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The effects of changing wind regimes on the development of blowouts in the coastal dunes of The Netherlands

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Abstract

Blowouts are the main features of aeolian activity in many dune areas. To assess the impact of future climatic change on the geomorphological processes prevailing in a dune landscape it is essential to understand blowout formation and identify the meteorological parameters which are important.

The development, that is, local erosion and accumulation, of six blowouts in a dune terrain along the Dutch coast has been related to wind velocity and wind direction, as measured at a nearby standard meteorological station. Blowout changes correlate best with wind velocities between 6.25 and 12.5 m/s (measured at 10 m height) which are the critical wind velocities for moving particles in the 0.15 to 0.42 mm range. These winds mostly blow from the southwest. Consequently, the blowouts are elongated in the same direction.

Extreme aeolian events such as northwestern storms have little effect on blowout development compared to events which have a lower magnitude but occur with a higher frequency. An eventual shift towards higher effective wind velocities would probably result not in larger blowouts but in a break-down of the whole system, especially if this shift were accompanied by a change in wind direction. The accumulation of sand in the blowouts during storms should be seen as a first step of adaptation to a higher energy level.

Introduction

The presence of blowouts is the best evidence of aeolian dynamics in the coastal dunes. For more than a century their formation has been suppressed by stabilization measures in most dune terrains along the Dutch coast. To save costs and to restore the ecological and geomorphological variety, the stabilization measures have been relaxed somewhat during the last decades. Where wind is allowed free play and other conditions are favourable, the characteristic saucer-shaped depressions are a common sight.

To understand the risks involved in suspending stabilization measures, monitoring programmes for studying blowout development have been carried out in the few areas where stabilization measures have been carried out for some time (Jungerius *et al.* 1981; Jungerius and Meulen 1989). The data collected with these programmes can also serve other purposes. It is one of the aims of the Landscape-ecological Impact of Climatic Change project (LICC) to predict the impact of future climatic change on dune landscapes (Eybergen and Huis 1988). For this purpose, geomorphological processes such as blowout formation should be understood in relation to the relevant meteorological parameters, preferably measured

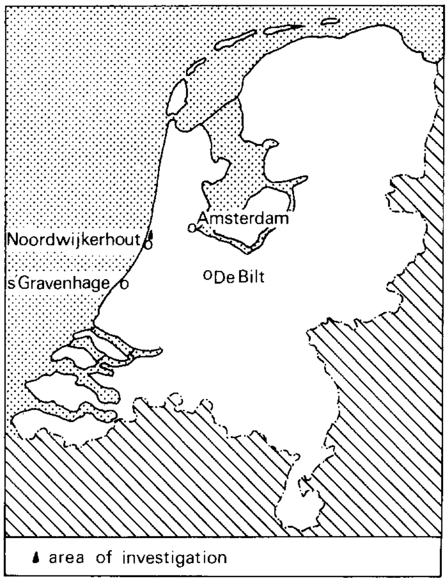

Fig. 1. The area of investigation.

at standard meteorological stations with long records. This relationship can be investigated with the data set collected for monitoring blowout development.

Standard meteorological observations to predict sand movement in coastal environments have been used before, but mostly for beach and foredunes (Sarre 1989; for the Netherlands see Adriani and Terwindt 1974). Rutin (1983) demonstrated that the wind regime in the inner dune zone is much less effective in terms of sand transport, presumably because the irregular topography and the presence of different types of vegetation prevent wind from blowing in prolonged gusts (Jungerius and Meulen 1988).

Blowouts are particularly abundant in De Blink near Noordwijkerhout (Fig. 1). This dune terrain has been closed to the public since 1962 so that a more or less natural development has progressed for over 25 years (Fig. 2). From the analysis of sequential air photographs it appears that the total number of blowouts increased from about 100 in 1958 to over 150 in 1986, in an area of just over 100 ha.

Surface changes in six blowouts in De Blink have been measured weekly over a period of two years (May 1976-May 1978). The lowering or raising of the surface in the blowouts has been compared with wind velocity and direction for the same weekly intervals, measured at a meteorological station in the area (Jungerius *et al.* 1981). For the purpose of this paper, the data have been analysed to assess the influence of wind events of various magnitude on the development of these aeolian features.

There are other climatic parameters which could control future aeolian processes in the coastal dunes. Increasing aridity may reduce the vegetation cover and increase the area exposed to the wind. On the other hand, increased rainfall could cause the water table to rise. Concomittant loss of organic matter could make the surface soil horizon even more susceptible to erosion. These aspects are outside the scope of the present paper.

