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Indicators and criteria to assess ecological status of the large shallow temperate polymictic lakes Peipsi (Estonia/Russia) and Võrtsjärv (Estonia)

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Pressure-based approach, morphoedaphic index and historical data were used in deriving reference conditions and classification criteria for the Estonian large lakes: Peipsi and Võrtsjärv. The comparison of the measured total phosphorus with the reference level based on the morphoedaphic index, shows that the water quality could be estimated as 'moderate' in lake Peipsi and 'good' in Võrtsjärv despite that the measured TP values were higher in the latter. Comparing the changes observed in different quality elements with the normative definitions for quality classes given in the Water Framework Directive yielded quality estimates from 'high' to 'moderate' for both lakes. Applying the "one-out all-out" principle according to which the ecological status is determined by the biological quality element, which shows the greatest anthropogenic disturbance, both lakes fall unequivocally into the 'moderate' category. Averaging the quality estimates for lakes Peipsi and Võrtsjärv no matter whether on a quality element level or a single parameter level would indicate good status in both lakes that is close to the subjective cognitive expert opinion of the authors.

Introduction

With increasing human pressure on surface water ecosystems it has become vital to maintain and, if necessary, to improve the surface water quality. Several strategic frameworks like those launched in the United States (U.S. EPA 2003), in Australia and New Zealand (ANZECC 2000) and in Europe (Directive 2000) address the biotic integrity or 'ecosystem health' that is "the capability of an ecosystem for supporting and maintaining a balanced, integrated and adaptive community of organisms having a species diversity, composition and functional organisation comparable to that of the natural habitats of the region" (Karr and Dudley 1981).

The Water Framework Directive (WFD) which came into force in the European Union in 2000 aims at maintaining and improving the aquatic environment in the European Community and has set a target for Member States to achieve 'good ecological status' and 'good surface water chemical status' in all bodies of surface water by 2015. To keep track of this process, the WFD requires a classification of surface water bodies into five classes from 'high' to 'bad' to reflect their ecological status as measured by the actual condition of specific biological, hydromorphological, chemical, and physico-chemical quality elements in comparison with reference conditions at which the human impact is virtually eliminated. Reference conditions should be type specific to take account of the different reactions and sensitivity of water bodies depending on their geographic location, morphometry, and basin geology. If there are undisturbed water bodies of the same type available in the area, reference conditions can be derived on a spatial basis. If this is impossible, reference conditions can be found using either historical records or palaeolimnological data from the same site or from another site of the same type. If the pressure–response relationships are well formalised, reference conditions for minimum pressure conditions can be modelled. Finally, if none of these methods is applicable, reference conditions can be established on the basis of expert opinion.

In the principal scheme suggested by the WFD for surface water status assessment, different quality elements play different roles (explained in detail in CIS 2003). The main emphasis is given to the biological quality elements, the status of which must be taken into account when assigning water bodies to any of the ecological status classes. If the biological elements reflect 'high' ecological status, the worse of the physico-chemical and hydromorphological quality elements decide whether 'high' status can be justified or not. To assign a water body to the 'good' quality class, the lower of the values for the biological and physico-chemical monitoring results should comply with the provisions for 'good' quality. If the biological elements indicate 'high' or 'good' but the physico-chemical elements indicate a lower status, the site should be classified as 'moderate'. The decision that a water body is at poor or bad status can be made on the basis of the biological quality elements only. The condition of the physico-chemical and hydromorphological quality elements only affects that decision indirectly through their influence on the condition of the biological elements, i.e., it is considered that the hydromorphological and physico-chemical status in these quality classes cannot be worse than status of biological elements, which integrate the effects of all pressures.

As evidenced by different studies (Vollenweider 1968, Vollenweider and Kerekes 1982, Sharpley *et al.* 2003), eutrophication can be considered the most important and most universal reason of water quality degradation in lakes. In most lakes in Europe the biological productivity is limited by phosphorus availability (Malmaeus and Håkanson 2004). Nitrogen limitation can be easily overcome by nitrogen fixers providing a nitrogen source also for nitrogen non-fixing species and, hence, phosphorus loading measured directly or as total phosphorus concentration (TP) in water represents the main pressure to many lakes. The WFD aims at an 'effect-related classification' rather than 'pressure-based classification' although the measures should be taken to mitigate the pressures. Given the often large variability of biotic responses to eutrophication in lakes of different types and the general scarcity of biological monitoring data (Heiskanen and Solimini 2005, Nõges P. *et al.* 2005), it seems reasonable as a first step to build up a TP-based preliminary classification scheme and as a second step validate the class boundaries using biological indicators sensitive to changes in the TP level. A similar system has recently been proposed to classify Danish lakes (Søndergaard *et al.* 2005) and used for a long time to define the ecological and management objectives to the Prealpine lakes in Italy (Premazzi *et al.* 2003). The Italian system establishes background concentrations (= reference conditions) for TP on the basis of the morphoedaphic index (Vighi and Chiaudani 1985) and sets type specific ecological and managerial objectives as per cent increments to the background TP (Premazzi and Chiaudani 1992, Premazzi *et al.* 2003). Although it does not use the term 'ecological quality ratio' (EQR) introduced by the WFD, the set numerical quality objectives can be easily recalculated into the normalised EQR scale ranging from 0 to 1. The Danish system does not use the reference conditions concept but sets arbitrary quality class boundaries on the TP scale separately for deep and shallow lakes. Based on a large set of monitoring data, the boundaries for other chemical and biological quality indicators are set thereafter as median values of these indicators within each TP category. Similar EQR values equal to 1, 0.75, 0.5, 0.25, and 0 are assigned for all quality indicators falling into quality classes from 'high' to 'bad' and the final EQR score is calculated by averaging the EQRs of all measured quality indicators. As exemplified by the Danish approach, national quality classifications are often based on the statistical distribution of data available in the country or region and, hence, depend strongly on the range of the disturbance the water bodies have experienced. The use of nonparametric statistical summaries, e.g., median and percentiles, provides a robust indicator of the typical values and spread of data (Ulrich *et al.* 2003) but cannot guarantee *per se* the consistency of the derived classification scale with the normative definitions of quality classes. The agreement upon what should be understood under "undisturbed conditions" and under "very minor", "slight" or "moderate" deviation from these conditions is a matter of the WFD intercalibration process, which should take account of the full ranges of changes of the quality elements along the pressure gradients in Europe (Heiskanen *et al.* 2004).

