CHAPTER 17

Typology of macrofaunal assemblages applied to water and nature management: a Dutch approach

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Summary

Multivariate analysis of an extensive dataset based on the macroinvertebrate fauna of surface waters in the province of Overijssel (The Netherlands) has resulted in the description of 42 site groups. These include springs, streams, rivers, canals, ditches, pools and lakes. The site groups are recognised on the basis of environmental variables and the abundance of organisms. For each group only a recognisable centroid and a limited range of variation is given; no clear boundaries are described between the groups. These site groups and their environment are defined as cenotypes.

The cenotypes are mutually related in terms of key factors which represent major ecological processes. The cenotypes and their mutual relationships form a web which offers an ecological basis for the daily practice of water and nature management. The web allows the development of water quality objectives, provides a tool for monitoring and assessment, indicates targets and guides the management and restoration of waterbodies.

The web is included in a software package named EKOO. The main modules in this package are (1) the assignment of a newly sampled site to one of the cenotypes, (2) the characterisation of a new sample in terms of diversity and biotic features, and (3) the option to choose a target for a newly sampled site and to establish a set of measures to reach this target.

Introduction

In a densely populated area such as The Netherlands, where human activities strongly affect the surroundings, there is great concern over conservation of the aquatic biota, all of which contribute to the scientific, aesthetic, recreational and sometimes commercial values of the landscape (Armitage & Petts 1992). The lack of information on the biological effects of human activities on aquatic biota led, in the 1970s, to the development of biological water quality assessment systems in The Netherlands (Moller-Pillot 1971; De Lange & De Ruiter 1977). As in other regions, initially the assessment of pollution (usually organic) was the main goal (Hellawell 1978). In the 1980s, more attention was focused on the entire environment, including all physical, chemical and biological conditions (Wright, Moss *et al.* 1984; Verdonschot 1990), in order to provide assessment with an ecological perspective.

Biological communities are well adapted to the environment in which they live and are sensitive to changes in this environment (Odum 1971). To apply community ecology in water management and nature conservation, one needs to relate biological communities to ranges in environmental conditions (Pennak 1971; Hawkes 1975). Historically, biological communities

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have been considered as classes comprising discrete groups of species (Tansley 1920), as a continuous gradient along which species merge into each other (Whittaker 1978), or as types in which species groups are identified by an "average" state (nucleus or centroid) but which merge into each other (Tuxen 1955).

An ecological approach to water and nature management should combine the pragmatic part of distinguishing classes with the realism of gradients in our environment (Macan 1961; Hawkes 1975). The typological approach meets this requirement to a certain extent. In an ecological typology, communities are described as nuclei/centroids without mutual boundaries. Each type shows a certain range of biotic variation and a certain range of environmental conditions. Furthermore, types grade into one another. Thus, types are seen as loci in a field of variation.

This chapter summarises the development of an ecological typology of surface waters based on a large regional-scale survey of aquatic environments in The Netherlands. The typology is based on the macroinvertebrate fauna as the main structural parameter. A number of arguments for and against the use of macroinvertebrates as indicator species are given, amongst others, by Wright, Armitage *et al.* (1985), Armitage *et al.* (1992) and Rosenberg & Resh (1993b).

Instead of looking at separate species, the study focused on assemblages of species, because they integrate the responses of individual species to the multiple and complex biotic and abiotic environment, and they are more robust and constant than individual species, which are not always present (temporal segregation, stochastic occurrence, contagious distribution).

Data collection and analysis: building a typology

Collection of samples

Samples were collected from 664 sites situated in the province of Overijssel (The Netherlands); 609 sites were visited in one season only and 55 sites were visited in two seasons. The sampling dates were spread over the four seasons as well as over several years (from 1981 to 1985, inclusive). For logistic reasons it was impossible to take all samples in the same season or to sample a site in more than one or two seasons. This is one of the disadvantages of extensive survey studies (Wiens 1981). "Noise" in the dataset, resulting from seasonal factors, can affect the results. Osborne *et al.* (1980) and Furse, Moss *et al.* (1984) argued that even though multiseason sampling is preferable, single season sampling (especially when all sites are sampled in the same season) is justified for certain purposes. Verdonschot (1990) demonstrated that seasonal differences as well as inconsistencies due to sampling technique and sampling frequency were of little significance compared to differences in water types. In this study, sampling effort was standardised for each site. Season was taken into account by defining sampling periods as nominal "environmental" variables within the analysis.

The objective was to capture the majority of species present at a given site, and assess their relative abundances. At each site, major habitats were selected over a 10 to 30 m long stretch of the waterbody and were sampled with the same sampling effort. At shallow sites, habitats with vegetation were sampled by sweeping a pondnet (20x30 cm, mesh size 0.5 mm) through each vegetation type, several times over a length of 0.5 to 1 m. Bottom habitats were sampled by vigorously pushing the pondnet through the upper few centimetres of each type of substratum, over a length of 0.5 to 1 m. The habitat samples were then combined for the site to give a single sample with a standard area of 1.5 m^2 (1.2 m^2 of vegetation and 0.3 m^2 of bottom). At sites lacking vegetation, the standard sampling was confined to the bottom habitats. At deeper sites, five samples from the bottom habitats were taken with an Ekman-Birge sampler. These five grab-samples were equivalent to one 0.5 m pondnet bottom sample. Habitats with vegetation were sampled with a pondnet as described above. Again the total sampling area was

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standardised as 1.5 m^2. Verdonschot (1990) showed that this sampling effort met the requirements for constructing a regional water typology. Macroinvertebrate samples were taken to the laboratory, sorted by eye, counted and identified to species level.

A datasheet was used to note a number of abiotic and some biotic variables in the field. Some were measured directly (width, depth, surface area, temperature, transparency, percentage of vegetation cover, percentage of sampled habitat), others (such as regulation, substratum, bank shape) were classified. Field instruments were used to measure oxygen, electrical conductivity, stream velocity and pH. Surface water samples were taken to determine chemical variables. Other parameters, like land use, bottom composition and distance from source, were gathered from additional sources (data from Water Boards and maps). In total, 70 abiotic variables were measured at each site.

Multivariate analysis

Data processing consisted of the following five main steps: (1) preprocessing of data, (2) clustering, (3) ordination and re-ordination, (4) rearrangement, recognition and removal of sites, (5) post processing of data (Fig. 17.1).

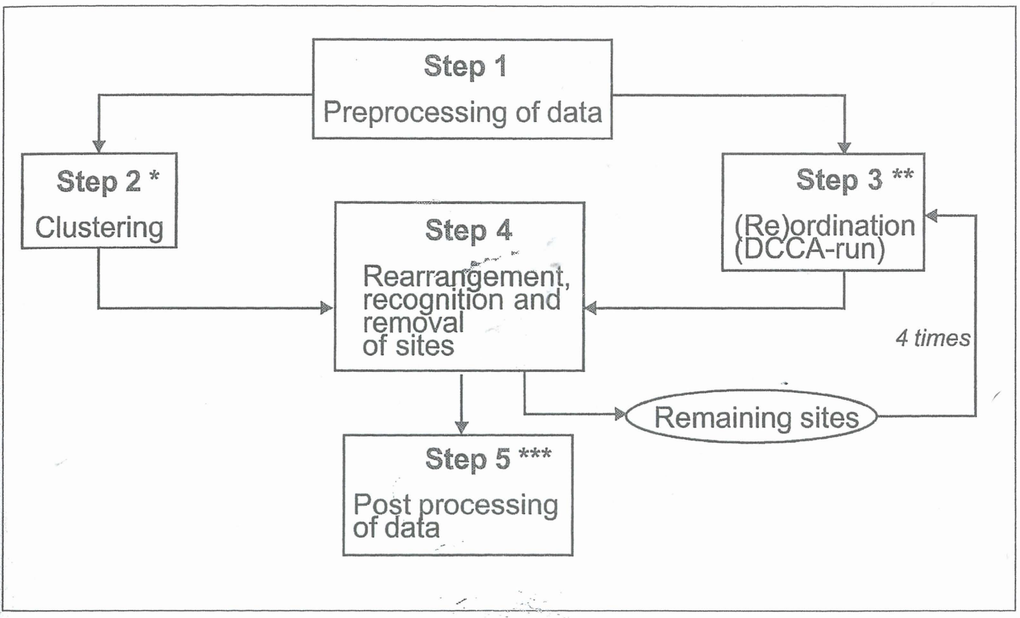

Figure 17.1. Flow-diagram of data processing used for classifying macroinvertebrates into cenotypes in the surface waters of The Netherlands (computer programs used were: FLEXCLUS*, CANOCO** and NODES*** – see the text).

