ENDANGERED DUNE SLACK PLANTS; GASTRONOMERS IN NEED OF MINERAL WATER

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Abstract

On the Dutch Wadden Sea islands endangered basiphilous dune slack species are generally found in young primary beach plains, in young dune systems with blown out slacks and in seepage areas of large hydrological systems. Many of these species have their optimum in the phytosociological association Junco baltici-Schoenetum nigricantis and require habitats with a low nutrient availability, a high pH and regular flooding.

A case is presented in which basiphilous dune slack plants have existed for decades in an old dune slack situated in the centre of the island of Schiermonnikoog, where infiltration conditions prevail. A hydrological mechanism is discussed that creates alkaline conditions in natural dune slacks surrounded by old, partly decalcified dunes. A hydrological modelling of the area was carried out and the simulated flow line pattern was compared with an interpretation of the macro-ionic composition of the groundwater of the hydrological system. The geochemical evolution of the dune water along the flow lines was interpreted from 250 water samples, most of them obtained from minifilters installed in deep borings to a depth of 24 meter below the surface.

The interactions between basiphilous vegetation types and the discharge of calcareous groundwater are easily disturbed by even small changes in the local hydrological conditions. The result is a rapid acidification and the decline of endangered dune slack species.

Nomenclature: Van der Meyden et al. (1983) for vascular plants; Westhoff & Den Held (1969) for vegetation types.

Introduction

Just a century ago inhabitants of the Dutch Wadden Sea islands were struggling to survive mainly as fishermen, farmers and beachcombers. Together with state organizations they fought the ever moving dunes, which sometimes threatened to bury whole villages under the sand, by planting pines and marram grass (*Ammophila arenaria*). Polders were established and dune valleys reclaimed for agriculture. Despite these activities the vegetation of most of the islands remained scarce. Some 30 years ago even scientists thought that the climax vegetation of the dry dunes were heathlands

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(Heykena, 1965). Only in sheltered moist places small forests could develop. Wet dune valleys were everywhere and covering 30% of the area.Villagers claim to have been able to skate across most of the islands in the winter period, because all large dune valleys were interconnected.

Nowadays shrubs and tall grasses have taken over most of the dune area and the dunes themselves are fixed. This dune fixation is mainly caused by afforestation and by prevention of sand blowing by covering bare soil with branches or even hay. The fixation of the coast line, especially, led to an ongoing succession in the hinterland. This process has been accelerated atmospheric by deposition from industrial areas.

Recent studies on dune slack vegetation in the Netherlands have shown that wet basiphilous species have become increasingly rare during the last 20-30 years, even in dune areas with a high lime content (Van Dorp et al., 1985). Among the species most affected are *Littorella uniflora, Schoenus nigricans, Liparis loeselii, Epipactis palustris, Dactylorhiza incarnata,* and *Parnassia palustris.* These species can still be found on several Wadden Sea islands in different pioneer stages in mainly three types of dune slacks: (i) primary beach plains; (ii) secondary, blown out, slacks; (iii) slacks in seepage areas of the main hydrological system of an island (Lammerts et al., 1992). The latter two types, especially, have become scarce in the Netherlands.

In this paper we will discuss the habitat requirements of endangered basiphilous vegetation types on the Dutch Wadden Sea islands and illustrate the importance of local hydrological systems for the regulation of site factors in a seepage slack on the island of Schiermonnikoog.

Description of the study areas

Field studies were done in dune slacks on all of the larger dutch Wadden Sea islands:

- on Texel in the "Moksloot valley", a 225 years old primary dune slack of c. 100 ha., with remnants of brackish groundwater and regular flooding with fresh surface water;
- on Vlieland in the "Kroon's Polders", a 70-90 years old beach plain of c. 200 ha., divided in several compartments by dikes and only periodically and locally influenced by brackish water;
- on Terschelling in the "Koegelwieck", a large, ± 80 years old. blown out dune slack of c. 50 ha., where different stages of vegetation development occur in sod cutting experiments from 1956, 1986, and 1990;
- on Ameland in the "Lange Duinen", one of the older (60 years old) primary dune slacks of ca. 60 ha., still periodically flooded by North Sea water;
- on Schiermonnikoog in a 35 years old primary dune slack of ca. 40 ha., with a well developed Schoenus nigricans vegetation, situated in a gradient of fresh and brackish groundwater;
- on Schiermonnikoog the "Vuurtoren valley", a 40 years old blown out dune slack of ca 0.1 ha., in which shrubs start to invade the basiphilous vegetation.