Study area

The Blink is part of the belt of dunes running along the coast of the Dutch mainland. In the area of study the belt is approximately 1.5 km wide and is separated from the sea by a narrow strip of foredunes. The dunes were formed since the 10th century AD and cover an older system of beach ridges (Jelgersma *et al.* 1971; Klijn 1981). The bulk of the sand was deposited between the 14th and the 17th century in a pattern of large parabolae. Most of the original patttern is now obscured by secondary erosion features. The present relief ranges from 5 to 25 m and is very irregular. The sand has its main diameter in the fractions 0.15-0.42 mm. Calcium-carbonate content, mostly occurring as shell fragments, ranges between 1 and 4%.

The vegetation is characteristic for 'grey' dunes rich in lime and consists of shrubs (*i.e. Hippophae rhamnoides*, *Salix repens*, and *Ligustrum vulgare*), grasses (mainly *Ammophila arenaria*), mosses, lichens and algae. There are many bare patches where the grey sand is exposed.

Methods

Six blowouts were randomly chosen for inclusion in the monitoring programme. Surface changes have been measured with erosion pins placed in a specific

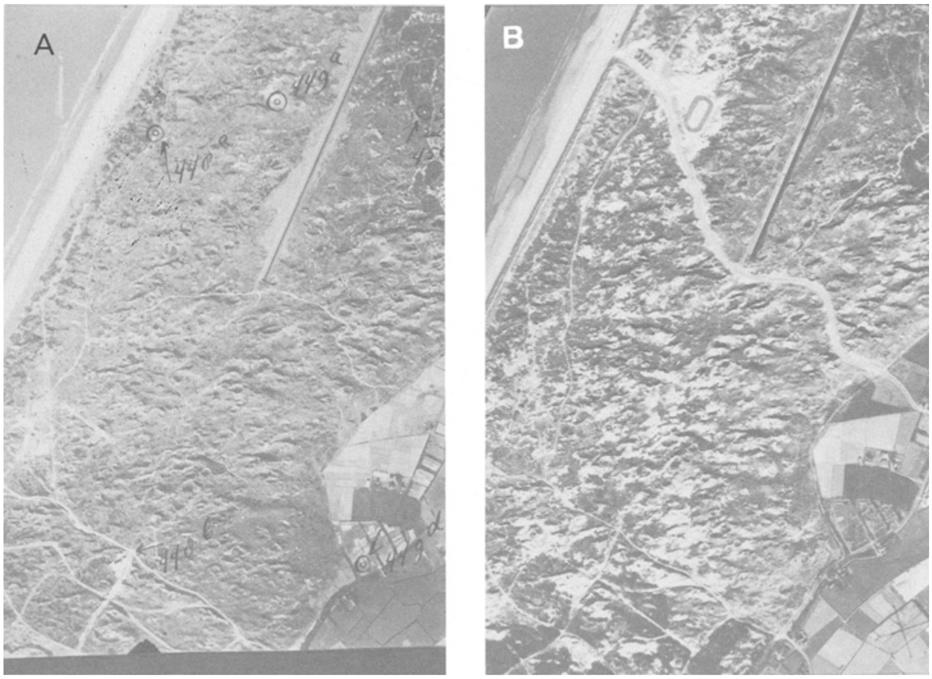

Fig. 2. Air photographs of 1938 (?,a) and 1977 (b) showing decreased vegetation cover and increase of blowouts.

pattern (Fig. 3). Welding rods of 3 mm diameter have been used which give little disturbance to wind flow. The surface changes have been compared with meteorological data from Valkenburg airbase, 14 km to the south and about the same distance from the sea as De Blink. At Valkenburg, hourly average wind velocity and direction are measured at standard 10 m height. Rutin (1983) found a strong correlation (r = 0.91, for the period 6-12-1978 to 30-10-1980) with the wind velocity recorded at 2 m height on top of a dune located in De Blink approximately 1 km from the coast. The following regression equation describes the relationship:

$$V_{(dune)} = 1.26 + 0.84\,(V)_{Valkenburg}$$

To obtain weekly wind data which could be matched with the weekly pin readings, the wind velocity (measured in .5m/sec = knots) was divided into 12 velocity classes. These classes were subdivided into four quadrants (NE, SE, SW and NW), thus leading to 48 velocity/direction classes. For each week the number of hours with wind in each of the wind classes was counted. The procedures described in Nie *et al.* (1975) were used for the correlation tests (mostly Spearman's correlation coefficient). The tests for the directional data are described in Doornkamp and King (1971). The term significant is used when the probability of occurrence under H0 is less than 0.05.

