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A SURVEY OF THE ACID WATER DIATOM ASSEMBLAGES OF TWO HEATHLAND RELICS IN THE BELGIAN NORTHERN CAMPINE (GROOT & KLEIN SCHIETVELD, BRASSCHAAT) WITH AN ASSESSMENT OF THEIR CONSERVATIONAL VALUE

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The diatom assemblages of 47 lentic heathland waters, mostly moorland pools, on two military range and · training grounds in. the Belgian northem Campine were surveyed. In: many of . the pools a marked dominance of *Eunotia exigua* and a very low species diversity was observed. In most of them only a trivial diatom flora remains. A few waters on the border of the terrains are clearly polluted by agricultural waste. Assemblages and taxa indicating meso-oligotrophic, less extremely acid conditions are restricted to deeper waters, slightly influenced by grmmd water, and sites apparently affected by more mineral-rich seepage from lowland strearnlets. These observations are discussed in the light of acidification and possible management of heathland waters.

INTRODUCTION

Although the Belgian Campine has attracted many naturalists throughout this century and the interest of ecologists in the region bas grown since the 1970s, the diatom assemblages of one of its most specific biotopes, the originally nutrient-poor and soft (± acidic) heathland waters, have received relatively little attention. Caljon (1975) investigated the phytoplankton of 13 moorland pools in the region of Turnhout, whereas diatom vegetation bas been studied in relation to the water quality in the nature reserve "De Zegge" at Geel (Remels *et al.* 1980). Van Dam & Beljaars (1984) have discussed the diatom pH spectra of a number of Campine pools and compared some of them with those from older samples; Denys *et al.* (1987) also presented a few relevant data.

It bas been amply demonstrated that the composition of aquatic diatom assemblages reflects the water quality and certain environmental conditions. Tuis seems to hold especially well for nutrient-poor soft waters, where cliatom assemblages may indicate low-amplitude but important environmental changes, which are not registered, for instance, by macrophytic vegetation or infrequent chemica! analysis. Diatoms are therefore very useful for monitoring acidification and eutrophication which, besides reclamation, present the major threats to the special characteristics and conservational value of heathland waters.

The present study deals with the diatom assemblages of various lentic water-bodies on two large military ranges and training grounds in the Belgian Campine, north of Antwerp, the Groot Schietveld and Klein Schietveld. The survey was initiated primarily to obtain a first assessment of the hydrobiological state of the waters, which would be helpful in planning and· evaluating future

· management. It was also intended to facilitate the selection of representative water-bodies for more intensive investigation and monitoring. This paper complements a floristic account by Denys (1985).

STUDY AREA

The Groot and Klein Schietveld (1560 and 360 ha respectively; 51° 21'N, 4° 35'E and 51° 22'N, 4° 30'E) are partly forested (mainly conifer) heathland relics on the interfluvium of the Schelde and Weerijs (Maas) drainage basins, at an altitude of 22 to 30 m above mean sea level. Both are typical infiltration areas. Podzolic features have developed in the rather thin Weichselian sand cover. The su9soil consists of sandy Tiglian deposits with less permeable clayey and loamy lenses, which locally may occur close to the surface and hamper percolation. The terrains have retained a considerable natural history value due to their hydrology, their slightly higher topography than the surrounding agricultural land, the land-use and the limited influence of modem agriculture (De Blust & Denys 1984). Numerous natural pools of aeolian origin and man-made waters are present. Most of them have very clear water, poor in humic substances, and have a sandy bottom with, at most, only a thin peaty layer on top. Their water-level depends strongly on precipitation. As the groundwater-table is subject to rather strong seasonal fluctuations and most water-bodies are very shallow with gently sloping banks, their surface area often varies greatly through the year and many dry up completely in summer. Because of the low availability of easily soluble minerals in the soil and their hydrological isolation, the chemical character of most of the waters is closely related to that of precipitation.

MATERIAL AND METHODS

Sampling was carried out in December 1983, January 1984 and December 1984 in 47 different water-bodies, 43 on the Groot- and 4 on the Klein Schietveld. General information on their nature is included in Fig. 1. Diatom samples (51 in number) were taken in the littoral zone at a waterdepth of 30-40 cm, except for the shallower ponds, where samples were taken from the centre. For diatom analysis, the upper few mm of organic bottom detritus or, when lacking, the surficial sand, were sampled by pooling three equal volume subsamples taken randomly from an area of about 1 m2. The fact that sediment assemblages, containing both living diatoms and empty frustules, can represent a relatively long time-span is not a disadvantage for this kind of survey. Water samples (81 in number) were taken halfway down the water column. All the water-bodies were sampled simultaneously for diatoms and water in the winter of 1983-1984. A number of them were resampled for water analysis the next winter.

Diatom preparations were made by oxidizing part of the sampled material with H_20_2 and $KMnO_4$. Strewn mounts were made with phenol-pleurax resin (von Stosch 1974). 500 valves were counted per sample along random transects on the slides, using a Leitz Orthoplan microscope at x1250 magnification (DIC opties). Taxa not encountered in the counts were noted by further scanning of the slides. Identifications were based mainly on the literature cited by Van Dam (1984) and on Krammer & Lange-Bertalot (1986, 1988).