Step (1). The study revealed 853 invertebrate taxa. The macroinvertebrate abundances were transformed into logarithmic classes (Preston 1962; Van der Maarel 1979). Quantitative environmental variables, except pH, were log-transformed because of skewed distributions. All other variables were nominal and dealt with by defining so-called dummy variables.

Step (2). The sites were clustered, based on the macroinvertebrate dataset, by means of the program FLEXCLUS (Van Tongeren 1986), an agglomerative clustering technique. The clustering strategy of FLEXCLUS is based on an initial, non-hierarchical, single linkage clustering, following the algorithm of Sørensen for a site-by-site matrix based on the similarity ratio. This initial clustering is optimised by relocative centroid sorting. Sites are relocated as follows. Each site is compared with each cluster (as it was before relocation of any site) and, if necessary, moved to the cluster to which its resemblance is highest. Before a site is compared with its own cluster, the site is removed from that cluster and the new cluster centroid is computed.

Clusters were accepted if they met a certain homogeneity (>0.4). The homogeneity of a cluster was defined as the average resemblance of its members (based on the similarity ratio) to its centroid.

The resulting clusters were further examined by comparing taxon composition and environmental variables of the sites within a given cluster. Based on biotic and abiotic similarities, in some exceptional cases clusters were divided or fused and/or sites were assigned to other clusters or set apart. The clustering finally resulted in macroinvertebrate site clusters.

Step (3). The sites were ordinated by detrended canonical correspondence analysis (DCCA), using the program CANOCO (Ter Braak 1986, 1987), an ordination (reciprocal averaging) technique which results in an ordination diagram. DCCA is an integration of regression and ordination and shows the response of taxa and sites to environmental variables (Jongman *et al.* 1987). Detrending by fourth-order polynomials was used. These techniques are fully explained by Ter Braak & Verdonschot (1995).

Step (4). Both the results of clustering (step 2) and (re-)ordination (step 3) were combined in ordination diagrams and used to establish site groups. The macroinvertebrate site clusters were projected on to the DCCA ordination diagrams of the first two axes, and sites that caused an overlap of clusters within a diagram were further examined as follows.

Firstly, spatial separation in the third and sometimes the fourth ordination axes were examined. If sites were clearly projected into one of the clusters they were assigned to that cluster. Secondly, comparisons were made of the characteristic and indicative taxa, and also the environmental variables of the site, in relation to the overall composition of characteristic and indicative taxa and ranges of important environmental variables for each of the overlapping clusters. Based on biotic similarity and abiotic correspondence, sites were either assigned to the most similar cluster (>50% identical taxa and all values within the range of the cluster) or set apart.

A site group (cenotype) is established if it is clearly recognisable along an identified environmental gradient and has a distinct macroinvertebrate fauna. Each site group in a diagram is represented by a centroid (indicated by an asterisk) and surrounded by a 90% confidence region (an ellipse) for the mean of the site scores of that group. A contour line around a centroid indicates the total variation of all site scores within the group (for these diagrams see Verdonschot 1990). In addition, groups that show no – or very limited – overlap with other groups and are positioned at the ends of the identified environmental gradients in the diagram, are identified as "cenotypes".

Two techniques were used to select the environmental variables with the highest explanatory power. In the option "forward selection" of CANOCO (version 3.0), the program indicates how well each individual environmental variable "explains" the variation in the species data. First, the program selects the variable with the highest explanatory power. Then it produces a list of how much each variable would contribute extra if that variable was added to the one previously selected. At each addition of a variable, the significance of the contribution of the variable is tested by a Monte Carlo permutation test. This selection is stopped at $p < 0.10$. Additional explanatory environmental variables were selected on the basis of the inter-set correlation

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(correlation >0.3) with the axes, i.e. the correlation between a variable and an ordination axis. Both options were applied in each of the (re-)ordinations. All variables selected by these two techniques were used to describe the environment of the cenotypes and were represented in the ordination diagrams. An environmental variable (indicated as an arrow) points in the direction of steepest increase of that variable, and the rate of change is represented by the length of the arrow. This means that the value of an important environmental variable, to a cenotype, is visualised by its perpendicular projection on the environmental arrow or its imaginary extension (in both directions).

When groups of sites (cenotypes) were identified along environmental gradients, and thus a continuum was partitioned, the remaining sites were subsequently re-ordinated. In this way, the impact of the originally observed variable(s) was greatly reduced. This strategy was developed by Peet (1980). After five ordinations all sites were assigned to distinctive groups. The combination of steps (2), (3) and (4) indicate the iterative nature of the analysis.

Step (5). Ordering and weighting of taxa was done by the NODES program (Verdonschot 1990). The cenotypes were used as input. In NODES the typifying weight of a taxon is calculated per cenotype by combining the formulae of constancy, fidelity and concentration of abundance (Boesch 1977; Verdonschot 1984). Taxa were ordered in a taxon-site group matrix according to their typifying weight. Small groups of sites, often composed of aberrant sampling sites (outliers), were excluded from the process of weighting.

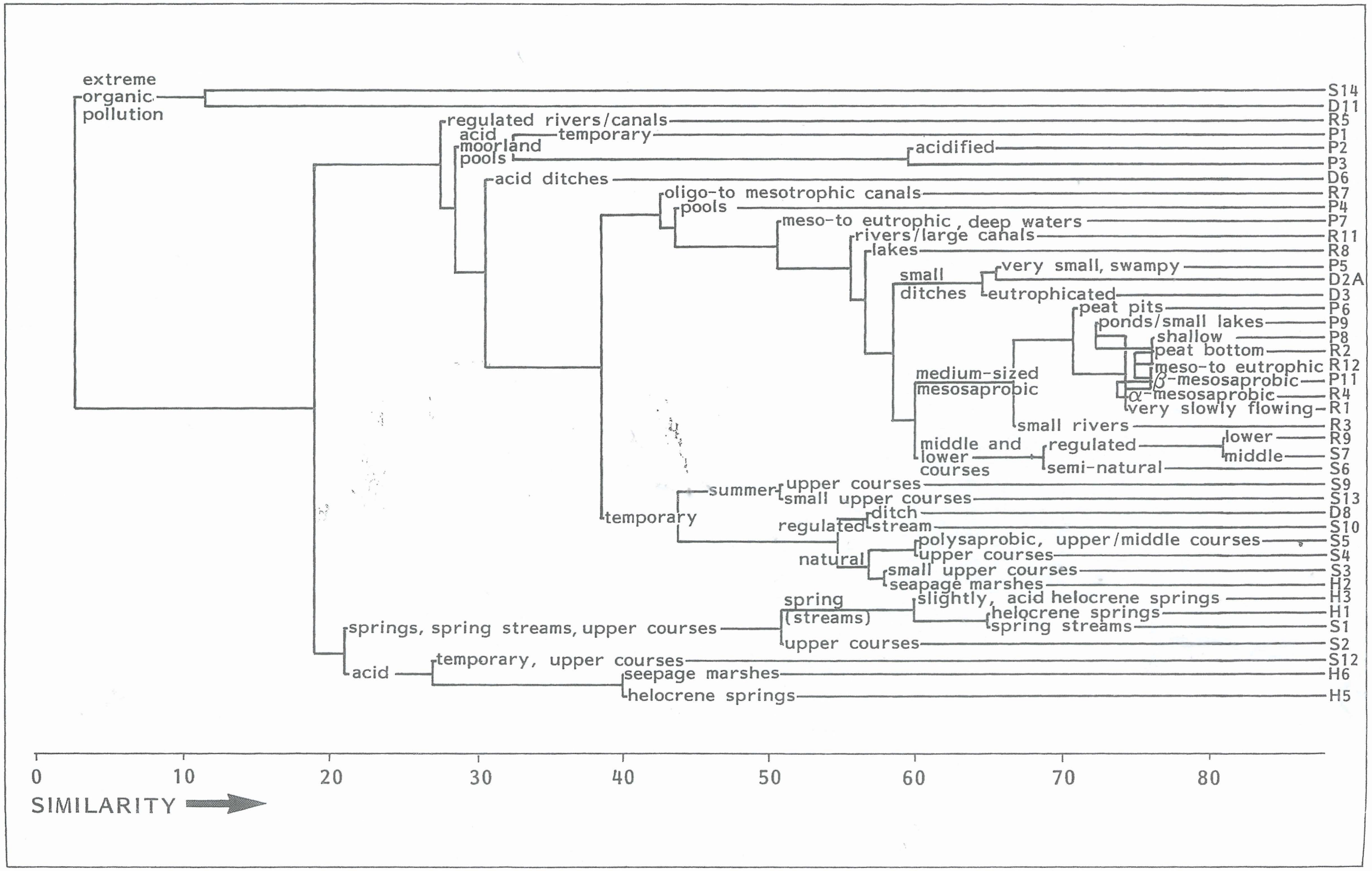
The numbers of sites, averages and standard deviations of the quantitative environmental variables, and the relative frequency of the nominal variables per cenotype, were calculated by means of the clustering program FLEXCLUS (Van Tongeren 1986).