Our aim was to work out a suitable set of indicators and criteria and an applicable procedure within the WFD context to assess the ecological status of Estonian large lakes, Peipsi and Võrtsjärv, both having a monitoring history of more than 40 years. We used the pressure-based approach and derived the reference conditions for TP from the morphoedaphic index. As a second step we validated the quality estimates using historical data, mostly the species composition of different biological groups. We address problems related with the establishment of appropriate reference conditions and setting quality class boundaries for parameters with a large seasonal variability.

Site description

Peipsi and Võrtsjärv are two large unstratified eutrophic lakes in Estonia (Fig. 1). The lakes are interconnected by the Emajõgi starting from Võrtsjärv and running into Peipsi.

Peipsi (3555 km^2, mean depth 7.1 m) is the fourth largest lake in Europe by surface area after lakes Ladoga, Onega, and Vänern. The volume of water in Peipsi is 25 km^3 at the long-term mean water level (30 m above sea level), and the mean residence time of water is about two years. The entire catchment area (47 800 km^2) involves Estonian, Russian, and Latvian territories. The Narva River forming the outflow of Peipsi runs into the Gulf of Finland. Located on the Estonian–Russian border, Peipsi is a transboundary water body and the largest international lake in Europe. The lake consists of three parts of which only the largest northern part, Peipsi *sensu stricto* (further referred to as simply as Peipsi) with an area of 2611 km^2 and mean depth of 8.3 m will be discussed in the present paper.

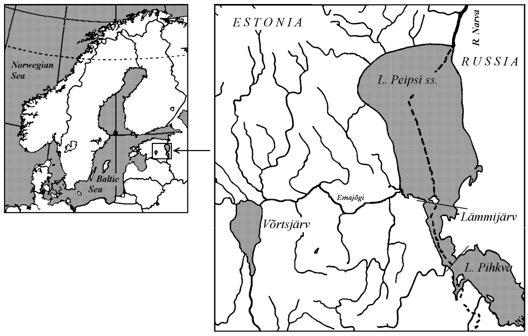

Fig. 1. Location map of lakes Peipsi and Võrtsjärv.

Võrtsjärv (270 km^2, mean depth 2.8 m) is the largest lake belonging entirely to Estonia. The volume of Võrtsjärv is 0.75 km^2 and the retention time around one year.

Both lakes have a rather natural regime of water level fluctuations with differences of about three meters between the highest and lowest water level. The lakes are ice-covered usually for five months a year. The long-term average alkalinity of water (1982–2002) was 2.25 meq l^{-1} in Peipsi and 3.16 meq l^{-1} in Võrtsjärv.

Material and methods

Material

Võrtsjärv and Peipsi are undoubtedly among the best studied lakes in Estonia. Scientific data on the biota of these lakes date back to the beginning of the 20th century (Samsonov 1914, Mühlen 1918, Mühlen and Schneider 1920). Regular investigations of the lakes began in the 1960s. To date, 40-year time series of data on water chemistry and biology have been collected within the frames of institutional programs and projects (Estonian Academy of Sciences) and Estonian State Monitoring Program (since 1992). As we considered eutrophication as the main pressure for the ecosystems of both lakes and TP as the most direct indicator of this pressure, we used 21-year (1982–2002) seasonal TP data and data on parameters significantly correlated with changes in TP (Table 1) to make the preliminary classification. In the analysis we used monthly split data that allowed us, besides selecting the appropriate variables, to decide also upon their seasonal applicability as quality parameters. We validated the classification by comparing the WFD normative definitions for quality classes with biological changes described in a number of publications on these lakes.

Establishing reference conditions

We calculated the reference level of the total phosphorus concentration (TP_{ref}) using eq. 1 of Vighi and Chiaudani (1985) over a large set of lakes in Europe and North America practically not affected by anthropogenic phosphorus input:

$$\log TP_{ref} = 1.48 + 0.33\ (\pm\ 0.09)\ \log MEI_{alk} \quad (n = 43,\ r = 0.83,\ p < 0.01) \qquad (1)$$

where MEI_{alk} is the morphoedaphic index calculated as the ratio between long-term average alkalinity (in meq l^{-1}) and mean depth of the lake (in m).

