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Nutrient dynamics in small mesotrophic fens surrounded by cultivated land

I. Productivity and nutrient uptake by the vegetation in relation to the flow of eutrophicated ground water

J.T.A. Verhoeven, S. van Beek, M. Dekker, and W. Storm
Dept. of Plant Ecology, The University of Utrecht, Lange Nieuwstraat 106, 3512 PN Utrecht, The Netherlands

Abstract. In a typical Dutch polder landscape the effects of nutrient transport from cultivated grassland to mesotrophic fen communities were studied. In a comparative approach, biomass production and nutrient (N, P and K) uptake were determined monthly in four fens and a hayfield differing in productivity and species composition. The interstitial ground water was sampled every two weeks for determinations of inorganic nutrient concentrations.

The differences in productivity between the fens were clearly reflected in the amount of N, P and K taken up in the above-ground vegetation. N and P proved to be limiting plant growth in the fens, whereas K was the main limiting factor in the hayfield. The ground water welling up from the sandy bottom into the fens proved to be rich in ammonia (3–5 ppm). There are strong indications that this continual seepage leads to a considerable input of N into the fens but not to a higher productivity, as the ammonia is absorbed by the lowermost peat layers covering the sand.

At this moment, the differences in productivity between the fens must be caused by differences in the rates of mineralization of the superficial peat layer. The degree of fixation of the floating vegetation mat, determining whether or not low water levels lead to an aerated soil top layer, is important in this respect. Within a period of decades, however, the continuous inflow of ammonia may eventually cause an increase in the productivity and a change in the species composition of the fens.

Introduction

Eutrophication has caused many problems in aquatic environments all over the world. The phenomenon is well-known and the basic mechanisms underlying it are relatively well-understood (Vollenweider 1971; Phillips et al. 1978; Parma 1980; Ringelberg 1980).

Due to transport of waste water and eutrophicated ground water, and to the increased amounts of N and S in the atmosphere, many (semi) terrestrial ecosystems are now becoming enriched with nutrients. Not much is known of the changes in structure and function of such terrestrial systems caused by these eutrophication processes.

Offprint requests to: J.T.A. Verhoeven

Freshwater marshes are known to accumulate nutrients and can sometimes function as a nutrient trap preventing neighbouring aquatic environments to become highly eutrophicated (Verry and Timmons, 1982). Further, much work has been done to investigate the possible use of swamps and marshes as accumulators of nutrients in order to further purify nutrient-rich wastewater (De Jong 1976; Whigham and Simpson 1976).

In the Netherlands, freshwater marshes, like fens and bogs, are commonly situated as small elements in a predominantly agricultural landscape. The species-rich plant communities are managed by nature conservation agencies to conserve their original composition and structure. Many of these oligotrophic or mesotrophic marshes are becoming more and more enriched with nutrients via groundwater flow and precipitation. This locally leads to undesirable shifts in the species composition of the marshes.

For a fundamental study of the processes of eutrophication, an area of small marshes embedded in a landscape of grassland used for cattle breeding was selected. The nutrient dynamics of the ground water-soil-vegetation system were investigated in four mesotrophic fen stands and a hayfield. In a comparative approach the plant communities were sampled frequently for one year to obtain a picture of the seasonal changes in the plant biomass and in the amounts of N, P and K contained therein. Further, the ground water table and ground water chemical composition were determined frequently, and an extensive experimental programme on decomposition processes in the peat soil was carried out.

This paper contains the results on biomass production and nutrient uptake in the vegetation in relation to the chemical composition of the upwelling ground water.

Study area

The investigations have been carried out in the "Vechtplassen" area north of Utrecht (Fig. 1). The area shows an elevational gradient from the "Utrechtse Heuvelrug" in the N.E. down to the river "Vecht" in the W. The "Utrechtse Heuvelrug" is a range of sandy hills dating from the "Riss" ice age (200,000 years B.C.). At present the hills are covered for the greater part with pine woods. To the S.W. the hills turn into very little sloping eolic sand flats (Polder Achttienhoven) that are drained and used for intensive agriculture (cattle breeding). Below 0 m N.A.P. (=mean sea level) the

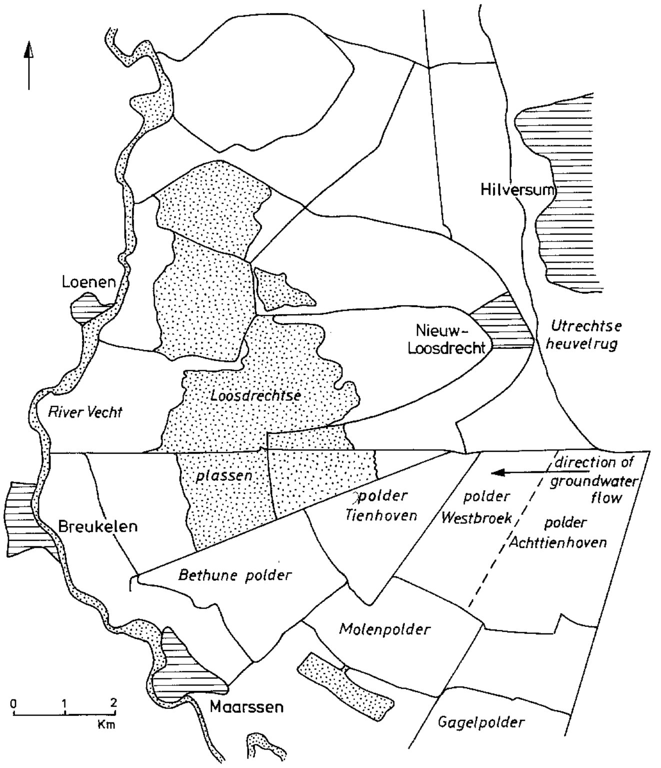

Fig. 1. Situation of the polders Westbroek and Tienhoven in the Vechtplassen area, The Netherlands. Dotted areas are lakes and rivers

eolic sands are covered with a peat layer that increases in thickness up to 6 m towards the river Vecht, the ground level decreasing gradually to −1 m N.A.P.

