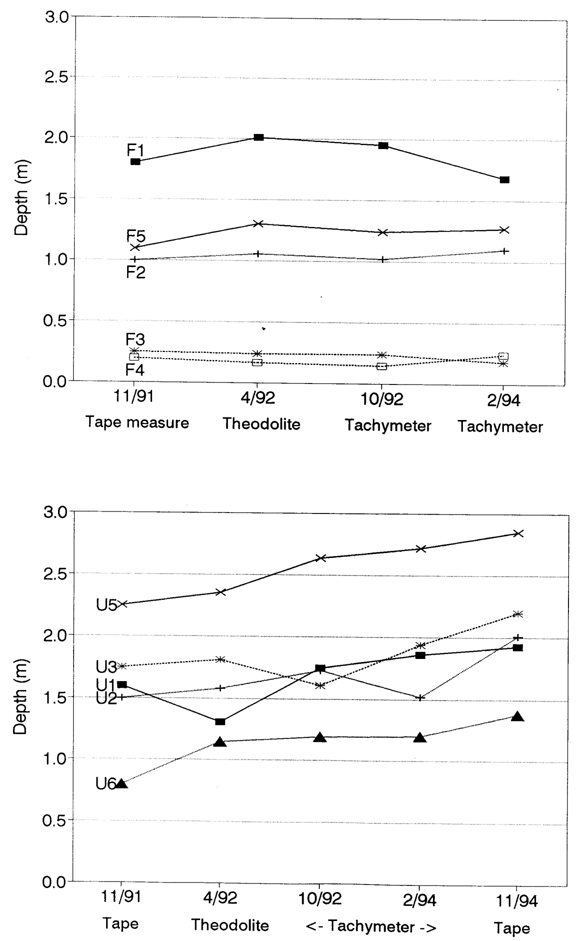

Fig. 3. Depth of the blowouts in the flat terrain (top) and undulating terrain (bottom). The method of measuring the depth is indicated at the bottom axis.

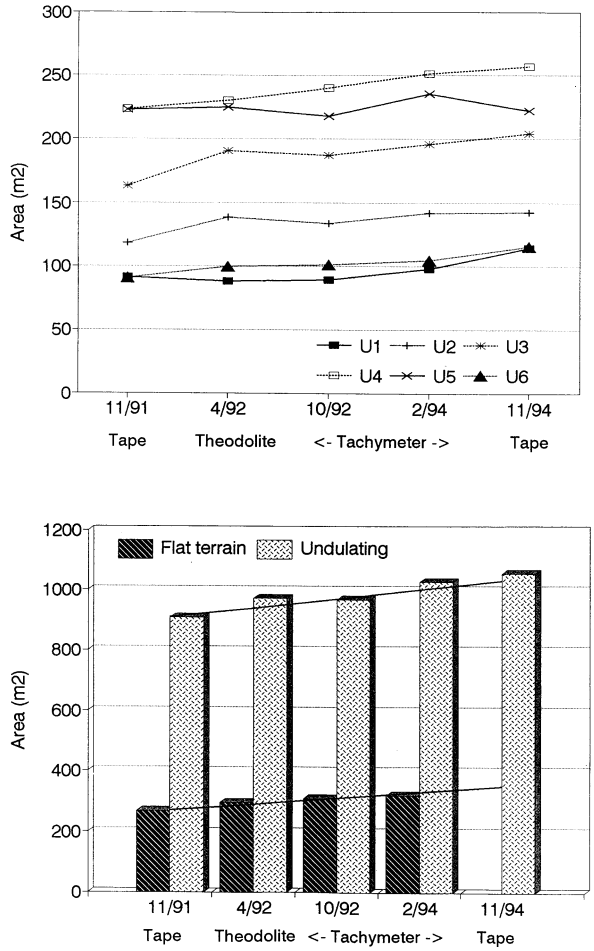

Fig. 4. Area of individual blowouts in the undulating terrain (top) and total area (bottom) of the blowouts in the flat terrain (F1-F5) and undulating terrain (U1-U6). The method of measuring the area is indicated at the bottom axis.

results of the 1992 measurements were more or less similar. In 1994 the blowouts in the undulating terrain (U1- U6) covered 709 m^2 whereas the deposition area was 2810 m^2 (Fig. 6), so the ratio is about 4.0.