As increased nutrient loading has been the most important anthropogenic pressure to lakes Peipsi and Võrtsjärv (Nõges and Nõges 2004) we considered pragmatically the lakes representing reference conditions until the onset of industrial methods in agriculture and application of artificial fertilizers, i.e. at least until the 1930s. Recent paleolimnological studies (Nõges T. *et al.* 2005a) indicated a breaking point in the sediment diatom series of both lakes around the 1950s. Hence, we used the earlier biological data as a reference in our comparison.

Setting class boundaries

We used a two-step procedure for setting the boundaries between quality classes: firstly we produced an overall estimate of the lakes based on the long-term TP record and comparing it with the TP_{ref}, secondly we applied a statistical percentile approach to the long-term data set split on a monthly basis in order to establish seasonal quality criteria, i.e. to eliminate the effect of seasonality from the quality estimates.

For the overall estimate we applied a fixed coefficient relating the TP_{ref} and the desirable water quality objective. As a basis we used the approach by Premazzi *et al.* (2003) who proposed the term 'ecological objective' to mark the maximum achievable water quality and 'intermediate' or 'managerial objective' to be intended as TP level in lake water acceptable for social use of the water resource. The above authors related both objectives to the sensitivity or buffering capacity of the ecosystem: the ecological objectives were established as TP levels exceeding the natural concentrations by 20% for oligo-mesotrophic waters (natural TP level < 20 mg m^3)

Table 1. Variables correlating with total phosphorus concentration in lakes Peipsi and Võrtsjärv, Spearman correlation coefficient (*r*, all data included) and the periods of significant ($p < 0.05$) relationship.

	Peipsi		Võrtsjärv	
	r	Months	*r*	Months
Secchi depth	–0.60	3–9	–0.57	1–12
Biochemical oxygen demand	0.23	3–6; 8; 11	0.35	3–6; 9
Chlorophyll *a*	0.40	3–4; 6–10	0.37	1–5; 7–12
Carotenoid/chlorophyll ratio	–0.31	5–8; 10		
Biomass of diatoms	0.30	4; 9	0.44	9
Percent of cyanobacteria in phytoplankton biomass	0.19	8		
Zooplankton/phytoplankton biomass ratio	–0.29	4–6; 9–11		

and by 40% for meso-eutrophic lakes (natural TP level > 20 mg m^3). Managerial objectives could be identified as the natural TP + 40% for oligo-mesotrophic lakes and TP + 80% for less sensitive, naturally-eutrophic lakes. Using the WFD vocabulary, we considered the ecological objective equal to the high–good quality class boundary and the managerial objective equal to the good–moderate boundary. The corresponding EQRs would then be 0.83 and 0.71 for lakes with a TP_{ref} < 20 mg m^3 and 0.71 and 0.56 for lakes with a TP_{ref} > 20 mg m^3. As both Estonian large lakes fell into the latter group, we applied the $1.4 \times TP_{ref}$ and $1.8 \times TP_{ref}$ as the corresponding boundaries for the high–good and for the good–moderate quality classes for the overall assessment (Table 2).

In order to avoid the situation in which the water quality estimate would be seasonally changing just because the quality parameters (TP, chlorophyll concentration, biomasses of algal groups, etc.) have a certain seasonal pattern, we split the long-term data into monthly sub-sets and applied a percentile-based approach to set the class boundaries. For Võrtsjärv there were enough measurements to calculate the percentile distributions for all months but for Peipsi there were too few measurements for December and January to calculate any class boundaries. Given the still large variability of the data within the monthly sub-sets we considered as a principle that at least one half of the measured values should be consistent with the quality class indicated by the overall assessment. For example, if the overall estimate indicated moderate status, then the moderate class boundaries were set as the 25th and 75th percentile values for each monthly subset (i.e. the moderate class remained within the 'box' of the 'box and whiskers' plot). The way how the class boundaries were set depending on the overall assessment is illustrated in Fig. 2. Similar percentiles (10, 25, 75 and 90) as in the case of TP we used also for class boundaries of other quality parameters (Tables 3–10).

As most of the analysed parameters were not normally distributed, throughout the analysis we used the nonparametric statistics (Spearman rank correlation coefficient, median, quartiles and percentiles) available in STATISTICA for Windows ver. 6.0.

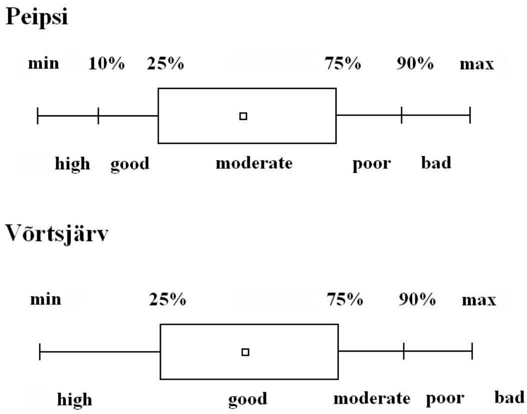

Fig. 2. Estimation of quality class borders for lakes Peipsi and Võrtsjärv on the basis of long-term database (1982–2002).

