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NUTRIENT SUPPLY OF HERBACEOUS BANK VEGETATIONS IN DUTCH COASTAL DUNES; THE IMPORTANCE OF NUTRIENT MOBILIZATION IN RELATION TO (ARTIFICIAL) INFILTRATION

H. W. J. VAN DIJK[1], M. A. W. NOORDERVLIET[1] and W. T. DE GROOT[2]

[1] Afdeling Milieubiologie, Rijksuniversiteit Leiden; [2] Centrum voor Milieukunde, Rijksuniversiteit Leiden, Postbus 9516, 2300 RA Leiden

SUMMARY

The occurrence of competitive tall hemicryptophytes with high nutrient demands in phreatophytic vegetations is generally related to an excessive supply of macronutrients. In unaffected areas of the Dutch coastal dunes these species can be found on locally humic soils. Plant species with an extremely high nutrient demand grow abundantly on the banks of infiltration ponds in dune areas which are artificially infiltrated with highly eutrophic water for public water supply purposes. There they overgrow the rare species of the authentic dune slack vegetations. In this paper it is investigated how the vegetation on banks of dune ponds is connected with the nutrient supply due to both mobilization (mainly mineralization) and infiltration water flow. This study leads to the conclusion that prepurification of infiltration water will suppress the growth of the most competitive species on the banks in infiltrated dune areas. Phosphate stripping seems to be the most effective strategy for this prepurification.

1. INTRODUCTION

Many of the coastal dune areas in the West of The Netherlands are being infiltrated artifically for the purpose of public water supplies. The infiltrated water is either surface water from the rivers Rhine or Meuse or superfluous polder water. This infiltration has a considerable impact on the environment. Despite plausible planological and environmental protection by the dune water boards, the ecological consequences of artificial infiltration have a negative over-all effect on the nature values of the dune areas (VAN DIJK et al. 1982; VAN DER MEULEN 1982). One of the most striking effects of infiltration is the abundance of species with a high nutrient demand on banks and in wet dune slacks, superseding the original vegetation. These species can be labelled competitive tall hemicryptophytes (after MUELLER-DOMBOIS & ELLENBERG 1974). VAN DIJK (1984) mentions that the 19 plant species which significantly increased with artificial infiltration are very nitrophilous; their average nitrogen indicator value (after ELLENBERG 1979) is 7.3. The 50 plant species which appeared to decrease or disappear in the infiltrated dune areas, prefer nutrient poor biotopes, their average nitrogen indicator value being 3.5.

The increasing abundance of competitive and nitrophilous species is particularly obvious on the banks of infiltration ponds which serve as entrances for infiltration water into the dunes. Nowadays this process also occurs on the banks of seepage pools. These pools are due to surfacing of ground water coming from the infiltration ponds. Even seepage pools at a distance of several hundred metres from the infiltration ponds are affected (VAN DER WERF 1974; LONDO 1975a; VAN DIJK et al. 1982).

VAN DIJK & VAN STRIEN (1984) argue that high loads of the macronutrients phosphorus, potassium and nitrogen in the ground water are the main cause of the increasing cover of tall hemicryptophytes. The impact of the nutrient load is not only determined by the increased concentrations of these macronutrients, but is also related to the highly increased ground water flux in the banks as a result of artificial infiltration. Therefore, the external nutrient load is considerably higher in infiltrated dune areas.

An abundant cover of tall hemicryptophytes may also be found in non-infiltrated areas, however, in these areas the process has developed less rapidly and is more localised. In these areas the cause of the abundance of tall hemicryptophytes cannot be sought in the external nutrient load as the nutrient concentration and the ground water flux are relatively low (BAKKER 1981; VAN DIJK & MELTZER 1981; VAN DIJK 1984). Therefore, here the cause of the change of the vegetation should be sought in a relatively high internal nutrient load by cyclic biological processes. ELLENBERG (1964), BAUMEISTER & ERNST (1978), CHARLEY & RICHARDS (1983) and others show that a high intensity of the mineralization of accumulated organic compounds in the soil can be the cause of an internal nutrient supply high enough to foster competitive tall hemicryptophytes. Under natural circumstances in the dune biotope nitrogen, phosphorus, and to a lesser degree, potassium are growth-limiting macronutrients (WILLIS 1963; OLSSON 1974). In other biotopes too, adding of nitrogen as well as phosphorus causes increased plant growth and changes in species assemblage (PIGOTT & TAYLOR 1964; TILMAN 1982, and others).

Under low external load conditions the occurrence of competitive tall hemicryptophytes varies greatly (VAN DIJK & VAN STRIEN 1984). A possible explanation for the varying intensities of occurrence may be found in varying mineralization values. *Fig. 1* presents a scheme of the parameters which may be determining the vegetation along pools and ponds in the dunes.

During the past few years some water companies have drastically lowered the orthophosphate concentration of the infiltration water for reasons of efficiency. Prepurification is applied to prevent algal bloom in the ponds which caused a decrease of the permeability of bank and bottom soils of infiltration ponds (VAN DER MEULEN 1982). At the same time it may put a halt to the increasing occurrence of tall hemicryptophytes. However, this will not be achieved until the present nutrient store is washed out by the ground water or is neutralised by management measures. If mineralization of accumulated organic soil compounds continues to produce a large nutrient supply, it may take a long time before the abundant growth of competitive tall hemicryptophytes will be repelled. The aim of the present study is to test this hypothesis.