From Figs. 5 and 6 it is clear that most sand is deposited rather close to the blowouts. In this terrain very little sand is deposited more than 30 m away from the blowouts. Accumulation is strongest at the northeastern sides of the blowouts, due to the action of the southwesterly winds. Sand is also deposited at the southwestern ends of the blowouts by northeasterly winds. Although northeasterly winds are less frequent and usually weaker, they have a relatively high contribution in the aeolian transport of sand because in The Netherlands easterly winds usually give dry weather (little rain and low relative humidity), whereas westerly winds often carry rain and cause high relative humidity.

Fig. 7 shows the vegetation map and the contour of the area with more than 1 cm accumulation during the years 1991-1994. Some results are striking. The mosses *Campylopus introflexus* and *Hypnum cupressiforme* are seldom found within the deposition area, because they do not tolerate burying by sand. The moss *Tortula ruralis* is often found near the accumulation border. It needs some sand in order to compete with *Campylopus* and *Hypnum*, but too much sand will bury this short vegetation.

In some of the blowouts marram grass has re-established on part of the surface. Also *Festuca rubra* is sometimes found within the limits of the reactivated blowouts, but in general most of the surface of the blowouts remains bare and active.

The results of the acid reaction test for the top soil (0 - 5 cm) in Fig. 8 show that the lime content is high within the blowouts (bare sand). The areas which receive sand from the blowouts are on average less calcareous than the sand in the blowouts, although they give a positive

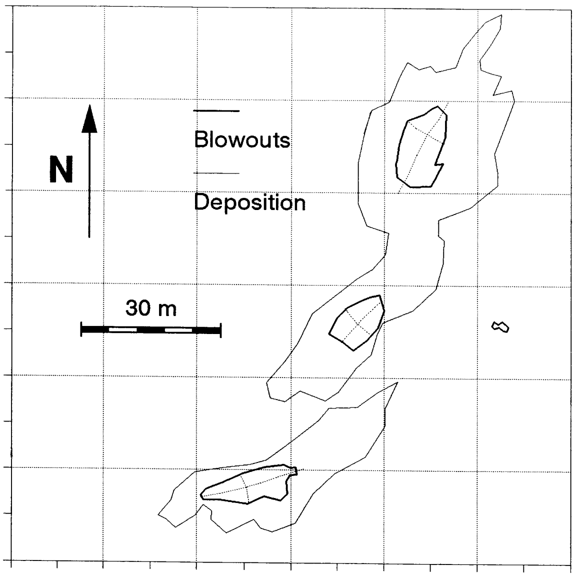

Fig. 5. Perimeters of the blowouts, measured transects through the blowouts and perimeters of the deposition area in the flat terrain in 1994.

response to the acid reaction test. These areas are not strongly decalcified. The stable shrubs and stable marram grass show a lower average response to the acid reaction test, so their lime content is less. The lowest response is found below the *Campylopus introflexus* vegetation, probably because this moss contributes to soil acidification.