In the polders Westbroek and Tienhoven, the main study area, the peat layer is 0.5–1 m thick. These polders have been reclaimed in the 12th century by the construction of numerous parallel ditches draining the peat. In the 18–19th century the peat has locally been dug up, leaving the excavated areas as shallow broads or lakes scattered in the landscape (e.g. the "Westbroekse Zodden"). Succession has proceeded, leading to Alder woodland or, under the influence of annual mowing in the summer, to floating fenlands containing a species-rich vegetation characteristic for mesotrophic conditions (Caricion curto-nigrae, see Westhoff and Den Held 1969).

The Alder woods and floating fens are embedded in a matrix of intensively fertilized grassland. The groundwater table in the polders is being kept at a rather constant level (fluctuations <20 cm). The direction of the groundwater flow is $E \rightarrow W$ (Fig. 1). The area is situated in a zone with local upwelling of ground water, so that nutrient transports from the fertilized grasslands towards the fens are to be expected.

Three fenland sites in the polder Westbroek and one in the polder Tienhoven were selected for a comparative study of productivity and nutrient uptake in relation to the input of nutrients from the ground water. For reasons of comparison, a hayfield in the area, managed in the same way as the fens (no fertilization, annual cutting in July) but with a densely packed peat bottom at a level of 40 cm above the ground water table, was studied with similar methods.

Methods

Biomass samples were taken monthly in the period March 1981–February 1982 at the sites under investigation. At each site a sampling spot was chosen in a representative part of the vegetation. At each occasion 10 20×20 cm (fens) or 10×10 cm (hayfield) squares were cut randomly out of the sampling spot. The above-ground plant parts were sorted into dead and living material in the laboratory. The living parts were further sorted according to species. The samples were dried (70 C, 48 h) and weighed. The dry plant material was ground; total C and N content was determined gas-chromatographically in a Carlo Erba Element Analyzer. To determine total P and K content the dry ground plant material was ashed (550 C, 3 h); the ash was solved in 3N HCL and diluted. The PO_4^{3-} content of the solution was determined colorimetrically with an autoanalyzer, the K^+ content by flame emission colorimetry. The significance of differences in maximum biomass between the stands was investigated with the Student-t test. The nutrient concentrations in the plant material were calculated as weighted mean values from measurements for each of the dominant species separately. All measurements were carried out in duplicate.

The ground water at the sites studied was sampled every two weeks. In the fens the water was collected at four different depths: the superficial water layer was sampled by simply filling a 100 cc flask: water was extracted from the root zone (-20 cm) and the peaty water layer underneath (-60 cm) with ceramic porous probes. The ground water in the sand (-150 cm) was sampled from ground water pipes. In the hayfield water was sampled with porous probes (-50 cm, near groundwater table in peat soil) and ground water pipes (-200 cm, sand). After the determination of pH and conductivity, all water samples were filtered over Whatman GF/C (mesh 2 μm) and stored at −15 C until analysis. Concentrations of NO_3^-, NH_4^+ and PO_4^{3-} were determined colorimetrically with an auto-analyzer, K^+ and Ca^{2+} were measured by flame emission colorimetry.

Floristic composition of the communities

Data on the floristic composition of the stands in the five localities studied are given in Table 1. Dominant species found in the biomass samples taken in June and July (period of maximum development of the vegetation) are listed together with their contribution to the living biomass of the stand.

There are distinct differences between the fens in species density and degree of dominance (J′ values). The '*Carex diandra* stand' is obviously richest in species and shows high S, H′ and J′ values. It is relatively low productive. The other three fen sites are more similar in species density but differ strongly in productivity. The degree of dominance is much higher than in the '*Carex diandra* stand'. The '*Holcus lanatus* stand' (hayfield) shows a smaller species density and an intermediate productivity and degree of dominance compared to the fen stands.

With respect to the species composition, the "*Carex acutiformis* stand" contains many species of the alliance Magnocaricion, whereas the species combinations in the other three fen stands point to the alliances of the Parvocaricetalia (Caricion davallianae and Caricion curto-nigrae). The '*Carex diandra* stand' contains many character species of the Scorpidio-Caricetum diandrae (see Westhoff and Den Held 1969).

Table 1. Distribution of the above-ground living biomass amongst the dominant plant taxa found in the samples (biomass is expressed as percentage of total living biomass in the period June–July). All species contributing more than 1% to the total biomass are listed. Further, the total number of species encountered in the samples, the total living biomass and the indices for diversity (H′) and evenness (J′) are indicated

Species list	Fens				Hayfield
	C. diandra stand	*C. rostrata* stand	*J. subnodul.* stand	*C. acutiformis* stand	*H. lanatus* stand
Utricularia minor	2				
Salix repens	2				
Potentilla palustris	1	1	2		
Carex rostrata	1	73	1		
Carex diandra	36		1		
Pedicularis palustris	4		1		
Juncus subnodulosus	17	5	70	1	
Menyanthes trifoliata	11	1	4	1	
Equisetum fluviatile	9	1	1	1	
Thelypteris palustris		$\frac{1}{2}$	6		
Carex acutiformis				83	
Phragmites australis				3	
Holcus lanatus	1	1	1		51
Iris pseudacoris	1			1	15
Poa trivialis	1				9
Phalaris arundinacea					11
Moss	8	4	1	1	1
Total number of species	34	20	24	19	13
Area sampled (m^2)	0.8	0.8	0.8	0.8	0.4
Total living biomass $g \cdot m^{-2}$	245	209	384	584	330
H′ (diversity index)	2.86	1.44	1.59	1.04	1.50
J′ (evenness)	0.81	0.48	0.50	0.35	0.58