Theoretical considerations

Thresholds of sand movement

The extent of the wind erosion in the area has been estimated on the basis of theoretical studies. In Bagnold (1954) the threshold drag velocity V*t is calculated as:

$$V^{*}t = A\sqrt{((\sigma - \rho)/\rho)gd)} \qquad (1)$$

where A : a dimensionless constant (0.1)
σ : grain density (quartz: 2650 kg/m3)
ρ : air density (1.248 kg/m3 at t = 10C and p = 1013 mbar)
g : acceleration due to gravity (9.8 m/s^2)
d : grain diameter (m)

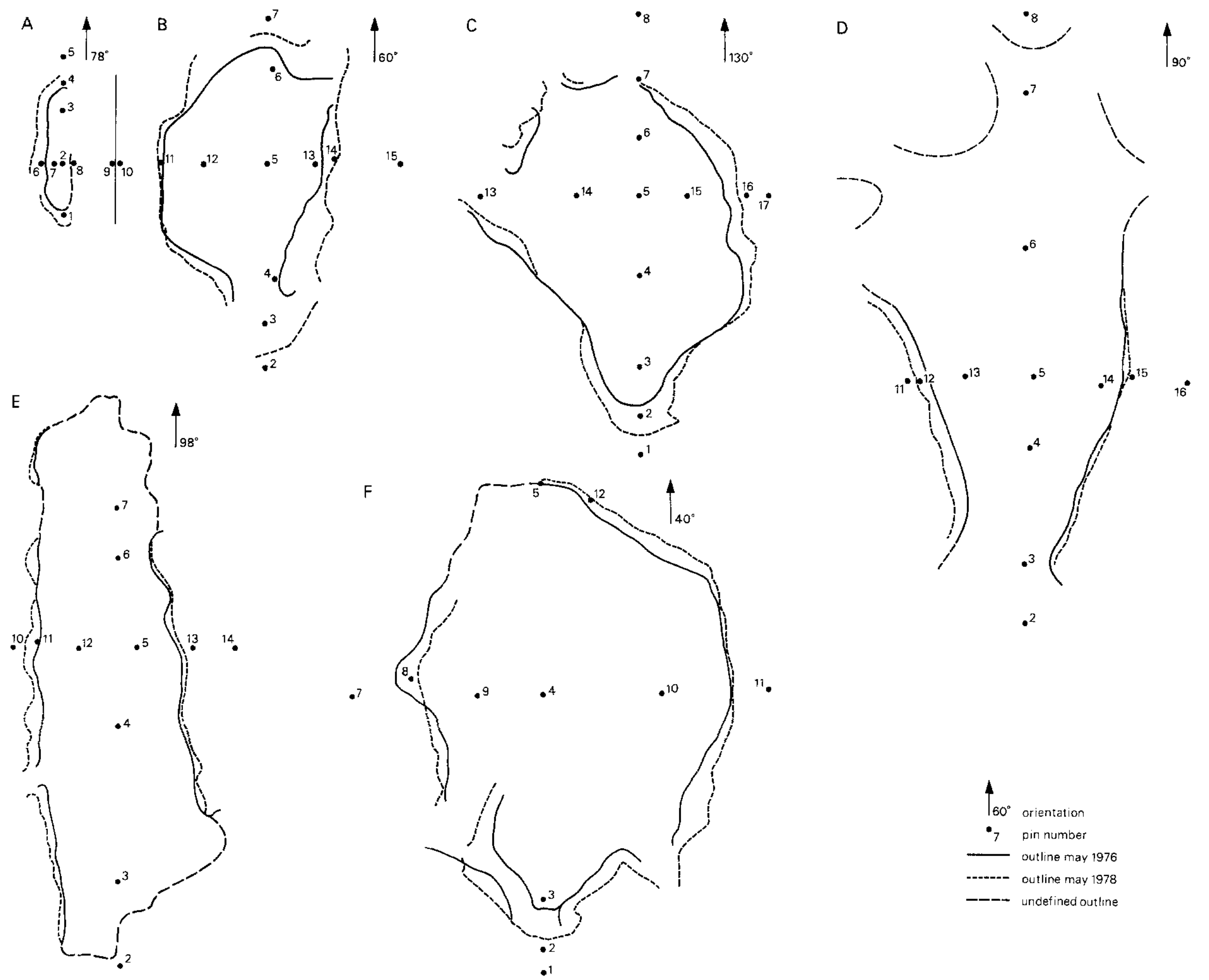

Fig. 3. Outline of the blowouts with the positions of the erosion pins (Jungerius *et al.* 1981).

