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EROSION PROCESSES IN A DUNE LANDSCAPE ALONG THE DUTCH COAST

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Summary

The landscape of the dunes along the Dutch coast is the result of the interaction of biological and geomorphological processes. Where the latter prevail, new landforms are created: blowouts by wind erosion, and rills and accumulation footslopes by overland flow. Spatial extent and rate of the erosion processes have been assessed by mapping and by measuring. It appears that dune sand is either sensitive to erosion by wind, or erosion by water, depending on the presence of organic material. Clean (yellow) sand is cohesionless and easily blown away, but has no surface runoff. Grey sand containing organic matter on the other hand will resist wind erosion, but it is waterrepellent and will be washed from slopes when rain follows a period of dry weather. Once the grey surface sand is removed from the surfaces by water erosion, wind erosion begins in the underlying yellow sand.

Present-day geomorphological processes reshape the slopes of the original parabolic dunes. **Wind** is particularly active in summit areas where new blowouts are formed, whereas **overland flow** creates concave south-exposed slopes. The stepped surface of the north-exposed slopes is due to mass movements following rabbit activity.

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1 Introduction

The formation of the dunes along the coast of the Dutch mainland began in the period between 10th and the 12th century (KLIJN 1981). Three phases of dune building have been recognised (JELGERSMA et al. 1970). The initial phase ended in the 13th century or somewhat later, and consisted mainly of filling-up the pre-existing undulating relief of the coastal barriers. The main phase is the second one when the large parabolic dune systems were produced which determine the geomorphological character of the dune belt. The age of this phase is assigned to the period between 1450 and 1750 AD. The third phase began in the 19th century with the formation of small parabolae on the western fringe, separated from the sea by a narrow strip of foredunes. These foredunes came into being after 1850 AD and are largely artificial (KLIJN 1981).

Since more than a century, man has protected the dunes against further wind action, mainly by afforestation with Pinus, and by planting marram grass (*Ammophila arenaria*) on exposed sites.

From the geomorphological viewpoint this meant that the dunes became fossolized.

To save costs and to increase the ecological variety in the dune landscape, the stabilization measures have been relaxed somewhat during the last decades, with the result that deflation and other geomorphological processes are now evident in several places (v.d. MEULEN & WANDERS 1984). Because of this development the dunes regain their importance for geomorphological research. Two aspects make the dunes particularly valuable for geomorphology:

1. the geomorphological processes operate in a more or less 'natural' environment in direct relationship with plants and animals; and

2. the rate of these processes is so high that their effects on the landscape can be readily studied.

2 Geomorphological versus Biological Processes

An essential characteristic of the dune landscape is its dynamics which result in a wide variation of landforms and vegetation cover. These dynamics can be expressed in terms of geomorphological and biological processes (fig.1). Every part of the dune landscape is characterized by the interaction of these two groups of processes. To what degree either the geomorphological or the biological processes dominate, is reflected in the soil profile.

The geomorphological processes comprise the action of wind and water. They lower the surface by erosion, or raise the surface by accumulation, thereby changing the relief of the dune landscape. In terms of soil development, the geomorphological processes add or take away soil material in various quantities, resulting in the incorporation of new parent material into the soil profile, or soil profile truncation, respectively. In extreme cases the soil profile is either completely removed, or buried.

The biological processes mainly consist of the establishment and further development of vegetation. This development essentially comprises the building up of structures from simple to more complex forms, and the change from one type of species composition to another. Underground biological processes include soil organic matter and biomass production. They cause soil profile differentiation in the accepted pedological sense. The role of animals is ambiguous. Rabbits reduce the vegetation cover by their grazing habits and add to the instability. They also dig up sand which is transported downslope by other processes. Many members of the soil fauna, on the other hand, stimulate stability by producing organic matter which binds the sand particles.

To the extent that either the geomorphological or the biological processes dominate, three compartments can be recognized in a dune ecosystem (fig.1). In the first compartment, the geomorphological processes are so active that new landforms such as blowouts and shifting dunes are created. Some plants such as marram grass (*Ammophila arenaria*) are adapted to the extreme conditions of geomorphological dynamics, but biological processes as such are of minor importance. No soil profile is formed in this compartment.