Validation of quality estimates

In the case of Võrtsjärv, we based our validation mostly on a recently published comparison (Nõges and Järvalt 2004) of the present taxonomic composition of biota with that described in 1911–1913 by the complex expedition to the lake (Mühlen and Schneider 1920). A special similarity index by Nõges and Feldmann (1999) was used to compare the historical list of species with nowadays data (Eq. 2):

$$K = \text{number of common species in two lists/ number of species in the shorter list} \quad (2)$$

Table 2. The overall quality estimate for lakes Peipsi and Võrtsjärv based on total phosphorus concentration (TP). The reference concentration for TP (TP_{ref}) was calculated from the regression with the morphoedaphic index for alkalinity (MEI_{alk}, Vighi and Chiaudani 1985) and the quality class boundaries set according to criteria suggested by Premazzi *et al.* (2003).

Lake	Peipsi	Võrtsjärv
Alkalinity (long-term mean, meq l^{-1})	2.3	3.16
Mean depth, m	8.3	2.8
MEI_{alk}	0.28	1.13
TP_{ref} (mg m^{-3})	19.9	31.4
$1.4 \times TP_{ref}$ (high/good, mg m^{-3})	27.9	44
$1.8 \times TP_{ref}$ (good/mod, mg m^{-3})	35.8	56.6
TP (average measured in 1982–2002, mg m^{-3})	40.0	45.0
Overall quality estimate	moderate	good

Table 3. Seasonal quality class boundaries for lakes Peipsi and Võrtsjärv based on the percentile distribution of monthly total phosphorus concentrations (mg m^{-3}). Quality classes marked as H = high, G = good, M = moderate, P = poor, and B = bad.

	Peipsi				Võrtsjärv			
	H/G	G/M	M/P	P/B	H/G	G/M	M/P	P/B
Jan					30	62	100	139
Feb	21	29	35	53	31	60	76	93
Mar	17	23	40	58	30	61	80	99
Apr	9	13	42	52	32	63	90	117
May	24	27	47	55	31	57	70	83
Jun	20	22	34	43	24	54	71	88
Jul	18	28	49	60	37	65	92	119
Aug	22	39	62	76	31	63	75	87
Sep	24	33	64	72	27	70	98	126
Oct	31	40	67	77	42	91	120	150
Nov	29	40	60	66	31	62	95	128
Dec					36	60	81	101

Table 4. Seasonal quality class boundaries for lakes Peipsi and Võrtsjärv based on Secchi depth (m). Quality classes marked as H = high, G = good, M = moderate, P = poor, and B = bad.

	Peipsi *s.s.*				Võrtsjärv			
	H/G	G/M	M/P	P/B	H/G	G/M	M/P	P/B
Jan					2	1.1	1	0.9
Feb					1.9	1.3	0.9	0.6
Mar	4.0	3.2	1.4	0.7	2	1	0.8	0.6
Apr	2.9	2.5	2.0	1.5	1.4	0.9	0.9	0.8
May	2.6	2.3	1.8	1.4	1.2	0.9	0.8	0.6
Jun	3.0	2.7	1.9	1.5	1	0.7	0.5	0.3
Jul	2.4	2.0	1.7	1.4	0.9	0.6	0.6	0.6
Aug	2.5	2.0	1.5	1.2	0.9	0.7	0.6	0.5
Sep	1.9	1.6	1.0	0.9	0.9	0.6	0.4	0.3
Oct					0.9	0.5	0.4	0.3
Nov					1	0.5	0.4	0.4
Dec					1.5	0.9	0.7	0.5

Table 5. Seasonal quality class boundaries for lakes Peipsi and Võrtsjärv based on chlorophyll *a* concentration (mg m^{-3}). Quality classes marked as H = high, G = good, M = moderate, P = poor, and B = bad.

	Peipsi				Võrtsjärv			
	H/G	G/M	M/P	P/B	H/G	G/M	M/P	P/B
Jan					2.8	7.4	17.9	28.5
Feb					1.6	10.5	22	33.6
Mar	0.8	1.3	4.8	9.8	2.7	13.3	20	26.7
Apr	9.4	9.8	35.5	55.9	8.5	27.8	33.1	38.4
May					21.5	34.2	39.5	44.9
Jun	5.0	7.4	15.4	19.9	21	45.5	57.6	69.7
Jul	7.2	9.5	19.3	24.2	20.8	34.1	41.8	49.5
Aug	10.7	15.7	27.8	35.9	27.1	41.8	47.5	53.3
Sep	16.8	19.5	30.9	37.0	24.3	44.9	51.5	58.1
Oct	11.2	14.2	30.4	39.9	27.8	50.3	62.8	75.3
Nov					26.3	45.9	52.7	59.6
Dec					8	25.4	32.3	39.3

Table 6. Seasonal quality class boundaries for lakes Peipsi and Võrtsjärv based on biochemical oxygen demand, mgO l^{-1}. Quality classes marked as H = high, G = good, M = moderate, P = poor, and B = bad.

	Peipsi				Võrtsjärv			
	H/G	G/M	M/P	P/B	H/G	G/M	M/P	P/B
Mar	1.00	1.00	1.80	2.80	1.6	2.9	3.8	4.7
Apr	1.60	1.80	3.00	3.30	3	4.3	4.9	5.5
May	1.60	1.80	2.60	3.00	3.8	5.1	5.6	6.1
Jun	1.30	1.45	2.15	2.50	4.1	5.9	6.3	6.7
Aug	1.10	1.40	2.50	4.10				
Sep					3.3	5.4	6.5	7.6
Nov	1.30	1.40	2.00	2.80				

Table 7. Quality class boundaries for lakes Peipsi and Võrtsjärv based on diatoms biomass (mgWW l^{-1}). Quality classes marked as H = high, G = good, M = moderate, P = poor, and B = bad.

