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Macrophytes and phytobenthos as indicators of ecological status in German lakes – a contribution to the implementation of the Water Framework Directive

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Abstract

A new assessment system for macrophytes and phytobenthos in German lakes according to the Water Framework Directive of the European Community is described. Based on biological, chemical and hydromorphological data from about 100 lake sites covering the main ecoregions, hydromorphological lake types and degradation forms, biocoenotic types could be defined. For developing a classification system the quality element macrophytes and phytobenthos was divided into two components: macrophytes and benthic diatoms. For macrophytes 4 and for benthic diatoms 4 lake types were identified. The benthic vegetation at reference conditions is described and 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 a few of the described lake types further investigations are necessary before a classification can be developed.

Key words: Water Framework Directive – benthic plants – macrophytes – phytobenthos – diatoms – ecological classification – reference conditions – species groups – lakes

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 bodies of water in lakes exceeding a surface area 0.5 km^2. This status shall be determined by the biological quality elements phytoplankton, macrophytes and phytobenthos, benthic invertebrate fauna and fish. As supporting elements, the physical and chemical properties of the water bodies are to be used as well as the hydro-morphological situation of the lakes. For each of the biological quality elements, the taxonomic composition and abundance of the taxa have to be determined, and five status classes (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, that means

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for each type reference conditions have to be identified, and degradation has to be described by quantifying the deviation in species composition and abundance from those present at reference conditions. For macrophytes and phytobenthos in Germany, no routine fulfilling these demands existed. Here, we present an overview over the results of a four year project in an exemplary way where methods for implementing the Water Framework Directive for macrophytes and phytobenthos in German lakes were developed. The detailed results for all lake 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. 2004a; http://www.bayern.de/lfw).

Material and Methods

Sampling design

Existing knowledge about different sampling methods, approaches for a classification of macrophytes and phytobenthos to determine the ecological status of lakes and existing data on species distribution were compiled and evaluated in a literature study (SCHMEDTJE et al. 2001). In about 100 lakes all over Germany (Fig. 1), diatom samples were taken and macrophytes were mapped, so that the main ecoregions in Germany (after ILLIES 1978) and different geomorphologic lake types (MATHES et al. 2002) were covered.

For the development of the classification system, the quality element macrophytes and phytobenthos was divided into two components: (a) macrophytes and (b) benthic diatoms. 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, diatoms have short generation times and show quick changes of environmental conditions. The number of sites and collections for each component is shown in Table 1.

At each sampling site, biological and morphological data were recorded. Chemical and physical data of the sites like concentrations of ammonium, nitrate, nitrite, total nitrogen, soluble reactive phosphorus (SRP), total phosphorus, chloride, calcium, pH and conductivity (20 °C) were determined by local German Authorities for Water Management, following the DIN-standard methods (vertical profiles at deepest lake point several times a year). For each lake, data of the year corresponding to the macrophyte and diatom surveys was used. Trophic status was calculated according to LAWA (1999).

Mapping, sampling and material treatment

The submerged and free floating aquatic macrophyte (Charophytes, Bryophytes and Tracheophytes) abundance was estimated once during late June to early August. At each lake, 1–15 sites were investigated according to the lake size. Site locations were chosen with at least 50 m distance to inlets and outlets, based on structural characteristics (e.g. surrounding vegetation and land use, sediment and slope). Aquatic vegetation was surveyed either by SCUBA diving following MELZER (1999) or by boat/wading (using a water viewer, a weighted or a double-headed rake on a rope, Ekman-Birge-grab sampler, as appropriate) according to STELZER & SCHNEIDER (2001). Both methods lead to comparable results (STELZER 2003). A minimum of 20 m of homogeneous lake shoreline was investigated, with each site being divided into four depth zones (MELZER 1999): 0–1 m; 1–2 m; 2–4 m; >4 m. Structural characteristics such as bottom type, degree of shading, slope and anthropogenic usage were recorded (STELZER 2003). The quantity of species was estimated based on a five degree scale (KOHLER 1978): 1 = very rare; 2 = rare; 3 = common; 4 = frequent; 5 = abundant, predominant. With the exception of Bryophyta (without *Fontinalis antipyretica*), determination was done at the species level.

In benthic diatom communities seasonal fluctuations with important changes of the species composition in lakes are well known (e.g. CASTENHOLZ 1960; HOFMANN 1994). These changes can differ between lake types. For the development of the classification samples were taken three times a year in spring, summer and autumn. The characterisation of the communities should be enabled as well as a decision, which season would be the best for the future sampling procedure. Samples were taken from type specific natural substrates allocated over the whole sampling site in a constantly submerged area. Where reed belts were present samples were taken from the waterside, crops of macrophytes were avoided. When hard substrates like stones were available the diatom layers were abraded with a spoon or spatula from the top sides of the stones. In cases of soft substrates like sand, gravel and organic matter the diatom layers were taken off by lifting them carefully with a spoon. The suspension was stored in a container and fixed with formaldehyde with a final concentration of 1% to 4%.

