

# Ecological classification of macrophytes and phytobenthos for rivers in Germany according to the Water Framework Directive

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## Abstract

A new assessment system for macrophytes and phytobenthos in German rivers meeting the requirements of the Water Framework Directive (WFD) of the European Community is described. Biocoenotic types based on biological, chemical and hydromorphological data from over 200 river sites covering the main ecoregions, hydromorphological stream types and degradation forms have been defined. For developing a classification system the quality element macrophytes and phytobenthos was divided into three components: macrophytes, benthic diatoms and remaining phytobenthos. For macrophytes seven types including one subtype, for benthic diatoms 14 types including three subtypes and for the remaining phytobenthos five river types were identified. The benthic vegetation at reference condition was described for most of the river types. Degradation is characterised as deviation in benthic vegetation species composition and abundance from the reference biocoenosis. For classification in five ecological status classes, several metrics were developed and used in combination with existing indices. For some of the described river types additional investigations are necessary before a classification system can be developed.

**Key words:** Water Framework Directive – aquatic plants – macrophytes – phytobenthos – diatoms – ecological classification – assessment – reference conditions – species groups – rivers

## Introduction

According to the Water Framework Directive (WFD; European Union 2000) the member states of the European Union are obliged to assess and report on the ecological status of all rivers exceeding a catchment area

size of 10 km<sup>2</sup>. This status shall be determined by the biological quality elements phytoplankton, macrophytes and phytobenthos, benthic invertebrate fauna and fish fauna. Physical and chemical properties of the water bodies are to be used along with the hydromorphological situation of the rivers as supporting elements. For each

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of the biological quality elements, the taxonomic composition and abundance of the taxa have to be determined, and five classes of ecological status (high, good, moderate, poor, bad) have to be defined following normative definitions in the Directive. The determination of the ecological status has to be done type-specifically, i.e. for each 'type' of running water, reference conditions have to be identified, and degradation described by quantifying the deviation in species composition and abundance from those that would be present at reference conditions. No method fulfilling these demands exists in Germany for macrophytes and phytobenthos. Therefore a four year project to develop a new classification system for implementing the Water Framework Directive for macrophytes and phytobenthos in German rivers was initiated. The aim of this paper is to give an overview of the concepts followed within the project, and present some important results. The complete results for all river types are published in the final report of the project (SCHAUMBURG et al. 2005). An English version of the mapping method including the classification system can be downloaded from the homepage of the Bavarian Water Management Agency (see SCHAUMBURG et al. 2004; <http://www.bayern.de/lfw>).

## Material and Methods

### Sampling design

Existing knowledge about different sampling methods and approaches for a classification of macrophytes and phytobenthos to determine the ecological status of rivers and existing data on species distribution were compiled and evaluated in a literature study (SCHMEDTJE et al. 2001a). About 200 river sites all over Germany (Fig. 1) were chosen so that the main ecoregions in Germany (ILLIES 1978) and different river types (SCHMEDTJE et al. 2001b) were covered.

In order to develop a classification system, the quality element "macrophytes and phytobenthos" was divided into three components: (a) macrophytes (including vascular plants, submerged Bryophytes and Charophytes), (b) benthic diatoms and (c) remaining phytobenthos. This differentiation was necessary due to the different spatial and temporal occurrence and distribution of these components, i.e. the different indication of environmental conditions as well as the different sampling routines. Macrophytes are rooted to the sediment and are long lasting organisms whilst diatoms typically have short generation times and respond quickly to changes in environmental conditions. The number of sites and collections for each component is shown in Table 1. In addition data from 76 sites of the Austrian alpine region were included into the data set as these sites have the same geomorphological characteristics as German sites in that ecoregion.

At each sampling site, biological, hydrological and morphological data were recorded (SCHAUMBURG et al. 2005). Chemical and physical data of the sites were received from the official monitoring programs of the regional water authorities.

### Mapping, sampling and material treatment

Macrophytes were mapped once during the main vegetation period (mid June to mid September). Surveys were taken out in ecologically homogenous sections of running waters, i.e. sections without major changes in current velocity, shading, sediment composition or land utilisation of the adjacent area as well as without tributaries or other influxes. The length of the survey site was approximately 100 m. All plants rooting below the middle water were recorded. An underwater viewing aid, and additionally – in deep or turbid waters – a rake with a long handle was used. In deep rivers, where wading was impossible, plants were investigated from the banks by raking an area of the streambed as far as possible from the bank. Plant abundance was estimated according to a five-point-scale established by KOHLER (1978): 1 = very rare; 2 = rare; 3 = common; 4 = frequent; 5 = abundant, predominant. Submerged and emergent growths of macrophytes were recorded separately. Abundance of plant taxa appearing submerged as well as emergent at the site were noted separately. Structural features of the survey site, such as current velocity, average width and average water depth were recorded. Additional information about general and physico-chemical features of the site, e.g. ecoregion, water hardness and influence of groundwater, were gathered.

A seasonal fluctuation in benthic diatom communities with important changes of the species composition can be detected (e.g. ENGELBERG 1987). These changes differ between river types. Therefore, in order to develop the classification samples were taken three times a year in spring, summer and autumn. This enabled the communities to be characterised and a decision about which season would be the best for sampling in the future to be made. Samples were taken according to the European Standard EN 13946 (CEN 2003) where type specific natural substrates allocated over the whole streambed in

**Table 1.** Numbers of rivers, sites, samples and taxa found; in brackets: together with Austrian sites.

	Macrophytes	Benthic diatoms	Remaining phytobenthos
Rivers	183 (198)	173 (216)	98 (143)
Sites	218 (239)	201 (295)	126 (196)
Samples		576 (694)	245 (380)
No. of taxa found	206	573	239