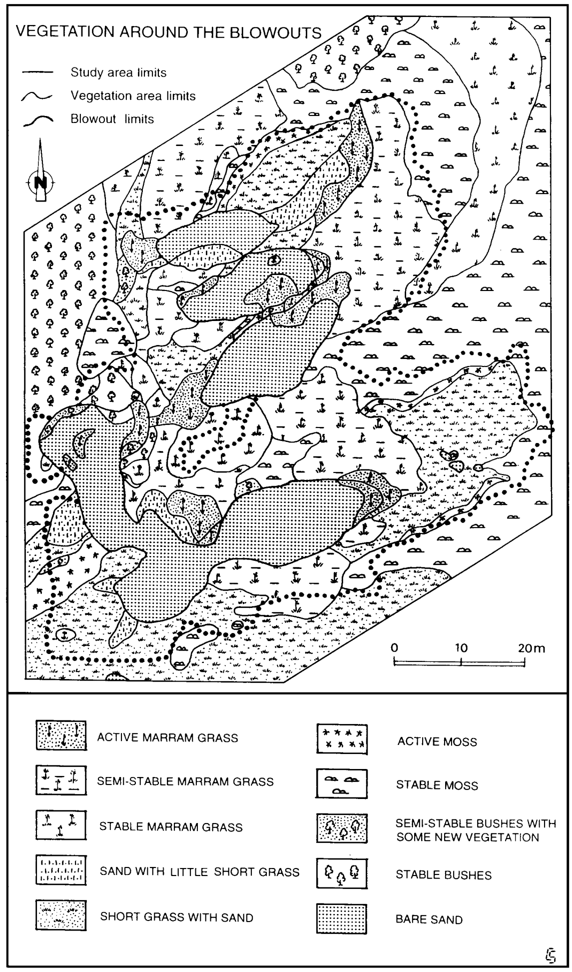

Fig. 7. Vegetation map. The fat dotted line indicates the contour of 1 cm deposition in the years 1991-1994.

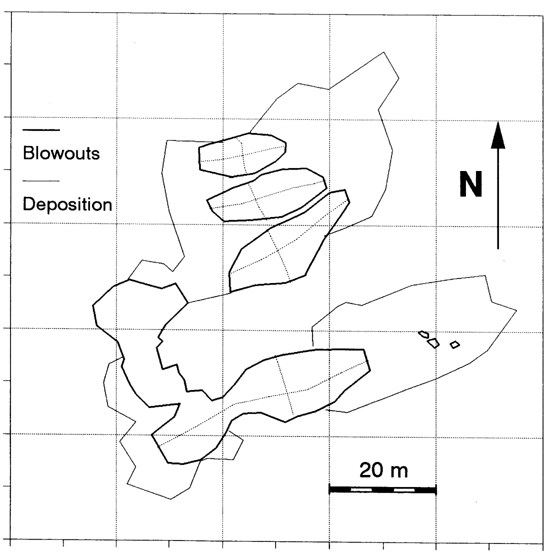

Fig. 6. Perimeters of the blowouts, measured transects through the blowouts and perimeters of the deposition area in the undulating terrain in 1994,

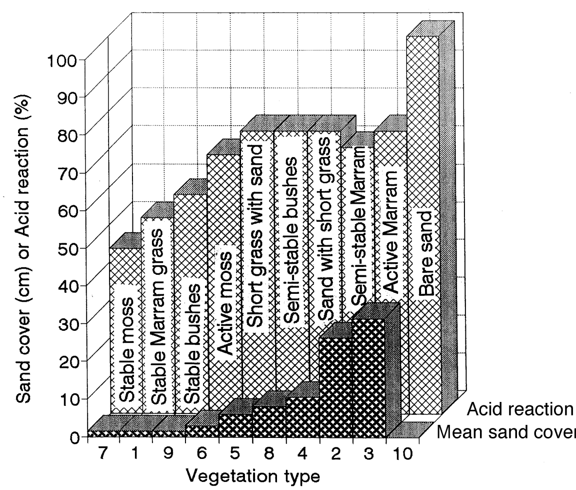

Fig. 8. Mean acid reaction and amount of sand deposition for each vegetation type.

Discussion and Conclusions

Most of the small patches that were reactivated stabilized spontaneously. This is not surprising, since also most naturally formed blowouts stabilize in the first years after their formation (Jungerius & van der Meulen 1989) while only a small percentage reaches maturity.

The reactivation of the medium-sized blowouts was successful. The blowouts remained active despite the inputs of nitrogen by atmospheric deposition. The area and depth of the reactivated blowouts increase slowly.

The deposition area is about four to six times the area of the blowouts. However, this result probably depends on the size of the blowouts and the topography of the terrain.

Most of the sand is deposited close to the blowouts. Here, most of the sand is found within 30 m of the blowout. On the isle of Terschelling, where some blowouts were located near the top of a high dune, sand deposition of 1 cm in three years was found more than 100 m away from the blowouts (van der Meulen et al. 1996).

Campylopus introflexus disappears if the accumulation of sand exceeds a few mm per year. There are no indications that shrub encroachment is prevented or limited by the sand accumulation. Probably much higher accumulation rates are needed to stop sea buckthorn (*Hippophae rhamnoides*) from expanding. Marram grass does not suffer from burying at all, on the contrary it seems to need accumulation of fresh sand (van der Putten 1989; van der Putten & Peters 1995) to remain vital. Nevertheless marram grass was also found outside the area influenced by the blowouts.

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