Conductivity and pH were measured in the field with a glass electrode (WTW VEL LF91 conductivity meter with automatic correction to 20°C, ORION pH-meter). Water samples were stored ovemight at 4°C and filtered through 0.45 µm membranes (MILLIPORE) prior to laboratory analysis. Bicarbonate was measured by titration of 50 ml with 0:01 N HCl to an end-point pH of 4.2. Other anions were analysed with a continuous flow autoanalyser (SKALAR). For cations and total P an I.C.A.P. emission spectrophotometer was used. The limited number of water analyses, representing only the period of highest water levels, is expected to indicate only the most striking differences between the water-bodies studied.

A classification of the diatom samples was obtained by a hierarchical cluster procedure based on a minimum variance strategy with Euclidean distance using the program KLUSTER80. Relative abondances of the taxa were transfonned as ln(x + 1). Only the 93 taxa occurring at least once within the counts were included in the analysis. The clusters were related to the winter 1983-1984 chemical data by means of a canonical correspondence analysis with the package CANOCO (Ter Braak 1987). In this analysis all data, except pH values, were transfonned logarithmically and sample scores were calculated as weighted mean species scores. Conductivity, Mg^{2+}, Na^+, ortho-PO_4, NO_2, and HCO_3 were omitted in the final analysis because of multicolinearity with other variables; all 93 taxa were used.

The evaluation of the assemblages is based on a classification developed by Van Dam & Mertens (1987, 1989) which considers 6 groups of diatoms found in moorland pools:

1. *Eunotia exi.gua* (Bréb.) Rabenh., a species resistant to extreme acidity and metal loadings.
2. "Trivia!" acid water taxa, found in most moderately acid, not too strongly polluted waters.
3. Target taxa – sensitive diatoms from meso-oligotrophic acid-neutral water, not tolerating extreme acidity, eutrophy or pollution and therefore becoming rarer.
4. *Achnanthes minutissima* Kütz., a widespread eurytopic diatom with a broad pH and trophic range, tolerating moderate pollution.
5. Eutraphentic taxa, occurring mainly in circumneutral to alkaline nutrient-rich water.
6. Disturbance indicators, related to severe organic pollution, metatrophic conditions or nonnally found in brackish water.

Higher frequences of eutraphentic taxa or disturbance indicators and extreme dominance of *Eunotia exigua* are considered negative attributes for heathland waters, whereas a high number and/or relative abondance of target taxa augments their conservational value. Assemblages dominated by trivia! diatoms (incl. *Achnanthes minutissima)* take an intennediate position.

RESULTS

Composition of the assemblages and relation to the environment

The cluster analysis on the diatom data separates 6 main sample groups (clusters A-F; Fig. 1). Table 1 lists the observed ranges and means of the chemica! parameters per diatom cluster, whereas Fig. 2 gives the position of the sample and selected species scores and the vectors of the chemica! parameters relative to the two first canonical correspondence axes.

Cluster A consists of only three samples (1-3) characterized by high proportions of *Eunotia exi.gua, E. rhomboidea* Hust. (incl. *E. tenella* (Grun.) Cleve *sensu* Hustedt) and *Frustulia rhomboides* (Ehrenb.) De Toni var. *saxonica* (Rabenh.) De Toni. The number of taxa per sample is relatively high ($\bar{x} = 34$). The samples are from pennanent less acid waters supporting *Juncus bulbosus* L., *J. effusus* L. and *Sphagnum lescurii* Sull. These waters are relatively rich in minerals, especially Ca^{2+}, and may have rather high bicarbonate concentrations. Similar diatom assemblages are well known from oligo-dystrophic lakes (J0rgensen 1948) and bogs of different wetnesses (Compère 1966, Niessen 1956). Wüthrich & Matthey (1978) described one, including *Navicula subtilissima* Cleve, from periodically emersed *Sphagnum cuspidatum* Hoffm. Compère (1966) found *Eunotia rhomboidea* mainly in dryer sphagna. According to Krammer & Lange-Bertalot (1991) this species is more characteristic of minerotrophic than of ombrotrophic bogs.

The B cluster (samples 4-19), is differentiated because of the pronounced dominance of *Eunotia exi.gua*. On average 23 taxa are found per sample. The accompanying taxa allow a subdivision of the cluster into two groups. In subcluster B1 (samples 4-15), *Eunotia exigua* attains 85-95% and occurs