x Sampling sites

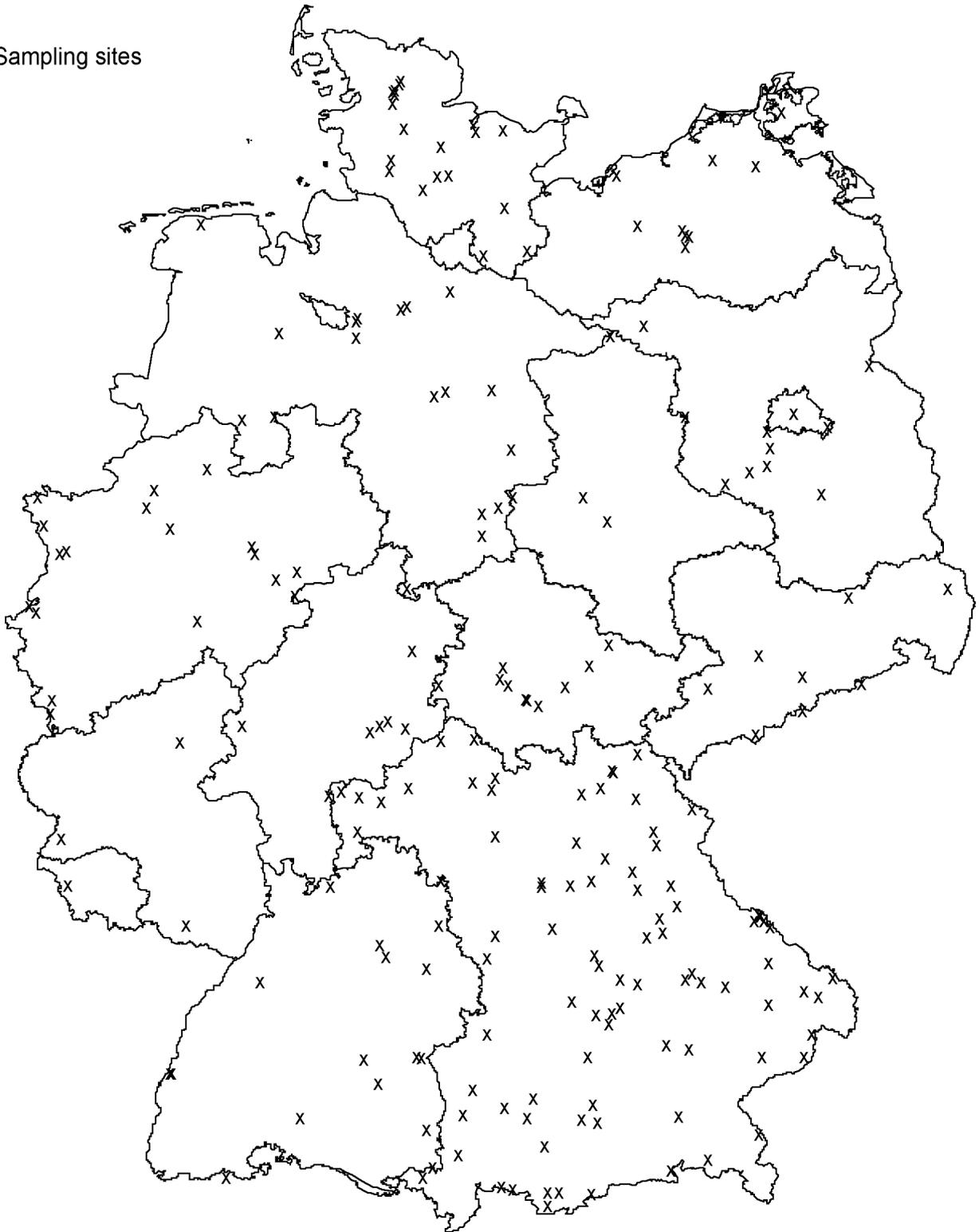


Fig. 1. Map of German investigation sites for benthic plants in rivers.

a constantly submerged area were chosen. Areas with high current velocity, the littoral zone and shady patches were avoided, except where they were characteristic for the type. Additional criteria such as substrate composition, light conditions etc. were noted. In rivers with high to moderate current velocity hard substrates such as stones were chosen. At least five stones of a size that were not moved by mean hydrological conditions were selected from locations throughout the site. The diatom layers were abraded with a spoon or spatula from the top sides of the stones or the other chosen substrates. In slow flowing rivers the procedure deviated from EN 13946 and the diatom sample was taken from soft substrates such as sand, gravel and organic matter by lifting it carefully with a spoon. The suspension was stored in a container. The material was fixed with formaldehyde with a final concentration of 1% to 4%. The material was cleaned by boiling in hydrochloric acid, followed by oxidation using concentrated sulphuric acid and potassium nitrate. After washing, the cleaned frustules were mounted in Naphrax and identified under oil immersion at a magnification of 1000x. Nomenclature follows KRAMMER & LANGE-BERTALOT (1986, 1988, 1991a, 1991b). At least 500 frustules were counted and species abundance was calculated as percentage occurrences.

For mapping the remaining phytobenthos, a multiple habitat sampling was carried out on a section (rivers 50 m, streams 20 m) in order to get a representative sample. The sampling procedure was developed in concordance with the method proposed by ROTT et al. (1997) and BARBOUR et al. (1999). Macroscopically visible stands of algae were mapped and sampled, and further samples for microscopic analysis were taken from different kind of substrates as well as from different situations in regard to current velocity, degree of shading, and depth. On average, 4–6 subsamples per site were taken. Samples were preserved by Lugol's solution or by cryo-preservation. Benthic algae were determined to species level whenever possible. Algae of the orders Zygnematales, Vaucheriales and Oedogoniales were kept in the laboratory but only in few cases reproductive organs were developed. Hence, these taxa could be determined to genus level only. The abundance of species was estimated on a 5-score scale (see Table 2).

85 sites were sampled twice (winter 2000/01 and summer 2001) to account for possible seasonal variation in the species data.

### Data treatment

For analysing the biocoenosis data (taxa and abundance) cluster analyses, correspondence analyses (CA) and canonical correspondence analyses (CCA) (TER BRAAK 1996) were used. Transformation for some of the abundance data was necessary as described by the following.

**Table 2.** Estimation of abundance of non-diatom benthic algae using a 5-score scale.

Estimated abundance	Description
5	dominant, covers more than 1/3 of the riverbed (>33%)
4	abundant, but covers less than 1/3 of the riverbed (5–33%)
3	just visible in the field (covers max. 5%) or microscopically dominant
2	microscopically abundant
1	microscopically rare

For macrophyte data, relationship between the five degrees of estimation and the actual quantity of the submerged macrophytes can be described best by a function  $y = x^3$  (MELZER 1988; KOHLER & JANAUER 1997). Therefore the ordinal values of the five-point Kohler-scale were  $x^3$ -transformed into quantitative values ("quantities"). Median values were calculated from the available chemical and physical data. Biological data were analysed by cluster analysis (average linkage within groups, distances cosinus; SPSS). Similarities in the species composition and the abundance of the species were investigated by means of vegetation tables (species-by-site matrix).

In an analogous manner, the abundance-values of the remaining phytobenthos were squared to get a better approximation of the degree of covering in the field. Purely planktonic taxa which were noted in the species lists of remaining phytobenthos were excluded from statistical analysis. For the multivariate analyses (CA, CCA; CANOCO 4.5), from the chemical data average values per sampling site per season (winter: October through March; summer: April through September) were calculated. These data were transformed by logarithmic transformations. For univariate analyses, an average value per sampling site was calculated for each environmental parameter of interest. Sites were grouped into classes and presence-absence data of species were used to calculate the percentage of sites per class where each taxon was found.

The analysis of the Diatom data was done by using cluster analyses (average linkage within groups, distances cosinus; SPSS), correspondence analyses and canonical correspondence analyses (TER BRAAK 1996; CANOCO). Furthermore similarities in species composition and abundance were analysed by means of vegetation tables (species-by-site matrix). Additionally ecological indices such as trophic state (e.g. CORING et al. 1999; KELLY 1996; ROTT et al. 1999); saprobic state (ROTT et al. 1997) and salinity (ZIEMANN 1999) were calculated.

**Results**

**Reference sites**

For developing a river typology, sites with only very minor human impacts were used. Only sites showing nearly undisturbed physico-chemical (e.g. pH, salinity, saprobic and trophic status), hydromorphological and biological conditions were chosen. As this is not a best available approach, for some river types only few reference sites could be detected. In the REFCOND Guidance of the EU (WALLIN et al. 2002) was defined that

high ecological status is equal to reference conditions. In the present project a total of 74 reference sites resulted to develop the typology for the three plant components.

**Biocoenotic typology**

To (1) distinguish different types of running water, and (2) compare these types with the geomorphologic types developed by SCHMEDTJE et al. (2001b), the taxonomic composition and abundance of the species found at the reference sites were compared by statistical methods,

**Table 3.** Biocoenotic river types for benthic plants in Germany.

Ecoregion	Macrophytes	Remaining phytobenthos	Diatoms
Alpine regions	MP(G) lowland rivers in mountainous areas, incl. subtype MPG (influenced by groundwater)	PB 1 Alpine rivers	D 1a calcareous alpine rivers, catchment area <1000 km <sup>2</sup>
			D 1b calcareous alpine rivers, catchment area >1000 km <sup>2</sup>
Fore-alpine regions	MRK fast flowing rivers and brooks of mountainous areas (hard water)	PB 2 Rivers of the fore-alpine region	D 3 siliceous rivers, catchment area <1000 km <sup>2</sup>
			D 2a calcareous rivers, catchment area <1000 km <sup>2</sup>
			D 2b rivers, catchment area >1000 km <sup>2</sup>
Central mountains	MP(G) lowland rivers in mountainous areas, incl. subtype MPG (influenced by groundwater)	PB 3 siliceous rivers of Central mountains	D 4 Central mountain rivers of variegated sandstone and crystalline basements catchment area <100 km <sup>2</sup>
	MRS fast flowing rivers and brooks of mountainous areas (soft water)		D 6 Central mountain rivers of volcanic regions, catchment area <100 km <sup>2</sup>
	Mg big streams of mountainous areas	D 5 Central mountain rivers of variegated sandstone and crystalline basement catchment area >100 km <sup>2</sup> and <1000 km <sup>2</sup>	
	MP(G) lowland rivers in mountainous areas, incl. subtype MPG (influenced by groundwater)	PB 4 calcareous rivers of Central mountains and lowlands of northern Germany	D 7a Central mountain rivers of loess- and keuper regions, catchment area <1000 km <sup>2</sup>
	MRK fast flowing rivers and brooks of mountainous areas (hard water)		D 7b calcareous Central mountain rivers, catchment area <1000 km <sup>2</sup>
	Mg big streams of mountainous areas		D 8 calcareous Central mountain rivers, catchment area >1000 km <sup>2</sup>
Lowlands of northern Germany	TN medium sized lowland rivers of northern Germany	PB 4 calcareous rivers of Central mountains and lowlands of northern Germany	D 9 calcareous lowland rivers of northern Germany, catchment area <1000 km <sup>2</sup>
	TR fast flowing rivers and brooks of northern Germany		D 10 calcareous lowland rivers of northern Germany, catchment area >1000 km <sup>2</sup>
	TNg big lowland streams of northern Germany	D 11 organic and siliceous lowland rivers of northern Germany, catchment area <1000 km <sup>2</sup>	



such as cluster analyses and correspondence analyses. As a result for macrophytes (M) seven types including one subtype, for benthic diatoms (D) 14 types including three subtypes and for the remaining phytobenthos (P) five river types could be defined. The description and overlap of these types is shown in Table 3.