The second compartment is characterized by various combinations of geomorphological and biological processes. The

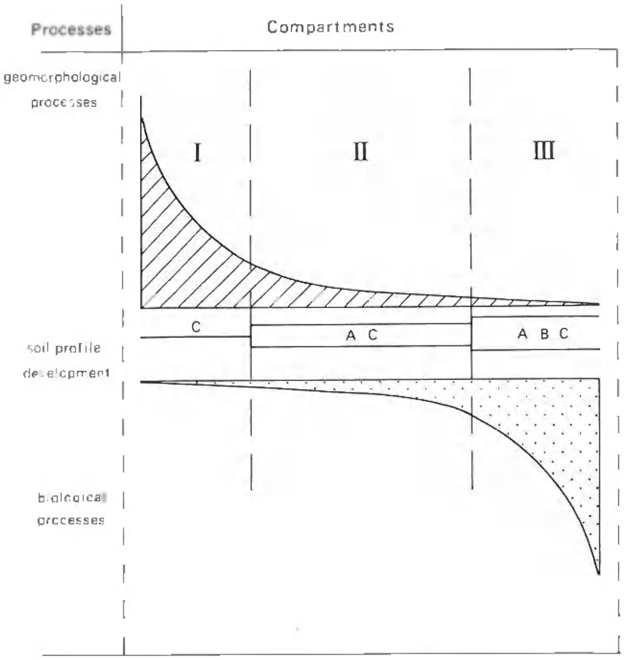


Fig. 1: *Schematic representation of the dune ecosystem.*

relative importance of the two groups of processes determines the ecological diversity. The geomorphological dynamics are not so intense that new aeolian forms develop. Neither are the biological dynamics so dominant that the soil surface is completely stabilized by vegetation. The soil is enriched with organic matter and developes to an AC sequence, but the profile as a whole is a record of alternating phases of truncation and/or incorporation of material transported from elsewhere (photo 1).

In the third compartment, the geomorphological processes have largely come to a stop because the vegetation has stabilized the surface. Soil profile formation is mainly determined by vegetation and soil fauna, eventually resulting in an ABC horizon sequence.

The compartments as defined above can appear to us in the field in various dimensions. When the entire dune strip in its full width is considered, compartment I mainly occurs in the outer dune zone, or foredunes, near the sea. This is the zone of the 'yellow' dunes (Weiße Düne, dunes blanches). Compartment III comprises the inner dunes which are completely covered with vegetation varying from grassland to woodland. Compartment II, intermediate between these two extremes, is the important central zone which is characteristically found in most dune areas. It is the zone of 'grey' dunes (Graue Düne, dunes grises). The vegetation has an open character and consists of algae, mosses, herbs and scattered shrubs.

On a smaller scale within compartment II, sometimes even on one and the same slope, one finds occurrences of compartment I, e.g. blowouts, rills and alluvial fans, and of compartment III, e.g. patches of woodland in sheltered positions.

Photo 1: *A sequence of A horizons buried by windblown sand, exposed in a blowout.*

Photo 2: *A blowout in the dunes along the Dutch coast.*

Photo 3: *Rill in dune slope with accumulation of sand at the base.*

Photo 4: *Wind erosion begins in the yellow, cohesionless sand exposed in the upper slope area (background) as soon as the grey, waterrepellent surface sand is removed by water erosion (foreground).*

This paper focusses on the two main erosive agents: wind and water in the grey dunes (compartment II). The relative importance of these two agents can be established by mapping and by measuring. The first method gives insight in the areal extent of the processes, the second method in their rate.

3 Erosion by Wind

The presence of wind erosion depends on the relationship between the erosivity of the wind and the erodibility of the site. The erosivity of the wind is largest near the coast and in exposed areas like dune summits and ridges. The erodibility of the site is determined by vegetation and soil properties. Higher plants like trees and shrubs break the force of the wind, but a continuous cover of plants as low as mosses and algae is also sufficient to protect the soil against erosion.

Compartment II shows many spots without vegetation cover, but whether or not these are attackd by wind depends on the soil. A small amount of organic matter present as a thin coating around sand grains appears to be sufficient to resist wind erosion, at least for some time. It is this coating which gives the sand in the grey dunes of compartment II its characteristic colour. Yellow or 'clean' sand, i.e. sand without organic material, is cohesionless and particularly sensitive to uptake by wind. Wind erosion often begins when this sand is at the surface.

The present eolian activity in the dunes resulted in modification of the original parabolic dune forms. Prevalent among these modifications is the blowout, shallow depressions of mostly elongated outline which are free of vegetation (photo 2). Depending on the extent of the stabilizing measures carried out, the density of the blowouts in the dune belt along the coast of the Dutch mainland varies from 0 to 100 per hectare. The mean length of the blowouts varies from 15 to 20 m, and their mean width from 5 to 7.5 m (NOEST 1987). Characteristic is the fairly constant ratio between length, width, and other form parameters which suggests that they are formed according to specific aerodynamic laws (JUNGERIUS et al. 1981).