Table 1. Numbers of lakes, sites, samples and taxa found.

	Macrophytes	Benthic diatoms
Lakes	96	101
Sites	272	123
Samples		339
No. of taxa found	169	499

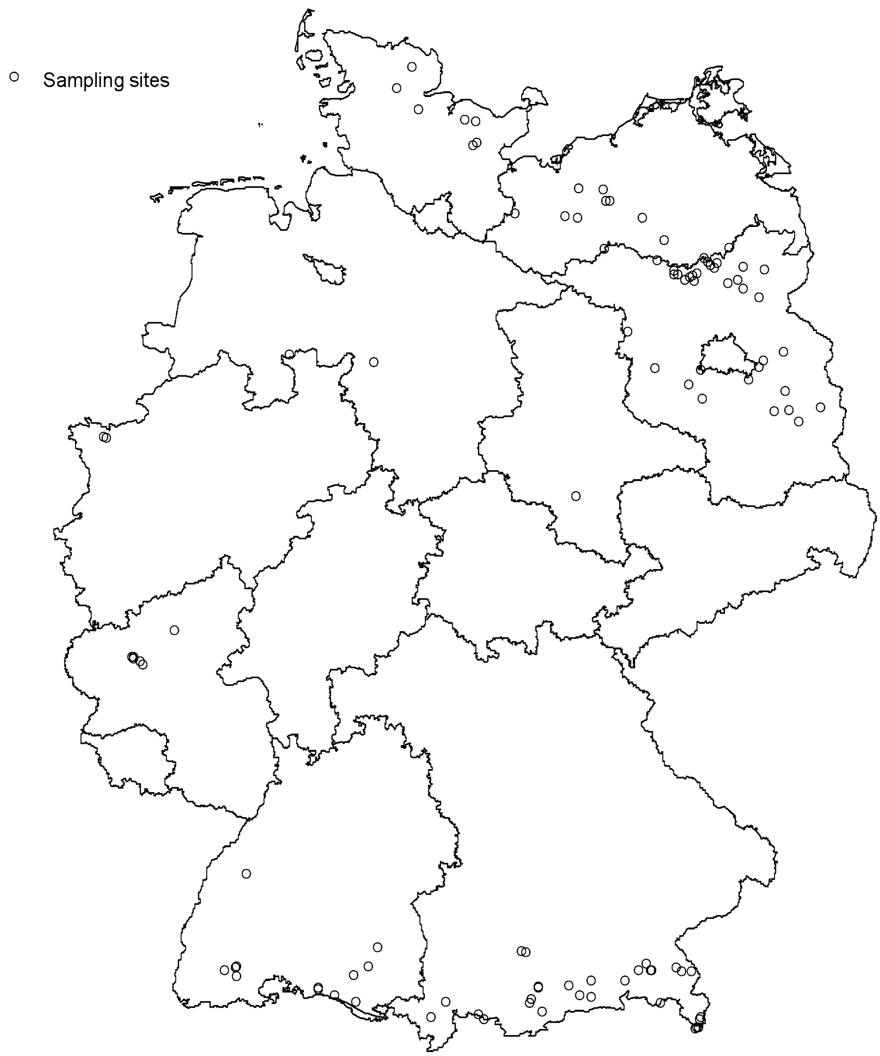

Fig. 1. Map of German investigation sites for benthic plants in lakes.

The material was cleaned by boiling in concentrated 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 1000. The nomenclature follows KRAMMER & LANGE-BERTALOT (1986–1991). At least 500 frustules were counted and species abundance was calculated as percentage of occurrence.

Data treatment

For analysing the biocoenosis data (taxa and abundance) cluster analyses, correspondence analyses (CA) and canonical correspondence analyses (CCA) were used. Transformation of the abundance data was partly necessary as described below.

To reflect the 3d-development of aquatic plants, the macrophyte abundance data were transformed into so called plant quantity using the function $y = x^3$ (JANAUER & HEINDL 1998; MELZER 1999). To determine natural lake site types (reference sites), correspondence analysis (CA; MVSP 3.12f) was performed. The Hill algorithm was used to ordinate sample scores. The number of axes to extract was identified by "Kaiser's rule" (STOYAN et al. 1997). Similarities in the species composition and the abundance of the species were investigated by means of vegetation tables (species-by-site matrix).

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). In addition to this similarities in species composition and abundance were analysed by means of vegetation tables (species-by-site matrix). The trophic diatom index was calculated according to HOFMANN (1999).