A more detailed eco-hydrological research on the functioning of a local hydrological system was carried out in a seepage slack called the "Kapenglop" on Schiermonnikoog. This slack, situated in the central (and oldest) part of the island and is enclosed by three dune ridges of different ages (150-400 years; Isbary, 1936). Orignally, the Kapenglop was a sandy beach plain. Some hundred years ago sea water flooding was prevented by the enclosure of the dune masses. From that time on the dune slack was influenced by fresh water only. Removing organic material by sod cutting occurred until the early 60s in the western part of the dune slack. Well developed stands of the *Samolo-Littorelletum* and the *Junco baltici-Schoenetum nigricantis* were observed here between 1952-1954 (Den Hartog, 1952; Westhoff, 1954). All basiphilous species, such as *Schoenus nigricans, Dactylorhiza incarnata, Epipactis palustris* and *Pedicularis palustris* practically disappeared between 1977 and 1983 (Grootjans et al., 1991). These changes were related to changes in the local hydrological system (groundwater abstraction) and not to decalcification of the top soil during that period.

Methods

Vegetation

The vegetation was recorded in plots of 2 x 2 meter, using the Braun-Blanquet cover-abundance scale, in the summer of 1991.

Soil

Soil samples were taken at all the sites where the vegetation had been recorded in June 1991. Samples were taken in triplo at each site. Each sample consisted of 10 sub-samples which were pooled. The organic and mineral layer was sampled separately. The pH(H_2O), pH(KCl), C-content, $N_{tot.}$ and $P_{tot.}$ were measured, using standard techniques.

Hydrology

Sets of groundwater tubes (PVC, diameter: 18 mm) were placed at each sampling site and the water table was recorded biweekly between May 1991 and June 1992.

In the Kapenglop case study the macro-ionic composition of 250 groundwater samples, was executed using standard techniques (see Stuyfzand et al., 1992; Grootjans et al., 1995). The water samples were obtained from minifilters installed in deep borings to a depth of 24 meter below the surface.

Data analysis

An Average Linkage Clustering was applied to the vegetation data using the computer program package VEGROW (Fresco, 1989). The species of the clusters obtained were arranged in phytosociological groups according to Westhoff & den Held (1969).

A Detrended Correspondence Analysis was applied to the vegetation data set and corresponding abiotic factors, using the computer program package CANOCO (Ter Braak, 1986)

Groundwater flow line patterns in the Kapenglop area were calculated using the computer program FLOWNET (Van Elburg et al., 1987).

Results

Dune slack vegetation

The analysis of vegetation data revealed six clusters (Table 1). Three clusters belonged to the basiphilous pioneer community *Junco baltici-Schoenetum nigricantis* of the alliance Caricion davallianae. The other three clusters consisted of vegetation types typical for more mature and acidophilous stages of dune slack succession. The three subtypes of the *Junco baltici-Schoenetum nigricantis* (clusters A, B and C) reflect differences in dune slack types.

Cluster A, with differentiating species of the *Armerion maritimae*, a salt marsh community, reflects the influence of brackish flood water. Dense stands of *Schoenus nigricans,* with accompanying species such as *Epipactis palustris* and *Parnassia palustris*, can occur in isolated brackish sites.

Cluster B represents a relatively species-rich *Schoenetum*-type on calcareous substrates and occurs in blown out slacks or in fresh water parts of primary dune slacks. *Schoenus nigricans* is not always present, but when the species occurs it often forms a dense vegetation.

Cluster C represents very open stands of the *Junco baltici-Schoenetum nigricantis,* with a relatively high abundance of pioneer species of the *Nanocyperion flavescentis* and the *Litorellion uniflorae*. They are found in wet slacks which are periodically flooded with fresh seepage water.

Cluster D consists of vegetation records from areas with a modest influence of base-rich groundwater. Species of the *Ophioglosso-Calamagrostietum* and the *Caricetum trinervi-nigrae* are usually present from the start of the succession and gain dominance within 25 years.