The investigation concerned the following relation studies: the relation be-

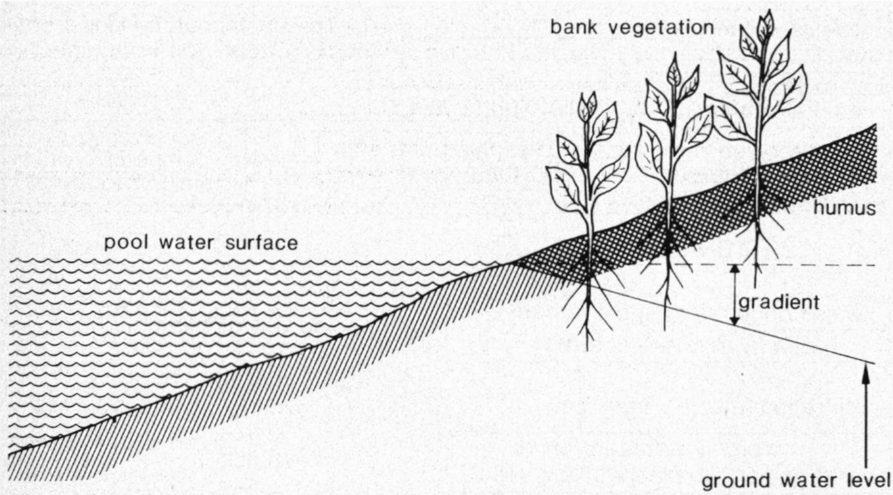

Fig. 1. Schematic representation of the parameters studied.

tween the occurrence of tall hemicryptophytes with a (suggested) high nutrient demand and (1) the external nutrient load, (2) the internal nutrient supply, (3) the internal and external supplies taken together.

The study is focused on the macronutrient phosphorus because it is easier to manipulate than the other nutrients and it appears to have the greatest impact on the fostering of competitive tall hemicryptophytes (VAN DIJK & MELTZER 1984). In order to give a broader scope to the study, the macronutrients nitrogen and potassium were also analysed.

2. METHODS

2.1. The framework of the study

The study concerns a momentary spatial comparison of the vegetations and abiotic environmental parameters. *Fig. 2* represents a conceptual model of the parameters studied. The environmental parameters have been derived from factors directly connected with the nutrient supply as well as from indirect factors. The nutrient supply concerns the supply of three macronutrients due to both the ground water flux and mineralization. The banks of ponds through which surface water infiltrates have been tested on the direct nutrient supply from infiltration water and the indirect nutrient supply from mineralization of organic compounds along the waterline.

It is presupposed that if the combined internal and external loads correlate better with the occurrence of competitive tall hemicryptophytes than they would separately, it may be concluded that the occurrence of these species will be reduced in case of decreased mineralization or in case of a reduction of the direct nutrient supply. This correlation makes it possible to predict the occurrence of these species under conditions of a reduced external nutrient supply.

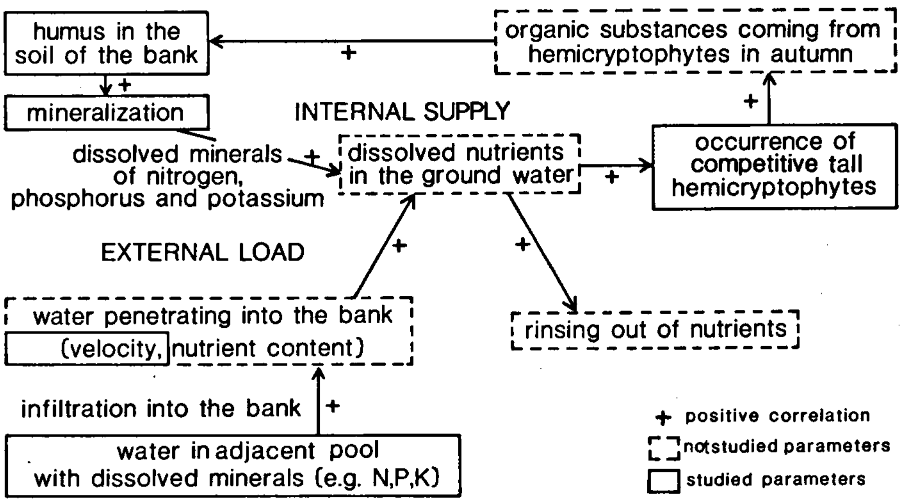

Fig. 2. Relation diagram of the parameters studied.

2.2. The research areas and the relevés

Fig. 3 gives the location of the research areas. The infiltrated areas included in this study are Meyendel (Wassenaar), the south side of the Noord-Hollands Duinreservaat (Wijk aan Zee) and Berkheide (Wassenaar – Katwijk). In the first area orthophosphate has been removed partly from the infiltration water during two years previous to this investigation. In the second area the water has been prepurified from the beginning of the infiltration, whereas no significant prepurification is applied to infiltration water brought into Berkheide. The selected non-infiltrated dune areas are Voorne's Duin (Voorne-Putten) and Zwanenwater (between Callantsoog and Petten). These reference areas are wet, with relatively low nutrient concentrations in the water (see *table 1*).

A total of twenty sampling plots on the banks of dune ponds have been analysed: 11 around pools in non-infiltrated dune areas and 7 around infiltration ponds and seepage pools (3 and 4 respectively) in dune areas with artificial infiltration. The two remaining plots were situated on the banks of seepage pools in an infiltrated area but were not influenced by infiltration in hydrological and water chemical aspects. The sampling plots in both types of areas have been selected so as to cover a maximum diversity in the occurrence of competitive tall hemicryptophytes, disregarding environmental parameters.

Between July and Mid-September of 1978 and 1980 vegetation relevés were made for each sampling plot ($2 \times 1\ m^2$) after the Braun-Blanquet method. A decimal scale has been applied to estimate the cover of each species (LONDO 1975b). The nomenclature is according to HEUKELS-VAN OOSTSTROOM (1977).