4 Erosion by Water

The traces of water erosion in the dunes are much less conspicuous and have generally not been subject to conservation measures by dune management authorities. Yet, much material is shifted downslope during rain, especially in summer when the sand at the surface had the opportunity to dry out on warm days prior to the rain shower (RUTIN 1983). In these circumstances, sand grains repel water so strongly that no water will penetrate the soil. Water repellence as a factor in erodibility was described i.a. by OSBORN et al. (1964). A necessary condition for water repellence in the dunes is the presence of organic matter in the soil (WESSEL, in prep.). It is possible that the same organic coating that protect sand grains from take-up by wind makes them sensitive to erosion by water.

The main types of erosion by water are splash and surface wash. A minimum slope angle of 6 degrees is required for the latter process. Both processes are particularly effective on south-exposed slopes where strong insolation results in a combination of incomplete vegetation cover and a high degree of water repellence (RUTIN 1983). The geomorphological evidence of water erosion in the dunes is not always easy to find because it is rapidly obliterated by other processes. Splash imprints are particularly shortlived but the well-developed rill patterns left by surface wash also disintegrate within two or three days after a storm. The depositional forms are more stable (photo 3). The eroded material is deposited at the foot of the slope; first the sand, then lower down the organic material that has been washed out.

5 Erosion Survey

Erosion surveys at scale 1:10000 have been carried out in various dune terrains (JUNGERIUS 1987). The spatial importance of the erosion processes can be assessed from these maps. Fig.2 shows a fragment of a dune area of a 5.5 km^2 which has been surveyed to support a study of the effect of recreation on the dune landscape (BISSELING et al. 1983). The area concerned is situated north of IJmuiden, in the 'Noord-Hollands Duinreservaat'. The geomorphological base for the survey (fig.2a) was prepared by WESTINGA (1982). He recognized 4 belts of parabolic dunes running parallel to the coast, separated from the sea by a narrow strip of foredunes. From west to east the parabolae increase in width (from 100 m to 500 m) and in height (from 15 to 35 m). In between these belts are lowlying interdune areas which have been interpreted as former beach flats across which the parabolae have travelled.

The interdune areas have been subdivided into the actual flat parts (V) and narrow, winding low ridges which are formed by recent eolian activity (0). The parabolic dunes have been subdivided into three parts depending on slope: steep (S: >15 degrees), moderate (M: 5–15 degrees) and level summit areas (P: < degrees).

Tab.1 shows the area of the landscape units with a discontinuous vegetation cover (compartment II) which suffered erosion by one or both of the two agents. The other two compartments are not included in this table. Compartment I is represented by the narrow strip of foredunes which is dominated by deposition of sand blown from the beach. Compartment III occupies roughly one third of the surveyed area and consists mainly of flat interdune areas planted with dense forest stands. This area is hardly affected by erosion processes.

As may be expected, the extent of erosion by surface wash is dependent on slope angle (tab.1). More complicated is the pattern of erosion by wind. The flat interdune areas (V) suffer wind erosion particularly where the vegetation has been removed for the maintenance of infiltration canals dug for drinking water catchment. For reasons which are not known, the low secondary dune ridges (0) are very sensitive to wind erosion. It is possible that they are situated in zones of high turbulence, or that their sand has become more rounded by the prolonged eolian treatment: rounded grains are transported more freely at high wind speeds (WILLETTS 1983).