	Peipsi *s.s.*				Võrtsjärv			
	H/G	G/M	M/P	P/B	H/G	G/M	M/P	P/B
Apr	1.1	1.7	7.6	8.1				
Sep	1.6	2.3	5.6	8.5	2.03	7.26	13.16	19.07

Table 8. Seasonal quality class boundaries for Peipsi based on carotinoid/chlorophyll *a* ratio (mg mg^{-1}). Quality classes marked as H = high, G = good, M = moderate, P = poor, and B = bad.

	H/G	G/M	M/P	P/B
May	61	57	39	28
Jun	68	56	36	31
Jul	56	49	32	21
Aug	55	47	27	20
Oct	39	35	18	1

The similarity index *K* can obtain values from 0 to 1 and is especially suitable for comparing historical data as it does not require equal elaboration level of both lists compared. Altogether 371 species, about which new information was available, formed the final list used for analysing the occurrence. Species originally arranged by their taxonomy by Mühlen and Schneider (1920) were rearranged into ecological groups. In addition to the similarity index we used some narrative criteria for single biological elements, e.g., loss of some single sensitive species was considered a 'minor' change while changes among dominating species in any biological group were considered at least 'moderate'.

For Peipsi mostly narrative criteria were used for validation. In order to follow the long-term behaviour of the selected water quality parameters in Peipsi, we assigned the value 1 to each single measurement indicating the class 'high', 2 for 'good', 3 for 'moderate', 4 for 'poor' and 5 for 'bad'. The class boundaries were set as follows: < 1.5 = 'high'; ≥ 1.5 and < 2.5 = 'good'; ≥ 2.5 and < 3.5 = 'moderate'; ≥ 3.5 and < 4.5 = 'poor'; ≥ 4.5 = 'bad', and annual scores were calculated by averaging monthly quality estimates.

Results

Considering the actual TP values measured in lakes Peipsi and Võrtsjärv since 1982 and the reference based on MEI_{alk}, the overall water quality could be estimated as 'moderate' in Peipsi and 'good' in Võrtsjärv despite that the measured TP values were higher in the latter (Table 2).

Table 9. Seasonal quality class boundaries for Peipsi based on zooplankton/phytoplankton biomass ratio (mg mg^{-1}). Quality classes marked as H = high, G = good, M = moderate, P = poor, and B = bad.

	H/G	G/M	M/P	P/B
Apr	0.18	0.15	0.02	0.01
May	1.92	0.82	0.08	0.01
Jun	2.92	1.42	0.35	0.21
Sep	0.52	0.17	0.07	0.03
Oct	0.68	0.39	0.08	0.03
Nov	0.23	0.09	0.03	0.02

Because of considerable seasonality in all water quality parameters, the class boundaries calculated as percentiles of the monthly distributions of data differed between months. For example, a TP value of 30 mg m^{-3} would indicate a moderate status in Peipsi from February to July, a good status in August, September, and November and a high status if the same value is measured in October when TP has its seasonal peak in both lakes (Table 3). Differences were caused not only by a shift in the quality scale but also by a different range of variability in different months. So the range for TP from high–good to poor–bad boundary in Peipsi was only 23 mg m^{-3} in June but more than double of that (54 mg m^{-3}) in August. Among other quality indicators selected on the basis of a significant correlation with TP (Table 1), Secchi depth showed the strongest and seasonally most persistent relationship (Table 4). Also chlorophyll *a* could be used as an indicator of the eutrophication pressure during most of the year (Table 5). For biochemical oxygen demand and for the biomass of diatoms the relationship with TP was significant for only some months (Tables 6 and 7). Three variables (the carotenoid/chlorophyll ratio, the percentage of cyanobacteria in phytoplankton and the zooplankton/phytoplankton ratio) were related with TP only in Peipsi.

Analysing the changes observed in different quality elements of the lakes and comparing the narrative criteria with the normative definitions for quality classes given in Annex V of the WFD (Directive 2000) yielded quality estimates from 'high' to 'moderate' for both lakes (Tables 11 and 12). On the basis of the normative definitions it was impossible to judge upon the decreasing bloom frequency of phytoplankton as those definitions presume an increase in bloom frequency with increasing human impact on lakes. Regular blooms caused in June by the N_2-fixing *Anabaena lemmermannii* were charac-

Table 10. Quality class boundaries for Peipsi based on cyanobacteria percentage in phytoplankton biomass. Quality classes marked as H = high, G = good, M = moderate, P = poor, and B = bad.

	H/G	G/M	M/P	P/B
Aug	12.5	41.5	71.9	82.0

teristic of Võrtsjärv under reference conditions and were supported by the low N:P ratio. Since the 1980s, when the nitrogen input from the agriculture increased, the blooms almost disappeared. Applying the "one out — all out" principle according to which "the final surface water status is determined by the poorer of the ecological status and the chemical status" (Directive 2000) and the ecological status is determined by the biological quality element, which shows the greatest anthropogenic disturbance (CIS 2003), both lakes fall unequivocally into the 'moderate' category. In the case of Peipsi the results based on the MEI approach and biological quality elements coincided while in Võrtsjärv the MEI approach indicated higher quality than could be validated on the biological basis.