2.3. Quantification of humus concentration and the nutrient mobilization (mineralization or internal nutrient supply)

The humus concentration was measured according to the method described by

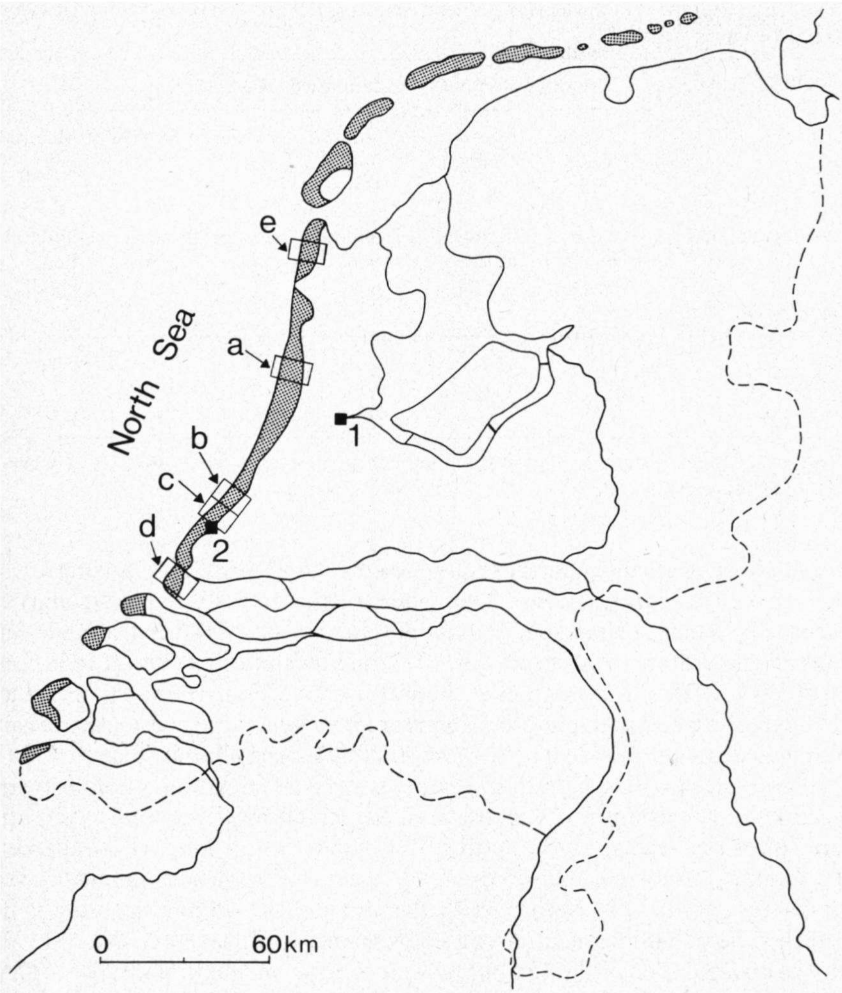

Fig. 3. Coastal dunes (hatched) in The Netherlands and location of the five areas studied. a, b and c influenced by artificial infiltration, d and e non-infiltrated wet dune areas. (1 Amsterdam; 2 The Hague; a Noordhollands Duinreservaat (southern part); b Berkheide dunes; c Meijendel dunes; d Voorne dunes; e Zwanenwater dunes).

ALLEN (1974). One gram of dry soil is exposed to a temperature of 450 °C for a period of two hours. The difference in weight of the soil sample before and after this treatment gives the quantity of carbon.

Mobilization of nutrients can be quantified under field- or laboratory-conditions (GERLACH 1973; ZÖTTL 1960). Quantification under field conditions gives an impression of the net result of soil processes such as mineralization, immobilization, adsorption, and denitrification (ZÖTTL 1960; ELLENBERG 1964; DE VRIES & DECHERING 1960), whereas quantification under laboratory conditions, car-

Table 1. Concentrations of three macronutrients in dune pools and ponds (mg/l) (annual averages per pool, averaged per area).

	Non-infiltrated areas		Infiltrated areas			
Area	Zwanenwater	Voorne's Duin	Noordhollands Duinreservaat	Berkheide	Meijendel	Meijdendel
Type of pool/pond	natural pools	natural pools	infiltration ponds	seepage pools	seepage pools	infiltration ponds
Number of pools/ponds	8	7	3	13	12	2
$PO_4^{3-}\cdot P$	0.03	0.02	0.02	0.24	0.03	0.20
$NO_3^-\cdot N$	0.02	0.08	3.2	0.38	0.66	2.7
K^+	2.2	2.7	2.9	9.9	4.1	6.9

Sources: Van Dijk & Meltzer (1981), Van Dijk (1984), Van Hezewijk (1984), Van Ommering (1981) and not yet published data.

ried out in controlled temperature and moisture conditions, gives an impression of the potential soil processes. The results of the field study are strongly influenced by seasonal changes in the climate (Ellenberg 1964) and annual variations in temperature (Stanford et al. 1973) and precipitation (Birch 1958, Gerlach 1973, 1978). Analyses under laboratory conditions check the influences of temperature and precipitation. Therefore they give more comparable results than field analyses and seem to be more suitable for the present study.