Table 1. Cluster groups based on Average Linkage Clustering of plots of different types of dune slacks on the Dutch Wadden Sea islands. The table shows the frequency of species within the cluster (I = is present in 1-20 % of the vegetation plots, II= 21-40%, present III= 41 -60 %, IV =61-80%, V= 81-100%) and mean % cover in the cluster group. Only differentiating and characteristic species are presented.

Cluster group	**A**	**B**	**C**	**D**	**E**	**F**
no. of plots:	10	10	12	10	9	8
Caricion davallianae						
Schoenus nigricans	III^{9}	IV^{12}	IV^{5}			
Carex flacca	IV^{2}	V^{3}	II	I		II
Juncus alpinoarticulatus	V^{2}		V^{2}		III	I
Parnassia palustris		II	II	I		
Dactylorhiza incarnata	I	I		I		
Epipactus palustris	III	III^{3}	I		I	I
Equisetum variegatum		II				
Linum catharticum	II	II^{2}	I			
Peducularis palustris					II	
Armerion maritimae						
Scirpus maritimus					II^{1}	
Juncus gerardii	III	I			II^{1}	
Glaux maritima	III	I				
Nanocyperion flavescentis and Litorellion uniflorae						
Radiola linoides			III			
Carex oederi	II	III1	V^{3}			
Littorella uniflora			III^{2}			
Samolus valerandi		I	IV^{4}		I	
Ophioglosso-Calamagrostietum						
Calamagrostis epigejos	IV^{2}	III	IV	V^{24}	III	IV^{1}
Ophioglossum vulgatum				III	II	
Phragmition						
Phragmites australis	II	I	I	I	IV^{2}	I
Galium palustris	I		V^{2}		V^{2}	I
Caricion curto-nigrae						
Ranunculus flammula		V^{3}		IV1		
Carex nigra	I1	I	II		IV^{24}	
Carex trinervis	I	IV^{2}	IV^{1}	IV^{1}	II	V^{2}
Oxycoccus macrocarpos			III	IV^{26}	II1	
Potentilla palustris					II^{11}	II1
Hydrocotyle vulgaris	I^{1}	IV^{3}	V^{3}	III	IV^{20}	II
Agrostis canina		II	III^{2}			II^{1}
Eriophorum angustifolium					II	
Ericion tetralicis						
Erica tetralix		I		I^{5}		V^{35}
Empetrum nigrum	I		IV^{1}	I1		II1^{3}
Calluna vulgaris						II
Potentilla erecta		III^{1}	I	II	II	III^{2}
Danthonia decumbens	III^{3}				II	
Dactylorhiza maculata					III	

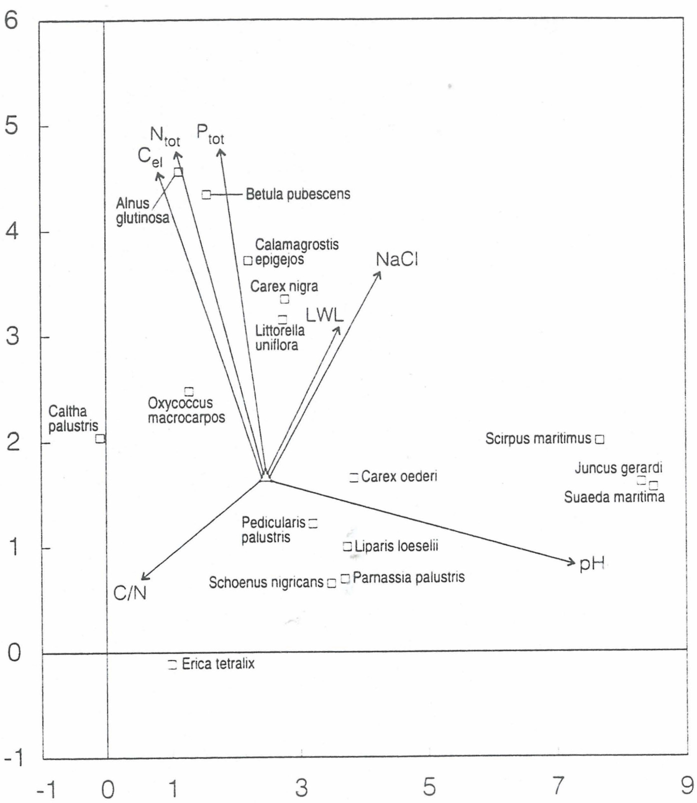

Fig. 1: Results of a Detrended Correspondence Analysis (DCA) biplot based on 75 vegetation plots with corresponding data on Lowest Water Level, NaCl-content, pH, Cel, Ntot, Ptot, and C/N, measured in the top soil.