Results

Reference sites

For developing a lake site typology, sites with only very minor human impacts were used. Information from historical diatom samples and sediment core investigations was included in the selection of reference sites. Only sites showing nearly undisturbed physico-chemical (e.g. pH, salinity, saprobic and trophic status), hydromorphological and biological conditions were chosen. 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 71 reference sites resulted to develop the typology for the two plant components.

Biocoenotic typology

To (1) distinguish different biocoenotic lake site types and (2) compare these types with the geomorphologic lake types developed by MATHES et al. (2002), the taxonomic composition and abundance of the species found at the reference sites was analysed. As a result, 4 types for macrophytes (M) and 4 types for benthic diatoms (D) could be defined. The description of these types and their correlation to the typology of MATHES et al. (2002) is shown in Table 2.

The main descriptors of these biocoenotic lake types for the assessment with macrophytes and phytobenthos according to the WFD are the following (M = macrophytes, D = diatoms):

– ecological region (according to MATHES et al. 2002) (MD);
– geology by calcium content (MD);
– stratification (MD).

A more detailed description how these lake site types were derived is given in SCHAUMBURG et al. (2005), STELZER (2003) and with the following example of benthic diatoms. The substantial typology criteria for taxa composition and abundance in the investigated lakes are alkalinity and trophic status. The separation of the biocoenotic lake site types with diatoms could also be shown at the genus level but less clearly then at species level. A correspondence analyses of the taxonomic composition and abundance of diatoms at reference sites shows the sites within calcareous lakes of the Alps, Fore alps and the Lowlands of northern Germany along an axis together with the sites within siliceous lakes of the Central mountains (Fig. 2).

The group of sites within calcareous lakes are clearly to separate in those of Lowlands of northern Germany and those of alpine and fore alpine region. In sites within siliceous lakes of the Central mountains the highest species diversity of the biocoenosis can be recognised. The range of taxa composition lasts from under natural conditions slightly acidified up to circumneutral as well as to dystrophic biocoenosis. These diverse communities were united in only one type because in Germany only in a few lakes reference sites could be found due to the high sensitivity of these lakes to eutrophication and acidification. There are more types to be expected in that ecoregion after further investigations. For the sites within lakes of the Lowlands of northern Germany a further separation of types could be reached by describing their differences of species composition and abundance. In case of those lake sites this could only scarcely be recog-

Table 2. Biocoenotic lake types for benthic plants in Germany compared to geomorphological typology from MATHES et al. (2002).

Ecoregion	Macrophytes		Diatoms		Lake typology of MATHES et al. (2002)
Alpine and fore alpine regions	AK(s)	Sites within calcareous lakes in the in the Alps and their foreland including the subtype of extremely steep sites in Alpine lakes	D 1	Sites within calcareous lakes in the Alps and their foreland	1 2 3 4
Central mountains	MTS	Sites within siliceous lakes of the Central mountains and the lowlands of northern Germany	D 2	Sites within siliceous and dystrophic lakes of the Central mountains	9
Lowlands of northern Germany	TKg	Sites within stratified lake water bodies of the lowlands of northern Germany	D 3	Sites within stratified lake water bodies of the lowlands of northern Germany	10 13
	TKp	Sites within polymictic lake water bodies of the lowlands of northern Germany	D 4	Sites within polymictic lake water bodies of the lowlands of northern Germany	11 12 14

nised by studying the correspondence analyses. Four biocoenotic lake site types could be described on the basis of the collected data (Table 2).

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 lake site 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 for each plant component separately and were combined later to give an integrated method for the whole benthic plant community (entire quality element). For the development of the classification system, the two plant components 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 two plant

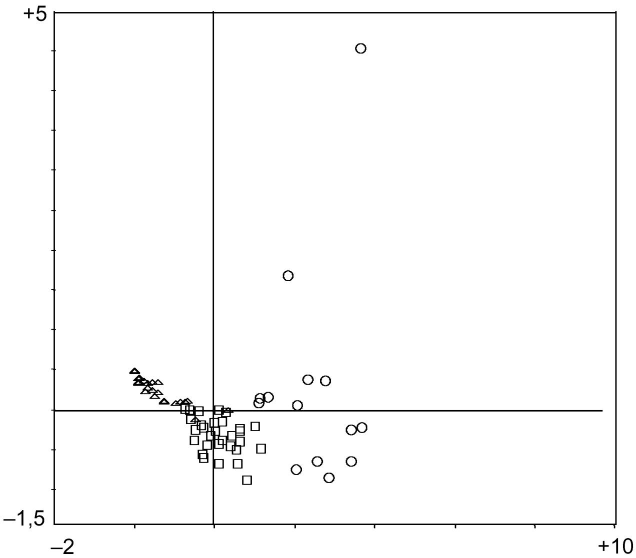

Fig. 2. Correspondence analyses (CA) of all samples of the potential reference sites, separation of ecological regions according to MATHES et al. (2002). Triangles: Alps and forealps; squares: Lowlands of northern Germany; circles: Central mountains.