From each sampling plot 15 soil samples were taken within a homogeneous vegetation at a distance of 1 metre from the waterline. They were taken after removal of the vegetation by putting PVC tubes, 30 cm long with a diameter of 2.4 cm, carefully into the soil down to 25 cm with rubber hammers to avoid compacture of the soil sample. With this method the original layering is not disturbed, so that mineralization caused by mixing of soil layers (Gerlach 1973) may be avoided. Ten of the 15 samples were used as 'incubation samples'. These samples remained in the tubes an incubation period of six weeks. Five of the incubation samples were held under a constant temperature of 25 °C and a relative humidity of 80%. The other five incubation samples were held under field conditions and were covered underneath to avoid rinsing out; flooding however, was possible. The remaining five samples were analysed immediately. They were mixed and analysed the same day for water content and volume weight (Allen 1974). The concentrations of some macronutrients in the mixed samples were measured with the following methods.

1. Ammonium: ion specific electrode (Orion 951000) after extraction in a 2 M KCl-solution
2. Nitrate: ion specific electrode (Orion 930700) after extraction in a solution containing 16.66 g/l $Al_2(SO_4)_3\cdot 18\ H_2O$, 1.24 g/l H_3BO_3, 4.67 g/l Ag_2SO_4 and 2.43 g/l NH_2SO_3H

3. Exchangeable phosphate: molybdate blue method (VAN SCHOUWENBURG & WALINGA 1978) after extraction in a 0,5 M $NaHCO_3$ solution (OLSEN et al. 1954)
4. Exchangeable potassium: direct measuring with an atom absorption spectrophotometer after extraction of 5 grams of soil which is dried for 24 hours at 105 °C, in 100 ml CH_3COOH 2.5% during 1 hour.

After the incubation period the five samples of each incubation set were mixed thoroughly and analysed for the same parameters as the original field samples. The net mobilization has been determined by subtracting the nutrient concentration of the fresh field samples from the nutrient concentration of the incubation samples. The mobilization process of six weeks has been quantified in volume weight (g/m^3).

2.4. Quantification of the external nutrient load supplied by infiltrated water

Monthly samples were taken from the pools in the vicinity of the soil sampling plots. These water samples have been analysed according to the analysing methods for the extraction solutions mentioned above.

Up to 1 metre from the waterline the gradient of the ground water table was measured in order to find the velocity of the ground water using Darcy's Law: $F = p \cdot g$, in which F = flux density (m/day), p = permeability constant (for dune sand the average p amounts to 11.4 m/day (VAN DIJK & VAN STRIEN 1984)), g = gradient (m/m).

The gross external nutrient load has been derived from the nutrient concentration and the flux density in the following way: $L = F \cdot C$, in which L = nutrient load ($g/m^2 \cdot day$), F = flux density (m/day), C = annual average nutrient concentration (g/m^3).

For C the annual average nutrient concentrations of the year previous to the relevés have been taken. Only in Meijendel C means the concentration average before the improvement of the purification of the infiltrated water (i.e. three years before the relevés) because the bank vegetation had not shown significant changes since this improvement.

2.5. Combining the internal and external nutrient supplies

The internal and external nutrient supply parameters cannot simply be added up because they have been measured under different conditions (laboratory and field conditions, respectively) and in different dimensions (volume and surface quantification). Multi-variate analysis techniques can be used to correlate such parameters (SEAL 1968 and others). These techniques allow for an estimation of the extent to which independent parameters can explain the variance of one or more dependent parameters. In ecology abiotic environmental factors are usually marked as independent parameters and biotic components of the ecosystem are marked as dependent parameters. In order to combine the two loads multiple regression ("new regression" in SPSS) has been applied (HULL & NIE 1981). With this technique one dependent variable is correlated with several separate independent variables through linear regression. All significant correlated independent variables are finally presented in one formula with the dependent parameter. The independent parameters are here the internal and external supplies of each of three macronutrients. The occurrence (cover) of tall hemicryptophytes with suggested high nutrient demands is regarded as the dependent parameter.

2.6. Definition of ecological species groups

An inventory of the bank vegetation in infiltrated and non-infiltrated areas (Van Dijk & Meltzer 1984) resulted in a list of the occurring species. The 53 species occurring in infiltrated areas which show the highest nitrogen demand as suggested by Meyer (1975), Kovacs (1969) and Ellenberg (1952,1979) are represented in *table 2*. The following ecological species groups were subsequently derived from this list: R53 and R20. R53 comprises all 53 species listed. R20 is a subgroup of R53 and comprises the 20 species with the highest suggested nitrogen demand. Another ecological species group R6 comprises the six herbaceous species which have shown the largest increase of their cover on banks in infiltrated dune areas (Van Dijk & Van Strien 1984). The six species are: *Urtica dioica, Epilobium hirsutum, Cirsium arvense, Eupatorium cannabinum, Mentha aquatica* and *Lycopus europaeus*. The first three species of R6 are also included in R20. The total cover per ecological species group was established by adding up the covers of the individual species. These total covers were treated as separate parameters in the analyses.

3. RESULTS

3.1. General

In the relation studies which will be treated in the following text, the nutrient mobilization in the field incubation samples did not show clear correlations with the vegetation parameters or with the mobilization in the incubation samples held under constant conditions. For this reason the presented results have been limited to the mobilization measurements done under constant humidity and temperature.

Table 3 gives the measured concentrations of humus in the soil, the internal mobilization and the external supplies of the three nutrients and the total covers per ecological species group for all sampling plots. The external nitrogen load is not known for the sampling plots in non-infiltrated areas. The quantification of the interal potassium mobilization gives negative values in some cases.

Table 3 reveals some distinct differences between sampling plots in infiltrated and non-infiltrated areas. In the case of infiltrated areas the external potassium and orthophosphate loads are generally much higher than in non-infiltrated areas and a similar difference may be found concerning the cover of the ecological species groups. The difference in total covers between infiltrated and non-infiltrated areas is most pronounced in group R20 (applying Wilcoxon's test). These observations confirm earlier discoveries concerning the nutrient loads

Table 2. List of plant species with a suggested high nutrient demand occurring in infiltrated dune areas (after BOL et al. 1977).