Results: a web of cenotypes

The results of clustering (FLEXCLUS) are shown in a hierarchical dendrogram to illustrate the biological similarity between cenotypes (Fig. 17.2). The cenotypes R1, R4, P11, R12, R2 and P8 are quite similar to each other but they differ markedly from the types H5 and H6, which are also completely different from each other (Fig. 17.2). In this way the similarity and differences between all cenotypes can be extracted from this text-figure. In the dendrogram, at the different divisions, the most important variables or complexes of variables related to that division are indicated. Figure 17.3 presents short descriptions of the cenotypes.

In total, five (re-)ordinations were necessary to analyse the entire dataset. Partial results of these analyses are published by Verdonschot & Schot (1987) and Verdonschot (1992a, 1992b, 1992c, 1995). All five ordinations were tested. The first four appeared significant at the 1% level. The fifth run was only significant at the 9% level. By using direct gradient analysis the environmental factors were related to the site groups in two-dimensional space. In fact, species–environmental relationships are multi-dimensional, but here the major patterns are reflected in a two-dimensional diagram.

The graphical result of the first run of the DCCA, i.e. axes 1 and 2, is used as a basis for illustrating the mutual relationships between the cenotypes (Fig. 17.4). The diagram provides a web, which is an integrated description of the cenotypes (based on taxon composition and abundances) versus environmental factors that represent major ecological processes. The contour line indicates the variation in faunal composition and environmental conditions present between the sites. All sites together form a continuum, but the macroinvertebrate site groups are represented as the centroids of the cenotypes (circles with codes) arranged along environmental gradients. Four major key factors, "stream character", acidity, duration of drought and dimensions, represent the environmental gradients that run through the whole diagram (see the inset on Fig. 17.4). Additional significant environmental relations between the


extreme organic pollution
regulated rivers/canals
acid moorland pools
temporary
acidified
acid ditches
oligo-to mesotrophic canals
pools
meso-to eutrophic , deep waters
rivers/large canals
lakes
small ditches
very small, swampy
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ponds/small lakes
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Figure 17.2 (*on facing page*). Hierarchical dendrogram of cenotypes found in the surface waters of Overijssel, with factors responsible for the divisions indicated. Codes of cenotypes are explained below in Figure 17.3

Ceno-type	Characterization
Helocrene springs	
H1	oligo- to β-mesosaprobic helocrene springs
H2	temporary or desiccating, neutral to slightly acid, β-mesosaprobic seepage marshes
H3	neutral to slightly acid, oligo- to β-mesosaprobic helocrene springs
H5	slightly acid, oligo- to β-mesosaprobic, oligo-ionic helocrene springs
H6	temporary, acid, oligo-ionic, oligo- to β-mesosaprobic seepage marshes
Streams	
S1	oligo- to β-mesosaprobic spring streams
S2	permanent, rainwater-fed, β-mesosaprobic upper reaches of natural streams
S3	temporary, α-mesosaprobic, small upper reaches of natural streams
S4	temporary, β-mesosaprobic upper reaches of natural streams
S5	polysaprobic upper and middle reaches of natural and regulated streams
S6	α-mesosaprobic middle reaches of semi-natural streams
S7	α-mesosaprobic middle reaches of regulated streams
S9	the summer aspect with α-meso- to polysaprobic conditions of temporary upper reaches of natural streams or temporary, α-meso- to polysaprobic regulated streams
S10	temporary, α-mesosaprobic, flowing upper reaches of regulated streams or ditches
S12	temporary, slightly acid, α-mesosaprobic upper reaches of regulated streams or ditches
S13	the summer aspect with α-mesosaprobic conditions of temporary, small upper reaches of natural streams
Ditches	
D2A	permanent, β-meso- to α-mesosaprobic, small, shallow ditches
D3	permanent, α-mesosaprobic, shallow, small ditches or stagnant regulated streams
D6	acid, oligo-ionic, α-mesosaprobic to polysaprobic small ditches
D8	temporary, very slightly flowing, α-meso-ionic, α-mesosaprobic small ditches
Rivers and canals	
R1	β-meso- to α-mesosaprobic, medium-sized to large very slowly flowing lower courses of streams and rivers
R2	β-meso- to α-mesosaprobic, large ditches and small canals on a minerotrophic peat bottom
R3	α-mesosaprobic, medium-sized, slightly meandering, slowly flowing small rivers
R4	α-meso-ionic, β-meso- to α-mesosaprobic, linear shaped small to medium-sized waters
R5	α-mesosaprobic, fairly large regulated rivers or stagnant canals
R7	oligo- to β-mesosaprobic, medium to fairly large stagnant canals
R8	β-mesosaprobic, α-meso-ionic, very large, round to irregularly shaped lakes
R9	α-meso-ionic, α-mesosaprobic lower reaches of regulated streams or slightly flowing very small rivers
R11	β-meso- to α-mesosaprobic, α-meso-ionic, mesotrophic, large, linear, slightly flowing rivers or stagnant waters
R12	β-meso- to α-mesosaprobic, meso- to eutrophic, large, less deep stagnant waters
Pools and lakes	
P1	temporary, acidified, oligo-ionic, α-meso- to polysaprobic, mesotrophic moorland pools
P2	permanent, acid to acidified, oligo-ionic, α-mesosaprobic to polysaprobic, mesotrophic moorland pools
P3	permanent, slightly acid to acid, oligo-ionic, α-mesosaprobic pools
P4	slightly acid to neutral, α-mesosaprobic, vegetation-rich, small, shallow pools
P5	permanent, α-mesosaprobic, eutrophic, very shallow (swampy), small ditches
P6	clear, well oxygenated, β-mesosapobic, meso- to eutrophic waters (peat pits) with a rich vegetation on a minerotrophic peat bottom
P7	β-mesosaprobic, clear, well oxygenated, meso- to eutrophic, medium-sized, deep stagnant waters rich in vegetation
P8	β-meso- to α-mesosaprobic, medium-sized, stagnant shallow waters
P9	α-mesosaprobic, fairly large ponds or small lakes
P11	β-mesosaprobic, medium-sized, deep stagnant waters

Figure 17.3. Characterisation of the site groups (cenotypes) found in the surface waters of Overijssel. Note: cenotypes S14 and D11, which suffer from extreme organic pollution, have been omitted.