A more detailed description how these types were derived is given in FOERSTER et al. (2004), MEILINGER (2003) and SCHAUMBURG et al. (2005). The main descriptors of the biocoenotic river types for the assessment with macrophytes and phytobenthos according to the WFD are the following:

- ecoregion (according to ILLIES 1978) (MPD)
- fluvial landscape (BRIEM 2003) (D)
- dimension of catchment area (D)
- mean width (M)
- mean depth (M)
- current velocity (M)
- effect of ground water (M)
- water hardness (MP)
- acid capacity (P).

Special attention was paid to parameters which are independent or nearly independent of anthropogenic impacts.

### Steps to the classification

In order to develop a classification system according to the normative definitions of WFD, biocoenotic reference conditions had to be defined for the different biocoenotic types, and deviations from these reference conditions had to be quantified to define the good, moderate, poor and bad status classes. The classification systems were developed separately for each group and were combined later to give an integrated method for the whole benthic plant community (entire quality element). For the development of the system, the three groups followed the same underlying notion: reference taxa were named and distinguished from taxa which indicate different degrees and forms of degradation. In some cases, additional metrics were used (see below). The following results show exemplary how different types, reference conditions, the classification system in the three plant components and finally for the entire quality element of the benthic plant community in rivers and streams were developed.

### Macrophytes

Biocoenoses of emergent water plants in running waters show a high degree of natural variability. Therefore, no change in taxonomic composition and abundance of emergent macrophytes is evident with increasing degradation of river sites. In contrast, submerged macrophytes

(hydrophytes) do show differences in taxonomic composition and abundance. Using vegetation tables (species-by-site-matrix) for each river type, reference biocoenoses were identified and the shift in vegetation with increasing degradation was shown. Table 4 shows an example matrix using sites of the river type “fast flowing rivers and brooks of mountainous areas (hard water)” in rows and species (with their abundance according to the KOHLER-scale) in columns.

Reference sites (bold letters) are placed at the top of the sites. They provide a point of reference to which the remaining sites can be compared. Species occurring mainly at reference sites are placed in the left part of the table. Subsequently, all other sites and species are arranged in the table due to their similarity or dissimilarity of their species compositions compared to the reference sites. Thus, river sites are sorted by their deviations from the anthropogenic undisturbed reference sites, as demanded in the WFD. Sites with the highest deviation in species composition and abundance from reference sites are placed at the bottom of the table. Additionally, species are arranged according to their occurrence at reference sites, i.e. taxa occurring at reference sites are placed at the left hand side, taxa not or only rarely occurring together with reference-taxa are placed at the right-hand side of the table. For developing an indication system, macrophyte species are classified into groups of ecologically similar taxa, separately for each river type:

- **Species group A** contains taxa showing high abundance at reference sites and low or no abundance under non-reference conditions. These taxa belong to the type-specific reference biocoenosis.
- **Species group C** are those taxa rarely found under reference conditions. They usually have high abundance at sites with very low or no abundance of Group A taxa.
- **Species group B** taxa show no preference for reference or non-reference conditions. They occur together with taxa from species group A and species group C.

These species groups are consistent with existing macrophyte autecology (MEILINGER 2003). Macrophytes described in the literature but not found in our river sites were incorporated into the relevant species group. A complete taxa list including type-specific classification into species groups can be found in SCHAUMBURG et al. (2004, <http://www.bayern.de/lfw>). As a measure of the deviation of a biocoenosis' species composition and abundance from an unaffected reference, the so-called **reference index (RI)** was used (Formula 1):

$$RI = \frac{\sum_{i=1}^{n_A} Q_{Ai} - \sum_{i=1}^{n_C} Q_{Ci}}{\sum_{i=1}^{n_g} Q_{gi}} * 100$$

where: RI = reference index;  $Q_{Ai}$  = quantity of the  $i$ -th taxon from species group A;  $Q_{Ci}$  = quantity of the  $i$ -th taxon from species group C;  $Q_{gi}$  = quantity of the  $i$ -th taxon of all groups (A, B, C);  $n_A$  = total species number of taxa from species group A;  $n_C$  = total species number of taxa from species group C;  $n_g$  = total species number of taxa from all groups (A, B, C).

The RI is an expression of the “plant quantity” of type-specific sensitive taxa compared to the “plant quantity” of insensitive taxa, and is therefore a tool for estimating the deviation of observed macrophyte communities from reference communities. The resulting index values range from +100 (only species group A taxa) to –100 (only species group C taxa).

Reference indices for each site are calculated, and the range of RI values occurring on reference sites is defined as a benchmark for ecological quality class “high” according to the WFD. Based on the vegetation tables, type-specific limiting values of the reference index are set according to the guidelines of Annex V of the WFD. These values are used to calculate index classes for the entire quality element (see below).

For some river types, further metrics are used in addition to the calculated values of the reference index to define the ecological status of a site. For river type TN (medium sized lowland rivers of the Central lowlands of Germany) additional metrics such as number of taxa, evenness, and plant quantity of C-taxa  $\geq 30\%$  (MEILINGER 2003) are used. For the assessment of the quality component macrophytes, a certain total plant quantity (as described in the chapter Data treatment) of plants at a site is considered necessary. The minimal re-

quired abundance depends on the river type. For a description of the requirements needed for an assessment of river sites based on macrophytes, see MEILINGER (2003). If the required abundance values are not reached, the assessment of the component is considered inconclusive.

## Benthic diatoms

In order to develop a classification according to the WFD numerous existing metrics as well as new developed ones were tested (SCHAUMBURG et al. 2005). The best results were achieved by combining four metrics. The first metric “species composition and abundance” meets the requirements of the WFD best. Two lists of reference-species were developed, one for calcareous and another one for siliceous river sites. The included species are limited to oligotrophic and mesotrophic rivers. In regions with heterogeneous geology in the catchment areas, both lists can be used. Additionally it was necessary to create special lists of reference species for each river type. These lists contain species which are more tolerant concerning the trophic state, in case of the large rivers even indicators for eutrophic conditions. These species are ubiquitous which are already abundant in high and good ecological status. A classification without them would be impossible in those rivers. The reference species lists were completed by species which were not found at the sampling sites. The autecology of these species is well known from unpublished data, expert knowledge and literature studies. The numbers of species of the several types are summarised in Table 5.

**Table 5.** Numbers of species in type-specific species groups of rivers.

Species group	Biocoenotic river type											
<b>Macrophytes</b>	MRK	MRS	MP(G)	TN								
Reference	62	28	51	54								
Indifferent/tolerant	53	70	60	42								
Indicator of degradation	34	26	26	9								
Indicator of acidification		10										
<b>Remainig phytobenthos</b>	P3	P4	P5									
Reference	14	17	9									
Indifferent/tolerant	37	28	15									
Indifferent/degradation	21	21	10									
Indicator of degradation	2	2	1									
<b>Benthic diatoms</b>	D1ab	D2a	D2b	D3	D4	D5	D6	D7a	D7b	D8	D9	D10
Reference	2	11	13	7	6	10	10	10	12	11	28	42
<b>Type-independent</b>												
Reference, siliceous						123						
Reference, calcareous						87						

The summed up percentages of the abundance of both kinds of reference species at a site are used for the classification.