No. species	M	K	E52	E79	O	R6
1 Sambucus nigra L.	5	5	–	5		
2 Galium aparine L.	5	5	–	5		
3 Urtica dioica L.	5	5	–	4.5	c	+
4 Elytrigia repens (L.) Desv.	5	3	5	4.5		
5 Epilobium hirsutum L.	5	4	–	5	cf	+
6 Cirsium arvense (L.) Scop	5	4	–	4	c	+
7 Poa annua L.	–	5	5	4.5		
8 Pimpinella major (L.) Huds.	–	–	5	4		
9 Rubus caesius L.	–	–	–5			
10 Chenopodium rubrum L.	–	–	–	5		
11 Rumex maritimus L.	–	–	–	5		
12 Atriplex hastata L.	–	–	–	5		
13 Ranunculus sceleratus L.	–	–	–	5	i	
14 Glechoma hederacea L.	4	4	4	4		
15 Polygonum amphibium L. f. terrestris	4	–	4	3.5		
16 Bromus mollis L.	4	–	3	–		
17 Calamagrostis epigeios (L.) Roth	4	3	2	4		
18 Solanum dulcamara L.	–	–	–	4.5		
19 Cynoglossum officinale L.	–	–	–	4.5		
20 Cirsium vulgare (Savi) Ten.	–	–	–	4.5		
21 Stellaria media (L.) Vill. ssp. media	–	–	–	4.5		
22 Typha latifolia L.	–	–	–	4.5	f	
23 Artemisia vulgaris L.	–	–	–	4.5		
24 Salsola kali L.	–	–	–	4.5		
25 Rorippa islandica aust.	–	–	–	4.5	f	
26 Eupatorium cannabinum L.	–	4	–	4.5	cf	+
27 Stellaria media (L.) Vill. ssp. pallida	–	–	–	4		
28 Acer pseudoplatanus L.	–	4	–	4		
29 Rumex hydrolapathum Huds.	–	4	3	4		
30 Linaria vulgaris Mill.	–	4	–	2		
31 Chenopodium album L.	–	–	–	4		
32 Populus nigra L.	–	–	–	4		
33 Verbascum thapsus L.	–	–	–	4		
34 Sonchus asper (L.) Hill.	–	–	–	4		
35 Allium vineale L.	–	–	–	4		
36 Veronica anagallis aquatica L.	–	–	–	4		
37 Geum urbanum L.	–	–	–	4		
38 Bryonia dioica Jacq.	–	–	–	3.5		
39 Elymus arenarius L.	–	–	–	3.5		
40 Fragaria vesca L.	–	–	–	3.5		
41 Populus alba L.	–	–	–	3.5		
42 Myosotis arvensis (L.) Hill.	–	–	–	3.5		
43 Sagina procumbens L.	–	–	–3.5			
44 Acer campestre L.	–	–	–	3.5		
45 Samolus valerandi L.	–	–	–	3.5		
46 Arctium pubens Bab.	–	–	–	–		
47 Rumex crispus L.	3	–	0	3		
48 Phragmites australis (Cav.) Trin. ex Steud.	3	–	2	3		
49 Veronica catenata Penell.	–	–	–	–		
50 Mentha aquatica L.	2.5	–	3	2.5	c	+
51 Lycopus europaeus L.	–	3	–	4	c	+
52 Epilobium parviflorum Schreb.	–	–	3	–	f	
53 Hippuris vulgaris L.	–	–	–	3		

The species are given in order of decreasing suggested nitrogen demand. R53 consists of all species listed here; R20 consists of the top twenty species and R6 consists of the species marked "+" under R6.
M, K, E52 and E79 indicate the suggested nitrogen demand; M = MEYER (1957), K = KOVÀCS (1969), E52 = ELLENBERG (1952), E79 = half of the nitrogen indicator given by ELLENBERG (1979), and O indicates the influence of artificial infiltration on the occurrence after VAN DIJK (1984) (c means an increase of the cover on banks of pools and ponds, f means an increase in whole areas).

Table 3. Total cover per ecological species group, average humus concentration[1], external nutrient supplies and average net nutrient mobilization of all sampling plots (plots in order of increasing R20-cover).

Total cover per ecological species group (%)			Area[2]	Infil-tration influ-ence	Humus (%)	External supplies by infiltrating water[3] (g/m^2/6 weeks)			Internal supplies (nutrient mobilization) (g/m^3/6 weeks)		
R20	R53	R6				P	N	K	P	N	K
0	0	0	N	–	0	0.0	–	2	1	0	–9
0	11	1	Z	–	4	0.3	–	24	1	11	7
0	12	11	Z	–	4	0.0	–	1	1	6	0
1	12	10	V	–	1	0.0	–	5	0	9	7
1	17	14	V	–	1	0.0	–	13	0	2	14
2	7	5	V	–	3	–	–	–	0	2	27
2	5	2	M	–	3	0.0	1	3	0	4	12
2	24	20	V	–	1	0.0	–	5	–1	6	0
4	99	5	M	–	1	0.1	1	4	0	2	12
12	24	2	Z	–	6	0.0	–	9	3	9	33
12	93	92	V	–	4	0.0	–	12	2	16	5
21	31	20	N	+	0	0.5	95	69	2	5	–16
33	114	92	M	+	3	1.8	56	67	1	1	0
40	41	0	Z	–	7	–	–	–	3	4	20
51	61	7	M	+	2	0.3	3	31	1	10	12
52	58	11	N	+	1	0.6	112	94	3	10	8
73	78	71	Z	–	9	0.6	–	11	7	17	26
83	83	80	B	+	1	3.9	1	–	0	14	–12
98	109	92	M	+	2	4.2	26	24	1	19	12
107	107	100	B	+	3	4.8	76	171	5	4	–12

[1] based on duplo observations
[2] B = Berkheide; M = Meijendel; N = Noordhollands Duinreservaat (southern part); V = Voorne's duin; Z = Zwanenwater
[3] – = not measured

(VAN DIJK 1984; BAKKER 1981) and the occurrence of competitive tall hemicryptophytes (VAN DIJK & VAN STRIEN 1984; VAN DIJK et al. 1982). In some non-infiltrated areas the external orthophosphate load approaches the minimum external load of infiltrated dune areas (Noordhollands Duinreservaat and seepage pools in Meijendel).

