

Ecological classification of large lakes in Finland: comparison of classification approaches using multiple quality elements

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Abstract Ecological classifications according to the Water Framework Directive (WFD) are presented for a set of 32 large (surface area $>75 \text{ km}^2$) Finnish lakes. We compared three different approaches: classification according to the strictest biological quality element (One-out, All-out approach, OoAo); numerical integration of biological quality elements

(BQE) to determine median scores; and the national classification based on weight-of-evidence (WoE) framework. We also examined the sensitivity of eutrophication metrics to phosphorus concentrations. The WoE based classification proposed that the ecological status in most lakes is high (12/32) or good (17), whereas the integration of BQEs ranked more lakes (18) to high status. Of the biological elements, macrophytes and phytoplankton indicated the status closest to those given by the national WoE classification whereas generally fish indicated higher and macroinvertebrates lower status. Compared to the

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OoAo classification, the national WoE approach gave similar, downgraded or upgraded status classes. Downgrading was due to the higher weight given to water quality and eutrophication pressures. Upgrading was due to the lower weight given to a single macroinvertebrate metric with poorly represented data. In our opinion, the classification based on the WoE approach produces more realistic status estimates than the OoAo classification. Nevertheless, in practical lake management the evidence from the strictest classification metrics still needs to be thoroughly considered.

Keywords Ecological classification · Lake status · Large lakes · Biological quality elements · Water quality · Water Framework Directive

Introduction

The implementation of the EU Water Framework Directive (WFD) has caused marked changes in the status assessment of surface waters due to the increased role of biological monitoring (EU, 2000). Earlier assessments of Finnish surface water status were based mainly on physical and chemical parameters, while biological elements were utilized only in separate statutory monitoring and impact assessment programmes (Rannikko, 2005). According to the demands of the WFD, the five ecological status classes of surface waters (high, good, moderate, poor and bad) should be assessed by calculating Ecological Quality Ratios (EQR), i.e. the ratio between the observed values and the reference values for the biological quality elements (BQE). The BQEs include phytoplankton, macrophytes, macroinvertebrates and fish. The worst biological or physical–chemical classification results should be used to define the ecological status class of a waterbody (EU, 2000). According to the WFD guidance (EU, 2005), the One-out all-out principle (OoAo), i.e. that BQE indicating the lowest status, should be used when defining the ecological status. However, we argue that this approach is neither strictly in line with the principles of the WFD nor is it optimal when the classification criteria and available monitoring data are still deficient. Most metrics assess only one pressure, for example in the present study the

pressure is eutrophication, but there may also be several interacting pressures present in the water body with largely unknown joint impacts. These are common problems currently tackled by most EU member states. Therefore, the weight-of-evidence (WoE) approach was applied in the first WFD classification in Finland. The applicability of these approaches was first discussed by Alahuhta et al. (2009), and is further evaluated here.

There are 47 lakes larger than 100 km² in Finland (Raatikainen & Kuusisto, 1990). In historical times, they have been important as waterways, fishing grounds, for water abstraction and recreation, but unfortunately also as waste water recipients. Consequently many large Finnish lakes were severely polluted in the 1960s and 1970s (Hakkari, 1992; Niemi et al., 2004). After implementation of national water legislation and subsequent investments in water protection, the situation improved and the general physical–chemical water quality of the large Finnish lakes had mainly recovered to a good or even high status by the end of the 1990s, according to the earlier assessment methods (Niemi et al., 2004; Rannikko, 2005).

In theory, the high ratio of hypolimnion to epilimnion volume in large lakes should facilitate the chemical and biological recovery of the ecosystems from pollution as in deep and stratified lakes the retention of total P is higher compared to shallow lakes. In practice, a sufficiently short water residence time for maintenance of predominantly oxidizing hypolimnetic conditions is often a prerequisite for the recovery which is also may be affected by basin morphometry and pollution history of lakes (Wilander & Persson, 2001). However, the mechanisms of recovery vary between different biological groups and lake communities, and are also often affected by other anthropogenic pressures, such as hydromorphological alterations, which are mainly the regulation of water level for hydro power production (Marttunen et al., 2006). The recovery potential is generally high for phytoplankton (Sommer et al., 1993; Tatrai et al., 2008), whereas aquatic macrophytes, benthic invertebrates and fish may show a delay in recovery depending on the degree and duration of past pollution and current pressures affecting hypolimnetic and littoral conditions (Scheffer, 1998). In view of these prerequisites, we hypothesize that the ecological status of our formerly heavily polluted large

lakes is likely to show good results for phytoplankton, but more variable results for the other quality elements.