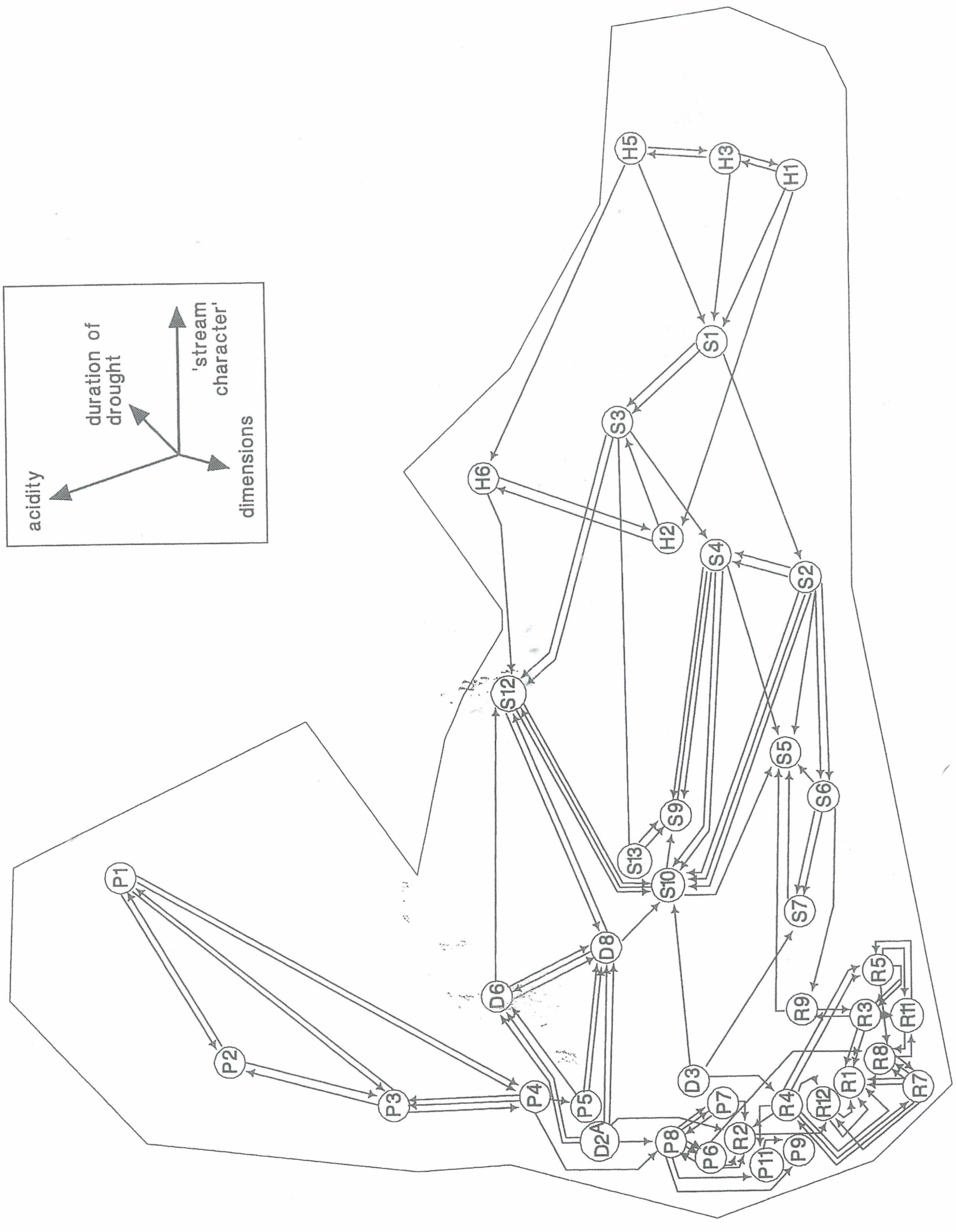

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Figure 17.4 (*on facing page*). The web of cenotypes in the surface waters of Overijssel. The contour line describes the total variation present in all site scores. The centroid of each cenotype is indicated by a site group code (Fig. 17.3). The arrows between cenotypes indicate the most important environmental relations (see Figure 11.1 in Verdonschot (1990) for further details). The inset represents the four most important environmental gradients (key factors) in the total dataset. For further explanation see the text.

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cenotypes have also been extracted from the environmental characterisation of the cenotypes (for further information see Appendix 2 in Verdonschot 1990). The spatial configuration of cenotypes in Figure 17.4 more or less corresponds to their ecological similarity.

The two most aberrant cenotypes are S14 and D11 (Fig. 17.2). Both types consist of only one extremely organically polluted site, which is reflected in the absence of almost all taxa. The few taxa that are present differ between these two types, and this explains their mutual dissimilarity. Both types were ignored in the ordination as they were outliers.

On the right-hand side of Figure 17.4, the most dissimilar cenotypes were helocrene springs and small streams (spring streams and small upper courses; all indicated respectively by the letter H or S1 to S4). These types were also identified by cluster analysis. They represent an environment inhabited by a characteristic macroinvertebrate fauna, clearly distinct from that of the other water types. All of these sites are situated on the steepest slopes of ice-pushed hill ridges. Their characteristic fauna is probably preserved by this natural physical protection (steep hill ridges) against environmental disturbances mainly caused by agricultural activities.

Further left in Figure 17.4 the cenotypes coded S5 to S13, and R9 and R3, represent larger running waters (middle reaches of streams to rivers). Thus, there is a gradient along the first axis from springs towards rivers, from the right towards the left side of the diagram.

The cenotypes at the top of Figure 17.4 include some acid waters, particularly moorland pools, as indicated by the codes P1 to P4. The upper one is most acidified, whereas P4 is a group of less acid pools. Macroinvertebrate fauna composition in these pools resembles the fauna composition in mesotrophic ditches (like D2A). Lakes (e.g. P8) occur below the pools.

The remaining groups to the left of Figure 17.4 can be separated into temporary versus permanent and running versus stagnant types. The polysaprobic upper and middle reaches of streams such as S5 appear to be similar to temporary upper reaches (i.e. D8 and S10), which can be seen in Figures 17.2 and 17.4. Both desiccation and extreme organic enrichment have, to a certain extent, a corresponding effect upon the fauna.

The similarity between middle and lower reaches of regulated streams, small rivers, ditches and medium-sized, more or less stagnant waters (R1 to P6), is shown both by clustering and ordination. The impoverishment of the macroinvertebrate fauna due to human-induced environmental disturbance can be seen, partly in the variables indicated (Fig. 17.2) and partly in the spatial arrangement of the cenotypes (Fig. 17.4). In particular, the cenotypes in the lower left corner of Figure 17.4 (mostly large waters) have been changed due to human disturbance. These stagnant, hypertrophic, mesosaprobic environments have part of their macroinvertebrate fauna in common. This shows, firstly, the decreasing dominance of current velocity as a key factor in these running waters and, secondly, the decreasing importance of shape, depth and bottom-type in stagnant waters. These trends are due to disturbance and stress induced by human activity (e.g. by regulation of streams, discharge of wastes and agricultural activity in the catchment) and are responsible for the impoverishment of the macroinvertebrate fauna.

It is concluded that there are now almost no truly oligo-mesotrophic waters in the province of Overijssel. For some of the cenotypes this would be a natural condition. The resulting web

(Fig. 17.4) does not distinguish between natural conditions and those that are due to anthropogenic effects; it merely reflects the cenotypes that occur under the present environmental conditions. The number of taxa which typify each cenotype is given in Figure 17.5.

Cenotype	H1	H3	H5	S1	S2	S4	H2	S3	H6	S12	P1	P2	P3	D6	D8	S13	S10	S9	S5	S6	S7
Turbellaria																	2				
Oligochaeta		1	1	1	4	5	2	2	1	2	1		1				3		4	4	1
Hirudinea					1												2				1
Crustacea	1	1		2	1									1							1
Ephemeroptera					1							1	1								1
Plecoptera		1	1	2		1		1													
Odonata												4	2	1							
Megaloptera			1																		1
Neuroptera																					
Coleoptera	1	2	1	1				1	2	3	11	4	10	15	17	13	4	1			2
Chironomidae	2	8	6	10	4	5	2	2	1	2	4	4	10	3	4		5	4	5	14	3
other Diptera	5	12	2	7	2	5	5	3	1	1	4	3	6	4		1		3		3	1
Trichoptera	4	3	1	5	3	1	4			3		2	2	2						2	4
Heteroptera												3	12		2	2		1			1
Lepidoptera																					
Acarina		1		2	3						1	1	1	1			2			6	4
Mollusca		1					1								2	1	4				1
Average number of taxa	21	28	15	35	38	36	27	19	8	18	23	31	51	33	47	25	39	17	25	46	57

cenotype	R5	R9	P5	D2A	D3	P4	P6	R7	R11	R8	R3	P7	R2	P8	P9	P11	R12	R1	R4	S14	D11
Turbellaria				2	2									1							
Oligochaeta	2	4		1		2	1	8	3	7	3		1	2	2		5	4	2		1
Hirudinea				1	3	2	1	1	1					4	3	1	1	1	1		
Crustacea					1					1	1				1	1		1			
Ephemeroptera				1		1					2	4	1	1			1		2		
Plecoptera																					
Odonata				1		2	2				1	1		2		1			1		
Megaloptera														1		1					
Neuroptera							1														
Coleoptera			13	14	7	17	2	1		1	2	1	5	2		3		1	7		
Chironomidae		5	1	6	2	3	5	1	4	7	11	11	3	7	5	9	10	4	6		
other Diptera			2	2		6	2					1		2			1			3	3
Trichoptera		1		2		1	6	1	1	1	4	4	1	4	1	3	3	6	3		
Heteroptera				2		8				1	1	5	1	5	3	6		2	4		
Lepidoptera						1															
Acarina		1	1	11	2	4	1	12		5	2	7	6	1		11	4	1	16		
Mollusca		1	5	12	14	3	1	1	2	6	2			2	1	1		1	3		
Average number of taxa	15	58	50	70	64	61	64	42	42	65	68	62	71	78	58	80	70	61	91	3	7

Figure 17.5. The numbers of characteristic taxa in the 42 centoypes of the surface waters in Overijssel, listed by taxonomic groups.