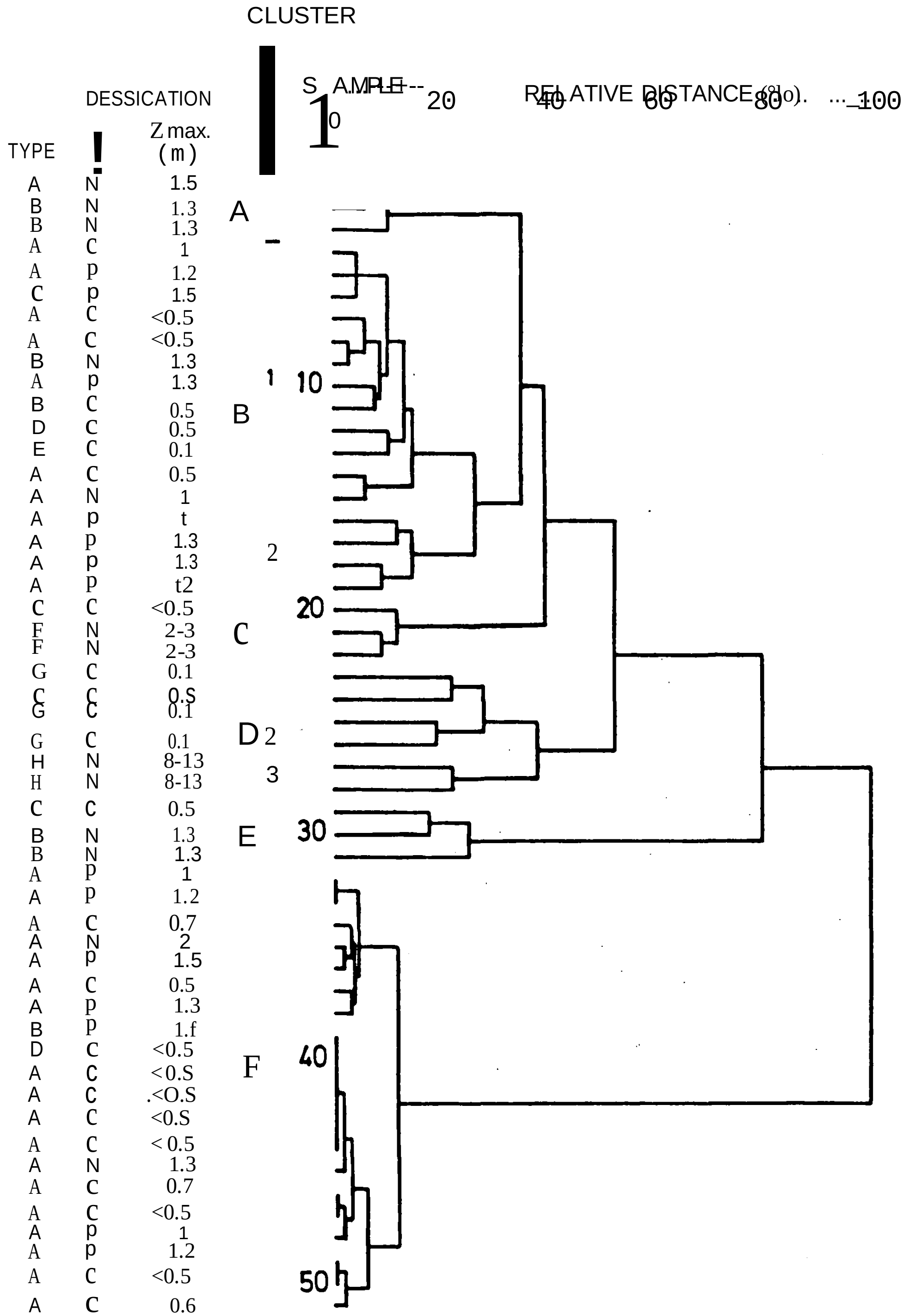

Fig. 1. Dendrogram resulting from cluster analysis of the diatom samples, with clusters A-F indicated (see text). Types: A = moorland pool, B = ditch, C = man-made pool, D = marshy pool, E = drainage rill, F = smaller sand pit, G = bog puddle, H = large sand pit Desiccation: N = negligible, C = completely, P = partly with sampling site falling dry. Zmax. = approximate maximum depth.

Table 1. Chemica! characteristics (mean value, minimum and maximum) of the investigated water-bodies (51 samples in winter 1983-84, 30 samples in winter 1984-1985).

	acidity pH	conductivity µS.cm-1	Al mgJ-1	Ca mg.I-1	total Fe mgJ-1	K mgJ-1	Mg mgJ-1	Na mgJ-1	total-P mgJ-1	Pb mgJ-1	Si mgJ-1	Zn mgJ-1	ammonium mgJ-1	sulphate mgJ-1	chloride mgJ-1	bicarbonate mgJ-1
Cluster A (N=5)																
mean	5.27	128.17	0.36	10.07	0.05	2.15	2.03	4.25	0.08	0	1.21	0.12	0.40	28.58	6.43	12.97
min.	4	64	0.01	2.94	0.01	0.87	0.49	2.11	0	0	0.02	O.ol	0.04	18.7	3.69	0
max.	6.7	200	1.3	24.28	0.09	2.69	3.17	5.37	0.41	O.Ql	2.64	0.33	1.32	34	8.9	67.1
Cluster B ili=26)																
mean	4.22	134.56	1.44	4.12	0.24	2.36	1.35	5.54	0.02	0.12	1.56	0.32	1.35	31.76	10.54	1.14
min.	3.7	55	0,07	1.85	0.04	1.06	0.68	3.29	0	0	0	0.01	O.Ql	11	6.59	0
max.	5.6	229	3.77	11.8	0.67	4.62	3.21	10.21	0.07	2.91	6.95	1.17	5.11	63	39.4	9.2
Cluster C (N=6)																
mean	4.20	96.50	1.26	3.27	0.07	2.10	0.94	3.68	0.03	0	0.09	0.09	0.16	23.67	7.87	0.47
min.	3.5	54	0.18	2.66	0.01	0.75	0.69	2.51	0	0	0	0.05	0.02	14.4	4.5	0
max.	4.8	114	2.45	4.21	0.11	3.55	1.33	4.47	0.06	0	0.2	0.14	0.38	34.8	10.2	1.8
Cluster D ili=l1l																
mean	4.78	168	1.40	9.14	0.56	3.18	2.29	7.18	0.02	0	4.26	0.10	0.16	46.80	10.62	5.26
min.	3.55	126	0.01	3.08	0	0.61	1.03	5.13	0	0	0.08	0.01	0.01	31.2	7.5	0
max.	6.4	233	5.2	15.5	4.26	14.77	2.81	8.78	0.05	0	6.8	0.39	0.31	66.9	15.8	19.5
Cluster E (N=4)																
mean	5.70	208	0.27	13.93	0.09	14.24	2.98	7.52	0.05	0	0.24	0.21	0.21	50.18	18.23	11.03
min.	5.4	169	0.05	10	0.03	9.97	2.32	6	0	0	0	0.02	0	27.2	15.4	5
max.	6	241	0.61	18.8	0.22	19.19	3.59	9.13	0.09	0.01	0.77	0.46	0.74	66	21.1	19.5
Cluster F ili=29)																
mean	3.83	185.17	2.73	4.82	0.49	3.19	1.63	6.37	0.02	0.01	1.61	0.52	1.89	36.26	12.05	0
min.	3.5	31	0.09	0.43	0.05	0.32	0.13	0.87	0	0	0.06	0.04	0.02	0	2.88	0
max.	4.3	454	11.5	23.14	3.07	16.9	4.8	14.97	0.05	0.22	7.28	3.18	10.8	91	36.11	0