Table 3. Vegetation table of lake site type MTS (mountainous soft water lakes); reference sites in bold letters; numbers representing plant quantity, summed up over different depth zones.

	Species Group A						Species Group B				Species Group C					
Site	*Isoëtes echinospora*	*Isoëtes lacustris*	*Elatine hexandra*	*Nitella opaca*	*Littorella uniflora*	*Myriophyllum alterniflorum*	*Nitella flexilis*	*Potamogeton berchtoldii*	*Fontinalis antipyretica*	*Chara aspera*	*Elodea canadensis*	*Ranunculus peltatus*	*Elodea nuttalli*	*Potamogeton crispus*	*Myriphyllum spicatum*	Reference Index
Feldsee 1	8	224		8		216										100
Feldsee 2				35		92										100
Feldsee 3				54		198										100
Titsee 2		125				64										100
Weinfelder Maar 1			62		16	24	8							1		91
Weinfelder Maar 2			133		285	8	8					27				87
Titisee 3						64			27							70
Pulvermaar 1				27		224	54	62						8		65
Pulvermaar 3				8		70	72	44								40
Pulvermaar 2						119	91	99								39
Schalkenmehrener Maar 1										250	54		341		93	–66
Schalkenmehrener Maar 2									1	125	35		243		160	–78
Schalkenmehrener Maar 3										8	54		341	8	92	–98
Gemündener Maar 2												35				–100
Immerather Maar 1															28	–100
Immerather Maar 2															8	–100

components and finally for the entire quality element of the benthic plant community in lakes were developed.

Macrophytes

For each lake site type, an unique assessment system was developed and reference sites as well as non-reference sites were evaluated to determine ecological status. In order not to neglect endangered species, rare taxa were not excluded. Using vegetation tables for each lake site type, reference biocoenoses were identified and the shift in vegetation with increasing degradation was shown. An example is given in Table 3, showing the vegetation table for the smallest data set, lake site type MTS (lakes of mountainous areas or the Central mountains with Ca^{2+} < 15 mg/l).

In Table 3, on top of the lines, undisturbed reference sites (bold letters) were placed. They provide a point of reference that the non-reference sites can be compared to. Species occurring mainly at reference sites are placed in the left part of the table. Subsequently, all other sites and species were arranged in the table according to their similarity or dissimilarity compared to the species composition at reference sites. Thus, lake sites were sorted by their deviations in species composition and abundance from reference sites, as demanded in the WFD.

For developing an assessment system, macrophyte species were classified into groups of taxa occurring under similar ecological conditions, specifically for each lake type. Three groups of species with the following ecological qualities were identified:

– Species group A contains taxa, showing high abundance under reference conditions 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, and usually have high abundance on 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 groups were confirmed from the literature (STELZER 2003) and in some cases slightly modified. A list of taxa for each species group for each lake type is given by STELZER et al. (2004, accepted). The following formula was used to calculate the Reference Index (RI) to determine the ecological status:

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

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

The resulting index values range from +100 (only species group A taxa) to –100 (only species group C taxa). For ranking of lake sites into classes of degradation, reference indices for each site were calculated. The range of RI values occurring on reference sites was defined as a benchmark for ecological quality class "high" according to the WFD. Based on the vegetation tables, the type specific deviation of the reference index was defined according to the guidelines of Annex V of the WFD. According to our experience, for a reliable assessment of the ecological status at least 75% of the total plant quantity at the respective lake site has to be obtained by indicative taxa (see STELZER et al. accepted) and the total plant quantity of indicative taxa has to be at least 55 for lake sites of type MTS. If one of these requirements is not met, the ecological status classified by macrophytes must be denoted as "unreliable" and should not be included in the assessment.

Benthic diatoms

WFD requires an assessment on the basis of changes in taxonomic composition and abundance. As useful tool for such a classification the combination of two metrics was proved successfully: The trophic index (TI) from HOFMANN (1994, 1999) and the calculation of the number of the species of four different ecological species groups containing 455 taxa in total. The main importance of the trophic status of lakes for the occurrence and abundance of diatoms could be confirmed as shown in Fig. 3.