The mobilization of nitrogen and exchangeable phosphate is roughly equal in infiltrated and non-infiltrated areas. The net mineralization of potassium seems to be a bit lower in infiltrated areas due to the occurrence of some not explained negative supply values. *Table 3* shows that the concentration of humus is significantly higher in Zwanenwater than anywhere else. This may be explained by the fact that it is the only study site which is low calcareous and therefore characterised by a slower decomposition of humus (i.e. BAKKER et al. 1979).

3.2. A first verification of the relations model

The "internal cycle" of the relations model given in *fig. 2* can be tested with

Table 4a. Pearson correlation coefficients of humus concentration and performance of ecological species groups in non-infiltrated areas.

Correlation between humus concentration and species group	Number of observations	Pearson's r	Significance
R20	13	0.82	< 0.5%
R53	13	0.32	> 5%
R6	13	0.37	> 5%

Table 4b. Pearson correlation coefficients of humus concentration and three macronutrients supplied by mineralization in all areas.

Correlation between humus concentration and net mineralization of	Number of observations	Pearson's r	Significance
phosphate	33[1]	0.69	< 0.5%
potassium	33[1]	0.57	< 0.5%
nitrogen	31[1]	0.43	< 5%

[1] including duplo observations, therefore significance for n = 20

facts concerning humus concentration and the occurrence of tall hemicryptophytes with a suggested high nutrient demand in non-infiltrated areas where the external load is low, and with relations between humus concentration and mobilization in all areas. If the model is a representative of the real situation, this implies that the humus concentration correlates positively with mobilization and with the occurrence of the tall hemicryptophytes concerned. These correlations have been studied by means of Pearson's product moment correlation tests and the results are given in *table 4a* and *4b.*

The expected positive correlations with the humus concentration are found to be significant for the cover of R20 and for the mobilization values of all three nutrients. The mobilization of exchangeable phosphate has the highest significant correlation with the humus concentration, nitrification the lowest. It must be noted that the high correlation coefficient of the cover of R20 with the humus concentration is based on four extreme values but that the correlation is verified with Kendall's non-parametric test.

The correlations between the humus concentration and the occurrence of competitive tall hemicryptophytes in infiltrated areas are not significant. The relation between a low humus concentration and a low nutrient mobilization as shown in *table 4b* does not extend to a relation between a low humus concentration and a moderate occurrence of competitive tall hemicryptophytes in infiltrated areas: the effects of mineralization seem to be overshadowed by the effects of the external load. This observation supports the model given in *fig. 2.*

Table 5. Significant Pearson correlation coefficients of the external and internal supplies of three macronutrients and the cover of three ecological species groups.

	N-supplies		P-supplies		K-supplies	
	external	internal	external	internal	external	internal
No. of observations	7	20	18	20	17	20
species group						
R20	ns	0.49 (24)	0.87 (76)	0.54 (29)	0.65 (42)	ns
R53	ns	ns	0.66 (44)	ns	0.47 (22)	ns
R6	0.74 (55)	0.46 (21)	0.75 (56)	ns	0.46 (22)	ns

ns = correlation coefficient is not significant; between brackets: the explained variance (in %)

3.3. The relations between the abundance of competitive tall hemicryptophtes and the external and internal nutrient supplies

Table 5 gives the significant simple correlation coefficients of Pearson's test. *Table 6* gives the results of a multiple regression analysis of the data presented in *table 3*; all the nutrient supplies with the exception of the external nitrogen load are used in this analysis as independent parameters. The results are based on non-transformed data. Data transformations to reduce deviations from normal distribution such as the logit transformation of the vegetation did not give more significant or deviating results.

Table 5 shows that the external load of phosphate gives the highest correlation coefficients with all three ecological species groups. This result is supported by the multiple regression analysis in *table 6*, in which analysis only the phosphate supplies appear to be variance explaining. The external load of phosphate explains the variance of the total cover of the ecological species group R20 to a percentage of 71, while the internal phosphate supply does the same to a percentage of 13. Thus the combination of the internal and external supplies of phosphate gives the maximum percentage of the totally explained variance

Table 6. Results of the multiple regression analysis of the cover of three ecological species groups and the external and internal supplies of three macronutrients (except external N-supply).

Species group	Explanatory independent variable	Multiple r	Explained variance (%)	Significance of F-ratio
R20	external P-supply internal P-supply	0.93	71 13	0.0000
R53	external P-supply	0.65	39	0.0046
R6	external P-supply	0.73	50	0.0009

number of observations: 17
analysis threshold: PIN = 0.050

(84%), whereas only the external load of phosphate can explain (to a much lesser degree) the variance of the cover of R6 and R53.

The use of the external load of nitrogen as an extra independent parameter, which confines the number of observations to 6, does not change the results of the multiple regression analysis essentially: the external load of phosphate is the only independent parameter which appears to be variance explaining according to the results of the analysis.