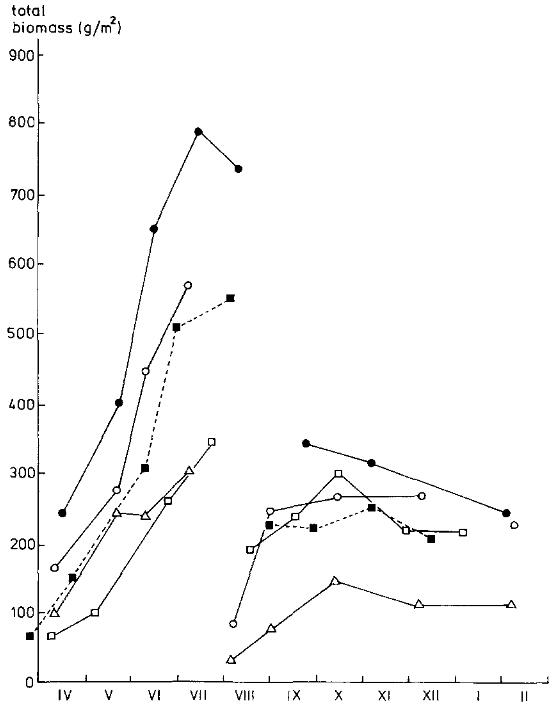

Fig. 2. Seasonal fluctuations in total above-ground biomass. Values are means of 10 400 cm^2 samples. Total biomass includes standing dead litter.

●——● *Carex acutiformis* stand (fens)
○——○ *Juncus subnodulosus* stand (fens)
△——△ *Carex rostrata* stand (fens)
□——□ *Carex diandra* stand (fens)
■----■ *Holcus lanatus* stand (hayfield)

The lines are disrupted at the moment of cutting

Seasonal changes in biomass

In Fig. 2 the seasonal changes in total above-ground biomass are indicated. The general pattern shows a rapid increase in the period April to August, a steep fall due to cutting in July/August and a more or less important second period of increase from August to October. In winter the biomass shows a very gradual decrease.

Using maximum summer biomass as a measure for productivity, three levels of productivity can be distinguished in the fens: the highest level for the '*Carex acutiformis* stand', a medium level for the '*Juncus subnodulosus* stand' and the lowest level for the '*Carex rostrata*' and '*C. diandra* stands'. The differences between the highest and the lowest level, as well as one of the differences between the medium and the lowest level are significant ($P<0.05$). The hayfield shows a summer biomass value comparable with the intermediate fen level.

It is worth noting that the differences in biomass are much smaller after mowing. The '*Carex acutiformis* stand' and the hayfield hardly show any regrowth, in contrast to the three remaining fens, that had been mown 4 weeks earlier. The '*Carex diandra* stand' exhibits a relatively high second biomass maximum in October.

Table 2. Significant differences in biomass maximum between the stands studied

Difference between stands dominated by	Level of significance
Carex acutiformis vs. *C. rostrata*	$P<0.05$
Carex acutiformis vs. *C. diandra*	$P<0.05$
Juncus subnodulosus vs. *C. diandra*	$P<0.05$

Uptake of nutrients by the vegetation; indications for nutrient limitation

In the Figs. 3A, 4A and 5A the P, K and N contents of the living above-ground plant parts are plotted against time. The "critical nutrient contents" indicated in each graph are derived from agricultural research in grassland vegetation (De Wit et al. 1963, Dijkshoorn, pers. comm. 1982).

If the content of a particular nutrient drops below the critical value, there are strong indications that this nutrient has been limiting the growth of the plants under investigation. In the Figs. 3B, 4B and 5B the total amounts of P, K and N in the above-ground plant mass (inclusive the standing dead material) are depicted.

The general pattern of fluctuation in the P content of the blank living plant material (Fig. 3A) comprises a decrease in spring and summer due to dilution of P in the