The value of the fluid threshold velocity Vt can be derived from the threshold drag velocity V*t by:

$$Vt = V^*t.\ln(z/z0)/K \qquad (2)$$

where z : height of measurement of wind velocity (10 m)

z0 : roughness length of dune sand (d/30)

K : Von Karman constant ($\approx$ 0.4)

In the study area more than 90 % of the sand is in the size classes from 0.15 to 0.42 mm. Solving above equations for these values of d, fluid threshold wind velocities result between 6.4 and 9.96 m/s.

The rate of sand transport

According to Bagnold (1954, p. 69) the sand flow q can be calculated as:

$$q = \alpha\ C \sqrt{d/D}\ \rho/g\ (Vz - Vk't)^3 \qquad (3)$$

where Vz : wind velocity measured at level z

z : height of measurement of wind velocity (10 m)J

k' : focussing point of wind profiles over moving sand (0.01 m)J

d : mean grain diameter (0.25 mm)J

D : standard value of grain diameter (0.25 mm)

C : constant (1.8)

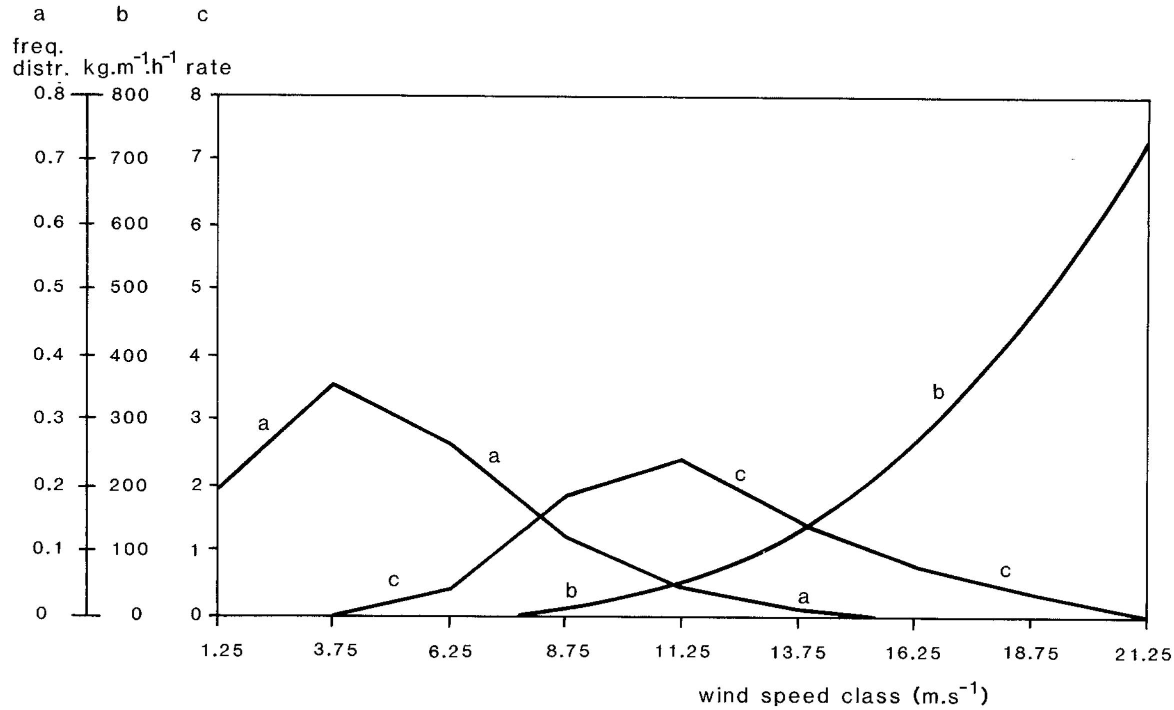

Fig. 4. Frequency distribution of wind velocity classes in the period from May 1976 to May 1978 (a), theoretical transport capacity as related to wind velocity (b), and expected rate of sand transport (a * b = c).