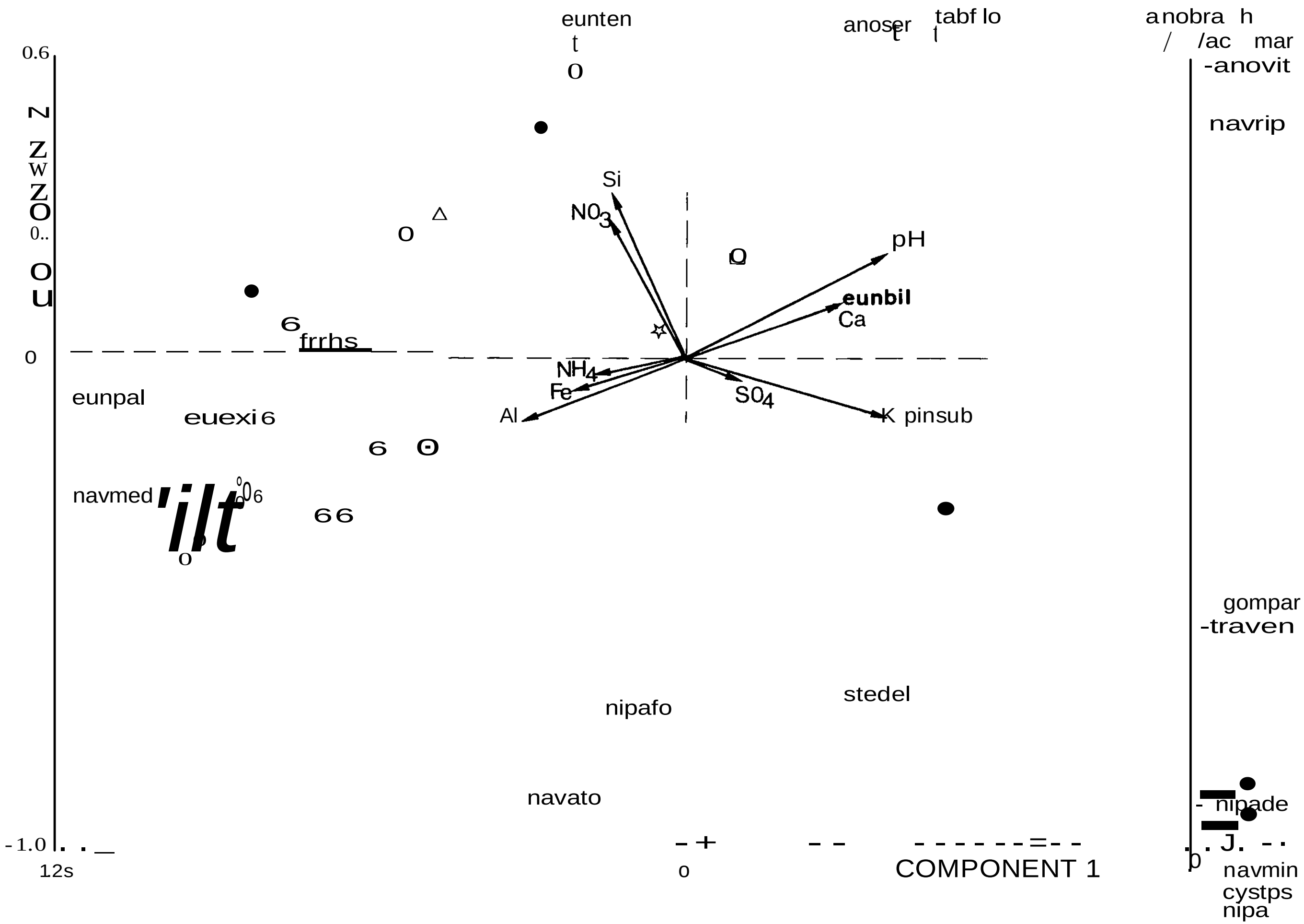

Fig. 2. CCA ordination plot of the first two axes (eigenvalues 0.57 and 0.40) with scores of samples (per cluster: A -k, Bl ll, B2 D, C A, D •. E e, F 0), selected taxa and direction of variation of selected chemical parameters; acronyms for taxa: ACHMAR *Achnanthes marginulata,* ANOBRA *Brachysira brebissonii,* ANOVIT *B. microcephala,* ANOSER *B. serians,* CYSTPS *Cyc/otella stelligera* var. *pseudostelligera,* EUNBIL *Eunotia bilunaris,* EUNEXI *E. exigua,* EUNPAL *E. paludosa,* EUNTEN *E. rhomboidea,* FRAVEN *Fragilaria construens* var. *venter,* FRRHS *Frustulia rhomboides* var. *saxonica,* GOMPAR *Gomphonema parvulum,* NAVATO *Navicula