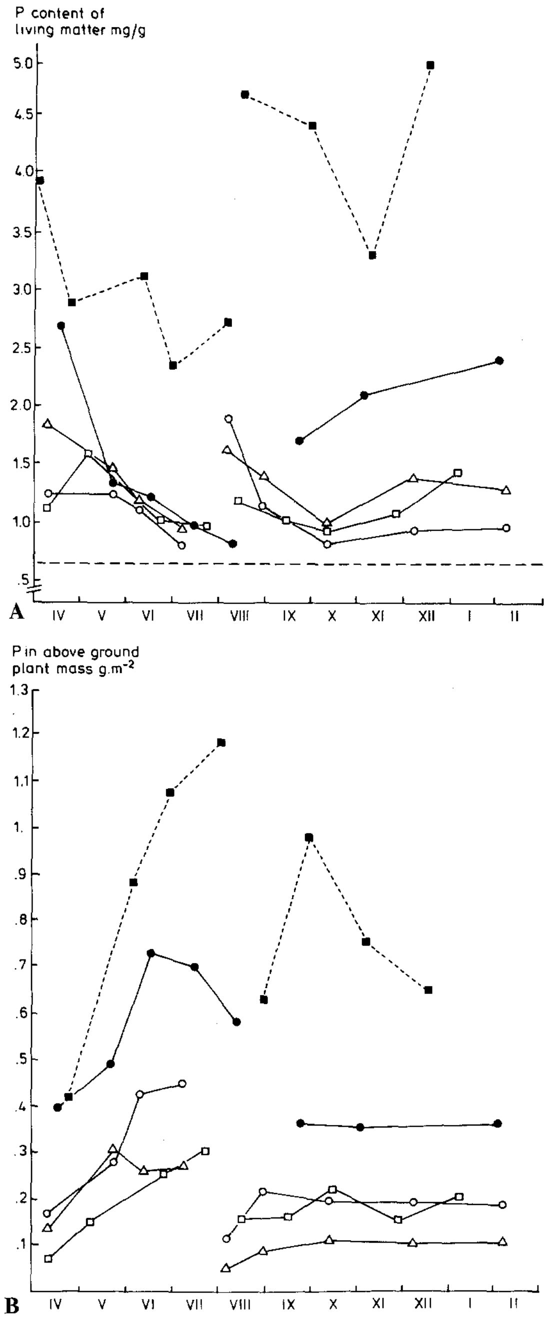

Fig. 3. A (upper graph). Seasonal fluctuations in the P content of the living plant material. The horizontal dotted line represents the critical P content; **B** (lower graph). Seasonal fluctuations in the total amount of P contained in the above-ground biomass (including standing dead material); For an explanation of the symbols see Fig. 2

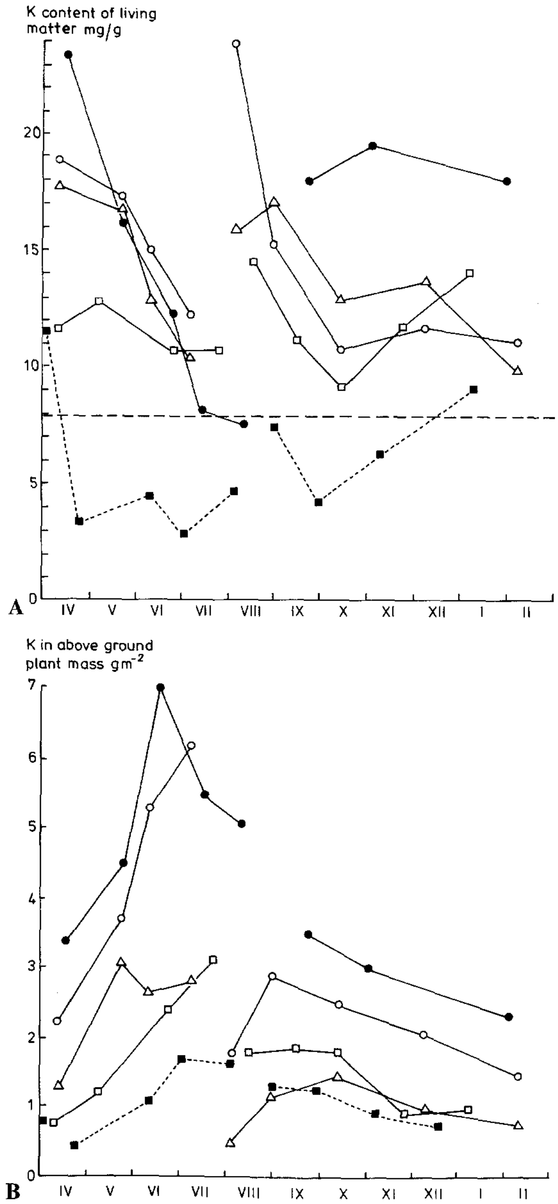

Fig. 4. A (upper graph). Seasonal fluctuations in the K content of the living plant material. The horizontal dotted line represents the critical K content; **B** (lower graph). Seasonal fluctuations in the total amount of K contained in the above-ground biomass; For an explanation of the symbols see Fig. 2

developing plant shoots. After mowing a second dilution takes place, except in the '*Carex acutiformis* stand', where hardly any regrowth occurred. Despite the great differences in productivity (Fig. 2), the P content of the material in the four fen stands shows remarkably similar values, particularly in the period May–August when the bulk of the living biomass is formed. The minimum values (July–August) are very similar and also close to the critical value. In the three fen stands with an important regrowth the P contents are down to similarly low levels in October. These results suggest a P limitation in the fens. The P contents of the hayfield plants are two to four times higher than in the fen stands. These values point to a high P supply by the hayfield soil.

The same trends are visible in the total amount of P present in the biomass (Fig. 3B). The hayfield stand accumulates much more P in its above-ground biomass than the fen stands. The three levels of productivity in the fens are also reflected in the amounts of P contained in the plant mass. The rather constant amounts of P in the fen biomass after mowing are remarkable.