The multiple regression analysis of the combination of phosphate supplies and the total covers of the ecological species groups gives the relations equations presented in *table 7*. The equations of *table 7* allow for a calculation of the total covers per ecological species group on the basis of known phosphate supplies. These calculations are compared with the measured values (*fig. 4*).

Many of the observed covers of R6 and R53 appear to be much higher than the calculated values. However, there is hardly any discrepancy between the two sets of values of R20 (Pearson's $r = 0.93$). It should therefore be possible to predict the cover of R20 fairly accurately with known phosphate supplies.

3.4. Phosphate stripping and the bank vegetation

Dune infiltration of eutrophic water for the purpose of public water supplies has so far always fostered competitive tall hemicryptophytes on the banks of infiltration ponds and seepage pools. The purpose of the present study is to find out to which degree management policies may repel or even eliminate the occurrence of these species. The results given in this paper and the results of VAN DIJK & VAN STRIEN (1984) and VAN DIJK & MELTZER (1984) indicate that the most effective policy is to reduce the orthophosphate concentration in infiltration water being less complicated than a reduction of the nitrogen or potassium concentration. An alternative measurement to lower the external nutrient load is reducing the ground water velocity, but this is not an acceptable policy from the point of view of the water boards as it would reduce the capacity of drinking water production.

The equations shown in *table 7* enable a long term prediction of the total cover of species group R20 with decreasing orthophosphate concentrations in the infiltrated water, under the condition that mineralization and subsequent internal supplies of nutrients remain constant. Internal nutrient stocks in the plant roots will delay this predicted species shift but will not prevent it. *Table 8* gives the predicted behaviour of R20 with a decreasing orthophosphate concentration down to the lowest measured level in infiltration areas (0.03 mg $PO_4^{3-}\cdot P/l$) and with a hypothetical absence of orthophosphate (0.00 mg $PO_4^{3-}\cdot P/l$).

Table 8 shows that according to the multiple regression correlations the total cover of species labelled R20 can be reduced by 30–90% as a result of phosphate stripping.

3.5. Summary of the results

1. Of three species groups distinguished on the bases of ecological indications a group consisting of 20 'nitrophilous' species (R20) has the most pronounced

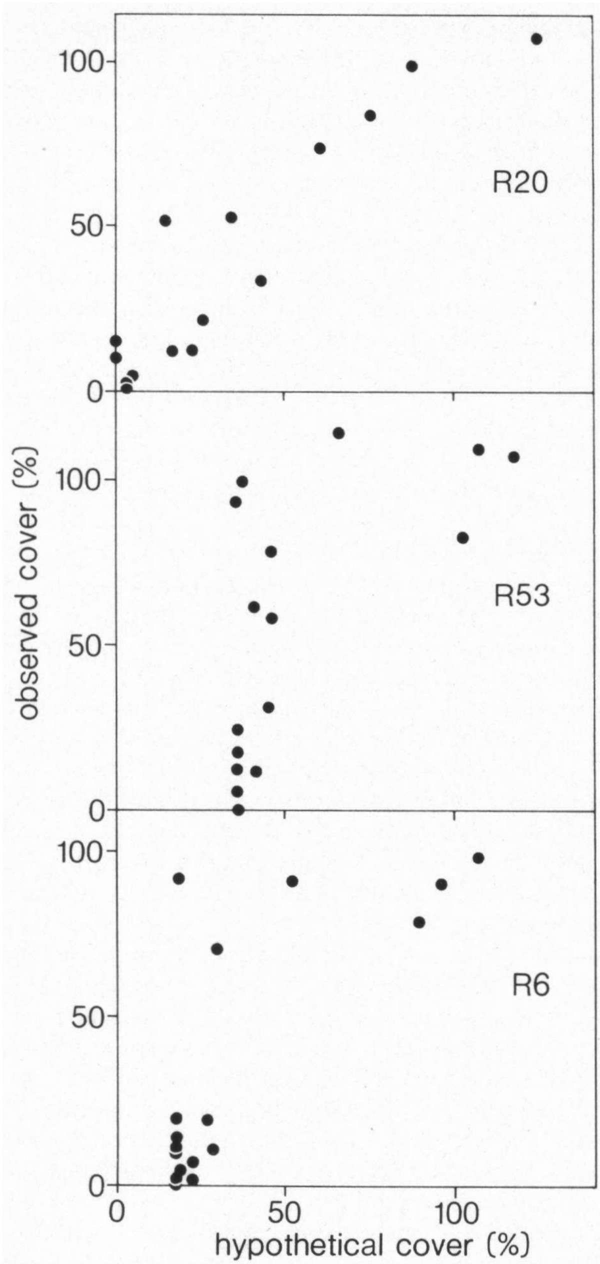

Fig. 4. Relation between observed total covers of three ecological species groups and the expectation based upon multiple regression analysis results.

correlations with the measured nutrient supply parameters.

Table 7. The total cover of three ecological species groups (%) estimated on the basis of the phosphorus supplies.

R20:	3.41 + 18.31 × external P-load + 6.57 × internal P-supply
R53:	36.20 + 16.75 × external P-load
R6:	17.58 + 18.34 × external P-load

2. A positive statistical correlation between the humus concentration in the soil and the total cover of the competitive tall hemicryptophytes has been demonstrated in the case of the 20 'nitrophilous' species in non-infiltrated areas. This could not be demonstrated in infiltrated areas.

3. A clear positive statistical correlation between the humus concentration and the net mobilization of phosphate and, to a lesser degree, potassium and nitrogen has been demonstrated.

4. The phosphate supplies show more distinct statistical correlations with the vegetation than the supplies of the macronutrients nitrogen and potassium.