With an evaluation of historical diatom samples from Bavarian lakes from the fist third of the 20^{th} century could be shown, that since that time the number of reference taxa in today still oligotrophic lakes decreased whereas the abundance sum did not show any trend (Bavarian Water Management Agency, accepted). This fact cannot be expressed with the indicated trophic status. Therefore as a second metric species groups were developed. Group A and group B combine taxa occurring at sites with high status. Group A contains reference taxa of soft-water lakes, group B those of calcareous lakes. These groups were formed by defining reference species from the current investigation and adding species of known autecology found in historical samples from these lakes. Furthermore species which can be expected in the German lake types were added based on autecological knowledge from literature. Most of the reference species show distinct geochemical preferences and could be added to the groups A or B. A few species

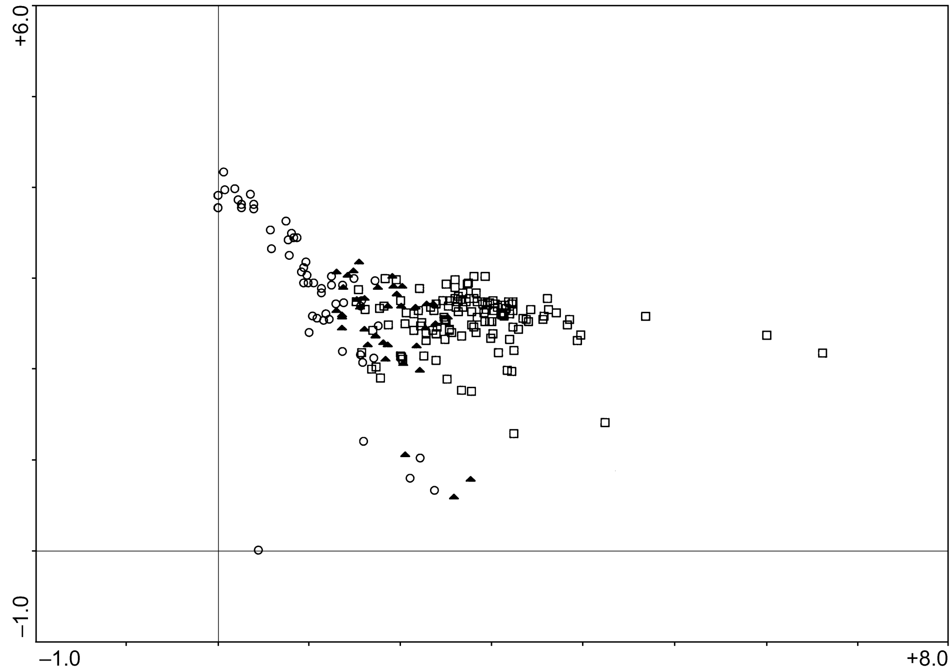

Fig. 3. DCA of all tested samples, classification according to trophic index from HOFMANN (1999). Circles: Oligotrophic and oligo-mesotrophic; triangles: mesotrophic; squares: meso-eutrophic and eutrophic.

are tolerant concerning alkalinity and therefore are members in both groups. Group A and group B combine taxa indicating a poor nutrient status. Group C includes species which are characteristic components of the diatom communities in lakes with reference conditions at a higher trophic status, e.g. lakes in the Lowlands of northern Germany. These taxa might be indicators of degradation in other lake types. Group D contains taxa which indicate degradation in all of the lake types. An index (Reference Taxa Ratio = RTR) is calculated by the following equations:

D-Type 1 and 3:

$$RTR_{Type1\,and\,3} = \frac{Number\ of\ taxa\ Group\ B - (Number\ of\ taxa\ Group\ C + Number\ of\ taxa\ Group\ D)}{Number\ of\ taxa\ Group\ B + Number\ of\ taxa\ Group\ C + Number\ of\ taxa\ Group\ D}$$

D-Type 2:

$$RTR_{Type2} = \frac{Number\ of\ taxa\ Group\ A - (Number\ of\ taxa\ Group\ C + Number\ of\ taxa\ Group\ D)}{Number\ of\ taxa\ Group\ A + Number\ of\ taxa\ Group\ C + Number\ of\ taxa\ Group\ D}$$

D-Type 4:

$$RTR_{Type4} = \frac{(Number\ of\ taxa\ Group\ B + Number\ of\ taxa\ Group\ C) - Number\ of\ taxa\ Group\ D}{Number\ of\ taxa\ Group\ B + Number\ of\ taxa\ Group\ C + Number\ of\ taxa\ Group\ D}$$

The results of the both modules, the Trophic Index and the RTR, are to be averaged to an ecological diatom index after having been converted to a comparable 0-1 scale. The deviation of the four ecological status classes from the reference conditions were defined type specifically for the reference index according to the guidelines of Annex V of the WFD.

Entire quality element

For the classification of the entire quality element according to the WFD the two components macrophytes and diatoms had to be combined to one system. The following overview shows the resulting main elements for this classification. In Table 4 the taxonomic groups and numbers of taxa in each type and component are summarised. Indices for the components macrophytes and diatoms are calculated as shown above. After converting to a comparable scale (0–1), the two index values were combined by averaging. To delimit different quality classes, type-specific borders were set. An example is given in Table 8. Additional metrics like high dominance of indicators of eutrophic conditions (macrophytes), were integrated in the system to quantify ecological sta-

Table 4. Numbers of species in type-specific species groups of lakes.