Cluster E is characterized by *Carex nigra* and *Carex trinervis*, and can be classified to the Caricetum trinervi-nigrae, an association of the Caricion curto-nigrae. Several species of the *Junco baltici-Schoenetum nigricantis* can persist in small numbers in these older stages.

Cluster F, consists of stands dominated by *Erica tetralix*, and represents the acidified stages of dune slack succession in an oligotrophic environment (*Empetro-Ericetum*). This vegetation type can occur on small elevations, but also in the lower parts of slacks which have been decalcified (De Vries, 1961).

Ecological relationships

The variation in species composition of the vegetation data set presented here is mainly determined by the soil-pH and the nutrients (N_{tot} and P_{tot}) stored in the organic matter (C_{el}). These soil factors explain most of the variation along the first and second axis of the DCA (Fig. 1). The lowest water level does not explain much variance. The ratio between carbon and nitrogen (C/N) is negatively correlated with the NaCl content, indicating more mesotrophic conditions in fresh water environments, but with regard to the vegetation types discussed here this is of minor importance.

Species of the *Junco baltici-Schoenetum nigricantis* (clusters A-C) are associated with a high pH and a low nutrient pool. Species of older vegetation stages (cluster D and E) are associated with relatively high nutrient pools. *Erica tetralix,* which is dominating in cluster F, is associated with a high C/N ratio and a low pH. These results stress the importance of a low nutrient status for the *Schoenetum* communities.

The mean values of the environmental factors are shown in Table 2. Again a clear distinction exists between the *Schoenetum* communities (clusters A-C) and the later successional stages (clusters D and E). The first group has pH(H_2O) values above 6.5, while the later successional stages are more acid. The stands dominated by *Erica tetralix* do not differ from the *Schoenetum* stands in nutrient pools, but their C/N ratio is higher compared to most *Schoenetum* stands. The most eutrophic vegetation type is the *Caricetum trinervi-nigrae* association.

Table 2. Mean values of soil factors measured in the top soil of various dune slack vegetation types. Values with the same letter do not differ significantly ($p < 0.05$). The cluster codes correspond to those used in table 1.

Cluster group	A	B	C	D	E	F
	(n=10)	(n=18)	(n=6)	(n=9)	(n=15)	(n=12)
pH-H_2O	7.11^{a}	7.21^{a}	6.63^{a}	5.22^{bc}	5.68^{b}	4.93^{c}
NaCl (%)	0.15^{a}	0.01^{b}	0.03^{ab}	0.03^{b}	0.07^{ab}	0.01^{b}
C-el. (%)	4.41^{ab}	2.80^{a}	1.83^{a}	4.82^{ab}	8.27^{b}	4.75^{ab}
N-tot. (%)	0.24^{ab}	0.17^{a}	0.15^{ab}	0.25^{ab}	0.47^{b}	0.21^{ab}
C/N	18.1^{ab}	16.9^{a}	12.9^{a}	19.7^{ab}	19.1^{ab}	23.3^{b}
P-tot.(mg/100gr)	46^{ab}	29^{a}	35^{ab}	53^{ab}	63^{b}	29^{a}

Water table fluctuation characteristics of the six vegetation types mentioned in table 1 and 2 are presented in figure 2. The water table measurements have been transformed into cumulative frequency lines (duration lines), which are grouped according to vegetation types. The vegetation types studied do not differ very much in duration line bundles, except for the stands dominated by *Erica tetralix*, which are less wet and never flooded. The vegetation types are best differentiated by the highest water levels. Some brackish *Schoenetum* stands and stands belonging to the *Caricetum* *trinervi-nigrae* are able to endure prolonged flooding, but most *Schoenetum* stands require prolonged presence of groundwater in the rooting zone during the wet season.