According to long-term changes in nutrient loading (Nõges T. *et al.* 2005b), the trophic status of Peipsi decreased after heavy loading in the 1980s but rose again in the second half of the 1990s and in the 2000s. Although the quality parameters were selected on the basis of their correlation with TP, they show rather different patterns (Fig. 3). The improvement of ecological quality in the first half of the 1990s is most

Table 11. Ecological water quality estimate for Võrtsjärv based on narrative criteria applied to various quality elements. *K* = similarity index used to compare historical species lists (Mühlen and Schneider 1920) with those from nowadays. *See* explanations in the text.

Quality element	Facts on status trends	Quality estimate	Reference
Hydro-morphology	Natural water level regime, missing shore modification, and good connection to adjacent wetland areas form the basis for high quality fish and bird habitats.	High	Järvet 2004
Secchi depth	No remarkable changes in ~100 years.	High	Nõges 2003
Phytoplankton species composition	*K* = 0.80. Succession of dominant species. Present dominants *Limnothrix planktonica* (Wołosz.) Meffert and *L. redekei* (van Goor) Meffert invaded the lake in the 1950s or 1960s. One half of the species including all dominants show considerable changes in their relative abundance.	Moderate	Nõges 2003, Nõges and Järvalt 2004
Frequency of phytoplankton blooms	Earlier regular blooms of *Anabaena lemmermannii* P. Richt. disappeared with increasing nitrogen loading.	?	Nõges 2003
Aquatic macrophytes composition	*K* = 0.75. Short bottom growing species replaced by taller plants able to reach the euphotic layer. Widening reed belt and an increased abundance of indicators of high trophic state like *Myriophyllum spicatum* L., *Ceratophyllum demersum* L.	Moderate	Nõges *et al.* 2001, Nõges and Järvalt
Zooplankton species composition	*K* = 0.81. Earlier dominating rotifers *Conochilus unicornis* Rouss. and *Kellicottia longispina* Kellicot preferring lower trophic state have disappeared. *Asplanchna herricki* Guerne has not been found after the 1960s.	Moderate	Nõges *et al.* 2001, Haberman and Virro 2004
Benthic macro-invertebrate composition	*K* = 0.82. All groups except Chironomidae and Oligochaeta have declined during recent decades. Small number of exotic species do not have any substantial role in the ecosystem.	Moderate	Nõges *et al.* 2001, Kangur *et al.* 2004
Benthic macro-invertebrate abundance	No clear trends. Biomass of *Chironomus plumosus* had its peak in the second half of the1980s–beginning of the 1990s but has decreased again.	Good	Kangur *et al.* 2004
Fish	*K* = 0.96. No major changes in species composition. Eel stockings since 1956. Abundance and age structure of commercial fishes are intensively managed by fisheries.	Good	Järvalt *et al.* 2004, Nõges and Järvalt 2004

evident from the quality indices calculated on the basis of chlorophyll *a* (Chl *a*), the carotenoid/Chl *a* ratio, and Secchi depth. The following deterioration of the lake quality is well seen in the quality indices calculated on the basis of Chl *a*, zooplankton/phytoplankton biomass ratio and, especially, cyanophyte percentage, while Secchi depth, carotenoid/Chl *a* ratio and diatom biomass show even an improvement. The Chl *a*-based quality estimate achieved the best fit with the loading pattern and with the common understanding of the lake quality. As the class boundaries for this parameter can be calculated nearly for all months from spring to autumn, we recommend using Chl *a* as the best quality descriptor for Peipsi. According to Chl *a*, Peipsi reached 'poor' quality by the end of the 1980s. There was a clear improvement until 1996 while in several years the average ecological status could be evaluated as 'good'. Since 1997 there has been a continuous and even accelerating deterioration in the lake quality, which reached in 2002 the 'poor' quality class again.

Discussion

Considering the state of several regions in Europe with intensive agriculture and population densities exceeding those in Estonia even

Table 12. Ecological water quality estimate for Peipsi based on narrative criteria applied to various quality elements.

Quality element	Facts on status trends	Quality estimate	Reference
Hydro-morphology	Natural water level regime, missing shore modification, and good connection to adjacent wetland areas form the basis for high quality fish and bird habitats.	High	Jaani 2001
Phytoplankton composition	Phytoplankton dominants remained generally unchanged since 1909. Shifts taken place in their proportions.	Good	Laugaste *et al.* 2001
Phytoplankton abundance	No clear trend in average total abundance, increased variability, levelling of differences between lake parts	Good	Nõges P. *et al.* 2003
Phytoplankton blooms	Cyanobacterial blooms documented already in the 19th century ceased in the conditions of heavy nitrogen loading in the 1980s and started again in the 1990s. Heavy water blooms have resulted in massive summer fish-kills.	Moderate	Laugaste *et al.* 2001, Nõges T. *et al.* 2003
Macrophytes	General appearance unchanges, signs of decreasing biodiversity, expansion of the reed belt.	Good or moderate	Mäemets and Mäemets 2001
Zooplankton	Slight changes in species composition and mean weight	Good	Haberman 2001
Benthic macroinvertebrate composition	After its invasion in 1935, *Dreissena polymorpha* (Pallas) has nowadays become the most significant animal population of the lake. Has favoured the development of *Valvata* and *Asellus*, which use clusters of *Dreissena* for shelter. High species diversity, survival of sensitive clean-water species.	Good(?)	Timm *et al.* 2001
Benthic macroinvertebrate abundance	Long-term abundance and biomass in June reveal considerable year-to-year fluctuation with a slight general trend of increase probably caused by eutrophication	Good	Timm *et al.* 2001
Fish	Heavily exploited by fisheries, overfishing mentioned already in the 19th century. In the beginning of the 1990s a sharp increase in pike-perch (*Sander lucioperca* (L.)) coincided with a decrease of vendace (*Coregonus albula* (L.)).	Moderate	Pihu and Kangur 2001