Species group	Biocoenotic lake type			
Macrophytes	AK(s)	MTS	TKg	TKp
Reference	21	19	27	30
Indifferent/tolerant	25	13	19	24
Indicator of degradation	22	17	14	
Diatoms	D1	D2	D3	D4
Reference, siliceous		212		
Reference, calcareous	142		142	142
Reference in D4, in other types indicator of degradation	40	40	40	40
Indicator of degradation	113	113	113	113

Table 5. Typology attributes of Lake Schermützelsee.

Typology attributes	Value
Ecological region (according to MATHES et al. 2002)	Lowlands of northern Germany
Calcium content	> 15 mg/l (calcareous)
Catchment influence (volume ratio)	VQ > 1.5 (large catchment)
Stratification	Yes
Residence time	> 30 d (lake, not riverine)

tus. The resulting metrics for the entire quality element are the following: species groups (MD), absence of macrophytes (M), trophic index after HOFMANN (1999) (D) and Reference Taxa Ratio (D).

For the assessment of the quality elements minimal necessary abundance is laid down specifically for each lake type. For the summed quantities and percentage of indicative species for macrophytes as well as number of indicative species of diatoms restrictions are to be recognised. If these requirements (see SCHAUMBURG et al.

Table 6. Lake Schermützelsee: taxonomic composition, abundance and type specific attributes of the taxa (all components sampled once in summer): Macrophytes: A: reference taxa; B: indifferent taxa; C: indicators of degradation. Diatoms: R: reference taxa; D: indicators of degradation.

Macrophytes

Taxon name	Quantity	Species group
Ceratophyllum demersum	9	B
Chara contraria	8	B
Fontinalis antipyretica	1	
Myriophyllum spicatum	70	B
Najas marina	32	B
Nuphar lutea	2	
Phragmites australis	8	
Potamogeton pectinatus	27	B
Schoenoplectus lacustris	9	

Benthic Diatoms

Taxon name	Abundance (%)	Species group	Trophic value (HOFMANN 1999)	Trophic weight (HOFMANN 1999)
Achnanthes sp.	0.6			
Achnanthes clevei	1.7	D	3.5	2
Achnanthes conspicua	0.4			
Achnanthes delicatula	1.4	D	5	3
Achnanthes delicatula ssp. *engelbrechtii*	0.2	D	5	3
Achnanthes grana	3.7			
Achnanthes lanceolata ssp. *frequentissima*	1			
Achnanthes lanceolata ssp. *rostrata*	15.4			
Achnanthes minuscula	3.1	D	4	2
Achnanthes minutissima	4.4			
Achnanthes ziegleri	1.4	D	3.8	2
Amphora libyca	0.2			
Amphora pediculus	16.2			
Cocconeis neothumensis	11.8	D	3.7	2
Cymbella caespitosa	0.2			
Cymbella microcephala	0.8	R		
Cymbella naviculiformis	0.2			
Cymbella prostrata	0.2	D	4.3	3
Cymbella silesiaca	0.6			
Cymbella sinuata	0.4			
Fragilaria brevistriata	11.4			
Fragilaria capucina perminuta	1.2	D	4.2	2
Fragilaria capucina var. *vaucheriae*	0.2	D	5	3
Fragilaria construens	0.2			
Fragilaria construens f. *venter*	1.9			
Fragilaria delicatissima	0.2	R	2	2
Fragilaria leptostauron var. dubia	0.2			
ragilaria pinnata	8.7			
Gomphonema olivaceum	0.2	D	4.1	2
Navicula sp.	0.2			
Navicula cari	0.2	D	4.3	3
Navicula cryptotenella	0.8			
Navicula decussis	0.4	D	3.9	2
Navicula hofmanniae	0.2			
Navicula menisculus var. *grunowii*	0.2	D	4	2
Navicula minima	0.8			
Navicula pseudanglica	0.2	D	4.1	2
Navicula reichardtiana	2.1	D	4.3	2
Navicula schoenfeldii	2.5	D	4.1	3
Navicula tuscula f. minor	1	D	3.5	2
Navicula utermoehlii	1.2	D	4	1
Nitzschia alpinobacillum	0.2	R		
Nitzschia archibaldii	0.2			
Nitzschia dissipata	0.2	D	4.7	3
Nitzschia inconspicua	0.5	D	5	3
Nitzschia lacuum	0.8			
Nitzschia sociabilis	0.4	D	4.5	3
Tabellaria flocculosa	0.4			

Table 7. Classification example Lake Schermützelsee: calculated metrics.

Attributes	Indices	Variation	Additional metrics
Reference index (macrophytes)	0.5	< 0.70–0.51	
Absence of macrophytes			none
Percentage of taxa group C (macrophytes)			0
Predominance of one taxon (macrophytes)			none
Diatom index (average from RTR and trophic index)	0.19	< 0.25–0.07	
Average entire quality element (MD)	**0.34**	**< 0.38–0.26**	

Table 8. Classification example entire quality element of one biocoenotic type for benthic plants; the selection shows the result of the example Lake Schermützelsee.