atomus,* NAVMED *N. mediocris,* NAVMIN *N. minima,* NAVRIP *N. riparia,* NIPA *Nitzschia palea,* NIPADE *N. palea* var. *debilis,* NIPAFO *N. paleaeformis,* PINS_UB *Pinnlaria subcapitata,* STEDEL *Stenopterobia delicatissima,* TABFLO *Tabellariafloccu osa.*

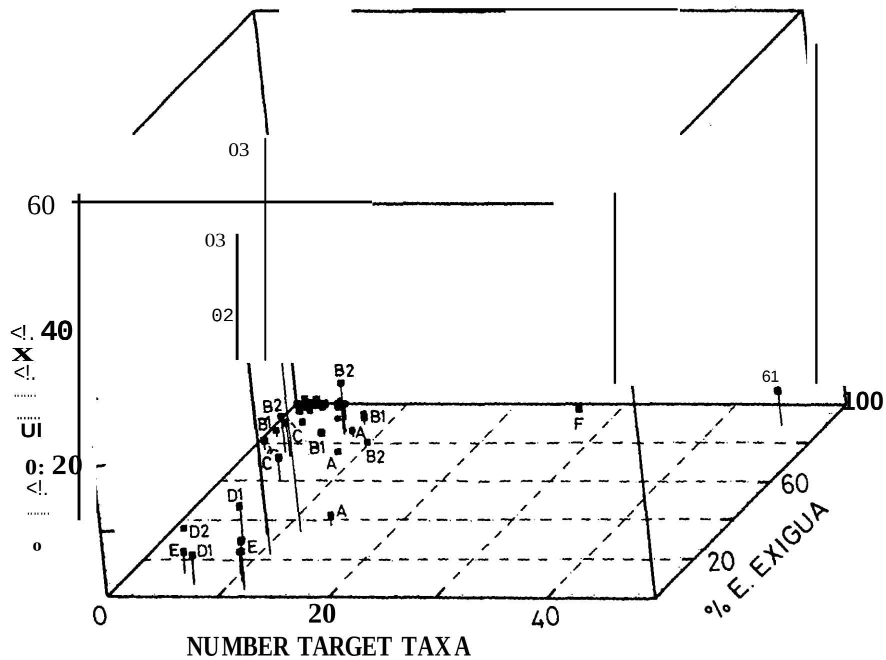

Fig. 3. Plot of the relati•• abundanee and nurober of target tai<• and the relati•• abUnd= of *Eunotia* exigua.

with reference to the diatom clusters.

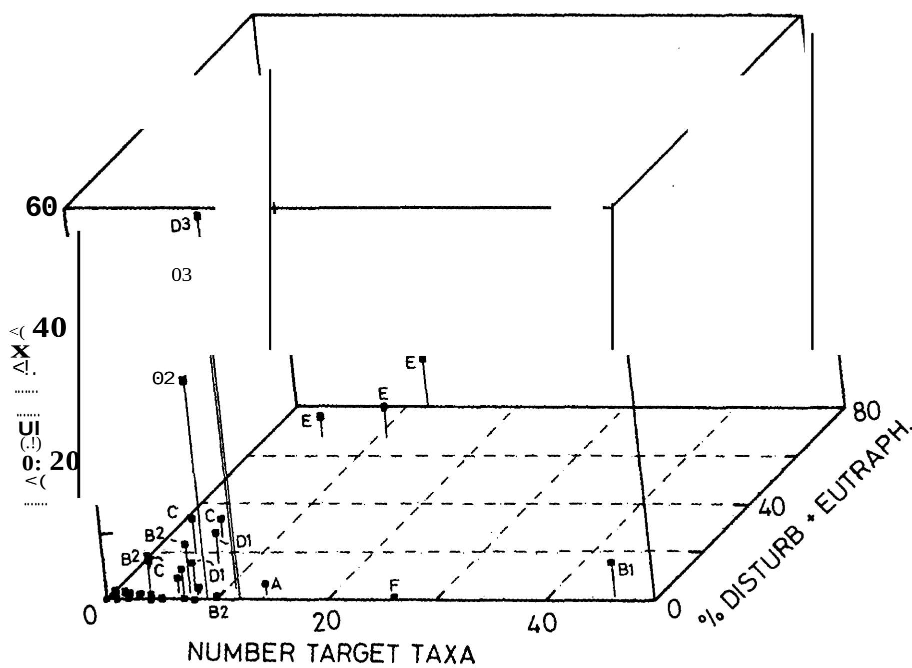

Fig. 4. Plot of the relati••abundanCO and nurober of tatll•I tai<• and the relati•• abundaJICO of euttaphentic t.aJ<• plus disnirbance indicatoIS. with reference to the diatom clusters.