5. The (external) orthophosphate load caused by the ground water flow gives a better explanation for the occurrence of competitive tall hemicryptophytes than the internal phosphate supply ("net mineralization").

6. The effects of phosphate stripping of infiltration water on the bank vegetation were estimated on the basis of the demonstrated relation between the phosphate supplies and the occurrence of competitive tall hemicryptophytes. From this, the cover of ecological species group R20 seems to be reduced to 30–90% of the present value by phosphate stripping.

7. The highly significant results support the choice of the applied method to determine mobilization using incubation samples under constant temperature and humidity.

4. DISCUSSION

The results are regarded in a wider perspective and will be discussed in view

Table 8. Predicted total cover of ecological species group R20 after phosphate stripping of infiltration water.

Area[1]	Flux density of ground water (m/day)	Total cover (%) of R20 species		
		observed[2]	predicted with	
			0.03 mg $PO_4^{3-}\cdot P/l$	0.00 mg $PO_4^{3-}\cdot P/l$
M	0.17	51	14	0
B	0.63	107	51	36
M	0.11	98	12	10
B	0.11	83	5	3
M	0.51	33	21	10

[1] B = Berkheide; M = Meijendel

[2] observed with momentary phosphate concentrations of 0.045 – 0.30 mg $PO_4^{3-}\cdot P/l$

of time factors, the external nutrient load, the main nutrients and other ecological parameters.

4.1. Time dimensions, other ecological factors and error terms

The results of this study are based on spatial observations in twenty sampling plots. From a statistical point of view this is a limited number. Therefore it is difficult to interpret the concerning spatial observations into the time dimensions of complicated processes at work. The occurrence of competitive tall hemicryptophytes must be seen as dependent on processes in time (a.o. VAN DER WERF 1974; LONDO 1975a) and so must the mineralization of organic compounds (ELLENBERG 1964; ZÖTTL 1960; SCHÖNHAR 1955). As for the time dimension in the present study, it must be noted that the succession of the wet vegetations in the sampled infiltration areas has been going on for at least twenty years (only the sampled areas in the Noordhollands Duinreservaat have had a shorter succession period). Vegetation studies on the banks of other infiltration ponds (VAN DIJK 1984; chapter 2) show that a fairly stable balance has been established in this period of time.

The error term of the soil nutrients and of mobilization is estimated by an analysis of each of the five soil samples separately which normally form one mixed sample. The values of these five individual samples vary within a sampling plot with mean standard deviations of 17% (maximum 26%) for nitrate and 31% (maximum 48%) for ammonium in the soil. The maximum variation between samples was found in the case of a high concentration of humus at the sampling plot. The high F-ratios in the multiple regression analysis indicate that these extreme variations in the individual samples of a sampling plot hardly affect the results; the variation between the individual sampling plots is apparently large enough to eliminate the error term.

Moisture, pH, calcium content, C:N-ratios, oxygen concentration, etc. may have a direct or indirect effect on the vegetation and on the mineralization process (a.o. GROOTJANS 1975; BAKKER et al. 1979; ELLENBERG 1964). However, the highly significant relationship shown in the multiple regression analysis indicates that a possible masking effect of these factors is negligible.

4.2. The range of the external load values

The results of the analyses give evidence that the external orthophosphate load is largely responsible for the fostering of competitive tall hemicryptophytes in infiltrated dune areas. The internal phosphate supply is complementary to this external load. It has been mentioned that under natural conditions with low external loads, the occurrence of competitive tall hemicryptophytes is related to local variances in the intensity of mineralization.

This study concerns an unnaturally large range of external nutrient loads partly due to the high velocity of the ground water caused by artificial infiltration. To test the hypothesis that mineralization is the dominating factor in the nutrient supply under natural conditions, the data set was split up according to being subject to infiltration or not. The two data sets have been subjected separately

Table 9. Results of the multiple regression analysis of infiltrated and non-infiltrated areas separately.

	Ecological species group	Explanatory independent variables	Explained variance (%)	Significance F-ratio
Infiltrated (n = 7)	R20	external P-load	73	0.0198
	R6	external P-load	72	0.0207
Non-infiltrated (n = 13)	R20	internal P-supply	83	0.0001
	R6	internal N-supply	54	0.0059

(R53 does not yield significantly explanatory variables)

to multiple regression analyses. *Table 9* gives the results of these analyses and includes all the variables given in *table 6*.

The significant results of R6 and R20 make plausible that under natural conditions with low external loads the total cover of the concerning species depends mainly on the nutrient supply due to local mobilization, while in the case of artificial infiltration the external load is dominant. The explained variance per factor appears to depend very much on the value range in which the factor is analysed. This gives an explanation for the wide spreading of R6-cover values found with low external nutrient loads as mentioned in the Introduction.

4.3. Scope to management policies

According to the present study in wet dune biotopes the phosphate supplies give generally better correlations with the species composition of the vegetation than the potassium and nitrogen supplies, especially in the artificially infiltrated dune areas. For this reason management should concentrate on the phosphate loads of the concerning biotopes. The results given in VAN DIJK & VAN STRIEN (1984) and VAN DIJK & MELTZER (1984) support the assumption that the gross orthophosphate load has a dominant impact on the bank vegetation of dune pools. Thus a reduction of the orthophosphate concentration of the infiltration water opens up reasonable perspectives in the case of repelling the cover of competitive tall hemicryptophytes with a high nutrient demand. However, it remains doubtful whether this will lead to a simultaneous recovery of the indigenous phreatophyte vegetation. To answer this question a further experimental study of the ground water, the development of the vegetation, its root system and nutrient stock is necessary besides knowledge about the mobilization of the accumulated nutrient in the soil.

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