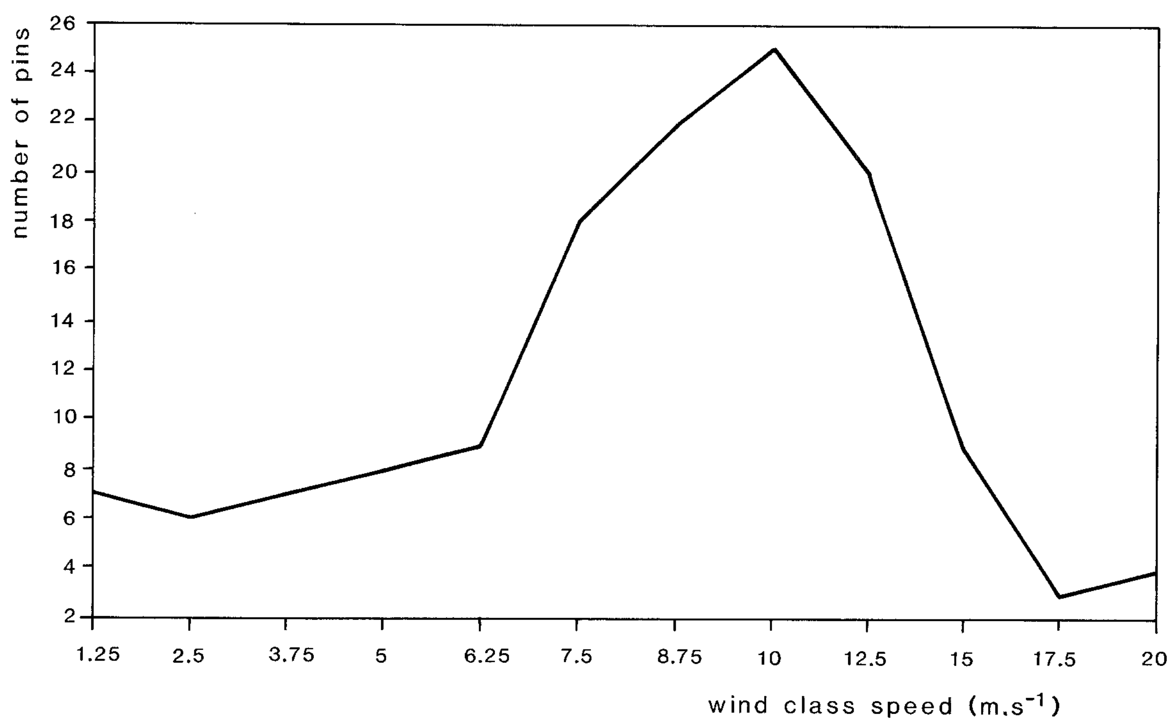

Fig. 5. The number of pinsites where lowering of the surface was significantly correlated with wind speed classes (two years measurements, n = 80).