Finally, from cluster B1, which otherwise only has a very low abondance and number of target taxa, one exception occurs: sample 25, which has no less than 46 target taxa, the highest number encountered. Tuis bog puddle is located next to a lowland streamlet which could slightly influence the water quality and thus cause its unique composition. Most of its water supply, however, comes from drainage from a bog situated on somewhat higher ground.

Only in two groups, Dl and A, do trivial diatoms from acid waters prevail. The abondance of *E. exigua* is not overwhelming, while indicators of enrichment are very rare. In some cases, the number of target taxa remains fairly high.

With increasing importance of *Eunotia exigua*, both target and trivial taxa tend to become scarcer, as in most B1 and B2 samples. Disturbance indicators and eutraphentic diatoms are equally scarce here.

Group C presents the highest abondance of disturbance indicators of all the clusters dominated by *Eunotia exigua*. This is mostly due to the proportion of *Nitzschia paleaeformis*, but in the counts *Navicula atomus* (Kütz.) Grun., *N. riparia* Rust. and *Fragilaria capucina* Desmaz. appeared with low abondances as well. On the other hand *Stenopterobia delicatissima* is a target species, which might occur here as a relic.

Most of the waters beloog to group F, which have little left except *Eunotia exigua*. The one species-rich sample does still contain a rather high number of target taxa. Surprisingly, it is a pool bordering pasture land and partly trampled by cows. Apparently the slight enrichment ensuing from this maintains diversity.

Group E represents the other, equally unwanted, extreme where the original microvegetation has disappeared through organic pollution and now a dominance of taxa from eutrophic and disturbed environments occurs.

DISCUSSION

Most of the waters studied are acid to extremely acid, very poorly buffered and poor in minerals, underlining the soil conditions and the infiltration characteristics of the study area. With their low pH and the presence of $S0^{4}+$ as the dominant anion, they agree fairly well with the extremely acid waters described by Vangenechten *et al.* (1981), although total ion concentrations and $SQ^{4}+$ loadings were somewhat lower in our studies. In general, higher conductivities and Ca2+ concentrations were measured than in waters of comparable pH elsewhere (e.g. Great Britain, Scandinavia). As expected, pH (down to 3.5) was negatively correlated with Af3+ (up to 11.5 mgJ-1; r = 0.59, all samples) and zn2+ concentrations (cf. Eider 1988). There was also a weak reverse correlation between acidity and sulphate content (r = 0.32), suggesting acidification by atmospheric deposition (Vangenechten 1980). Ammonium was the dominant nitrogen ion in the more acid waters. High ammonium concentrations in acidified waters result from deposition of ammonium sulphate combined with reduced nitrification (Arts & Van Leuven 1988, Schuurkes 1986). Some ditches and sand pits, however, were less acid and presented a relatively higher mineral content, suggesting some influence of ground water. Acidity and bicarbonate content were the most differentiating chemica! parameters in these waters.

As evidenced by the ordination results, the main ecological gradient (first axis) in our data is formed by pH and correlated parameters. A dense group of uniform samples is nested at one end of this gradient, corresponding to extremely acid conditions, and the heterogenous group E at the other. Even with slightly higher pH more diverse assemblages of various composition occur. A distinct second gradient, strongly influencing the occurrence of the so-called target taxa and disturbance indicators, appears to be active as well, but its interpretation in terms of water chemistry is not very evident from the present data set.

Although it is obvious that the pragmatic approach applied here to evaluate diatom assemblages for the management of heathland habitats can only give limited information about the overall

D ·

mostly together with *Frustulia rhomboides* var. *saxonica, Pinnularia subcapitata* Greg. and *Navicula mediocris* Krasske. Tuis assemblage, closely related to cluster F (cf. Fig. 2), is found in moorland pools and ditches, generally colonised by *Juncus bulbosus* and *Sphagnum cuspidatum.* Sites with permanent water and sites exhibiting seasonal drought are both included. Acidity, Al^{3+}, and Fe values are high. A very high lead concentration (2.9 mg.I-1) was measured in a pool within the range of a clay-pigeon shooting stand. In the ordination this cluster takes an intermediate position along the first axis between cluster F and the remaining samples. Subgroup B2 (samples 16-19) splits off through the higher abondance of *Eunotia bilunaris* (Ehrenb.) Mills (up to 16%) and/or *Tabellaria jlocculosa* (up to 6%), which might point to a somewhat higher degree of minerotrophy (Hosiaisluoma 1975). The ordination plot does not contradict this possibility. All sites are from moorland pools that dry out The heterogeneity of the group of waters gathered in cluster B also appears in the chemical data (Table l); both weakly buffered and very acid waters are included.

Group C comprises three samples (20-22) with low taxonomie diversity (19 taxa per sample). Like the group B samples, they are dominated by *Eunotia exigua*, but with a notable abundance of *Nitzschia paleaeformis* Hust. *(N. gandersheimiensis* Krasske s.l. in Denys 1985). The latter species is characteristic of nutrient-enriched, metatrophic, acid waters, often growing with *Sphagnum* (Krammer & Lange-Bertalot 1988, Van Dam & Mertens 1989). Accompanying taxa include *Pinnularia subcapitata* and the rare *Stenopterobia delicatissima* (Lewis) Van Heurck, which may reach 5%. The latter species is reported to thrive best in dystrophic mountain waters with a low to medium electrolyte content (Krammer & Lange-Bertalot 1988). The samples are from a rather shallow sandpit and a periodically dry pool. Chemically these waters are comparable with those of cluster B, but tend to have somewhat lower conductivities and calcium concentrations. Tuis cluster bas the most negative scores along the second ordination axis, underlining its special character.