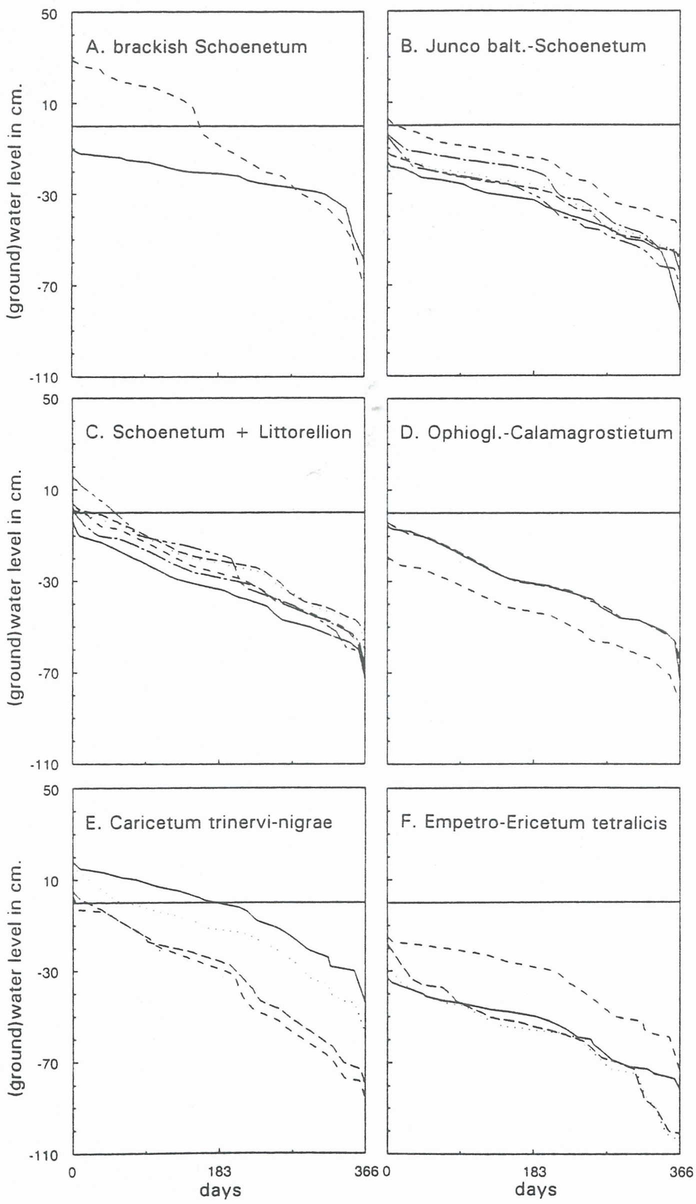

Fig. 2 Groundwater duration lines of six vegetation types mentioned in Table 1 and 2.

The organic matter content (% dry weight) of all samples is depicted in figure 3, showing mean values sorted from low to high. The white bars represent the sites where a well developed stand of the *Junco baltici-Schoenetum nigricantis* is present. It is clear from these results that this community and the endangered species in it will disappear if the percentage organic matter in the top soil exceeds 10%.

Organic matter accumulation in relation to the hydrological regime

The rate of organic matter accumulation in dune slacks shows marked differences between slacks. In some slacks the accumulation of organic matter starts as soon as plants have established themselves, but in other slacks pioneer species persist for decades, whereas almost no accumulation of organic matter takes place. This is illustrated in figure 4, showing the increase in percentage organic matter in the top soil of various succession series. The increase in organic matter in the top soil (0-10 cm) is enormous in an embanked sand flat in the reclaimed Lauwersmeer polder (site 1 in Fig. 4), where infiltration conditions prevail in a slightly brackish environment.