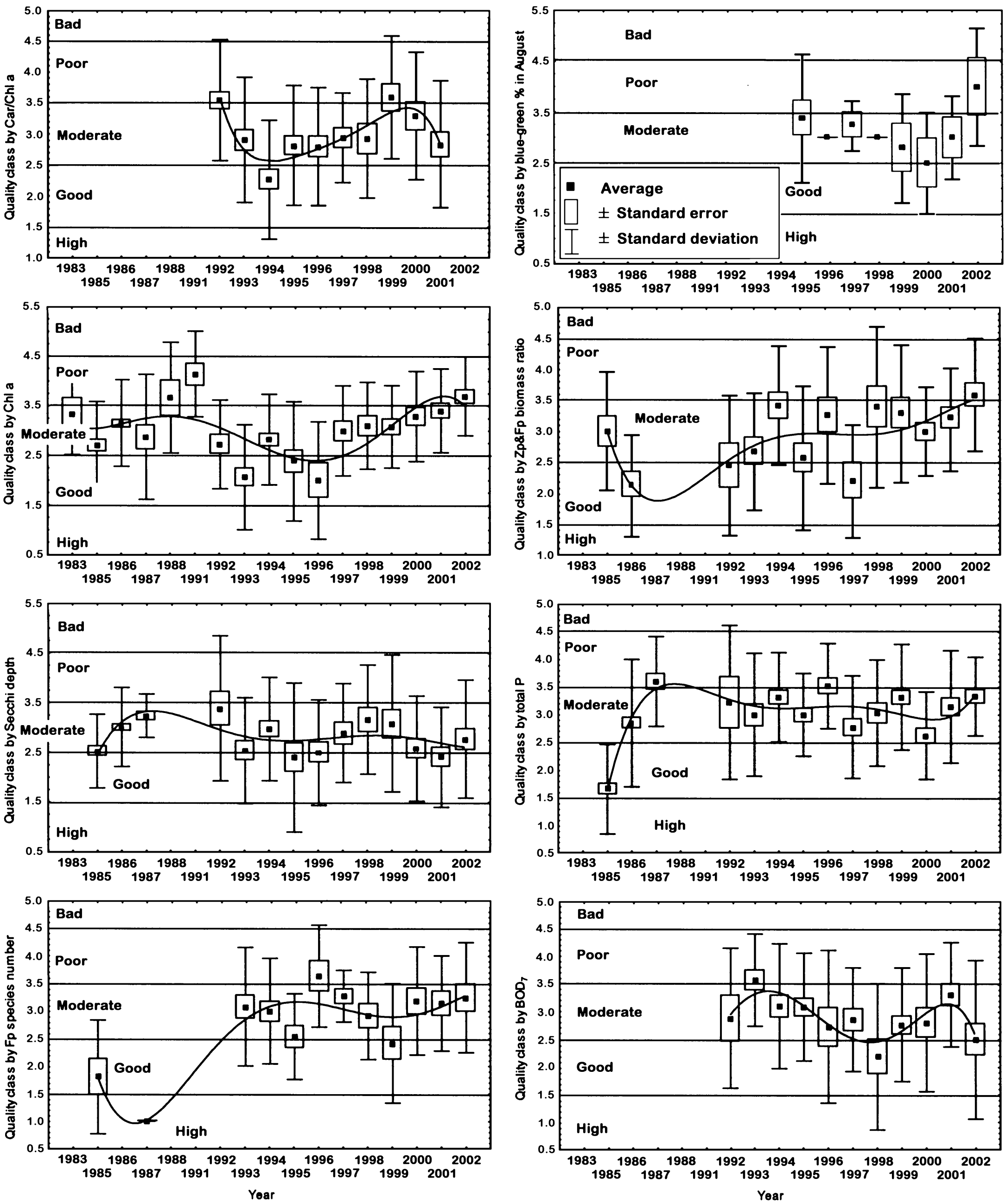

Fig. 3. Long-term changes in the ecological quality of lake Peipsi as estimated according to monthly criteria of different quality parameters presented in Tables 5–10 in the present paper. A polynomial fit is added for better visualisation of changes.

by an order of magnitude, one could expect that the status of lakes Võrtsjärv and Peipsi should still be rather good. Generally the authors of this paper agree with this relative and subjective estimate. Obviously similar considerations were behind the initial idea of selecting these lakes as references to maximum ecological potential for the Dutch lakes Markermeer and IJsselmeer (Wessels *et al.* 2005). The fact that Võrtsjärv and Peipsi failed to meet the 'good' quality criteria when estimated according to the guidance of the WFD common implementation strategy (CIS 2003) is rather alarming. It may be an indication that most of the water bodies in Europe will not meet the WFD provisions for 'good' quality by the year 2015. On the other hand, it may indicate that the reference conditions for these lakes have been set erroneously or that the method for making the final decision on the ecological quality is not applicable.