Typology	Type
MATHES et al. (2002)	Type 10 and 13
Diatoms	Type D3
Macrophytes	Type TKg
Ecological status class	Ranges of classification
1 (high)	1.00–0.69
2 (good)	< 0.69–0.38
3 (moderate)	< 0.38–0.26
4/5 (poor and bad)	< 0.26–0.00

2004a) are not met, the assessment of the component is considered unreliable 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 4 biocoenotic macrophyte types and 4 biocoenotic diatom types. 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 diatoms, the following steps have to be taken:

– the sampling site has to be assigned to the relevant type;
– mapping and sampling the macrophytes and the benthic diatom 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.

As an example, the results of the sampling site at the Lake Schermützelsee near Berlin will be presented here. Table 5 shows the typology attributes of the sampling site.

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

Macrophytes and diatoms: Sites within stratified lake water bodies of the Lowlands in northern Germany.

In Table 6 the data collected at the site to taxonomic composition, abundance and the type-specific attributes of the taxa are summarised.

Table 7 shows the results of the calculated indices and additional metrics for each plant component from Table 6 separately and for the entire quality element.

The index value for the entire quality element indicates a moderate ecological status for this site. Since the additional metrics do not show a reason for a deviation due to e.g. eutrophication, 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. 2004a). These tables assign the class boundaries according to WFD. The macrophyte and phytobenthos community indicate a moderate ecological quality for this sampling site (Table 8).

Discussion

Macrophytes and phytobenthos are an important part of the littoral system of lakes. They are primary producers, provide habitats for animals and stabilise sediments (DIEHL & KORNIJÓW 1998; HORPPILA & NURMINEN 2003). Numerous human impacts can be detected with the use of aquatic plants (TREMP & KOHLER 1995; MELZER 1999; HOFMANN 1994). As primary producers many of them are indicators of eutrophication, others are sensitive to acidification or salinisation. The developed classification system provides simple yet reliable multi metric assessment of ecological quality according to the WFD, superseding trophic status as an indicator of water quality. The Reference Index (M) as well as the Reference Taxa Ratio (D) quantify any deviations from reference conditions influencing the biocoenoses. For a classification according to the WFD only lakes >0.5 km^2 are relevant. Since for German lakes exceeding this size, eutrophication is the main impact the developed systems do not include metrics for acidification or salinisation. In addition to the above mentioned indices the trophic diatom index shows lake site degradation by eutrophication. Furthermore remaining phytobenthos as used for the classification of ecological status in running waters (SCHAUMBURG et al. 2004b) is not used for the assessment of lakes. Although remaining phytobenthos is able to raise high levels of biomass in some lake types e.g. polymictic lakes of the Lowlands in northern Germany, any knowledge of temporal and spatial occurrence as well as knowledge of assessment of remaining phytobenthos is not developed. In the opposite there are well known methods for sampling and mapping macrophytes and diatoms as well as methods are available for the assessment of these components of the benthic plants. The developed system is sufficient for a lake assessment according to the WFD.

Macrophytes

Although the typology is based on a wide variety of surveyed sites throughout Germany, it was not possible to find all imaginable types of lake sites by the use of CA on reference sites. The intensive human influence in the past led to a loss of reference sites all over Europe. We therefore expect that additional lake types will have to be established for submerged macrophytes. The reliability of the method used for macrophyte mapping is essential for assessing ecological quality. Although the two sampling techniques, referred to in this paper, lead to comparable ecological classification of sites (STELZER 2003), using SCUBA is highly recommended, for better accuracy concerning rare taxa (RASCHKE & RUSANOWSKI 1984; MELZER & SCHNEIDER 2001). Aquatic plant biocoenoses respond to environmental changes by modifying their taxonomic composition as well as increase or decrease of plant abundance. Additionally, rooted aquatic plants in contrast to diatoms link sediment and floating water. While submerged macrophytes respond to changes in the environment within years, diatoms are reacting within weeks (TREMP 1996; HOFMANN 1994). Comparing the reference index for macrophytes and the RTR for diatoms can therefore give useful information on environmental changes within the lake (SCHAUMBURG et al. 2001). Classification with aquatic macrophytes is restricted to sites with sufficient macrophyte cover and therefore fails to indicate extreme eutrophication leading to depopulation of submerged macrophytes. The evolved system integrated this extreme impact by assigning sites with very low or missing vegetation to bad status (unreliable), if natural reasons for low macrophyte abundance such as coarse substrate, high degree of shading, wave action or high DOM can be excluded. If natural reasons for low macrophyte abundance can not be excluded, a classification based on macrophytes is not possible.