As second metric, the trophic state as one of the main criteria for the distribution of diatoms is used for the classification system (Fig. 2).

For rivers in the high and good status a high resolution for nutrient poor conditions has to be reached. The best differentiation for these conditions was recorded using the Trophic-Index from ROTT et al. (1999). The range of the trophic index occurring on reference sites was defined as a benchmark for high ecological quality, the class boundaries were set according to the guidelines of Annex V of the WFD. For diatom types where no sites with high ecological quality exist (e.g. larger rivers), the range of trophic conditions was widened, resulting in a species composition on a lower trophic level. For rivers of the Central lowlands of Germany with a high trophic level in good status the existing classification systems for determination of the trophic state are not useful. In this river type the saprobic index from ROTT et al. (1997) was proved to be a more adequate tool. Compared to the trophic index, the saprobic index can be used in a larger range of degradation in rivers affected by higher human pressure. Both metrics “species composition and abundance” as well as “trophic index or saprobic index” are combined by averaging after the values have been converted to a comparable scale (0–1).

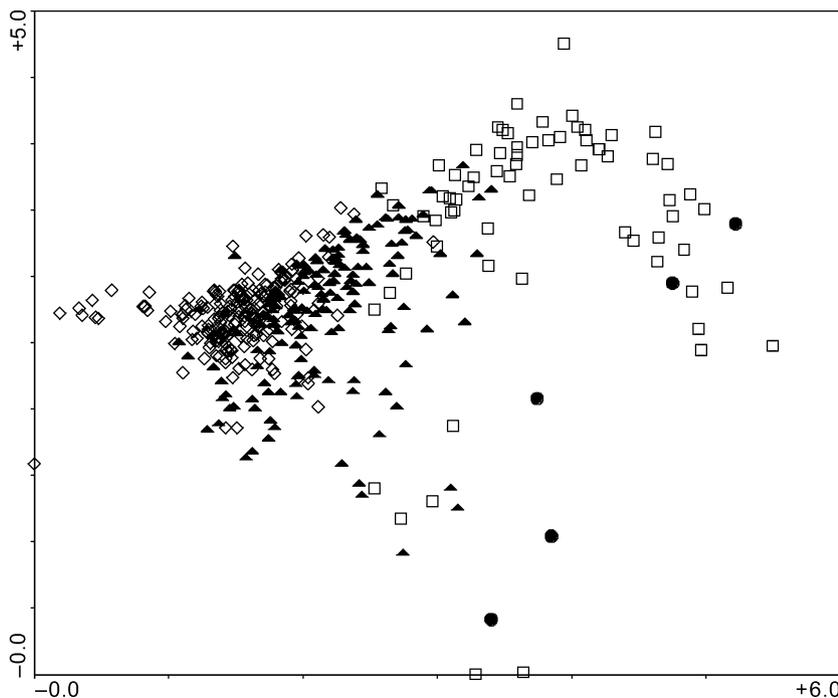
For the classification of acidified rivers in the Central mountains an acidification tool is needed. A special list

of acidification indicators was developed. The species of this list are also elements of the reference list for siliceous river sites. But at high ecological status only a few individuals are to be recognised. If the abundance-sum of the acidification indicators concerned exceeds a defined percentage of the biocoenosis, the result of trophic- and reference-taxa calculation will be devaluated. In a similar way, the calculation will be devaluated if the degree of salinity in a waterbody exceeds a certain amount (SCHAUMBURG et al. 2004) using the “Halobien-index” of ZIEMANN (1999) as a metric.

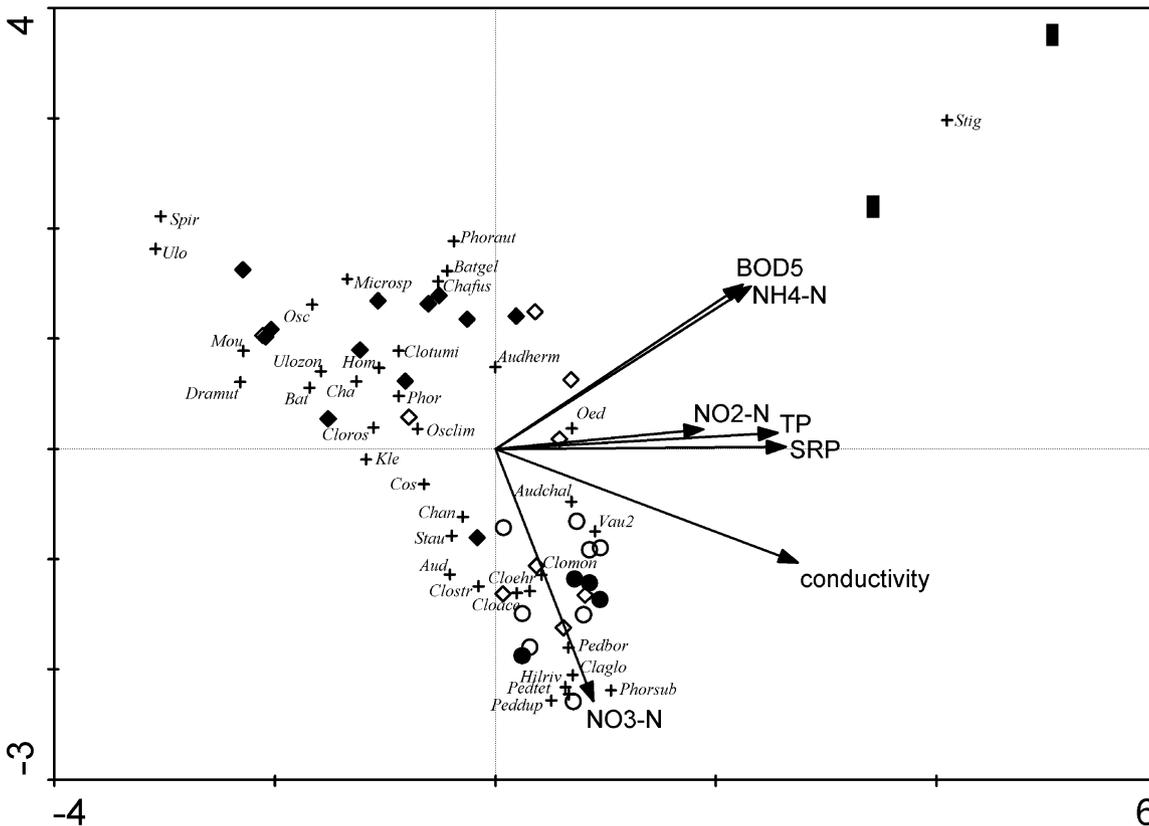
### Remaining phytobenthos

In order to develop an assessment method, information was gathered about the distribution of taxa with regard to relevant environmental factors. Multivariate analysis within each type were performed to see (a) whether there was a grouping of species and sites and (b) which environmental factors would explain the distribution of the species. These analyses were most successful for the sites belonging to PB-type 3, i.e. siliceous sites in the Central mountains. Fig. 3 shows the first and second axes of a CA ordination diagram.

Sampling sites which lie closely together show a similar species composition. The crosses represent the centre of each species’ distribution. Environmental variables which have a significant influence on the species distribution are depicted as arrows. They start from the origin with their average value and extend towards high-



**Fig. 2.** DCA, diatom-biocoenoses of all investigated river sites. Classification according to KELLY (1996). Index-value: 1.00–1.99 = circles; 2.00–2.99 = squares; 3.00–3.99 = triangles; 4.00–4.99 = rhombs.



**Fig. 3.** CA ordination diagram with data from 51 remaining phyto-benthos sampling events at 26 sampling sites which had been classified as siliceous sites in the Central mountains.

Explanations: Filled diamonds = sampling sites which were pre-classified as very good sites; open diamonds = sites which were pre-classified as good sites; open circles = presumably moderate sites; filled circles = presumably bad sites; filled squares = sampling events from a site pre-classified as poor; crosses = the center of the species' distribution; arrows = relevant environmental variables, they start from the origin with their average value and extend toward higher values.