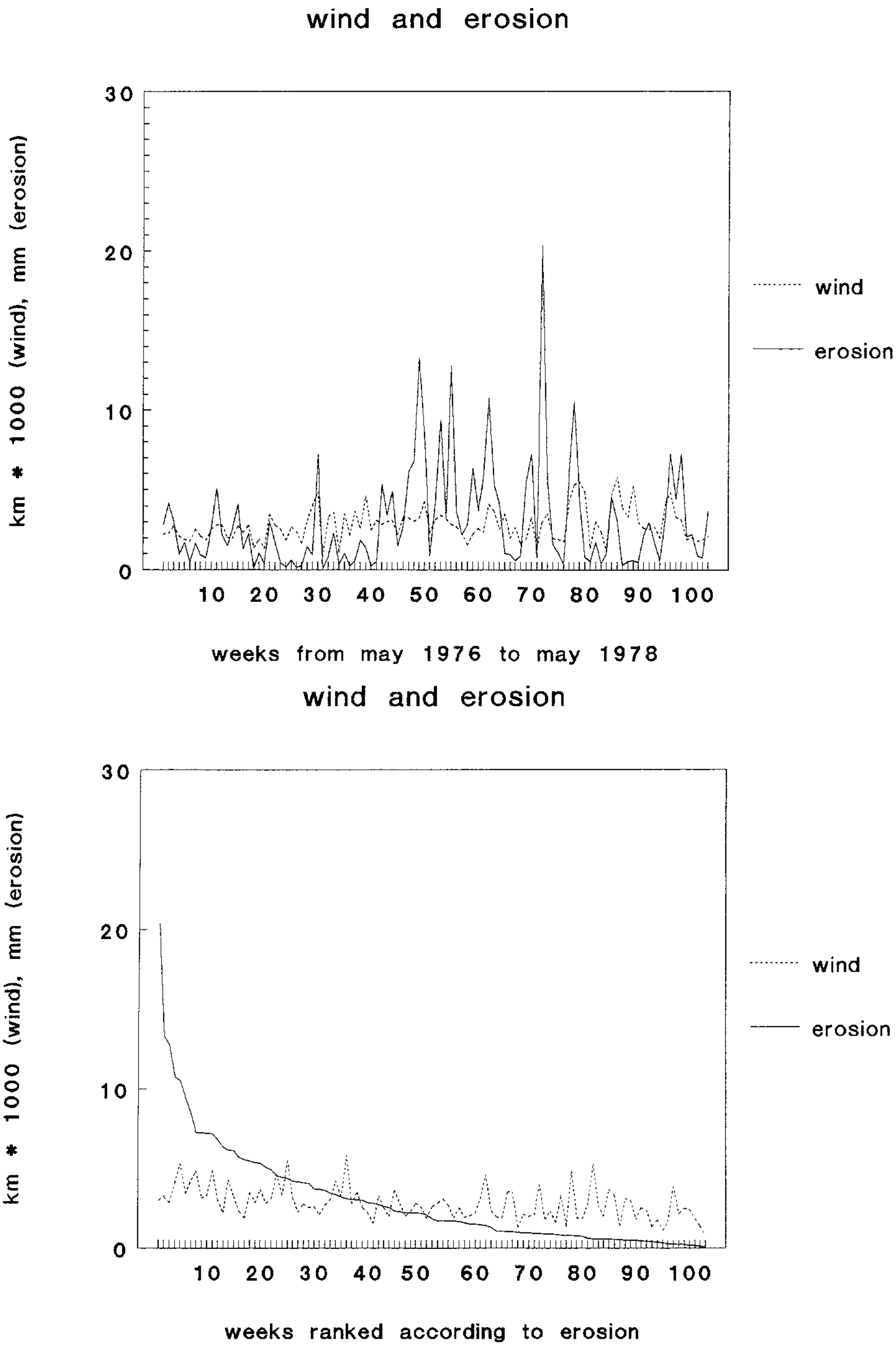

Fig. 6. Total distance covered by wind in each week during the period of measurement, and concomittant average erosion recorded at 56 erosion pins in 4 blowouts. a: weeks in sequence; b: weeks ranked according to amount of erosion.

α : $(K/\ln(z/k'))^3$
Vk't : threshold velocity Vt measured at level k', can be calculated with equations (1) and (2) by replacing z by k'

The effect of increasing transport capacity with velocity is counteracted by the tendency of strong winds to blow less frequently. In Fig. 4 this is shown for the wind measurements of Valkenburg during

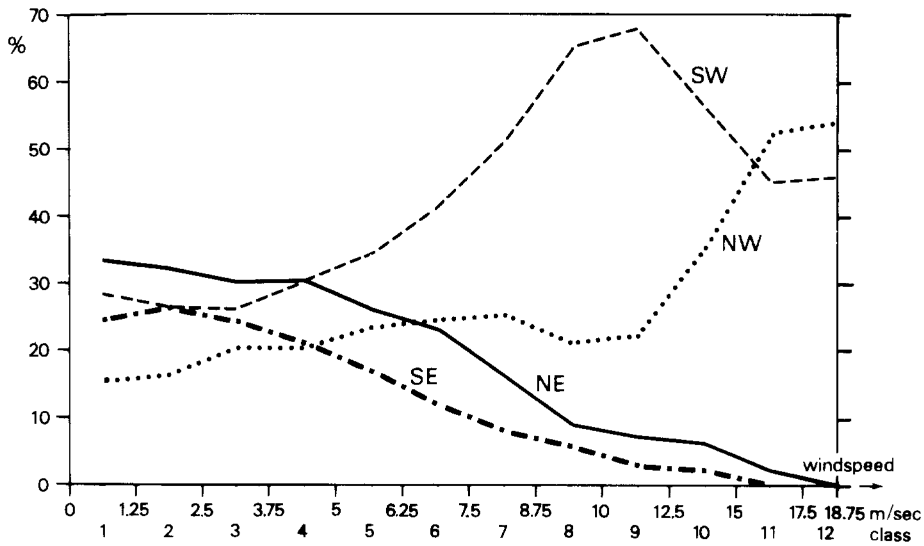

Fig. 7. Relative frequency distribution of wind velocities per quadrant (percentage of each wind speed class; Jungerius *et al.* 1981).

the period of observation.