Here, we present the results of the first ecological classification of a set of large Finnish lakes. We compare the performance of different classification approaches: numerical integration of BQEs (median scores across elements); the OoAo approach; and the national Finnish classification utilizing WoE on biological, hydromorphological and physicochemical status and overall pressures on the lakes. We discuss the sensitivity to phosphorus concentrations of those classification metrics mostly indicating eutrophication status, and the suitability of recent classification tools.

Materials and methods

We studied a set of 32 large (surface area $>75 \text{ km}^2$) Finnish lakes or their parts, from which we had data for all or most of the four biological quality elements needed for the classification of their ecological status. The most distant lakes are almost 1,000 km apart, in southwestern Finland (Lake Pyhäjärvi) and Finnish Lapland (Lake Inari), but most of the lakes are situated in the lake district of central Finland (Fig. 1). Twelve of the lakes were reference lakes for most of the quality elements. All impacted lakes are affected by diffuse nutrient loading and one-third of them also by point source pollution. Four of the lakes are regulated with an annual water level fluctuation amplitude of more than 1 m (Keto et al., 2008).

The biological data and the classification outputs were obtained from the databases of the Finnish Environmental Institute and the Finnish Game and Fisheries Research Institute. The biological data have been produced using national or EU standard methods as follows: phytoplankton (Olrik et al., 1998; CEN, 2006), macrophytes (Leka et al., 2008), macroinvertebrates (SFS, 1989) and fish (Olin et al., 2002; CEN, 2005). In the Finnish lake typology (Pilke et al., 2002), our study lakes (surface area $>40 \text{ km}^2$, mean depth $>3 \text{ m}$) fall evenly into two types: large oligohumic (water colour $<30 \text{ mg Pt l}^{-1}$) and large humic (colour $>30 \text{ mg Pt l}^{-1}$) lakes (Table 1).

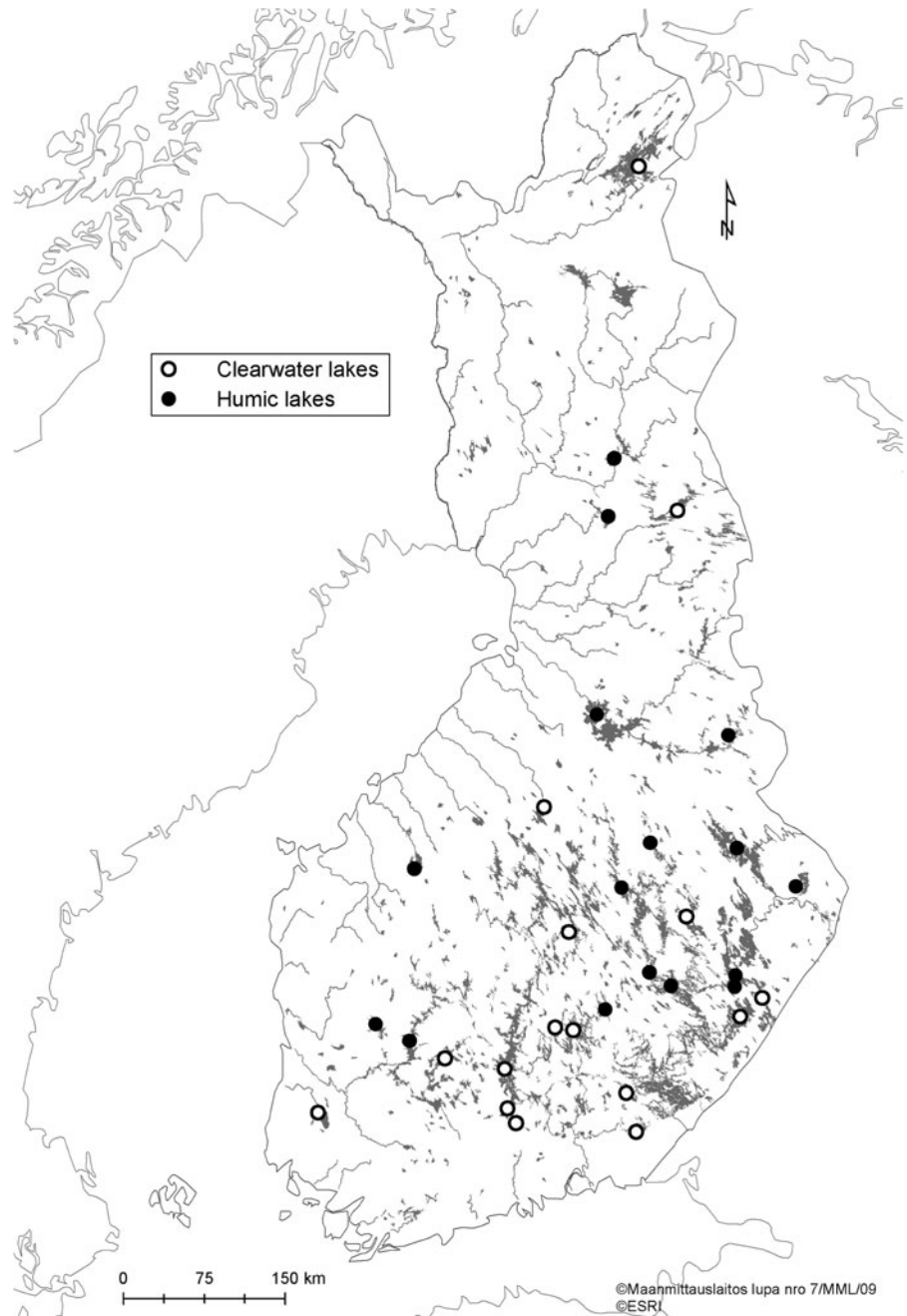
Two phytoplankton metrics, chlorophyll-*a* and phytoplankton total biomass, both sensitive to eutrophication, were used in the classification. In addition,