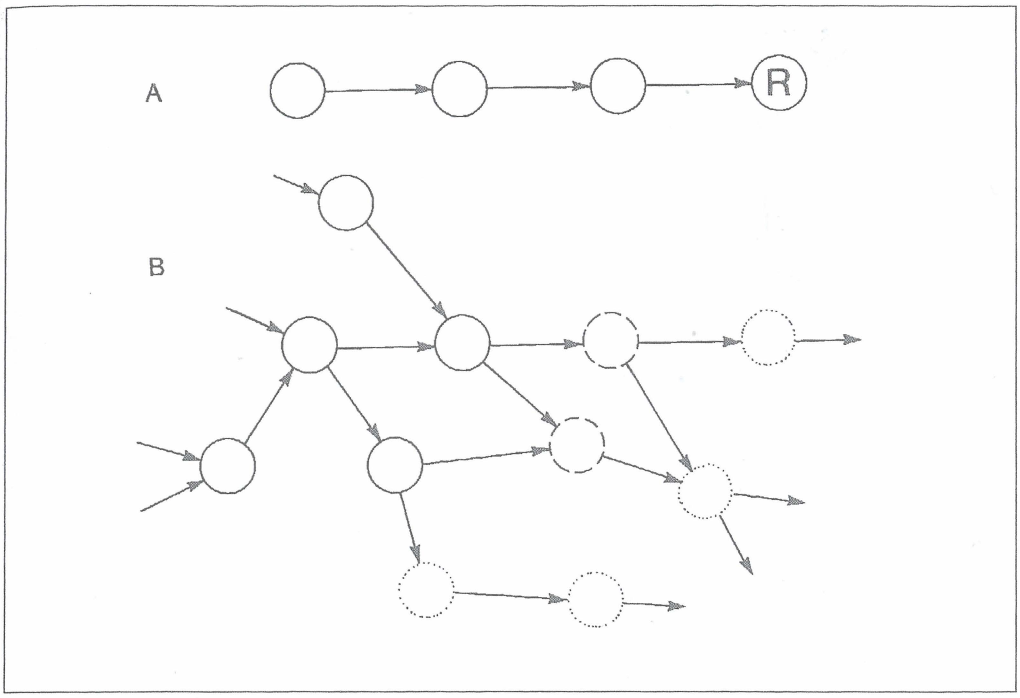

Figure 17.6. Schematic representation of assessment systems applied to surface waters. A represents a univariate system with a fixed end-point (R) and a singular series. B represents a multivariate system with more development stages in different directions (a web) and more or less well defined stages (open and dotted circles).

Web approach

In water assessment, targets are needed for waterbodies. In biological assessment systems these targets are usually unpolluted conditions. Most assessment systems use a singular succession series, with one static end-point as the unpolluted state and thus the optimum in ecosystem development (Fig. 17.6A). However, a static end-point and a singular assessment series is of limited use in water management. This is because target communities of unpolluted sites will differ, depending on the environmental conditions (Verdonschot 1994).

In The Netherlands, a discussion is taking place on the definition of the unpolluted or natural state. Terms such as "unpolluted", "natural", "desired" and "pristine" are all subjective conceptions, and each concept often has different definitions. Four definitions of the target community guide the discussion below. (1) A community in the past: the "former", "historical" (for example the year 1900) or "original" community, known from the literature. (2) A natural community: defined as the community developed under the given climatological, geological, geomorphological and biogeographical circumstances, with or without certain extensive human interference. (3) A present (current) optimal community: the "optimal" community which can be measured, and in which optimal is defined as the condition whereby an ecosystem under the given natural conditions is self-maintaining. (4) A potential community: the "potential optimal" community, taking the present and the future environmental conditions into consideration.

These alternative definitions of the target community are often used arbitrarily without clarification. Sometimes even the most natural or developed stage needs human interference to remain stable (in a dynamic sense). For example, some artificial waters such as ditches and

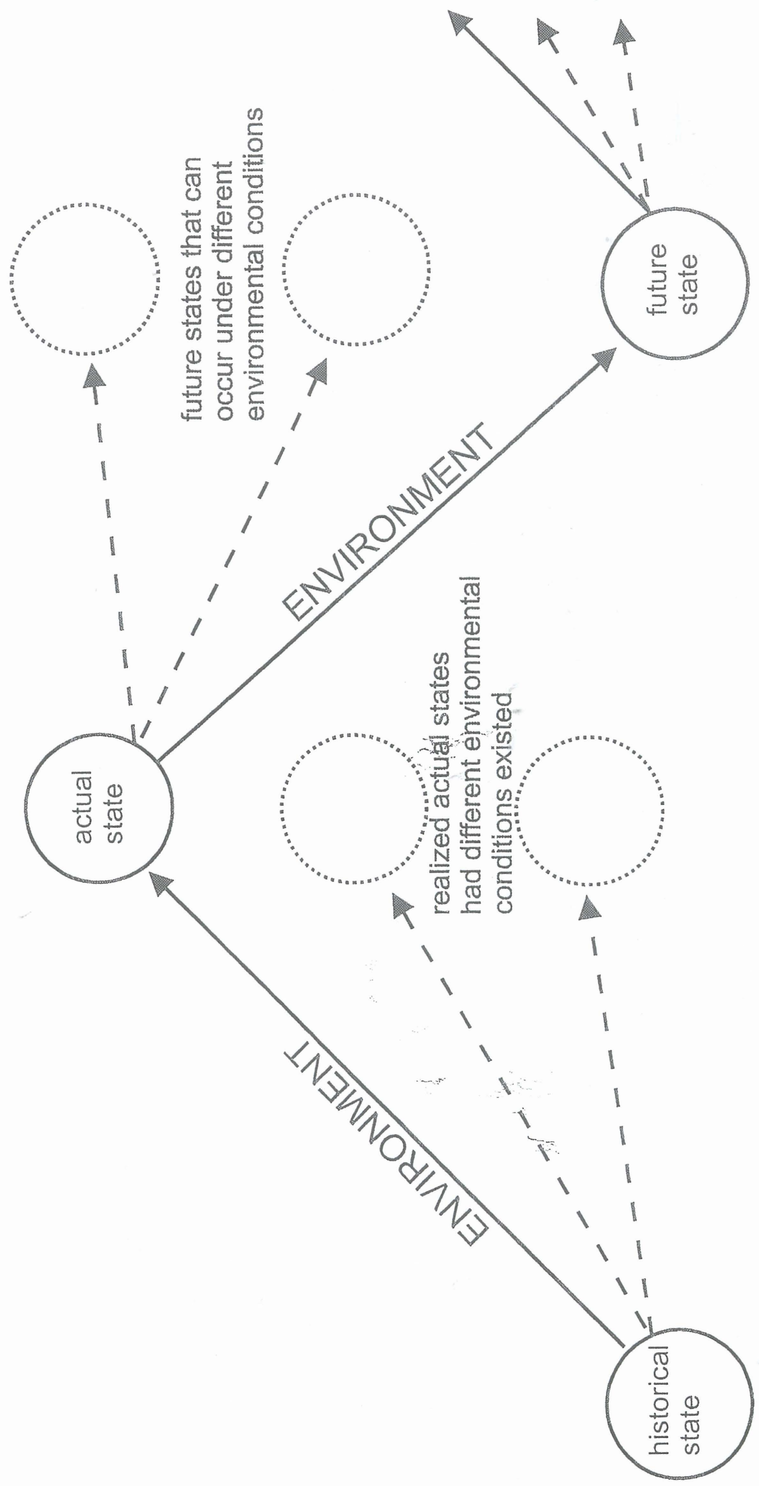

Figure 17.7. The capacity of a biological community (adapted from Warren *et al.* 1979).