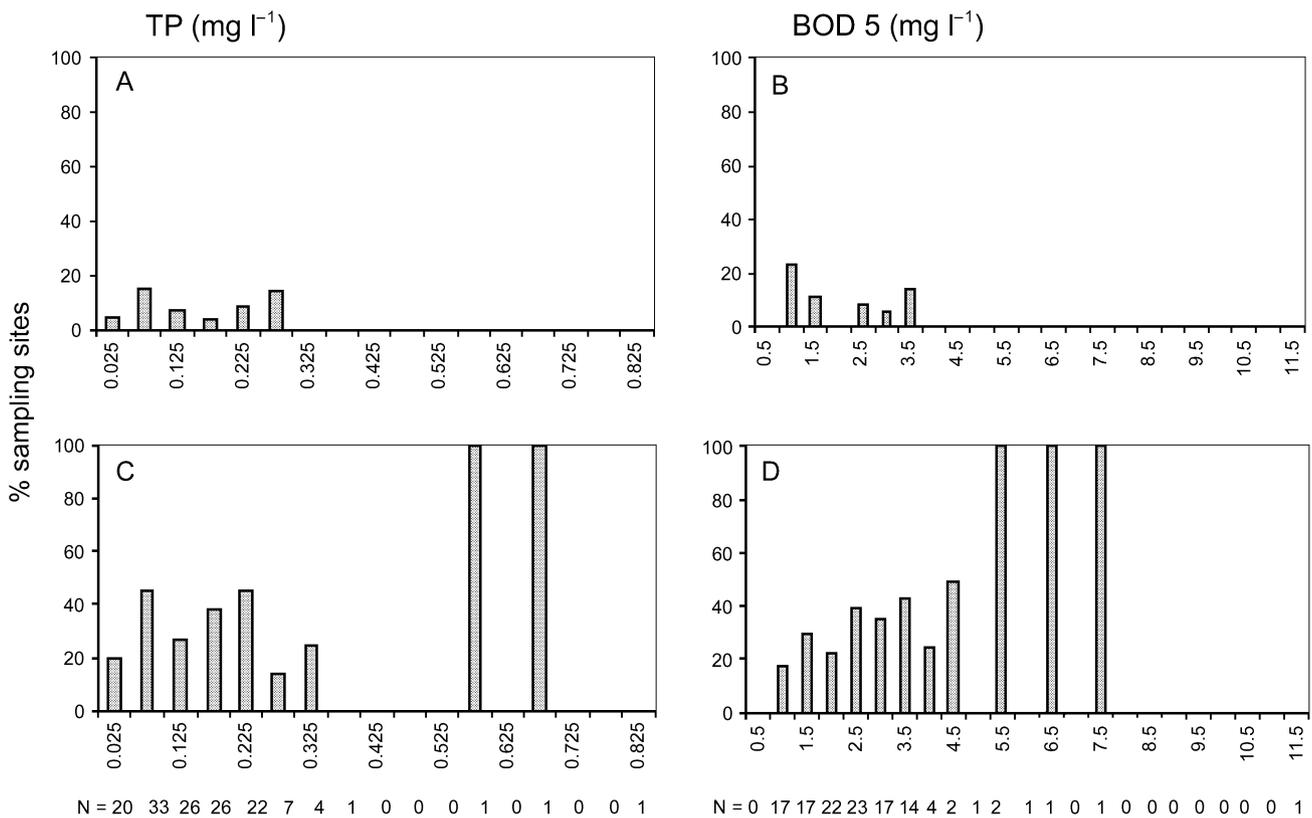
er values. As can be seen from Fig. 3, there are two sampling events (which stem from one sampling site) which are characterised by high levels of BOD<sub>5</sub> and NH<sub>4</sub>-N. *Stigeoclonium* sp. (*Stig*) is shown as a characteristic species for these samples. All other sampling sites form a more or less contiguous group. Sampling sites in the 4th quadrant are characterised by higher values for NO<sub>3</sub>-N and conductivity, thus representing more impacted sites. Species which have their centre of distribution close to these sites are *Phormidium subfuscum* (*Phor-sub*), *Cladophora glomerata* (*Claglo*), *Hildenbrandia rivularis* (*Hilriv*), *Closterium ehrenbergii* (*Cloehr*), *Cl. acerosum* (*Cloace*), *Cl. moniliforme* (*Clomon*), *Cl. strigosum* (*Clostr*), *Vaucheria* sp. (*Vau2*), *Audouinella chalybea* (*Audchal*). Opposite to these sites, in the 2nd quadrant, there are sampling sites with lower than average values for all environmental parameters shown in the diagram. Here, taxa such as *Spirogyra* sp. (*Spir*), *Ulothrix* sp. (*Ulo*), *Ulothrix zonata* (*Ulozon*), *Mougeotia* sp. (*Mou*), *Draparnaldia mutabilis* (*Dramut*), *Batrachospermum* sp. (*Bat*), *Batrachospermum gelatinosum*

(*Batgel*), *Chamaesiphon* sp. (*Cha*), *Chamaesiphon fuscus* (*Chafus*), *Closterium rostratum* (*Cloros*), *Cl. tumidum* (*Clotum*), *Phormidium* sp. (*Phor*), *Phormidium autumnale* (*Phoraut*) and *Audouinella hermannii* (*Audherm*) can be found. The environmental gradient is quite strong along the first and the second axis and explains 16.5% of the variance in the species distribution (Table 6).

Such an ordination diagram gives a first idea which species might be characteristic for polluted or non-polluted situations. However, the crosses on the ordination diagram represent only the centre of the species distribution but convey no information about the species' tolerances. Therefore, additional univariate analyses were conducted, and the species' occurrences in regard to the following environmental variables was investigated: hardness of water, pH, conductivity, NO<sub>3</sub>-N, total phosphorus (TP) and BOD<sub>5</sub>. As an example, Fig. 4 shows the presence of *Batrachospermum gelatinosum* (N = 18, Fig. 3A, B) and the presence of *Closterium acerosum* (N = 61, Fig. 3C, D) over the range of TP-values and BOD<sub>5</sub>-values present at the sampling sites.

**Table 6.** Variance of distribution of remaining phytobenthos species; results of CA analysis (Fig. 3).

Axes	1	2	3	4	Total inertia
Eigenvalues	0.474	0.452	0.399	0.339	5.606
Species-environment correlations	0.755	0.862	0.278	0.469	
Cumulative percentage variance					
of species	8.5	16.5	23.6	29.7	
of species-environment relation	19.1	42.8	45.0	50.3	
<hr/>					
Sum of all eigenvalues					5.606



**Fig. 4.** Records of *Batrachospermum gelatinosum* (A, B) and *Closterium acerosum* (C, D) in relation to the range of values for TP (A, C) and BOD<sub>5</sub> (B, D). Below, the absolute number of sampling sites per class (N) is given.

*Batrachospermum gelatinosum* occurs at sites of moderate values of TP and BOD<sub>5</sub>. *Closterium acerosum* could be found over almost the whole range of TP-values, this species also tolerates high values of BOD<sub>5</sub>. Additional information about the species distribution was gathered from the literature and compiled in a database. These sources of information (multivariate, univariate and literature data) jointly provided indication on tolerances and preferences of taxa with regard to geomorphology (pH, conductivity, hardness), trophic, and sapro-

by (NO<sub>3</sub>-N, TP, BOD<sub>5</sub>). Based on these results, species were classified into 4 categories:

- A: sensitive species, characteristic of a certain type of water bodies;
- B: less sensitive species, more widely distributed, indicating good conditions;
- C: tolerant species, indicating eutrophication, when present in high abundance;
- D: species prefers strongly eutrophicated conditions.