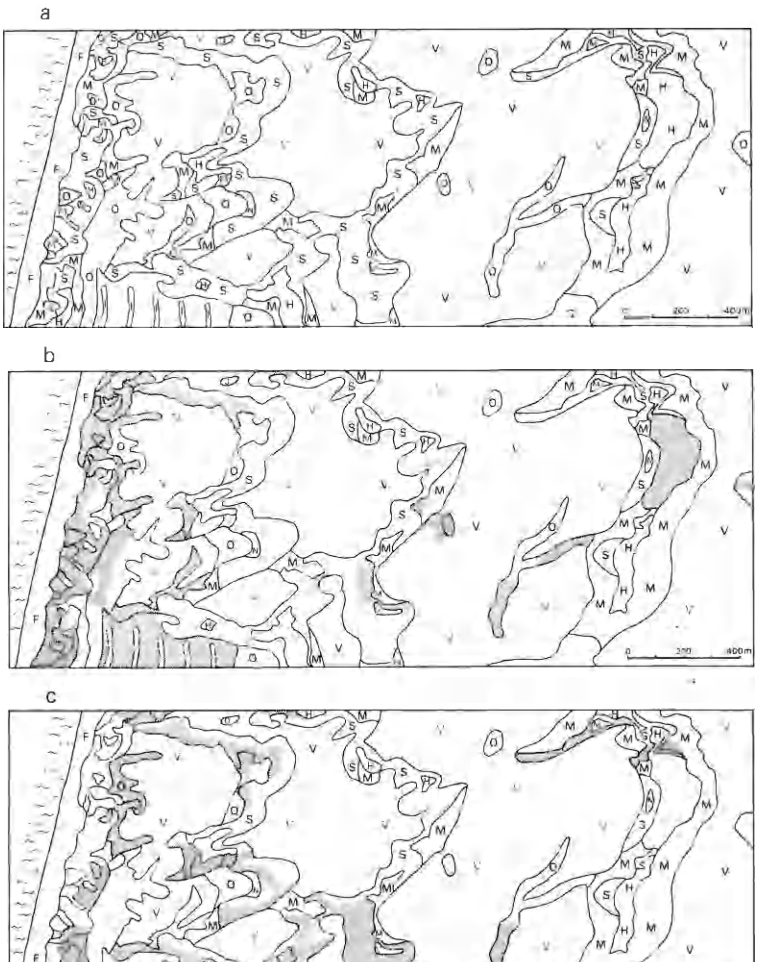
On the parabolic ridges, wind features such as blowouts are manifest particularly at the upper part of the steep slopes (S) and on the level summits (H).

The relationship between processes by wind and by water can be inferred from the figures between brackets. With the exception of steep slopes, the association between the two types of erosion is generally weak. This agrees with the notion that dune sand is either sensitive to erosion by wind, or sensitive to ero-

Fig. 2: *Part of the surveyed area north of IJmuiden.*

a) The terrain units (simplified after WESTINGA 1982)
b) Surfaces affected by wind erosion
c) Surfaces affected by water erosion.

V = interdune area
0 = do, with secundary dunes
S = parabola, steep slope
M = do. moderate slope
H = parabola, level summit area
F = foredunes
I = infiltration channel



Code	landscape unit	total surface ha	erosion					
			wind		water		(both)	
			ha	%	ha	%	ha	%
V	interdune area	36	18	50	2	6	(1	3)
0	do, with secundary dunes	23	11	48	4	17	(2	9)
M	parabola, moderate slope	25	4	16	10	40	(3	12)
S	do, steep slope	50	17	34	42	84	(16	32)
P	do, level summit area	19	5	26	4	21	(1	5)
Total		153	55	36	62	41	(23	15)

Tab. 1: *The surface of the landscape units with a discontinuous vegetation cover (Compartment II) which has been eroded by wind and water in the surveyed area (total surface 546 ha). Between brackets the surface which suffered from erosion by both processes.*

sion by water, depending on the absence or presence of organic matter which induces waterrepellence. It could be said that the two processes are mutually exclusive in space. However, their combined occurrence on steep slopes (S) indicates that they are not mutually exclusive in time: when humic sand is washed away from the upper slope sections by overland flow, wind can easily take hold of the cohesionless clean sand which becomes exposed (photo 4). Paradoxically, water erosion has to be checked in order to prevent wind erosion in many of the dune landscapes along the Dutch coast!

6 Erosion Measurements

RUTIN (1983) measured the erosion processes on an arm of a parabolic dune between IJmuiden and The Hague. Fig.3 shows a transect through the ridge and indicates the trajectory which is subject to the two erosional agents. Most of the sand blown from the blowout in the top of the dune is deposited on the upper slope. The slopes are subject to splash and surface wash. The material eroded by these processes is deposited at the foot of the slope. Added to the erosion processes is the activity of rabbits which also has geomorphological consequences.

The measurements cover a period of 18 months. From the published data (RUTIN 1983) it has been calculated how much sand was deposited at the foot of the slope in one year. Tab.2 shows the results. It appears from this table that, on a volume base, rabbits contribute little to the erosion budget. According to RUTIN they dug many holes (more than 3 per 100 m^2) and shallow scrapes (about 30 per 10 m^2), but most of the material remained on the slope around the diggings.