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canals are constructed by man; these would gradually fill and become shallow or disappear without regular human interference in the form of cleaning and dredging. Their climax would not be aquatic but more or less terrestrial, and would conflict with the objectives of water and nature management. The meanings of terms like "natural" and "optimal" are subjective and depend on the objectives being pursued. There are a number of arguments against a theoretical definition of the target as the most natural state of an ecosystem on an assessment scale. The target will depend on aspects of naturalness, information from the past, variability of the optimum and unfamiliarity with future circumstances. It is clearly impossible to give objective criteria for the definition of a target as a static end-point.

Therefore, we chose a more pragmatic approach. The target should be a condition that indicates a direction of improvement with respect to the objectives of the water manager. In addition, the target must fit within the ecological potential of the respective waterbody. This directional process is described as ecosystem development (Verdonschot 1991). The degree of ecosystem development indicates the stage of the aquatic ecosystem and its potential direction of development. The choices which determine the direction of improvement are made by the water and nature manager, and depend upon important ecological processes. The web of cenotypes offers a basis for deciding which potential developmental directions are possible and what environmental processes should be steered by means of management measures.

In Figure 17.6B a web of more and less well-defined states and their relationships is illustrated. It is an abstraction of the web of cenotypes (Fig. 17.4). Within this web it is possible to indicate different potential developmental directions, from actual states towards ecologically more optimal states. Such a web can serve as a reference framework. New samples can be referred to this framework because it contains both clean and more or less disturbed types. The stage, and the potential directions (targets) in ecosystem development of a waterbody, further depend on the intrinsic character of each waterbody. For a description of this intrinsic character it is important to obtain knowledge of the former conditions and their development towards the actual state, knowledge of the present conditions in terms of abiotic and biotic parameters, knowledge of the potential ecological conditions and processes related to water type (e.g. succession, production and decomposition), and knowledge of the feasibility of change with respect to management, policies and developments in society.

To describe the intrinsic character of a waterbody, a list of abiotic conditions is even more important than a list of rare and/or characteristic species.

To describe the potential of a waterbody, knowledge is needed on the relevant processes. According to Warren *et al.* (1979) only the structure of a community can be measured; its functioning can only be represented indirectly and incompletely. This is true for our web. The parameters that relate cenotypes in our web are extracted from structural community characteristics. However, they reflect underlying processes, such as the relation between profile shape and the processes of erosion and deposition, or phosphorus and nitrogen content in relation to eutrophication. The actual state and the ecosystem's potential capacity is given in Figure 17.7. The potential capacity is the predetermination of all possible states and structures which can evolve from the actual system. The interaction of system capacity and the state of the environment determine the system structure realised at any moment (the realised capacity). If the environment had been different, another sequence of realised capacities would have been the result (Warren *et al.* 1979). This hypothesis is applicable to our web. In practice, management should focus on processes.

Example of the use of the web

The web is best explained by means of a simple example. Figure 17.8 and Tables 17.1 and 17.2 show a small part of the web. Cenotype S5 represents polysaprobic upper and middle reaches of natural and regulated streams. Organically polluted streams are indicated in the transverse profile by black substratum. The relationships between this type and both cenotypes S7 and S6 are illustrated by the arrows indicating organic material. Cenotype S7 represents α-mesosaprobic middle reaches of regulated streams, and is related to cenotype S6 (α-mesosaprobic middle reaches of semi-natural streams) by two parameters: transverse profile shape and nutrient concentration. The first parameter is related to morphology and hydrology of the stream, and the second is related to the agricultural activities in the catchment. A general feature in this region is the combination of intensive agricultural activity and increased discharge by stream canalisation and land drainage. Through these human activities, streams belonging to cenotype S6 shift towards those of S7. The construction of a sewage treatment plant which discharges into a stream belonging to cenotype S6 or S7 will cause a shift towards cenotype S5.

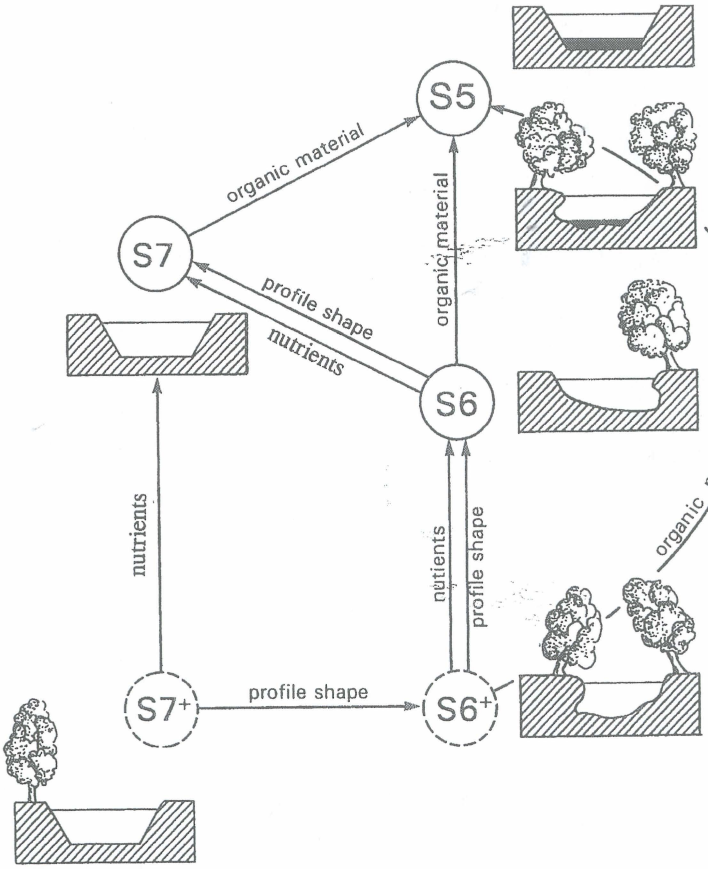

Figure 17.8. A small part of the web of cenotypes (Verdonschot 1990) with three actual cenotypes (closed circles), two potential cenotypes (dotted circles), the most important environmental relationships (the arrows) and some profile shapes. For further explanation see the text.

canals are constructed by man; these would gradually fill and become shallow or disappear without regular human interference in the form of cleaning and dredging. Their climax would not be aquatic but more or less terrestrial, and would conflict with the objectives of water and nature management. The meanings of terms like "natural" and "optimal" are subjective and depend on the objectives being pursued. There are a number of arguments against a theoretical definition of the target as the most natural state of an ecosystem on an assessment scale. The target will depend on aspects of naturalness, information from the past, variability of the optimum and unfamiliarity with future circumstances. It is clearly impossible to give objective criteria for the definition of a target as a static end-point.

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In this study, none of these cenotypes represent pristine conditions, in the sense that they are unaffected by human activities. Nevertheless, we need stages in development towards more ecologically optimal conditions.

Table 17.1. *Some biotic characteristics of the cenotypes for sites in Overijssel, used in Figure 17.8.*

Cenotype	Number of typifying taxa	Dominant taxonomic group(s)
S5	9	Oligochaeta
S7	21	Coleoptera Megaloptera
S7+	30–40	Trichoptera Odonata
S6	29	Trichoptera Chironomidae Acarina
S6+	30–35	Ephemeroptera Plecoptera Trichoptera

Table 17.2. *Some abiotic characteristics of the cenotypes for sites in Overijssel, used in Figure 17.8*

	Cenotypes				
Parameters	S5	S7	S7+	S6	S6+
pH	7.1–7.7	7.1–7.7	5.5–7.0	6.7–8.3	5.5–7.0
Conductivity (μS cm^{-1})	205–595	334–550	<200	226–626	<200
NH_4 (mg N l^{-1})	1.6–11.8	0–5.9	0–0.4	0–4.8	0–0.4
NO_3 (mg N l^{-1})	3.0–8.6	2.4–8.6	<1	2.1–7.7	<1
Total P (mg P l^{-1})	0.63–4.43	0–2.03	0.01–0.04	0–3.37	0.01–0.04
Silt (cm)	0–27	0–24	0–5	0–2	0
Width (m)	1.4–4.8	0–9.0	0–9.0	1.7–4.5	1.7–4.5
Depth (cm)	12–54	1–107	1–107	12–64	12–64
Slope (m km^{-1})	0.4–3.8	0.3–25	0.3–2.5	0.2–2.4	0.2–2.4
% Vegetation cover	0–34	0–44	50–80	0–41	<40

Our example of part of the web (cenotypes S5, S6 and S7) is extended with two developmental stages towards an ecological optimum (Fig. 17.8). These stages were not included in the web of cenotypes (Fig. 17.4) and are indicated by plus signs. Knowledge of type-related processes, and present and historical data on comparable waters, were used to describe these potential developmental stages (Tables 17.1 and 17.2). The potential cenotype S6+, β-mesosaprobic middle reaches of natural streams, and S7+, β-mesosaprobic middle reaches of regulated streams, are shown. The relationship between cenotype S6 and S6+ is mainly due to four parameters: profile shape, morphology, hydrology and nutrient concentration. The latter is also important between cenotypes S7 and S7+. Streams that belong to cenotype S6 or S7 can be managed in the direction of more optimal stages S6+ and S7+, respectively. This web and its extension can also be used for assessment and valuation by adding a valuation scale to the different cenotypes, including their developmental stages, or by relating the observed assemblage to the expected one (the chosen target for a site).