So far, 84 taxa were grouped into these categories. Further investigations will hopefully yield more useful species, which then can be added to the list of indicative species. For the assessment of the ecological status of the sampling sites an index was developed which takes into consideration the abundance of the type-specific indicator species. Different weighting was assigned to the four indicator groups. The index is calculated by formula (2):

$$BI = \frac{\sum_{i=1}^{n_A} Q_{Ai} + \frac{1}{2} \sum_{i=1}^{n_B} Q_{Bi} - \frac{1}{2} \sum_{i=1}^{n_C} Q_{Ci} - \sum_{i=1}^{n_D} Q_{Di}}{\sum_{i=1}^{n_A} Q_{Ai} + \sum_{i=1}^{n_B} Q_{Bi} + \sum_{i=1}^{n_C} Q_{Ci} + \sum_{i=1}^{n_D} Q_{Di}} * 100$$

where:  $Q_{Ai}$  ( $Q_{Bi}$ ,  $Q_{Ci}$ ,  $Q_{Di}$ ) is the squared abundance of a taxon  $i$  belonging to category A (B, C, D) with  $i$  in the summations running over all taxa belonging to A (B, C, D), i.e.  $i$  from 1 to  $n_{A(B, C, D)}$ , respectively.

Theoretically, the index lies between +100 (only species from category A are present) and -100 (only species from category D are present). Type-specific limits were set to derive the five ecological quality classes. In order to calculate an index and to derive the ecological status class of a sampling site, at least 5 indicative species have to be found, or (if there are less species present) the total sum of the squared abundance must be  $\geq 16$ . A more detailed example of the calculation of this index is given in GUTOWSKI et al. (2004). At present we were able to develop type-specific systems for an assessment of the ecological status of a sampling event for PB-types 3, 4 and 5. Due to a lack of data no assessment routine could be proposed yet for types 1 and 2 (see Table 3).

### Entire quality element

For the classification of the entire quality element macrophytes and phytobenthos according to the WFD the three single components had to be combined to one system. As described above, for each component relevant types were defined and lists of reference and other indicator species were compiled. Table 5 shows the number of the species used.

Indices for the macrophytes, diatom and remaining phytobenthos components are calculated as shown above. After converting to a comparable scale (0–1), the index values are combined by averaging. To delimit different quality classes, type-specific borders were set. An example is given in Table 10.

The assessment of the ecological status is based primarily on the classification of taxa to different groups which are either characteristic for reference conditions or which indicate different degrees of deviation from such conditions. Additionally, parameters like dominant

species (M), number of taxa (MP), evenness index (M), trophic index after ROTT et al. (1999) (D), saprobic index after ROTT et al. (1997) (D), salinity index (“Halobienindex”) after ZIEMANN (1999) (D) and acidification status (D) are taken into consideration as well. Therefore, the proposed classification system is an integrated system to indicate the changes of benthic plant biocoenoses in species composition and abundance at different levels of degradation as well as the degree of some major impacts like eutrophication, acidification, and salinisation.

As mentioned above, for the assessment of the quality elements minimal necessary abundances are laid down specifically for each river type. For the summed quantities, percentage of species and number of taxa for macrophytes as well as for the coverage and number of taxa of remaining phytobenthos restrictions are to be recognised. If these requirements are not met, the assessment of the component is considered unsafe and will not be included in the assessment of the entire quality element.

Following these principles, it was possible to establish a classification method for 5 macrophyte types, including one subtype, 3 phytobenthos types and 13 diatom types, including three subtypes. For the classification of the entire quality element macrophytes and phytobenthos, the following example is given.

### Example: Application of the classification system

In order to assess the ecological status of a sampling site by means of macrophytes and phytobenthos, the following steps have to be taken:

- asignment of the sampling site to the relevant type;
- mapping and sampling the benthic flora;
- compilation of species list including abundance;
- calculation of the indices for each component separately;
- calculation of additional metrics, if necessary;
- calculation of the index for assessment for the entire quality element;
- determination of the ecological status.

**Table 7.** Typology attributes of the river “Mordgrundbach”.

Attribute	Value
Ecological region (according to ILLIES 1978)	Central mountains
Fluvial landscape (BRIEM 2003)	crystalline basement
Dimension of catchment area	< 100 km <sup>2</sup>
Mean width	2.5 m
Depth category	1 (0–30 cm)
Current velocity	3 (0.1–0.3 m s <sup>-1</sup> )
Effect of ground water	none
Water hardness	< 1.4 mmol/l
Acid capacity	< 1.4 mmol/l

**Table 8.** Macrophyte- and phytobenthos-data of river "Mordgrundbach" (all components sampled once in summer).  
 Explanations: \* A: taxa showing high abundance at reference sites and low or no abundance under non-reference conditions. C: taxa rarely found under reference conditions. They usually have high abundance at sites with very low or no abundance of Group A taxa. B: taxa show no preference for reference or non-reference conditions. They occur together with taxa from species group A and species group C.  
 \*\* R: reference taxon, T: type-specific reference taxon.  
 \*\*\* A: sensitive species, characteristic of a certain type of water bodies. B: less sensitive species, more widely distributed, indicating good conditions. C: tolerant species, indicating eutrophication, when present in high abundance. D: species prefers strongly eutrophicated conditions.

Macrophytes						Benthic diatoms					
Taxon name	Species group*	Abundance (KÖHLER 1978)	Acidification			Taxon name	Species group**	Abundance (%)	Trophic value (ROTT 1999)	Trophic weight (ROTT 1997)	Acidification
<i>Agrostis stolonifera</i>	B	1				<i>Gomphonema</i> sp.		0.2			
<i>Callitriche hamulata</i>	A	2				<i>Gomphonema olivaceum</i>	R	0.6	1.2	2	
<i>Chiloscyphus polyanthos</i>	A	2				var. <i>minutissimum</i>					
<i>Fontinalis antipyretica</i>	C	3				<i>Gomphonema parvulum</i> -Sippen		3.6			
<i>Glyceria fluitans</i>	B	2				<i>Meridion circulare</i>		1	2.5	2	
<i>Mentha longifolia</i>		2				<i>Meridion circulare</i>	R	0.2	1.2	2	
<i>Myosotis nemorosa</i>		2				var. <i>constrictum</i>					
<i>Nasturtium</i> sp.		1				<i>Navicula cryptocephala</i>		1.7	3.5	4	
<i>Petasites albus</i>		2				<i>Navicula exilis</i>	R	0.6	2	1	
<i>Phalaris arundinacea</i>	B	2				<i>Navicula gregaria</i>		0.6	3.5	4	
<i>Ranunculus aquatilis</i>	B	3				<i>Navicula ignota</i>	R	0.2	1.8	2	
<i>Ranunculus repens</i>		2				var. <i>acceptata</i>					
<i>Rhynchosstegium riparioides</i>	C	3				<i>Navicula lanceolata</i>		1.5	3.5	4	
<i>Veronica beccabunga</i>		1				<i>Navicula minima</i>		0.2	2.9	2	
-----						<i>Navicula rhynchocephala</i>		0.4	2.3	1	
Benthic diatoms						<i>Navicula suchlandtii</i>	R	1.5	0.6	2	
Taxon name	Species group**	Abundance (%)	Trophic value (ROTT 1999)	Trophic weight (ROTT 1997)	Acidification	<i>Nitzschia acidoclinata</i>	R	1.2	2.3	2	
<i>Achnanthes helvetica</i>	R	1.3	0.6	3	X	<i>Nitzschia amphibia</i>		0.2	3.8	5	
<i>Achnanthes kranzii</i>	R	2.3				<i>Nitzschia dissipata</i>		0.6	2.6	1	
<i>Achnanthes lanceolata</i>		2.7	3.3	3		var. <i>media</i>					
<i>Achnanthes lanceolata</i> ssp. <i>frequentissima</i>		0.6	2.8	3		<i>Pinnularia</i> sp.		0.4			
<i>Achnanthes minutissima</i>	R	37.2	1.2	1		<i>Pinnularia schoenfelderi</i>	R	0.2			
<i>Achnanthes oblongella</i>	R	0.4	1	2		<i>Pinnularia silvatica</i>	R	0.2			X
<i>Amphora pediculus</i>		0.4	2.8	2		<i>Pinnularia subcapitata</i>	R	0.2	0.9	2	X
<i>Cocconeis placentula</i>	T	2.9	2.6	2		<i>Stauroneis kriegerii</i>	R	0.2	3.3	2	
<i>Cymbella minuta</i>	R	0.6	2	1		<i>Surirella brebissonii</i>		0.4	3.6	5	
<i>Cymbella naviculiformis</i>	R	0.4	1.8	1		<i>Surirella roba</i>		0.2	0.6	2	
<i>Cymbella silesiaca</i>		0.4				<i>Tabellaria flocculosa</i>	R	0.6	0.8	2	
<i>Cymbella sinuata</i>	T	0.6	2.1	1		-----					
<i>Diatoma anceps</i>	R	0.2	0.3	2		Remaining phytobenthos					
<i>Diatoma mesodon</i>	R	2.9	0.7	4		Taxon name	Species group***	Abundance (Table 2)			
<i>Eunotia exigua</i>	R	0.2	0.5	3	X	<i>Aphanocapsa</i>		1			
<i>Eunotia incisa</i>	R	0.2	0.6	2	X	<i>Chamaesiphon</i>	B	1			
<i>Eunotia minor</i>	R	3.6				<i>Chantransia</i>	B	2			
<i>Eunotia rhomboidea</i>	R	0.2	0.6	2	X	<i>Closterium moniliferum</i> var. <i>concaum</i>	C	1			
<i>Fragilaria bicapitata</i>		0.4	1.1	1		<i>Closterium rostratum</i>	A	1			
<i>Fragilaria brevistriata</i>		0.4	3	1		<i>Closterium strigosum</i> var. <i>elegans</i>	C	1			
<i>Fragilaria capucina</i>		1				<i>Closterium tumidulum</i>	B	1			
<i>Fragilaria capucina</i> var. <i>gracilis</i>	T	18.8	1.1	2		<i>Closterium tumidum</i>	A	1			
<i>Fragilaria construens</i> f. <i>venter</i>	T	1.5	2.3	2		<i>Cosmarium</i>		2			
<i>Fragilaria exigua</i>	R	1	0.6	2		<i>Klebsormidium</i>		1			
<i>Fragilaria pinnata</i>		0.6	2.2	1		<i>Lemanea</i>	B	4			
<i>Fragilaria ulna</i>		2.5	3.5	4		<i>Microspora</i>		1			
<i>Fragilaria ulna</i> acus-Sippen		0.2	1.8	2		<i>Oedogonium</i>	C	1			
<i>Fragilaria virescens</i>	R	0.4	1.4	1		<i>Phormidium</i>		1			
						<i>Scenedesmus</i>		1			
						<i>Staurastrum</i>		1			
						<i>Tribonema</i>	B	1			