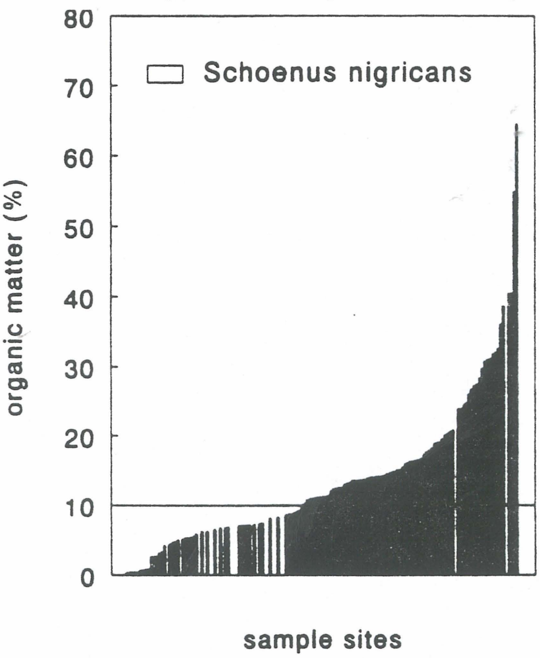

Fig. 3 Mean organic matter content (% dry weight) of all samples sorted from low to high values. The white bars represent the si-tes where a well developed stand of the Junco baltici-Schoenetum nigricantis is present.

Contrarily to this observation, pioneer vegetation types (*Samolo-Littorelletum* and *Junco baltici-Schoenetum nigricantis*) have existed for at least 80 years in a seepage slack on the island of Terschelling (Holkema, 1870; Visser, 1971). (site 6 in Fig. 4). From our own research we concluded that the organic matter content, therefore, would be much lower than 10% during that period. In the Kapenglop area on Schiermonnikoog (site 5) we know for certain that a pioneer vegetation (*Samolo-Littorelletum*) has existed for at least 30 years, and probably much longer. Sod cutting experiments in a dune slack on Terschelling (site 2 in Fig. 4; the Koegelwieck, Terschelling) have shown that the pioneer stages disappear within 10-20 years. From this particular area we know that the water table has dropped at least 60 cm, due to drainage activities and a retreating coast line (Visser, 1971; Beukeboom, 1976).

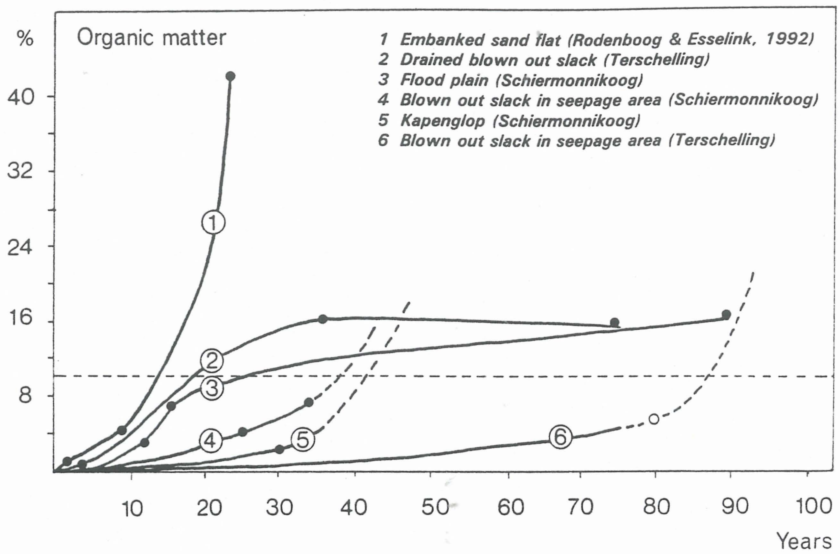

Fig. 4: Rate of increase in organic matter content in the top soil of various dune slacks differing in hydrological regime. Black dots represent mean values of sites with known age. White dots are estimates.

Although some values in figure 4 are estimates, it is clear that in dune slacks of the Wadden Sea islands the hydrological regime has a marked influence on the rate of accumulation of organic matter in the top soil.