Application of the web in management

Ecological typology aggregates the variability in species combinations, and the variability in environmental conditions, into discrete units. Therefore, ecological typology can serve as a basis for water and nature management in fresh waters, in lowland regions. Nowadays, assessment is not enough to carry out management. Ecological typology offers more possibilities, and is a basis for the development of tools to describe and monitor, evaluate and assess, set standards, formulate and assign ecological objectives/targets, predict and test, and advise on management measures.

To use these tools, it is necessary to compare a waterbody with the communities present in other waterbodies with similar major environmental conditions (key factors) as well as under less disturbed conditions. This requires a specification of the present and potential conditions of the waterbody under study. The ideal is the use of a web of reference conditions with which the present condition can be compared and from which potential development can be extracted. This web of reference conditions should include "dead" or "barren" water as well as all intermediate conditions towards and including ecologically pristine conditions.

To use the web of cenotypes as a reference framework, a new sample should first be assigned to a position or type within the web. A software package was developed to undertake this task. Next, it is necessary to establish the target (reference condition) for a certain site. The distance between the present and target stage, and the processes to be steered by management, finally determine the management measures to be taken.

Software development to support ecological management

The database of the web of 42 cenotypes contains lists of species, associated typifying weights and abundances, and environmental variables for each cenotype. These data constitute the basis of a software package entitled EKOO. This software package contains three main modules (Table 17.3). These modules are (1) arithmetic assignment of a newly sampled site to a cenotype, based on the macroinvertebrate fauna composition, (2) characterisation (diversity and biotic description of all species) of a newly sampled site, based on macroinvertebrate fauna composition, and (3) choice of a direction of ecological development and advice on measures to be taken.

Each of these modules will be described and illustrated by a case example, based on a sample of macroinvertebrate fauna from the middle reach of the small Springendalse stream, situated in the eastern part of the province of Overijssel.

Case example 1 (Module 1)

Three techniques are used to assign macroinvertebrate samples to cenotypes. These are passive DCCA (Ter Braak 1987), similarity indices (Hellawell 1978) and weighting, a method which uses typifying weights of species (Verdonschot 1990). Each of these three techniques comprises two different methods (Tables 17.4 and 17.5). The web of cenotypes was constructed on the basis of mathematically transformed abundances; the assignment of samples is therefore also based on transformed data.

All samples used to construct the web of cenotypes were used to test the internal consistency of the program. The percentage of correct assignments was a measure of internal consistency. Table 17.5 shows that the highest consistency (85%) was obtained by using the Czekanowski coefficient. However, by using a combination of the results from both passive analysis techniques, both similarity indices, and weighting on all taxa, the best assignment results were

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Table 17.3. *Modules in the program package EKOO.*

SOFTWARE PACKAGE EKOO

NEW SAMPLE => WEB OF CENOTYPES (sample oriented)

Module:	1	2	3
Organisation level:	Assemblage	Taxon	Cenotype
Program type:	Arithmetic	Arithmetic	Expert system
Technique:	Passive analysis Weighting Similarity	Diversity Biotic description	Set target Select measures

Table 17.4. *Arithmetic assignment of newly collected macroinvertebrate fauna samples to the web of cenotypes, using two methods (columns down) for each of three different techniques (columns across).*

Techniques are based on: similarity indices (Hellawell 1978), weighting (Verdonschot 1990) and passive DCCA (Ter Braak 1987).

Similarity ratios	Weighting	Passive andysis (DCCA)
Czekanowski coefficient (Czekanowski 1913)	Including all taxa	Mahanalobis distance (Mahanalobis 1936)
Squared Euclidean distance (Jongman *et al.* 1987)	Typifying weight >3	Euclidean distance (Gauch 1982)

Table 17.5. *Internal consistency of sample assignment to cenotypes, using the original dataset and applying six methods and two combinations of methods.*

Methods	Correct assignment (%)
(1) Mahanalobis distance	81.6
(2) Euclidean distance	79.0
(3) Weighting all taxa	66.1
(4) Weighting typifying taxa >3	61.5
(5) Czekanowski coefficient	85.0
(6) Squared Euclidean distance	77.0
(7) Methods (3), (5) and (6)	88.0
(8) Methods (1–3), (5) and (6)	93.0

obtained (93% for methods (1), (2), (3), (5) and (6), Table 17.5). By using the program to assign a new sample, the final result of the combination of these five methods is then presented to the user. The results of assignment in the case example are given in Table 17.6.

Table 17.6. *Arithmetic assignment of a new sample from the Springendalse stream in Overijssel*

Method of assignment	Assigned cenotype
Mahanalobis distance	R9
Euclidean distance	S7
Czekanowski index	S7
Squared Euclidean distance	S7
Weighting on all taxa	S6
Weighting on typifying taxa only	S6
Overall assignment	S7

Table 17.7. *Diversity of a new sample (see Table 17.6) from the Springendalse stream in Overijssel, compared with the mean, range and standard deviation of three indices applied to cenotype S7.*

Diversity indices are from: Shannon & Weaver (1949), Simpson (1949) and Alatalo (1981).

Parameters of the indices	Diversity index values Shannon	Reciprocal Simpson	Alatalo
Mean for S7	0.086	52.1	587
Minimum for S7	0.067	35.3	334
Maximum for S7	0.102	60.8	863
SD for S7	0.011	9.6	166
New sample	0.106	51.3	450.3

Case example 2 (Module 2)

Two types of sample characterisation, "diversity" and "biotic description", are available to describe the biotic status of a new sample. Three diversity measures are included, namely Shannon index (Shannon & Weaver 1949), reciprocal Simpson index (Simpson 1949) and Alatalo index (Alatalo 1981). Table 17.7 gives the diversity measures obtained for a new sample from the Springendalse stream, in relation to the mean and range of values obtained for cenotype S7.

Each taxon is indicative of a number of features of a waterbody. In the option "biotic description", metrics that are indicative of the following features are calculated using the fauna in the new sample: geomorphological water type, habitat, saprobic level, current velocity class, frequency of occurrence (or rarity), higher taxonomic group (order/class), trophic level, functional feeding group, behavioural habit and extreme biotic conditions. Each of these features is classified into about six classes, according to the percentage of taxa indicative of each class.

"Diversity" and "biotic description" measures can be compared only within a cenotype or with other samples from the same waterbody, because taxon richness differs due to differences in the natural environment. It is also essential to keep in mind any differences due to sampling effort and difficulty of sampling. Therefore, it is important to use the standard procedures