**Table 9.** Classification example "Mordgrundbach": calculated metrics and their variation for this river type.

Additional metrics: \* ecological status class is to be set to 3 when acidification indicators reach 100%; \*\* deviation of ecological status class: one class if acidification indicators reach 10%, two classes if acidification indicators reach 26%, three classes if acidification indicators reach 51%, four classes if acidification indicators reach 76%.

Attributes	Indices	Variation	Additional metrics
Reference index (macrophytes)	0.13	<0.67 – 0.10	
% indicators of acidification (macrophytes)			0*
Diatom index	0.68	0.71 – >0.47	
% indicators of acidification (diatoms)			2.3**
Phytobenthos index	0.78	1.00 – 0.75	
Average entire quality element (MPD)	0.53	0.71 – >0.39	
Deviation (additional criteria)			None

**Table 10.** Classification of the entire quality element of one biocoenotic river-type for benthic plants, \*\* circle shows the result for the example river Mordgrundbach.

Phytobenthos	Siliceous rivers of Central mountains			
Diatoms	Central mountains rivers of variegated sandstone and crystalline basement, catchment area < 100 km <sup>2</sup>			
Macrophytes	Lowland rivers in mountainous areas, subtype MPG (influenced by groundwater)	Lowland rivers in mountainous areas	Fast flowing rivers and brooks of mountainous areas (soft water), Phanerogams	Fast flowing rivers and brooks of mountainous areas (soft water), Bryophyta
Ecological status class	Ranges of classification			
1 (high)	1.00 – >0.78	1.00 – >0.73	1.00 – >0.69	1.00 – >0.71
2 (good)	0.78 – >0.53	0.73 – >0.44	0.69 – >0.53	0.71 – >0.39
3 (moderate)	0.53 – >0.34	0.44 – >0.29	0.53 – >0.36	0.39 – 0.00
4/5 (poor and bad)	0.34 – 0.00	0.29 – 0.00	0.36 – 0.00	–

As an example, the results of the sampling site at the river Mordgrundbach in Saxonia, near the frontier of the Czech Republic, will be presented here. At this site all of the three plant modules have been found and could be classified. Table 7 shows the typology attributes of the sampling site.

According to these attributes, the sampling site was assigned to the following biocoenotic types:

- Remaining phytobenthos: siliceous rivers of the Central mountains;
- Diatoms: Central mountain rivers of variegated sandstone and crystalline basement, catchment area < 100 km<sup>2</sup>;
- Macrophytes: fast flowing rivers and brooks of mountainous areas (soft water).

In Table 8 the data collected at the site to taxonomic composition, abundance and the type specific attributes of the taxa are summarised.

Table 9 shows the results of the calculated indices and additional metrics for each plant component from Table 8 separately and for the entire quality element.

The index value for the entire quality element indicates a good ecological status for this site. Since the additional metrics do not show a reason for a deviation due to e.g. acidification, no further changes are required. To determine the ecological quality class on the basis of the entire quality element macrophytes and phytobenthos tables for each combination of biocoenotic types can be used (SCHAUMBURG et al. 2004). These tables assign the class boundaries according to WFD. The macrophyte

and phytobenthos community indicate a good ecological quality for this sampling site (Table 10).

## Discussion

Benthic aquatic plants are an important part of the riverine environment. They are primary producers, provide habitats for animals and stabilise sediments. Numerous human impacts can be detected by the use of aquatic plants. They are indicators of eutrophication and are sensitive to acidification or salinisation. Hence macrophytes and phytobenthos are an important and useful quality element for an assessment according to the WFD.

### Macrophytes

Macrophyte response to anthropogenic river habitat disturbance allows them to be used as bioindicators. Aquatic plant communities respond to degradation with changes in taxonomic composition, as well as an increase or decrease of plant abundance (KÖHLER 1975). Additionally, rooted aquatic plants link sediment and overlying water and are therefore able to indicate conditions in both river compartments (SCHNEIDER & MELZER 2003). Beside this spatial integration, macrophytes can also integrate temporal changes because of their relatively long generation times, which include at least one vegetation period up to several years. These features make them very suitable indicators for the purposes of the WFD. As a further advantage, aquatic macrophytes can be recorded relatively easily in the field, and their determination is normally not time consuming or expensive.

Aquatic macrophyte biocoenoses in some cases show a high degree of natural variability. Therefore, the attempt to develop an assessment tool for river sites based on helophytes proved unsuccessful. A depopulation of macrophytes can occur as a result of anthropogenic influences, e.g. eutrophication, but can also be due to flowing velocity or shading, i.e. natural reasons (STRAND & WEISNER 1996). Therefore, the absence of macrophytes at a river site cannot be interpreted as degradation. An indication of the ecological status by macrophytes requires a certain minimum plant quantity. If this type specific plant quantity is not met and the reasons of the absence cannot be clarified, the reference index (RI) must be denoted as inconclusive (for description of type specific requirements see MEILINGER 2003). In that case, the macrophyte component must be excluded of the classification of the entire quality element. Further problems could occur with the fact that an assessment system could not be developed for three of the macrophyte river types (Mg, TR, TNg, see Table 3) due to insufficient data.

Compared to other biological groups (e.g. diatoms), species numbers of macrophyte biocoenoses are relatively low. Therefore, type-specific species groups were developed on the basis of vegetation tables (species-by-site matrices, see Table 4) containing the data collected in the field. Macrophytes described in the literature but not found in our river sites, were incorporated in the relevant species group (MEILINGER 2003 for review). Thus, the classification of submerged taxa into ecologically similar groups of species provides good assessment system applicability and furthermore allows a controlled addition of new taxa, if necessary. The reference index for macrophytes is a tool for describing the deviation of the observed macrophyte communities from reference conditions. Therefore, every factor affecting the taxonomic composition and abundance of aquatic macrophytes is detected.