The attempt to create an assessment tool for lake sites based on helophytes proved unsuccessful, because biocoenoses of emergent water plants in lakes show a high degree of natural variability. Thus, an indication of structural degradations by using macrophytes was not possible (STELZER 2003).

Benthic diatoms

Diatoms are used as indicators for the assessment of environmental conditions since the beginning of the 20th century (KOLKWITZ & MARSSON 1908). Many assessment methods to quantify different kinds of human impacts have been developed from the beginning of the seventies (see SCHMEDTJE et al. 2001). Because of the short generation time, they are able to build an new biocoenosis in a few weeks. In case of changing environmental matters, a modification in taxonomic composition and abundance is indicating different kinds of impacts immediately. Diatoms are wide spread and almost everywhere existent. Therefore diatoms are a suitable organism group according to WFD.

The system which was developed for rivers (SCHAUMBURG et al. 2004b), i.e. calculating the summed abundance of reference species does not fit for lakes. The reason for that is the occurrence of some highly dominating species which are vital without any restriction at high to moderate ecological status. But as a very useful tool there was developed the metric RTR index, where the numbers of species of ecological groups which are indicating different ecological quality were connected.

The ability of diatoms for indicating nutrients was used in the past for establishing a trophic index, HOFMANN (1994, 1999) which was proved to be a useful module of the developed assessment system. The two modules for calculating the ecological diatom index, Trophic Index (TI) and Reference Taxa Ratio (RTR), are in agreement of the demands of WFD, taxonomic composition and abundance. The developed system for diatoms is suitable for almost all German lake types with the exception of the types 12 and 14 after MATHES et al. (2002). For these polymictic lakes of the Central plains the database is insufficient. Natural lakes smaller than 0.5 km^2 surface area could be assessed too if necessary. The system can be extended for other natural and artificial lake types. For example soft water lakes of the Central mountains probably could be specified in case of further investigations.

A tool for the determination of acidification was not developed yet, because no acidified natural lakes >0.5 km^2 appear in Germany. If necessary, an acidification metric for these lakes could easily be raised. Salinisation is also no problem of German lakes >0.5 km^2 and therefore will not be assessed.

Entire quality element

The comparison with the 9 types of natural lakes of the abiotic typology from MATHES et al. (2002) allows the following conclusions: first there is less differentiation of lake water bodies across Germany with the benthic plant components, i.e. for the classification with the plant components less types are needed. Further development of the system might lead to some more types e.g. at soft water lakes. Second there is quite a good comparability of the biocoenotic plant types with the abiotic types (see Table 2). Each macrophyte type is directly comparable to each diatom type and abiotic type respectively with the exception that diatoms do not cover all the polymictic lakes of the Lowlands of northern Germany like the macrophytes do.

According to our experience, for the entire quality element macrophytes and phytobenthos two samplings a year are recommended: one in summertime for both of the components and a second one in autumn only for diatoms. When sampling all components at the same date a special order is to be recognised: one should start with sampling diatoms and end with the that one of macrophytes.

The question how to assess a whole lake water body with the described method is not answered yet.

On the one hand, SCUBA diving the whole shoreline, as is done to calculate the macrophyte index (MELZER 1999), demands high sampling effort. On the other hand, the question of how to select representative transects in a lake is still unsolved. At present, only the assessment of lake sites is possible. For the classification of lakes according to the WFD, a complete species list is not necessary to get an overview over the main impacts and the ecological status in the sense of the WFD. In future projects, we like to answer the question of how to select representative transects in a lake.

To complete the scientific background of an ecological classification which is described for the implementation of the WFD a lot more of research in this field is needed. Hence all the upcoming suggestions of new ecological classification systems must be seen as first drafts. All scientific projects in Europe dealing with this subject could spend additional years to define water body types, reference conditions and classification tools for the biological elements. But the time schedule of the WFD does not give us much time. So these first drafts are raised on the basis of the best scientific knowledge which is available right now. 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 correlate 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 recognise. 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 known metrics, but should also reflect the reaction of the biocoenosis to the impacts. We tried to describe the latter with the reference indices of the two plant components and included the impacts as additional or integrated metrics. The main impact expressed with the benthic plants is probably eutrophication and the trophic situation of lakes. Therefore we included the metrics which express eutrophication into the plant classification modules which were averaged at the end. This is conform to the classification guidance of the EU which suggests averaging of similar impacts on the quality element level. Different impacts like acidification and eutrophication should not be averaged; for German lakes >0.5 km^2 there is no need of more metrics to combine with eutrophication.

Also further human pressures which are not expressed by additional metrics can be detected with our classification. The reference index is a tool for describing the deviation of the observed benthic plant communities from reference conditions. Therefore, almost every factor affecting the taxonomic composition and abundance of benthic plants in German lakes > 0.5 km^2 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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