The fifth cluster, D (samples 23-28), is the most heterogeneous of all. *Eunotia exigua* reaches only 35% at the most. Subgroup Dl (samples 23, 24) bas up to 50% *Eunotia bilunaris;* 23 and 24 taxa were noted in the two samples. Besides *E. exigua, E. rhomboidea* and *Pinnularia subcapitata* are also important. *Eunotia bilunaris,* and even more so *Pinnularia subcapitata,* are considered to be minerotraphentic by Hosiaisluoma (1975). *E. bilunaris* can be abundant in both permanent and periodic water-bodies (Germain 1936, Opdam *et al.* 1983). Both samples of subgroup Dl are from periodic pools with a macrophyte and moss vegetation indicating some enrichment *(Juncus effusus, Phragmites australis* (Cav.) Trin., *Drepanocladus jluitans* (Hedw.) Wamst). One pool harbours a large population of *Littorella unijlora* (L.) Aschers. Cluster D2 includes two samples (25, 26), with 22 and 6 taxa respectively, from small temporary puddles in a *Sphagnum* bog (S. *papillosum* Lindb., *S. cuspidatum, S. tenellum* (Brid.) Brid., *S. compactum* DC.) next to a lowland streamlet. Besides *Eunotia exigua* (about one-third of the assemblage), *Navicula mediocris, Eunotia paludosa* Grun. and *E. rhomboidea* are also abundant here. *Navicula mediocris* bas its optimal occurrence in oligosaprobic water containing humic acids and poor in electrolytes (Krammer & Lange-Bertalot 1986). It often lives subaerially (Krasske 1938, Hustedt 1961-1966), as generally does *Eunotia paludosa,* which often populates moist ombrotrophic mosses (De Vries 1984, Kingston 1982, Krammer & Lange-Bertalot 1991, Petersen 1950, Schlüter 1961). The last subgroup, D3 (samples 27-28) comprises samples from a large (24 ha), deep sand pit with a meso-oligotraphentic littoral vegetation of *Potamogeton polygonifolius* Pourr., *Scirpus fluitans* L., *Juncus bulbosus, J. effusus* and *Sphagnum lescurii.* The assemblage consists of 22-33% *Eunotia exigua,* 6-25% *E. rhomboidea* and 7-47% *Brachysira brebissonii* Ross. Other taxa of quantitative importance include *Brachysira microcephala* (Grun.) Compère, *B. serians* (Bréb.) Round & Mann, *Tabel/aria jlocculosa* and *Achnanthes marginulata* Grun. The diversity (28-38 taxa per sample) is fairly high. Cluster D comprises waters that are chemically comparable to those of groups B and C, but which tend to be less acid and somewhat richer in minerals and bicarbonate. In the ordination D samples are scattered throughout, except in the range of clusters C and E, emphasizing its heterogeneity.

In cluster E (samples 29-31) *Navicula minima* Grun. dominates (20-40%), whereas *Nitzschia palea* (Kütz.) W. Smith var. *debilis* (Kütz.) Grun. reaches 8 to 19%. The species diversity is rather high (40-62 taxa per sample). *Navicula minima* is prolific in meso- to polysaprobic conditions (Krammer & Lange-Bertalot 1986), as in polluted moorland pools (Van Dam 1982). This is also the case for *Nitzschia palea*. *Nitzschia palea* var. *debilis* is considered to live in oligotrophic mineral-poor waters, according to Krammer & Lange-Bertalot (1988), who alsè> .note that they can occur in great abondance in the mucilage sheaths of green algae. Our observations do not fully agree with this and we consider them as disturbance indicators. Various other taxa indicating nutrient-enriched conditions attain considerable abondance (e.g. *Cyclotella stelligera* (Cleve & Grun.) Van Heurck var. *pseudostelligera* (Host.) Haworth & Hurley, *Gomphonema parvulum* (Kütz.) Grun., *Fragilaria construens* (Ehrenb.) Grun. var. *venter* (Ehrenb.) Grun.). At most 13% of *Eunotia exi.gua* was noted. The samples were taken from a ditch and a pool with eutraphentic vegetation *(Drepanocladus fluitans, Juncus effusus, Alisma plantago-aquatica* L., *Lycopus europaeus* L., *Lemna minor* L.) and abundant decaying plant litter on the bottom. Por the ditch it is known that illegal dumping of liquid manure has taken place and this is reflected in the relatively high conductivity and pH, and in the elevated concentrations of K^+, Ca^{2+} and Cl^-. Cluster E shows the most positive correlation with the first axis and diverges strongly from the other samples.