### Benthic diatoms

Diatoms and their demands and habitats have been known since the beginning of the 20<sup>th</sup> century (KOLKOWITZ & MARSSON 1908). Because of the short generation time, they are able to build a new biocoenosis in a few weeks. In case of changing environmental matters, a modification in taxonomic composition and abundance is indicating those impacts immediately. Diatoms are widespread and can be found in almost all running waters. Therefore diatoms are a suitable organism group according to WFD.

Their ability for indicating nutrients, salinity, acidification and saprobic status was used in the past for establishing several indices for monitoring running waters (e.g. KELLY 1996; ROTT 1997, 1999; CORING et al. 1999; ZIEMANN 1999). Some of these indices are modules of the developed assessment system. Trophic index, saprobic index and summation of reference taxa abundance are modules for calculating the diatom index. All of these modules are based on taxonomic composition and abundance, as demanded by the WFD. The developed system for diatoms is effectual for nearly all German river types. Only small siliceous and organic stamped brooks and rivers of Northern Germany cannot be evaluated yet because of insufficient data. The additional criteria acidification and salinity indicate forms of human impacts which cannot be identified by the other modules (except acidification by macrophytes).

### Remaining phytobenthos

Benthic algae are a main component of the flora of running waters which are embedded into the flow-balance of input and output of matter. They are important primary producers and are among the first to accumulate inor-

ganic phosphorus and nitrogen. By reacting to environmental conditions, phytobenthos gives an integrated picture of influences to the water body and may tell us about the status of nutrients, thermal and oxygen conditions, salinity, acidity, and toxic influences. Therefore analysing this component may give valuable information for the monitoring routine and can make the presently applied methods more robust (see FRIEDRICH 1996; ELORANTA & KWANDRANS 1996; PIPP & ROTT 1996).

Unfortunately, no long-lasting research tradition using benthic algae excluding diatoms and Charales as indicators has been established in Germany so far, and data to classify the species according to the ecological status is deficient. Taxonomical and nomenclatural problems make things even harder. For practical use there is a guidance for trophic indication, which includes about 15 macroscopically visible benthic algae of different taxonomic level (MAUCH et al. 1995, 1998). Most of them are eutrphent taxa. Based on a literature study, SCHMEDITJE et al. (1998) classified 138 non-diatom taxa of benthic alga with regard to trophic indication. Many of them indicate the oligo- and mesotrophic range. In Austria, however, an extensive database exists which gives indicator values for benthic algae in running waters. These allow to indicate trophic and saprobic conditions as well as the geochemical type of water (ROTT et al. 1997, 1999). For Germany, new analyses were necessary in order to characterise the algal flora associated with different ecological regions.

In this paper, we present our attempt to elaborate an evaluation of ecological status for some types of running waters in Germany on the basis of analyses of data of 13 classes of benthic algae (excl. diatoms and Charales) at 152 sites all over Germany. A first method to assess the ecological status of running water by means of benthic algae was developed which is in accordance with WFD. Further investigations are definitely necessary to consolidate the evaluations made so far and to work out further details. Additional sampling sites in the alpine and fore alpine region need to be characterised by own investigations. In our studies the calcareous sites in the Central mountains and the Central lowlands seemed to be especially heterogeneous and need further investigation. Organic sites (influenced by peat) in the Central Lowlands proved also to be interesting.

Further investigations will probably also allow to add more indicator species to the type-specific lists. This would improve the basis of assessment and enhance its applicability. Therefore, the autecology of species has to be investigated by correlating the occurrence of species with physico-chemical data of the sampling site. In the ideal case ecophysiological studies in the laboratory would support work in the field.

## Entire quality element

A common problem of all new developed classification systems concerning the WFD is the lack of naturally undisturbed reference sites in some regions of Germany. In this study, sites with only very minor human impacts were used to develop river typologies and to acquire type specific species groups. To compensate low numbers of reference sites within some types, literature review and expert knowledge were used supplementary (see SCHAUMBURG et al. 2005).

The comparison with the abiotic typology (20 types) from SCHMEDITJE et al. (2001b) allows the following conclusions: (1) There is less differentiation of water bodies across Germany with the single benthic plant components, i.e. for classification with the quality element macrophytes and phytobenthos fewer types are needed. (2) There is quite good agreement between the biocenotic plant types and the abiotic types. The original abiotic typology of SCHMEDITJE et al. (2001b) has been further developed by POTTGIESSER & SOMMERHÄUSER (2004). Compared to this typology there is some more differentiation with the biocoenotic plant types in a few cases e.g. volcanic streams in the Central mountains of Germany. Because of the overlap of the types of the three single plant components there are 19 reasonable theoretical combinations of these biocoenotic types of macrophytes, diatoms and remaining phytobenthos. But for practical purposes there will be fewer because not all of the theoretical combinations really occur.

The three components of the entire quality element in some cases show differences in the calculated results of one site although in most cases these results are comparable. The expected differences can be explained by the biological differences in occurrence, growth and lifetime of the elements. Macrophytes are long living organisms and are rooted to the sediment, therefore they integrate environmental conditions for a longer time. Diatoms can raise new populations in a very short time, therefore they react very quick to environmental changes. They show quite different seasonal aspects of appearance over a year. Remaining phytobenthos contains both, short reacting species and longer lasting ones.

According to our present experience, for the entire quality element macrophytes and phytobenthos two samplings per year are recommended to cover important situations for assessment: one in summertime for all three components and a second one in autumn only for diatoms and remaining phytobenthos. In the alpine and fore alpine ecoregion the latter two should be sampled in late winter or early spring. When sampling all components at the same time, attention should be paid to a special order. To avoid damage to one of the components one should start with sampling the diatoms, then the remaining phytobenthos, and end with the macrophytes.

The classification system as developed and presented here allows for the assessment of the ecological status of sampling sites at rivers in Germany by means of macrophytes and phytobenthos. Like all the upcoming suggestions of new ecological classification systems, it must be seen as a first draft, and further research in this area is necessary to validate the results and fill existing gaps. For the use of macrophytes and diatoms numerous tools and metrics which are useful for the WFD (e.g. trophic indices) already exist. A completely new dimension for routine monitoring is to adapt these metrics to ecoregions and regional types respectively. Another challenge are the normative definitions for the quality elements. It is not trivial to define references and the deviations from these references. There are at least two aspects to recognize. First the variations of the biocoenosis (i.e. taxa composition and abundance) and second the reasons for these variations mostly coming from human activities which are summarised as impacts of pressures. The classification should not only express the measurement of these impacts with some of the existing metrics, but should also reflect the reaction of the biocoenosis to these impacts expressed by the deviation of taxonomic composition and abundance from the reference conditions. The classification system is in accordance with the criteria laid out in WFD. It is based on biocoenotic data, on the species composition and the abundance of the species of the entire quality element of macrophytes and phytobenthos. It takes into consideration the different characteristics of different types of rivers, and the assessment of the ecological status is done by comparing the actual situation in regard to the community composition to type-specific reference conditions. The plant community will indicate mostly the trophic status of the river and react to eutrophication. However, additional criteria are available which allow for the detection of other forms of human impacts, such as acidification and increased salinity. The EU-Classification-guidance (ECOSTAT 2003) proposes to average indices which will react to similar impacts on the level of each quality element, whereas effects of different impacts (like acidification and eutrophication) cannot be averaged because some species are reference indicators according to eutrophication but indicators of degradation according to acidification. Hence these impacts have to be considered separately. Therefore we included the metrics which express eutrophication into the plant classification modules which were averaged at the end, but degradations other than eutrophication (as shown by the additional metrics) can lead to a subsequent lowering of the ecological status class.

Also further human pressures which are not expressed by additional metrics can be detected with our classification. The reference index is a tool for describ-

ing the deviation of the observed benthic plant communities from reference conditions. Therefore, every factor affecting the taxonomic composition and abundance of benthic plants is detected. The classification system therefore provides an integrating assessment of the ecological status rather than simply indicating trophic status. It combines scientific demands with the aims of applicability. The requirements of the European Water Framework Directive are thus fulfilled. In the years 2004 and 2005 a test in practice gives us the possibility to show deficiencies but also the applicability of the proposed method.

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