The amount of splash depends on the vegetation cover and the slope angle. Regression analysis of RUTIN's splashboard measurements resulted in an equation of the form:

$$Qs = 0.133 \times (1.6 \times s + 50) \times exp(-0.05 \times V) \times P$$

in which

Qs	=	amount of splash in cm^3 per m slope width per year
s	=	slope angle in degrees
V	=	vegetation cover in %
P	=	precipitation in cm per year

(The term (1.6 × s + 50) is introduced

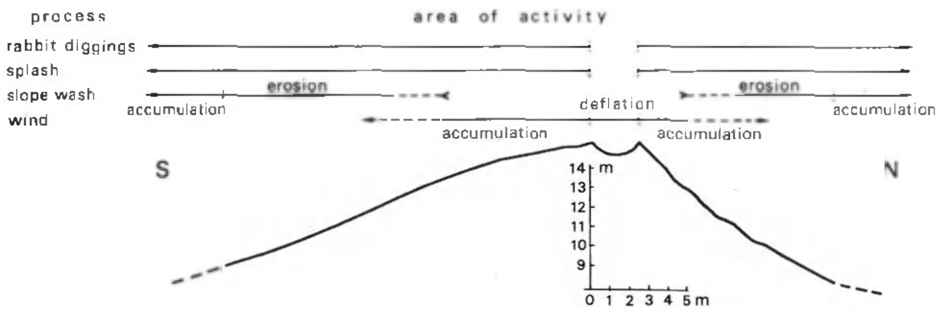


Fig. 3: *North-west section of parabolic dune in the dune terain between IJmuiden and The Hague investigated by RUTIN (1983). The indicated processes are quantified in tab.2.*

Process	exposure of slope	season	vegetation cover (%)	transport (cm^3 per m slope width)
Splash	north	winter	50	38
		summer	76	8
	south	winter	12	256
		summer	18	145
Slope wash	north	winter		0
		summer		224
	south	winter		3431
		summer		12072
Wind	north			<250
	south			250–2500
Rabbit diggings				16

Tab. 2: *Amount of sand reaching the base of the dune slopes of fig.3, in the period between 1-10-1979 to 30-10-1980. The figures have been calculated from data by RUTIN (1983, mainly tables III.2 and IV.2, and Fig. VI.8).*

to calculate the difference between upslope and downslope splash, from EKERN 1950)

The south-exposed slopes which are exposed to the sun and have a lower vegetation cover are more subject to erosion by splash. However, the actual amount of splash is of minor importance compared to erosion by surface wash. Two facts are clear:

1. the summer is much more important for erosion than the winter; and
2. south-exposed slopes produce much more material than north-exposed slopes.

The measurements confirm the findings of the erosion survey, particularly in respect of the importance of the waterrepellence properties of dune sand for erosion. The grey sands exposed on the south-exposed slopes are extremely waterrepellent when dry. Storms in summer have therefore a devastating effect on the slopes. In fact, more than half of the summer production came from two storms (RUTIN 1983).

The pattern of wind erosion and accumulation is complementary to that of erosion by water. Whereas surface wash increases in importance with the amount of overland flow downslope, wind activity increases in the other direction towards the summit where the blowout is formed. Most of the sand drift is deposited immediately around the blowout on the upper slopes (RUTIN 1983). The amount which reached the base of the south-exposed slope is only 10 to 20% of what left the blowout in the same period. For the north-exposed slope this is not even 1%.

7 Geomorphological Implications

The present geomorphological development of dune slopes can be inferred from the investigations presented in this paper. Generally speaking, the processes here discussed all result in lowering of the relief: the top of the dune is blown away, and all transport on the slopes is essentially directed downwards and filling up the depressions. However, slope profile development is not the same for the various processes, and wind action creates a relief which is much more irregular than a landscape modelled by water erosion.

In the case of parabolae and other dune ridges, a distinction should be made between summit area, south-exposed slopes and north-exposed slopes. The summit area is the domain of the wind. As long as there is an active blowout, 'yellow' sand will be deposited on the upper slopes. Where the sand is caught in stands of vegetation, secondary dunes may be formed. Particularly active in this respect are marram grass (*Ammophila arenaria*), buckthorn (*Hippophae rhamnoides*) and creeping willow (*Salix repens*). This sand is free of organic matter and therefore not waterrepellent. This means that the upper slopes will be little affected by surface wash because all rainwater sinks away into the soil.

The south-exposed slope is the domain of surface wash. This process creates a smooth slope profile. The upper end of this profile is not lowered, because there is no water repellence here and consequently no erosion. The lower end of the profile is equally not lowered because accumulation begins here. With both ends of the profile being fixed, erosion by surface wash will create an increasingly more concave slope profile.

The north-exposed slope is the domain of the rabbits. It is here that they dig most of their holes and where they trample the soil and cause shallow mass movements. This results in the stepped profile which is characteristic for many of these slopes in the dune landscape along the Dutch mainland.

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