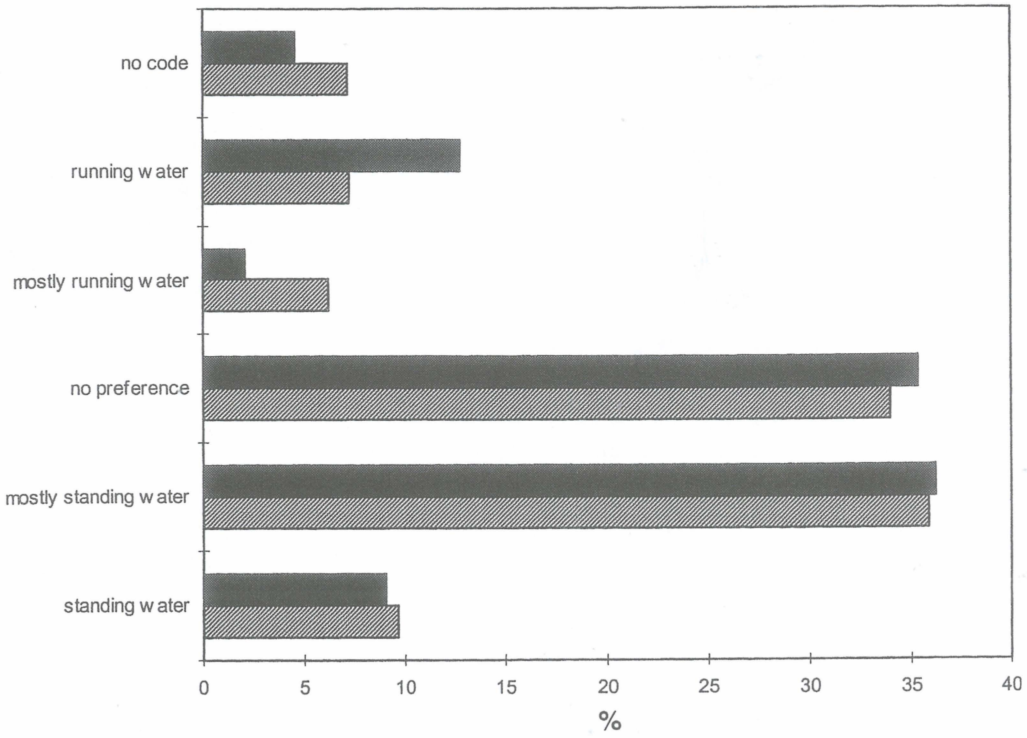

Figure 17.9. An example of a "biotic description" of all macroinvertebrate taxa found at a particular sampling site in relation to an abiotic parameter. In the example, taxa are classed in terms of their known preferences for current velocity, ranging from standing to running water; taxa included in the "no code" category have not been classified for current velocity preferences. Horizontal bars show the proportions (%) of taxa in each of six categories (classes); shaded bars represent cenotype S7 for comparison with the new sample (solid bars).

described in the section on collection of samples. For example, stagnant mesotrophic waters are inhabited by many more taxa than are found in streams (Verdonschot 1990). However, comparison of these diversity and biotic description measures can be useful in monitoring and evaluating the development of a waterbody.

An example of diversity measures for a new sample from the Springendalse stream has been given in Table 17.7. Figure 17.9 shows the biotic description (relation to rheophily) of the same sample. Note that the distribution of species over the classes in the new sample closely follows type S7.

Case example 3 (Module 3)

To be able to choose the developmental direction of a newly sampled site, one has to know the cenotype and its characteristics. The cenotype is calculated by arithmetic assignment and, together with a knowledge of potential characteristics, the manager has to choose a target cenotype. A part of the web of cenotypes is shown in Figure 17.8. After choosing a target, the manager is offered a number of questions in an expert system. These questions relate to the environmental parameters that indicate the processes relevant to the present and target cenotypes. The questionnaire leads the manager through all potential management options and assists in selecting the measures to be taken to reach the target. Relevant questions and measures are listed by the program.

In the case of the Springendalse stream, the overall cenotype assigned was S7. The target direction chosen was from S7 through S6 to S6+; in other words the target cenotype was S6+. The target direction and final target cenotype imply an improvement in the following factors: regulation, organic matter and nutrients, i.e. improvement in the processes of morphology and eutrophication (saprobication). The questionnaire is summarised below, but includes only those questions which lead to action. Disturbances that are not relevant at this specific site are excluded from the list.

Questionnaire on morphology

Question: Is profile consolidation present?
Advice: Remove the profile consolidation or replace it with natural materials. If necessary, use gravel or stones on vulnerable spots. Include migration (water to land) facilities for fauna.

Question: Has the longitudinal profile been changed?
Advice: Induce spontaneous meandering, rehabilitate old meanders or dig a new meandering profile. When this is not possible, insert objects in the stream (e.g. tree-trunks or stones).

Question: Has the transverse profile been straightened?
Advice: Heighten the bottom of the stream-bed, narrow the stream width for low flows and create berms to take high flows.

Question: Are the stream banks morphologically affected?
Advice: Vary the bank profile by creating deposition zones and overhanging or steep banks (create/induce an asymmetric profile shape).

Question: Is a weir present?
Advice: Remove the weir and dig an extension of the longitudinal profile of the stream at this site or construct a cascade or fish ladder.

Questionnaire on eutrophication (saprobication)

Question: Does manuring or fertilisation take place in the up-stream catchment?
Advice: Prevent over-fertilisation by legislation and control. Reduce it further by buying adjacent land, stimulating the development of buffer strips, or inducing a change of land use (such as afforestation).

Question: Does surface and subsurface runoff take place?
Advice: Fill up side streams and drainage ditches, remove drain pipes, create buffer strips or horseshoe-shaped wetlands, plant adjacent woodland and create stream-bank elevations.

Question: Is the adjacent land over-fertilised?
Advice: Decrease the amount of nutrients by mowing and removing the vegetation or remove the upper layer in the infiltration zone without affecting the natural bottom profile.

Conclusions and future developments

Many early works on the classification of surface waters were restricted to a limited number of running waters (Illies & Botosaneanu 1963; Hawkes 1975), stagnant waters (Margalef 1958; Brinkhurst 1974) or both (Thienemann 1955). Most of these works were purely descriptive. More recently, with the introduction of automated data processing techniques, larger classifications have been made of running waters (Braukmann 1984; Wright, Moss *et al.* 1984) and stagnant waters (Kansanen *et al.* 1984; Johnson & Wiederholm 1989). All used indirect gradient analysis techniques to derive their classes but were still limited to certain water types.

The ecological typology presented in this study is based on direct gradient analysis techniques and includes a wide range of water types. As expected, differences were found between waterbodies such as helocrene springs, streams, ditches and ponds. During the study, the relationships between these types were visualised and intermediate types were recognised. Furthermore, a number of types within each of these major categories were described (e.g. five types within helocrene springs, eleven types within streams, and four types within ditches). In general, this means that ecological water types are more than (either) visually, physically, chemically or biologically recognised entities. Of course the number of types also depends on the sampling methods and analysis techniques used. Sampling methods, in terms of sample size, effort and level of identification, were shown to be representative for sites. During the analysis, options were standardised and results were tested statistically, resulting in non-stochastic, reproducible results.

In water management, easily recognisable parameters are often used as simple and practical criteria to distinguish water types. As a result, only some of the features of the ecosystem are taken into account. For the assessment and evaluation of a waterbody, community composition as well as environmental conditions should be used. In the present ecological water typology, each cenotype is the result of its specific biological and environmental complex. By using direct gradient analysis, biota and environmental conditions are directly related to each other. This typological approach offers a method that combines the advantages of using tables incorporating complex data into a relatively simple diagrammatic presentation.

The web of cenotypes can be used as a practical tool in water management. In analysing a waterbody, first the key factors should be distinguished, followed by the other less important environmental factors. All of these factors are responsible for the actual state of the system. Second, a direction of improvement should be chosen. Third, one should distinguish those processes that are responsible for potential improvement and look for related factors that are manageable. Typology can be used to solve water management problems if they are considered together with the appropriate ecological concepts and if the user is aware of the uniqueness of each individual waterbody.

Management also needs to predict the effects of intended measures. May (1984) stated that it is doubtful whether any community is sufficiently well understood for confident predictions to be made about its response to particular disturbances. Hawkes (1975), Resh & Unzicker (1975), Maitland (1979) and Persoone (1979) have all stressed the predictive value of the results of an ecological survey, despite the fact that it is based on conceptual ideas and correlation of data, rather than on causal proof. A comprehensive ecological survey of sites in a given region has a descriptive value and the results can, with caution, be used to predict effects of management measures. In this way, the relationships described in the web are being harnessed.

In conclusion, the web of cenotypes offers a basis for the daily practice of regional water and nature management. It has been developed at the small-scale level of regional water types and can be used from the bottom (small scale) up (large scale = national water and nature management and policies). This means that the web can be used at a larger-scale level by aggregation. The web supports the development of water quality objectives and standards in terms of cenotypes, and supports the methods used to monitor and assess waters. It indicates the potential of waters and can be used to predict and further inform about the management and restoration of waters.

In future the following parts of the package need further development: assignment of new samples based on biotic and abiotic parameters considered together; target selection supported by an expert system to optimise the choices; prediction of the probability of a new site belonging to a particular cenotype, based on known environmental parameters; the arithmetic assignment of a newly sampled site to a particular cenotype, based only on environmental parameters. Furthermore, webs will be developed for different regions as well as for different major physico-geomorphological water types on a national scale.

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