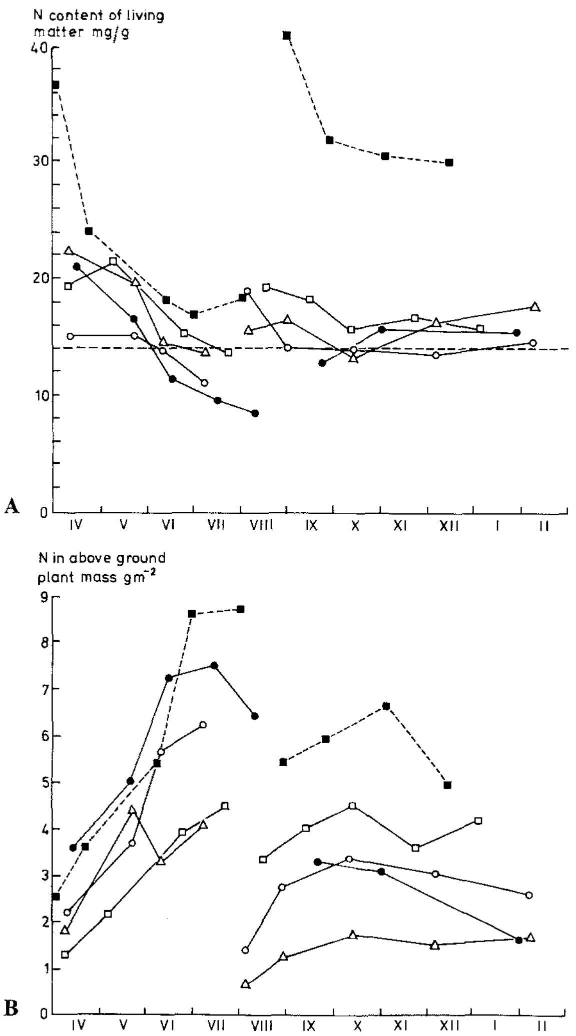

Fig. 5. A (upper graph). Seasonal fluctuations in the N content of the living plant material. The horizontal dotted line represents the critical N content; **B** (lower graph). Seasonal fluctuations in the total amount of N contained in the above-ground biomass; For an explanation of the symbols see Fig. 2

The pattern of fluctuation of the K contents of the living biomass (Fig. 4A) resembles that of the P contents in that the K content decreases sharply in periods of exponential growth. There are, however, differences between the fens in the minimum values; further, for each fen there is a difference between the minimum values reached before and after cutting. Almost all minimum K contents of the fen plant material remain well above the critical value. In the hayfield the K contents of the plant material are much lower: they remain below the critical value for most of the year, so that limitation of growth by K has to be assumed.

The total amount of K in the above-ground biomass (Fig. 4B) is much larger in the fens than in the hayfield. The easy leaching of K from senescent and dead plant material is reflected in the decrease of the K content in all stands from August onwards. In the '*Carex acutiformis* stand' biomass reached its peak one month before cutting (Fig. 2): the gradual senescence and death in July led to a decrease of the amount of K in the vegetation.

The N content of the living plant material (Fig. 5A) in the fens drops slowly during the period of exponential growth. It is below the critical value at the moment of maximum biomass in all four fens. Plant communities strongly dominated by tall plants (*Carex acutiformis*, *Juncus subnodulosus*) dilute their nitrogen to a lower level than those consisting of smaller species. After cutting the N contents remain close to or below the critical level. The N contents in the hayfield biomass are higher at any specific point in time than those in the fens during the whole year. The N content of the hayfield vegetation only approaches the critical value in the two months before cutting. It can be concluded that the fen communities are limited in their biomass production by the availability of N during the greater part of the year. In the hayfield there are indications of N-limited growth in the period June–August.

The amount of N accumulated in the above-ground biomass (Fig. 5B) is primarily related to productivity.

Dissolved nutrients in the interstitial soil and ground water

The results of the frequent year-round measurements of dissolved nutrients in the ground water sampled at different depths are given in Fig. 6. The pH of all water samples was within the range of 5–7.

The concentration of NO_3^- has also been determined. It proved, however, generally below the limit of detection (0.01 ppm). Higher NO_3^- levels were measured in he upper ground water layer in the hayfield, where an annual mean value of 1,37 ppm was determined 40 cm below soil surface.

The main soluble nitrogen compound in the sites studied proved to be ammonia. High ammonia concentrations (3–5 ppm) were measured in the interstitial ground water in the sand layer, 150 cm below soil surface in the sites situated in the polder Westbroek. The ground water in the sand layer below the fen in the polder Tienhoven ('*Carex acutiformis* stand'), however, contained much less ammonia, the concentration being similar to that in the shallower peat layers. It is remarkable that in the peat layers covering the sand the NH_4^+ concentration is at a low level in all sites except for the hayfield, where the good aeration of the soil apparently results in large amounts of NO_3^- and NH_4^+.

The PO_4^{3-} concentration is much lower (note the different scale). It is particularly low in the sand layer and locally higher in the shallower peat.

The K^+ concentration is mostly high in the superficial water layer; it is low in the deeper ground water in the sand.

Concentrations of Ca^{2+} are high in the ground water in the sand. There is a distinct difference between the values in the Westbroek localities and the '*Carex acutiformis* stand' in Tienhoven: the Ca^{2+} concentration in the sand layer is 4 times higher in Tienhoven. This high Ca^{2+} level is also found in the shallower peat layers.

These data show that there are remarkable differences in the concentrations of NH_4^+ and Ca^{2+} in the ground water between the polder Westbroek and Tienhoven. These differences can be explained by considering the hydrological situation in the Vechtplassen area. Figure 7 gives a geohydrological profile in west-east direction. Within the thick sand layer covering the impervious layer of Sterksel-Kedichem there is a groundwater flow from the sandy hills in the N.E. towards the lower polder areas. Rainwater drains