the percentage of harmful cyanobacteria, also indicating eutrophication, was used as a supporting metric (Vuori et al., 2009). The reference value for the metrics was the median value of the type-specific reference lake group. The high/good (H/G) boundary was set to the 75th percentile of the values of the reference lakes, the good/moderate (G/M) boundary was the 95th percentile of the values of the reference lakes together with the reference values that were divided by two (Vuori et al., 2009). The moderate/poor (M/P) boundary was two times the G/M boundary and the poor/bad (P/B) boundary two times the M/P boundary. The chlorophyll metric has been intercalibrated according to the demands of the WFD (EU, 2000). This intercalibration exercise is intended to achieve comparability in the classification procedures among EU member states.

The preliminary macrophyte classification (Alahuhta et al., 2009) was based on a multimetric index consisting of three parameters: the proportion of type-specific taxa (Leka et al., 2008), Percentage Model Affinity (PMA) expressing taxonomic composition (Novak & Bode, 1992) and modified reference index (RI) showing the share of eutrophication-tolerant and -intolerant species (Stelzer et al., 2005; Penning et al., 2008). The upper quartile of each parameter in the reference lakes was used as a reference value. The lower quartile of the metrics is used as the H/G boundary and other boundaries were set at even distances downwards from the H/G class boundary. The final multimetric index was calculated as a median value of the three parameters described above.

The classification for profundal macroinvertebrates uses a single metric, the Benthic Quality Index (BQI), which is based on the proportions of seven chironomid taxa tolerant and intolerant to increased sedimentation of organic matter and oxygen depletion, phenomena associated with nutrient enrichment (Wiederholm, 1980). In spite of being initially a tool for assessment of eutrophication, BQI effectively integrates the variation of the whole profundal macroinvertebrate community structure (Kansanen et al., 1990; Jyväsjärvi et al., 2010), and thus it may also act as a proxy for multiple pressures. Classification of profundal macroinvertebrates followed the national guidance (Vuori et al., 2009). Site-specific reference values for BQI were estimated using a linear regression model with lake mean depth as the

Fig. 1 The location of the lakes included in the study



predictor variable. As site-specific reference value compensates for the effect of depth on the BQI of a lake, the classification output is more reliable than using a lake type based approach (see Jyväsjärvi et al., 2009, 2010). As zero values of BQI (no indicator species present) were ignored (see Jyväsjärvi et al., 2010), a value of 1 was subtracted from both the reference and observed BQI values to anchor the

theoretical minimum BQI value to 0. The sites were then classified using the following class boundaries for observed values—H/G: 75% of the site-specific reference value; G/M: 60%; M/P: 30% and P/B: 10% of the site-specific reference.