The line showing the power relation between transport capacity and wind velocity derived from equation (3) intersects the line representing the Poisson-type distribution of magnitude between 10 and 12.5 m/s. The line representing the product of wind frequency and transport capacity has its maximum here. Theoretically this wind speed class should be most effective in transporting sand.

Field investigations

Figure 5 shows how many values of the correlation coefficient between wind speed (as defined above) and the 104 weekly pin readings in the blowouts were significantly negative (indicating deflation). Winds in the 6.25 to 12.5 m/s velocity classes appear to be most erosive. This agrees well with the results of Bagnold's equations discussed in the previous section.

At wind velocities above 12.5 m/s the number of significant negative values of the correlation coefficient decreases rapidly (fig. 5). From field observations it is known that high winds shift large amounts of sand, but this does not always result in net lowering of the floor of the blowout. In fact, there is a tendency for the blowouts to be filled at high wind velocities. Fig. 6a shows for the erosion pins (n = 56) of four of the most active blowouts, that it is not the strongest winds which cause most of the erosion. The peaks in the erosion pattern coincide poorly with peaks in the windspeed. This can be demonstrated even more clearly when the weeks are ranked according to length of wind range (Fig. 6b).

Another indication for the relative incompetence of strong winds can be derived from their direction (Fig. 7). Southwesterly winds are particularly frequent in the 6.25 to 12.5 m/s wind classes which are the most effective. This is supported by the preferred direction of the blowouts. The orientation of 100 blowouts have been measured in De Blink in 1976. The vector calculated from these data has a direction of 72 - 252 NE and a relatively high strength (r = 0.86; angular deviation s = 31). This agrees with the mean vector for the wind classes between 6.25 and 12.5 which is 251 NE (r = 0.43). At higher wind velocities NW winds become more important but they are apparently not very effective as eroding agent because they have not been able to contribute much to the orientation of the blowouts: the mean vector for the wind speed class above 15 m/s is 277.1.

The conclusion must be drawn that the blowouts are formed by winds which are most frequent in the velocity classes just above the threshold velocities. In the area under consideration these are south-westerly winds in the 6.25 to 12.5 m/s range. Stronger winds and winds from other directions are unable to adjust the blowout shape to their aerodynamical characteristics.

Discussion

To forecast the possible effect of future climatic changes on the aeolian dune landscape, it is not sufficient to understand the relationship between wind characteristics and blowout development. There is a whole set of conditions and processes which lead to the characteristic dune landscape. In so far as these conditions and processes have a relationship with climate, they should be taken into account, but this is clearly beyond the scope of the present paper.

The results of this study indicate that the effects of high- magnitude wind events on aeolian features of the inner dunes are spurious and of minor importance compared to events with a lower magnitude but a higher frequency. This is in accordance with the well-known concept of magnitude and frequency developed by Wolman and Miller (1960). This concept indicates that most of geomorphological work is done by events which are somewhat larger than those which occur most frequently.

Although the response time of the system to react to changes is short (see Eybergen and van Huis 1988, p. 13), which should be expected in view of the ease with which sand is moved by wind, the relaxation time is too long in respect to the recurrence interval of the extreme events. This means that the sensitivity of the landscape to high-magnitude events is low: gales occur too infrequent and are too shortlived to change the landscape configuration which is adjusted to a lower energy level.

Assuming no changes in land use, management, vegetation and sub-surface hydrological conditions, an assessment of the behaviour of the present system makes it possible to predict how the blowouts will respond to eventual future changes of the wind regime:

- A lower incidence of effective wind velocities will lead to stabilization of the blowouts.
- A higher incidence of effective wind velocities would give the blowouts other dimensions.
- A shift towards higher effective wind velocities would alter the whole system, especially if this shift were accompanied by a change in wind direction.

The accumulation of sand in the blowouts durings storms should be seen as a first step of the adaptation to a higher energy level. It is possible that a new landscape with wandering dunes will replace the present landscape of stabilized dune pock-of marked with blowouts.

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