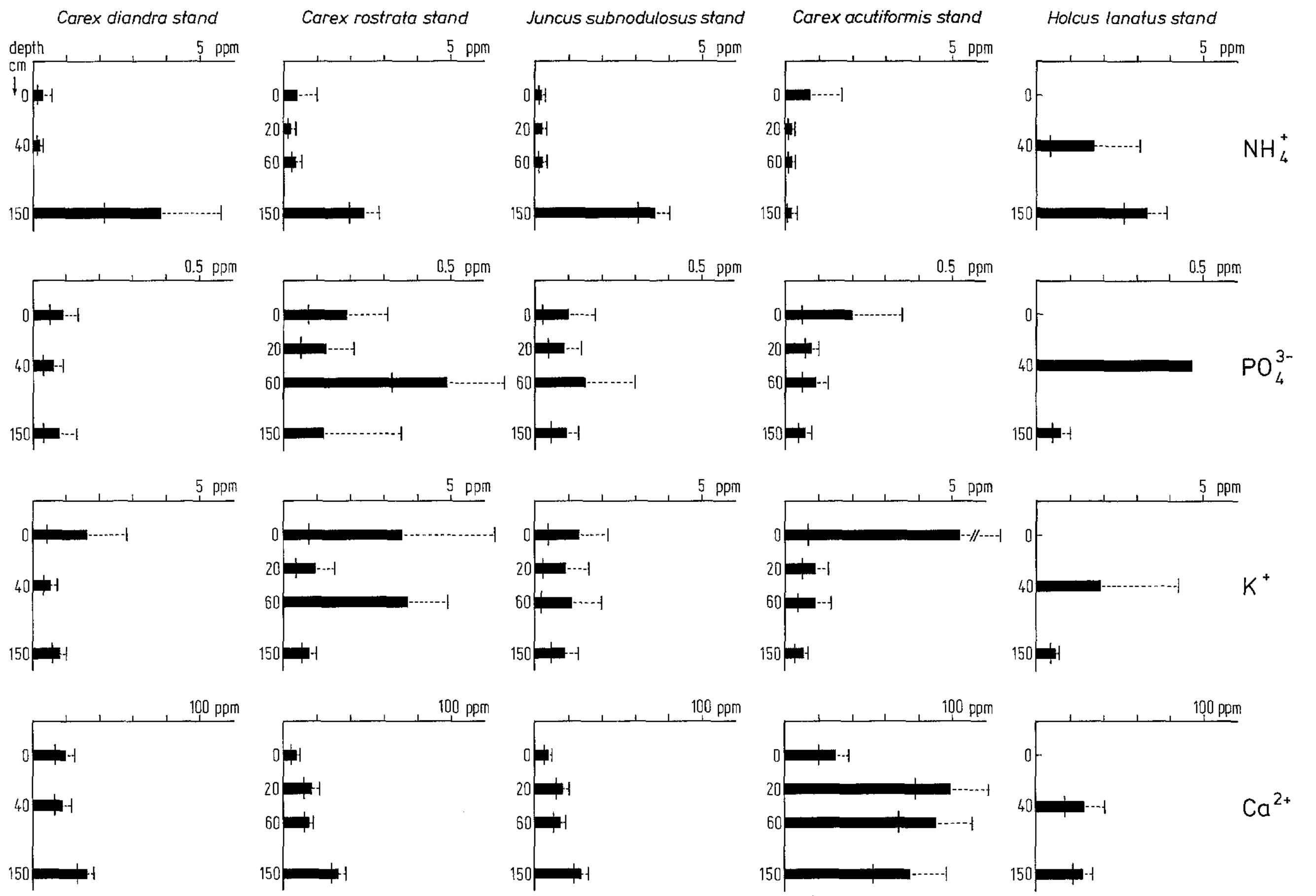

Fig. 6. Annual mean concentrations of NH_4^+, PO_4^{3-}, K^+ and Ca^{2+} in the interstitial ground water at different depths in the fens and the hayfield. Bars are mean values of two-weekly observations, vertical lines indicate the standard deviations

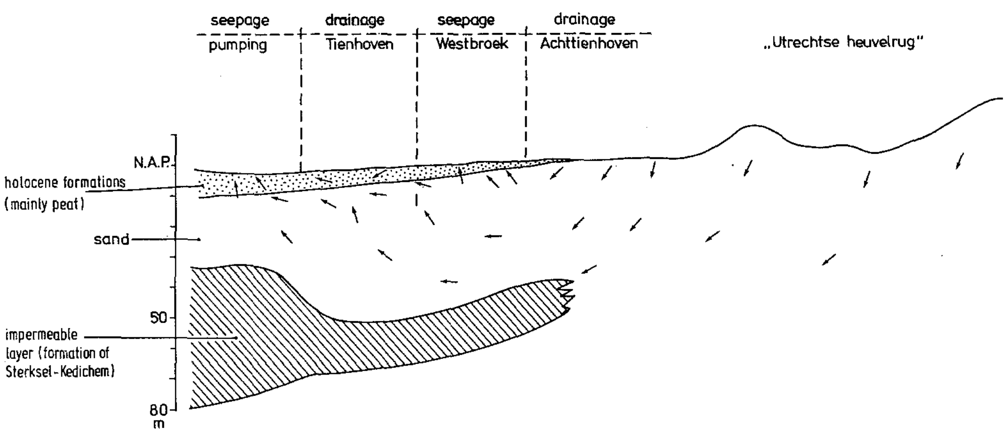

Fig. 7. Geohydrological profile of the Vechtplassen area (after Schouten, 1974). The probable directions of ground water flow are indicated

into the sandy hills and the bordering polder Achttienhoven with a sandy bottom. The water drained in the hills takes a long route trough deeper sand layers and reaches the surface again in the Tienhoven-Bethunepolder area, where locally strong seepage occurs. In the Bethunepolder much seepage water is pumped away for drinking water preparation, leading to a lateral ground water flow in the neighbouring area of the polder Tienhoven, where the '*Carex acutiformis* stand' is situated. In the polder Westbroek there is a continual upward ground water flow. The water seeping up from the sand has taken a much shorter route through more superficial sand layers; it originates from a much closer location, i.e. the polder Achttienhoven. The difference in Ca^{2+} content of the ground water in the polders Westbroek and Tienhoven can be explained by the difference in length of the route through the sand. The difference in NH_4^+ content must be due to the fact that the polder Achttienhoven is used for intensive cattle breeding accompanied by the application of high levels of fertilizer and