The quality criteria established by the WFD (Directive 2000) and the classification guidance document (CIS 2003) set rather strict rules for water bodies to meet the 'good' water quality: as a result of human impact the values of the biological quality elements may "deviate only slightly from those normally associated with the surface water body type under undisturbed conditions". For large lakes in Europe, each of which can be considered rather unique and having no undisturbed reference sites available for comparison, the only way to assess the changes is through establishing site specific reference conditions. This will arise two types of questions:

1. How far back in the history should one go to find undisturbed conditions (*see* also Søndergaard *et al.* 2005), i.e., to "get rid" of human impact?
2. How to disentangle the changes caused by direct human impact from those accompanying the natural evolution of lakes and associated, for example, with the multi-annual climatic cycles (like the North Atlantic Oscillation or El Niño–Southern Oscillation phenomena) and climate change.

We assume that the answer to the first question does not presuppose a total elimination of any human impact from the ecosystems but rather aims at finding the threshold when a generally sustainable management of nature resources became replaced by a consumer culture in the industrial era. Obviously, WFD also aims at restoring the natural conditions in water bodies changed as a result of prehistoric or early historic land use changes in some parts of Europe (Fritz 1989, Renberg *et al.* 1993, Anderson *et al.* 1995, Santos 2004) although the lakes may never recover to the predisturbance state (Ekdahl *et al.* 2004). For lakes Peipsi and Võrtsjärv perhaps fisheries have been the most ancient human activity directly influencing the ecosystems. The fish stock of both lakes was heavily exploited already more than one hundred years ago. Baer (1852) showed that overfishing was the mean reason for decreasing bream catches in Peipsi. Describing the decrease of catches of all important fish species in Võrtsjärv at the end of the 19th century, Braun (1885) pointed out the devastating effect of catching young-of-the-year fish practised increasingly in the lake at the turn of the 19th and 20th centuries. Especially destructive for the fish stock were the large traps designed to catch the fry of migrating perch and pikeperch in the outflowing Emajõgi. According to calculations, more than five million young pikeperch were caught during one season (Haberman *et al.* 1973). Through cascading effects in the food chain fisheries have undoubtedly an effect on all trophic levels (Jeppesen *et al.* 1996) that makes the defining of reference conditions for these lakes even more complicated. As a result of the chosen management strategy, the fishery in Võrtsjärv has recently reached the optimum level as evaluated on the basis of the ratio of valuable/non-valuable fish (Järvalt *et al.* 2004) and similar measures have been planned for Peipsi in order to improve the fish composition from the fishery point of view (Pihu and Kangur 2001).

The question of disentangling direct anthropogenic changes in lake ecosystems from changes caused by other factors is tightly related to the previous one. Reference conditions based on historical or paleolimnological data, i.e. established using the methods most suitable for deriving site specific reference conditions, will include all kinds of changes. Cultural eutrophication generally accelerates the natural processes leading to aging of lakes (Sharpley *et al.* 2003). Similarly, the climate warming foreseen to continue in the predictable future (IPCC 2001) may enhance the nutrient turnover (Hamilton *et al.* 2002) leading to an internal eutrophication. Perhaps a modelling approach based on a detailed catchment model and a lake model could be used to correct the reference conditions and to set realistic management goals for the future.

The different status estimates for Võrtsjärv derived from the pressure-based and response-based approaches arise the question of the suitability of the MEI-TP_{ref} relationship for this lake. The biological elements gave a more confident estimate (at least using the "one out — all out" principle) as four indicators yielded the same 'moderate' result. The MEI_{alk}-TP_{ref} relationship was described by Vighi and Chiaudani (1985) on the basis of 43 lakes from Italy, Germany, Canada, and USA showing a wide range of values both for morphometric parameters (mean depth from 4.8 to 313 m) and for chemical characteristics (alkalinity from 0.04 to 2.86 meq l^{-1}). It is easy to see that the parameters of Peipsi fall into these ranges while those of Võrtsjärv remain outside. There is no reason to expect the validity of the relationship outside the ranges for which it was calculated. Cardoso *et al.* (2005) who are revisiting the correlation between the MEI index and phosphorus concentrations in a larger data set of European regional reference data gathered within the EC FP6 Project REBECCA revealed a large scatter of data in the whole range of the relationship including the high alkalinity end (oral communication with the authors).

The EU 5FP project ECOFRAME tested the risk of misclassification of sites depending on the final scoring method (Moss *et al.* 2003). Using the percentage of variables falling into a given or higher status class as a measure of reliability that this status is the true assessment, it was shown that expectations of 100% compliance or 50% compliance were unreliable, but 75% compliance gave a pattern that was not significantly different from that expected from the choice of sites. The 100% compliance if applied on the quality element level is equivalent with the "one out — all out" principle recommended by the classification guidance (CIS 2003). Averaging of the normalised indicator values was also used in the Danish classification approach (Søndergaard *et al.* 2005) because the "one out — all out" principle proved to be unfeasible due to high risk of underestimation of the water quality. Averaging the quality estimates for lakes Peipsi and Võrtsjärv (Tables 11 and 12) no matter whether on a quality element level or a single parameter level would indicate 'good' status in both lakes that is close to the subjective cognitive expert opinion of the authors. The last developments in Peipsi, especially the heavy bloom of *Gloeotrichia echinulata* in 2002 accompanied by a massive fish kill demonstrate a certain lability of the ecosystem, however a combination of high water temperature and decreasing water level was proved to trigger these events (Kangur *et al.* 2005, Milius *et al.* 2005).

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