Hydrological factors sustaining nutrient poor, alkaline conditions

Stuyfzand & Moberts (1987) proposed a possible mechanism of the functioning of artificial seepage ponds in the Dutch coastal area (Fig. 5a). The flow lines presented were inferred from analysis of groundwater composition at various depth around the dune slacks. In this particular dune area artificial infiltration of surface water, carried out as part of the production of drinking water, created a rather steep hydrological gradient. As a consequence a part of the dune slack receives groundwater from (eutrophic) infiltration ponds. This groundwater proceeds as surface water in the slack and is depleted in CO_2, Ca^{2+} PO_4^{3-} and NH_4^+ by aeration, biological uptake and (co)precipitation (Stuyfzand, 1993). In the downgradient part of the slack the water infiltrates again through the organic slack layer. This passage through an anaerobic layer with CO_2 producing plant roots creates a water type which is highly reduced and is aggressive toward calcareous substrates in the subsoil. It has also higher phosphate levels due to phosphate mobilization in the anoxic slack layer.

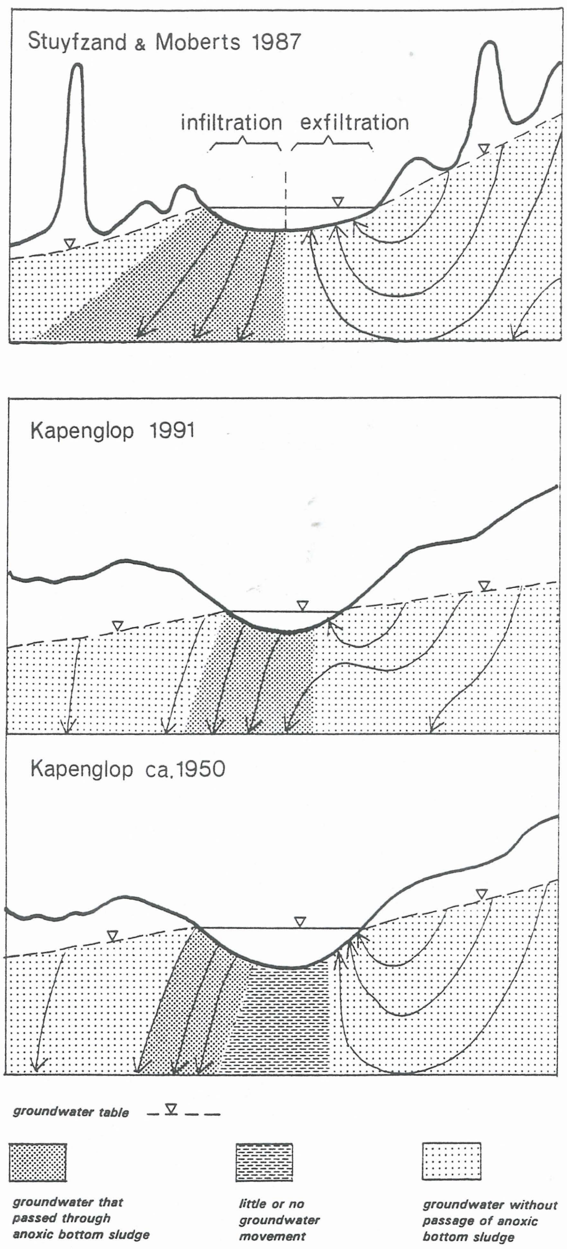

Fig. 5: Hydrological mechanism of an artificial seepage slack (Fig. 5a; proposed by Stuyfzand & Moberts, 1987) and that of a natural seepage slack (Fig. 5b; Kapenglop, proposed by Stuyfzand et al. 1992). Figure 5c represents an hypothesis of the hydrological regime without the influence of groundwater abstraction and other interferences with the hydrology.

In a natural seepage slack the hydrological gradient is often much smaller. This may lead to a different kind of flow pattern. In order to study the hydrological system, responsible for the longterm existence of nutrient poor and alkaline conditions in the rooting zone, we carried out a hydrological modelling of the research area and analysed the chemical composition of the ground- and surface water. The water samples were obtained from minifilters installed in deep groundwater wells in a transect across the dune valley (Grootjans et al., in press). We indeed found a highly reduced groundwater facies underneath the dune slack, which was characterized by very low values of SO_4^{2-} and very high contents of Ca^{2+} and HCO_3^-. This was interpreted as outflowing groundwater. A detailed analysis of the inflowing groundwater revealed that this groundwater was moderately rich in Ca^{2+} and HCO_3^- and had fairly low values of SO_4^{2-} (Sival & Grootjans, in press).