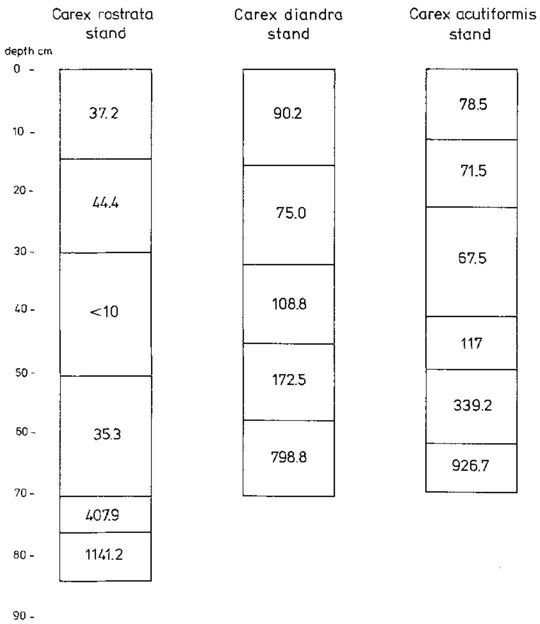

Fig. 8. Soil profiles of the sites studied. Bulk densities of the different layers are indicated as g dry weight. l^{-1}. Samples were taken with a plexiglass corer. Bulk density was determined in duplicate for all layers distinguished by visible characteristics in the field

cattle dung. NO_3^--nitrogen leaches out of the sandy soil and is reduced to NH_4^+ in deeper layers. The sandy hills, however, are covered by oligotrophic heather and woodlands. Therefore, the NH_4^+ levels are low in the Tienhoven ground water. The explanation given above has been based on existing data on the ground water regime of the area (Schoute 1974; B. Beltman and R. Kemmers, pers. comm. 1982); it is being further checked by a detailed study of ground water flow in the area (B. Beltman, pers. comm. 1982).

Vertical stratification

In Fig. 8 the soil profiles of the fens and the hayfield are indicated. The fens are characterized by a distinct floating mat (30–40 cm), where nearly all roots are concentrated. This layer consists for more than 90% of dead plant remains and shows bulk densities in the range of 35–90 g/l. Below the floating mat, there is a layer with a variable bulk density, depending on the age of the fen. In relatively younger fens there is a more or less open water layer below the mat (bulk density <30 g/l), whereas in older fens this layer gradually becomes filled up with peat.

Table 3. C/N ratios of the peat soil at different depths

Fen dominated by	Depth (cm)	C/N ratio
Carex diandra	10	25.6
	60	33.4
Juncus subnodulosus	10	27.0
	60	34.1
Carex acutiformis	10	24.1
	60	33.0

Figure 8 shows that the fen dominated by *C. rostrata* is younger than those dominated by *C. diandra* and *C. acutiformis*. A dense peat layer (bulk density 150–400 g/l), 10–20 cm thick and partly consisting of "gyttja", covers the sandy bottom of the fens (bulk density > 750 g/l), which is located at a depth of 60–75 cm.

In Table 3 the C/N ratios of the peat soil of the fens is indicated. The peat near the fen surface is compared with the peat layer covering the sand. It is obvious that the overall C/N ratios are low. The C/N ratios are lower in the surface peat layers than in the layers covering the sand.

Discussion

The primary aim of this study is to determine the degree to which plant communities under mesotrophic conditions are changed or disturbed when nutrient levels increase distinctly due to eutrophication.

There is much evidence for a relationship between the species density of a plant community and its productivity. Al-Mufti et al. (1977) and Grime (1979) combined data on a variety of different plant communities and found that species density increased with increasing biomass production up to a certain maximum, and decreased gradually again with further increasing production. A similar relationship has been found by Willems (1980) for limestone grasslands and by Vermeer and Berendse (1983) for fens and grasslands in the Vechtplassen area. Wheeler and Giller (1982) found a negative correlation between species density and productivity in "rich-fen" areas in the Norfolk Broads area, Great Britain.

Vermeer and Berendse (1983) found the maximum species density at a biomass production of 400–500 g/m^2. If the productivity depasses this limit, the species rich fen communities are becoming more and more dominated by competitive tall marsh plants, such as *Glyceria maxima*, *Carex acutiformis*, and *Calomagrostis canescens*, that gradually oust the typical fen species. This results in a plant community with a smaller species density and diversity, consisting of much more common species than the original community.

In this traject of high biomass production the differences will be directly related to nutrient availability. The results of this study show that such differences are clearly reflected in the amount of nutrients taken up in the plant material. This can only be explained by differences in nutrient supply, as N and, to a lesser extent, P have shown to limit plant growth in the fens. A similar joint limitation of plant growth by N and P occurs in North American bogs (Moizuk and Livingstone 1966). In our study area, the N and P supply to the fen vegetation is the resultant of the supply by rain, the supply by upwelling ground water and the net result of the decomposition of the large nutrient stocks in the peat. The supply by rain will not differ between the fens. Hence, the differences in productivity will be caused either by different inputs via the ground water, or by different mineralization rates.