The last and largest cluster, F (samples 32-51) shows an extreme dominance of *Eunotia exi.gua* (95-100%) and generally a very low number of taxa (2-18; one sample has 53 taxa, while the mean is 13). All samples are from moorland pools, permanent as well as periodic, nearly always with abundant *Juncus bulbosus* and *Sphagnum cuspidatum*. In one-fifth of the pools *Eriophorum angustifolium* Honck. and *Sphagnum lescurii* are encountered. The waters within this cluster are extremely acid (pH < 4.3) and have no bicarbonate left Al^{3+}, Fe and Zn^{2+} loadings are generally high to very high, which may result from leaching of soil particles at very low pH. As with group B, some show elevated NH_4^+ levels. In the ordination the F samples form a compact cluster at the most negative extreme of the first axis, illustrating its relation to pH and metal concentrations. *E. exi.gua* is known to reach a 100% dominance especially at a pH below 4.5 (Ter Braak & Van Dam 1989). It can live either in extremely mineral-poor or in mineral-rich water and tolerates very high metal loadings (Besch *et al.* 1972, Hargreaves *ei al.* 1975). Van Dam *et al.* (1981) found its abondance in moorland pools to be closely related to the sulphate concentration (especially relative to other ions). Although often dominating assemblages from *Sphagnum* (cf. Denys & Beyens 1987), it will flourish in other bog types as well (e.g. Scherer 1988). Bruno & Lowe (1980) consider it to be more dependent on substrate than on particular water chemistries. Kingston (1982) reports it to have the same distribution as *E. paludosa*.

Evaluation of conservation value

Plots of the samples, considering the number and abondance of target taxa, the frequence of *Eunotia exi.gua* and the sum of indicators of disturbance or eutrophy, along with their correspondence to the clusters, are given in Figs 3-4.

Even a glance will show that only a few samples contain a high proportion or even a large number of target taxa. Cluster 03, from the large sandpit (not a natural heathland biotope!) stands out because of the dominance of this group. Although a rather polluted streamlet drains into the pit, this seems to have little adverse effect on the assemblage composition at some distance from the inflow, where the samples were taken. One of the samples from the 02 bog assemblage also contains a remarkable abondance of target taxa (33%), mostly *Navicula mediocris*. It should be noted that although the vegetation of the bog shows that it is influenced somewhat by seepage from an adjacent lowland streamlet (the stand of *Phragmites* growing next to the stream gradually thins out further away from it), no indications of disturbance or nutrient enrichment are apparent from the diatom assemblages.

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biologica! value of the waters investigated, a clear pattem emerges which could be used to monitor future developments. From the present data it appears that few of the waters have suffered from severe eutrophication or disturbance, and these are situated at accessible sites near the margins of the study areas. A more severe problem is indicated by the remarkably monotonous microvegetation of most of the pools, viz. the extreme dominance of *Eunotia exigua.* Van Dam & Kooyman- Van Blokland (1978), Van Dam *et al.* (1981) and Van Dam (1987a, b) have demonstrated that, since the beginning of this century, the abondances of *Eunotia bilunaris, Frustulia rhomboides* var. *saxonica* and *Navicula subtillisima,* among others, have decreased in Dutch moorland pools with a low humic content, while *Eunotia exi.gua* has increased dramatically. High relative abondances of the first three would point to a non-acidified state and dominance of *Eunotia exigua* would indicate acidification. Van Dam & Beljaars (1984) observed a considerable increase of acidobiontic diatoms in a comparison of recent and older (1935-1950) samples from 10 Belgian moorland waters. In the Campine region (Turnhout) this results from a replacement of mainly *Eunotia bilunaris, E. incisa* Greg., *E. paludosa* and *Frustulia rhomboides* var. *saxonica* by *Eunotia exigua* after 1935 (H. Van Dam, personal communication 1989). Beyens (1984) attributed the replacement of *Frustulia rhomboides* var. *saxonica* and *Eunotia bilunaris* by *E. exigua* and *E. tenella* in the most recent peat deposits of a moorland pool at Ipenrooi (some 25 km NE of Brasschaat) to acid precipitation. Vangenechten (1980) argues for a considerable acidification of certain moorland pools in the Belgian Campine, on basis of water chemistry. It is tempting to interpret our data in this sense, viz. the overwhelming importance of *Eunotia exi.gua* in a large majority of the studied water-bodies, in contrast to the generally low abondance of more acid-sensitive taxa. Noteworthy in this respect is the complete absence of *Navicula subtillissima,* a common bog diatom in many other regions, where it often occurs with *Eunotia exigua* and *Frustulia rhomboides* var. *saxonica* (Hosiaisluoma 1975, Hustedt 1961-1966, Walker & Paterson 1986, Wüthrich & Matthey 1978). It remains unknown whether intensive acidification has occurred recently or whether the water-bodies studied became extremely acid long ago. If acidification is still taking place and further biological impoverishment is to be prevented, careful counter-measures will be necessary. Arts & Leuven (1988) and Arts *et al.* (1989) have demonstrated that hydrologically isolated moorland pools are very sensitive to acidification. It is therefore not surprising that the sensitive meso-oligotrophic assemblages less resistant to acidity (especially cluster D3) and certain taxa seem to be restricted to deeper water-bodies, which are in contact with the slightly more mineral-rich aquifers at depth. Sites that appear to be influenced somewhat by seepage water from streamlets have also retained a less trivial diatom vegetation. Tuis may indicate more promising ways of management for acidified heathland waters than direct timing, which seems to have unwanted effects such as development of opportunistic species (especially *Achnanthes minutissima)* and disturbance indicators and, at least in the short term, seems to be of limited value for restoring the pre-acidification flora (Round 1990, Van Dam & Mertens 1987, Van Dam *et al.* 1989). For the present, management should aim at conserving the remaining refugia for sensitive soft-water diatoms and other organisms by ensuring their hydrological regime and preventing eutrophication.

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