A simulation of the groundwater flow pattern, based on measured water tables and estimated vertical flow resistance (C-) values, showed that the inflow of seepage water was only possible when the slack was flooded. The best match with the distribution of separate ions was obtained with a predominance of infil
tration over the whole slack and only little seepage on the valley flank (on the right side (Fig. 5b). It is plausible that the seepage intensity was more pronounced in former days and that the basiphilous vegetation types disappeared, due to interferences with the hydrology, such as abstraction of groundwater by a nearby well field, by drainage in upstream areas and by afforestation and natural succession to shrubs (Rus et al., 1988, Van Dijk & Grootjans, 1993).

A simulation of the hydrological situation without these influences led to a reconstruction of the flow pattern as shown in figure 5c. The flooding and seepage intensity was higher during the winter period (Van Immerzeel, 1993). Consequently the infiltration was also more pronounced at the downstream side of the slack. Underneath the centre of the slack, little movement of groundwater was likely (Veldhuijzen, 1991).

Discussion

Biological control of organic matter accumulation?

In the centre of a natural dune slack the conditions are distinctly mesotrophic, meaning that the availability of nutrients is low, due to a very low rate of accumulation of organic matter, very low concentrations of nutrients in the groundwater and a low flow velocity of the groundwater. These conditions may persist for a long time as long as the groundwater is not polluted and the flow rates do not change considerably. Van Dijk (1984) has demonstrated that the combination of a high nutrient concentration and a high flow velocity, leading to the a high nutrient charge, is responsible for a rapid eutrophication of certain dune slacks (see also Meltzer & Van Dijk, 1986; Stuyfzand, 1994). In a natural seepage slack the vegetation zonation seems to reflect these hydrologically imposed trophic gradient rather well. In the centre of the slack the very low productive *Littorella uniflora* is dominant, whilst *Schoenus nigricans* is found at the borders of the slack, quite often with well developed microbial mats (Den Hartog, 1954). Both species have very low nutrient requirements (Roelofs, 1983, Ernst, 1991) especially with respect to phosphate. Both species are able to leak oxygen from there roots (Roelofs et al., 1984; Ernst & Van der Ham, 1988), which stimulates the decomposition of organic matter. So these species are not only well adapted to the nutrient poor slack environment, but they may stimulate a feed back mechanism against a build up of nutrients in the slack and consequently prolong the pioneer stage. Eventually *Schoenus nigricans* is replaced by species such as *Calamagrostis epigejos* and *Molinia caerulea. Littorella uniflora* is replaced by *Carex nigra* or *Carex trinervis*. It would be interesting to know if these species can leak oxygen from their roots. If not, their growth would speed up the build up of organic material.

It is not clearly understood which processes trigger the rapid build up of organic material in the dune slack. Clearly a lowering of the water table will affect the whole delicate hydrochemical gradient and consequently the competition between *Schoenus nigricans* and *Littorella uniflora* on the one hand and *Calamagrostis epigejos* and *Carex nigra* on the other hand. It would be very interesting to test the hypothesis that in undisturbed seepage slacks the build up of organic material is retarded by interactions between microbial mats (that keep anoxic conditions predominant in the top soil), phanerogams that leak oxygen from their roots, and marsh plants and shrubs that accumulate nutrient in the rooting zone.

Implications for management

The interactions between basiphilous vegetation types and the discharge of calcareous groundwater are easily disturbed by changes in the local and regional hydrological conditions. Drainage in the surroundings of the slack, the planting of pine forests which increases the evapotranspiration, and the abstraction of groundwater all contribute to a rapid build up of the nutrient pool in the slack. Also the acidification of the top soil increases. Both processes will lead to the extinction of basiphilous pioneer species.

Increasing the water levels in a slack by retaining precipitation water is not sufficient to compensate for the negative effects of, for instance, groundwater abstraction.This will lead to further acidification. It is important that rewetting takes place in the surroundings of the slack. Furthermore, restoration of mesotrophic species will not be successful, when the organic layer, formed in the period of dune slack degradation, is maintained. An effective measure to reduce the nutrient pool of the dune slack system is sod cutting. A more natural way to restore species-rich dune valleys is to allow sand blowing in the dune areas.

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