There is a distinct difference in ground water regime between the polders Westbroek and Tienhoven. The three fens in the former polder are continually supplied by ground water welling up from the sand, whereas the *Carex acutiformis*-dominated fen in Tienhoven is situated in an area with downward groundwater percolation. Considering the large

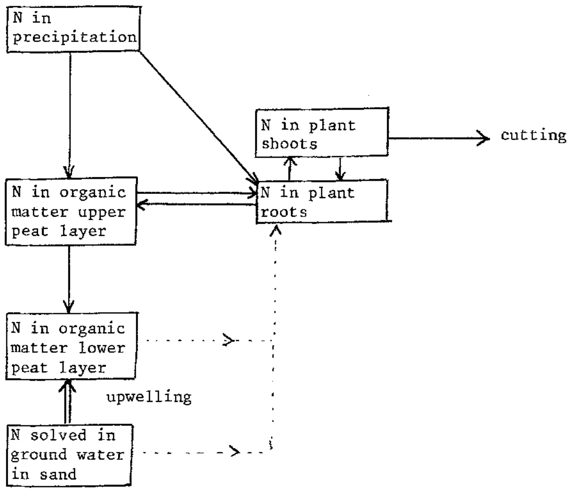

Fig. 9. Model of the N pathways in the fen ecosystem

amounts of NH_4^+ in the ground water welling up in Westbroek, it is rather unexpected that the three fens there are less productive and accumulate less nutrients in the aboveground plant material than the *C. acutiformis*-dominated fen.

There are two indications for the assumption that the upwelling ammonia cannot be taken up by the roots of the fen plants. In the first place, the ammonia concentration in the interstitial water of the deeper peat layer covering the sand (−60 cm), where virtually no plant roots occur, is continually low. Further, there are no season-bound fluctuations in the ammonia concentrations in the interstitial water in the peat. Such fluctuations would have been expected due to the seasonal pattern of activity of plant roots.

As an explanation, the following hypothetical model of the pathways of N in the fen ecosystem can be given (Fig. 9). The N entering the system by upwelling groundwater has to pass the peat layer covering the sandy fen bottom. This layer differs in various aspects from the upper peat layer that forms the floating mat. It has a higher C/N ratio, a higher bulk density and is in a much further state of decomposition. Parnas (1975) developed a model for the decomposition of organic material. His model predicts that mineralization of N will take place if the C/N ratio of the decomposing material is below a "critical" level (±20–25). Immobilization of N occurs at higher C/N ratios. This model is, however, only applicable in the initial stages of decomposition. In later stages, complex biochemical processes, such as humification and tanning take place (Godshalk and Wetzel 1978a, b). Organic material in well-decomposed peat layers can absorb N even at low C/N ratios due to chemical and biological absorbance in the tanning and humification process (Isotalo 1951).

In the fens studied it is probable that N is continually immobilized and mineralized in the upper floating peat layer. This layer consists of a mixture of fresh organic material and material in the initial stages of decomposition. There will be a net mineralization in this layer as a whole.

In the lowermost well-decomposed peat layer N will be absorbed due to humification, tanning and immobilization. Preliminary measurements of the decomposition of material each of these layers have confirmed this picture.

Therefore, we propose the assumption that all ammonia flowing into the fen is absorbed by the lowermost peat layer. This hypothesis needs further testing by an experimental programme in which the decomposition and humification of peat under various circumstances of nutrient supply is investigated.

Although the amount of P in the upwelling ground water is comparatively small, similar processes of "nutrient trapping" by deeper peat layers might occur for this element.

Another possible explanation for the small N and P seepage in the Westbroek fens is that the flow rate of the upwelling ground water decreases as peat accumulation proceeds. Peat layers are reported as acting as a barrier for water flow (Gosselink and Turner 1978).

However, typical seepage phenomena, such as layers of iron-oxidizing bacteria, brown-coloured ice layers in winter, can be commonly observed in the fens. Further studies of the ground water flow rate are in progress.

Thus, it is assumed that the N and P supply from the ground water to the fen vegetation is absent or very small. Hence, the differences in productivity and nutrient uptake must be caused by differences in the rate of mineralization of the upper 40 cm of peat. The high productivity of the *Carex acutiformis*-dominated fen can be explained by the fact that the ground blank water table in the polder Tienhoven fluctuates somewhat more than that of the polder Westbroek. In the summer season the ground water table in this fen dropped more than 10 cm below the surface. In the fens in the polder Westbroek the fluctuations were so small that the upper peat layer always remained floating. In this way aeration of the upper peat layer in the first fen can lead to a higher degree of mineralization.

In the present study it is shown that the effects of eutrophication in fen ecosystems can be delayed considerably by nutrient trapping in layers of organic material. Absorbance of N and P in freshwater marshes is a well-known phenomenon (Gaudet 1977; Verry and Timmons 1982).

The exact mechanisms involved in the retention process are complex and difficult to analyse. These mechanisms include chemical absorbance to cation exchange sites (organic acids), immobilization by micro-organisms, biochemical absorbance due to tanning and humification. It is very important to know more details on the kinetics of this process. Which such data, the limits for the retention capacity of a certain freshwater marsh can be indicated. This information is very important for a prediction of the effects of prolonged eutrophication processes upon the plant communities in the marsh.

The capacity for nutrient trapping may seem advantageous and is often utilized in nutrient-added technologies, such as wastewater treatment in freshwater marshes (De Jong 1976; Whigham and Simpson 1976).

It has to be realised, however, that this capacity is limited and that the changes in the marsh vegetation will be drastic and irreversible if the absorbed nutrients are suddenly released.

Further studies are in progress to determine the limits to the retention capacity of the fens under investigation.

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