Fish-based ecological classification applied an index of four fish community parameters (EQR4) sensitive to eutrophication pressure (Holmgren et al.,

Table 1 The observed nutrient concentrations and parameter and index values of the biological quality elements (mean, SD) included in the ecological classification of the oligohumic and humic lakes of the present study

	Oligohumic lakes			Humic lakes		
	Mean/Ref	SD	<i>n</i>	Mean/Ref	SD	<i>n</i>
Nutrients						
Total P, $\mu\text{g l}^{-1}$	9.4/8.0	5.8	16	14.2/12.0	6.2	16
Total N, $\mu\text{g l}^{-1}$	341/350	91	16	455/400	164	16
Phytoplankton						
Chlorophyll a, $\mu\text{g l}^{-1}$	3.6/3.0	1.7	16	7.0/4.5	3.7	16
Total biomass, mg l^{-1}	0.81/0.4	0.77	14	1.18/0.7	0.96	15
% of Cyanobacteria	6.0/3.3	4.2	14	5.8/4.2	4.5	14
Macrophytes						
Type-specific taxa	0.58/0.72	0.15	10	0.63/0.86	0.6	11
PMA	50.5/56.1	9.1	10	50.2/65.7	12.5	11
Reference index	57.6/57.5	24.6	10	43.6/52.3	18.9	11
Macroinvertebrates						
BQI	1.33/model	0.91	14	1.04/model	0.94	14
Fish						
BPUE, g per gillnet night	784/895	595	16	552/596	236	16
NPUE, n per gillnet night	33/39	31	16	21/31	14	16
% of cyprinid fish	30/41	10	15	34/38	11	16
Indicator species	0.85	0.09	16	0.82	0.12	16

Type-specific taxa, Percentage Model Affinity (PMA) and reference index of macrophytes are index-type parameters with no specific units. So is the indicator species of fish, which is based directly on the presence/absence of certain species and therefore has no reference values. Site-specific reference values for Benthic Quality Index (BQI) are obtained from a linear regression model. For more details, see material and methods and references therein

Ref values used as reference values in the Finnish classification system, *n* number of lakes

2010; Rask et al., 2010). The lake type-specific values of the three of these parameters were obtained from gillnet test fishing: (1) total biomass of fish per unit effort (BPUE, g per gillnet night); (2) total number of fish individuals per unit effort (NPUE, n per gillnet night) and (3) biomass proportion of cyprinid fish. The fourth parameter, the presence of indicator species, was based on all available information for specified, eutrophication-sensitive species (Rask et al., 2010). The reference value of each parameter was the median of the type-specific reference lake group and the high/good boundary was the 25th percentile from the EQR distribution of the reference lakes. The range of EQR values from the H/G class boundary to the extreme EQR recorded was then divided into even distances to set the other class boundaries (Holmgren et al., 2010; Rask et al., 2010). The final EQR4 value was obtained as the median of the parameter-specific EQR values.

The hydromorphological status of Finnish lakes is assessed with a scoring system (Vuori et al., 2009) based on the following alterations: winter drawdown, its effects on the mean depth or surface area of the lake, elevation or lowering of the water surface, percent change of shore line, bridges and embankments, and migration barriers.

The water quality status of Finnish lakes is based on the lake type-specific average concentrations of total phosphorus and total nitrogen in surface water (0–2 m) during the growing season (Vuori et al., 2009).

The BQE-based classification of the ecological status of the lakes applied an integrated approach (Alahuhta et al., 2009; Vuori et al., 2009). This integrated classification system harmonizes the available data for individual parameters and quality elements by scoring them and expressing the overall status class for a lake as a median score value across

all quality elements. For the national decision on the status class, the classification results were further evaluated by using a WoE approach (e.g. Lowell et al., 2000), in which all quality elements and monitoring results are weighted according to their relevance and reliability and the strength of their associations with environmental pressures. According to this approach, results based on low sampling frequency/replication and/or representing only a small proportion of the water body, as well as results having no credible associations with anthropogenic pressures, may be given lower weights in the final classification. By the same token, representative and comprehensive data with credible associations to pressures may be given a higher weight.

Analysis of variance was used to test the differences in total phosphorus (total P) and total nitrogen (total N) concentrations between the two lake types. Analysis of covariance was used to compare the relation between total P and different parameters of BQEs in the two lake types. When necessary, the

variables were ln-transformed to achieve a normal distribution.

Results

The total nutrient concentrations of the lakes were rather low and their ranges narrow (Table 1). Both total P and total N concentrations were higher ($P < 0.001$) in humic lakes ($7\text{--}23 \mu\text{g total P l}^{-1}$, $255\text{--}785 \mu\text{g total N l}^{-1}$) than in oligohumic lakes ($4\text{--}23 \mu\text{g total P l}^{-1}$, $155\text{--}470 \mu\text{g total N l}^{-1}$). Despite the narrow ranges of nutrients, selected biological quality parameters correlated significantly with total phosphorus (Fig. 2). For chlorophyll *a*, the increase along the increasing total P gradient was steeper in humic than in oligohumic lakes (Fig. 2A) though not significantly so (total P*lake type-interaction: $P = 0.126$). For macrophytes the modified reference index correlated relatively strongly with phosphorus in oligohumic lakes, but in humic lakes

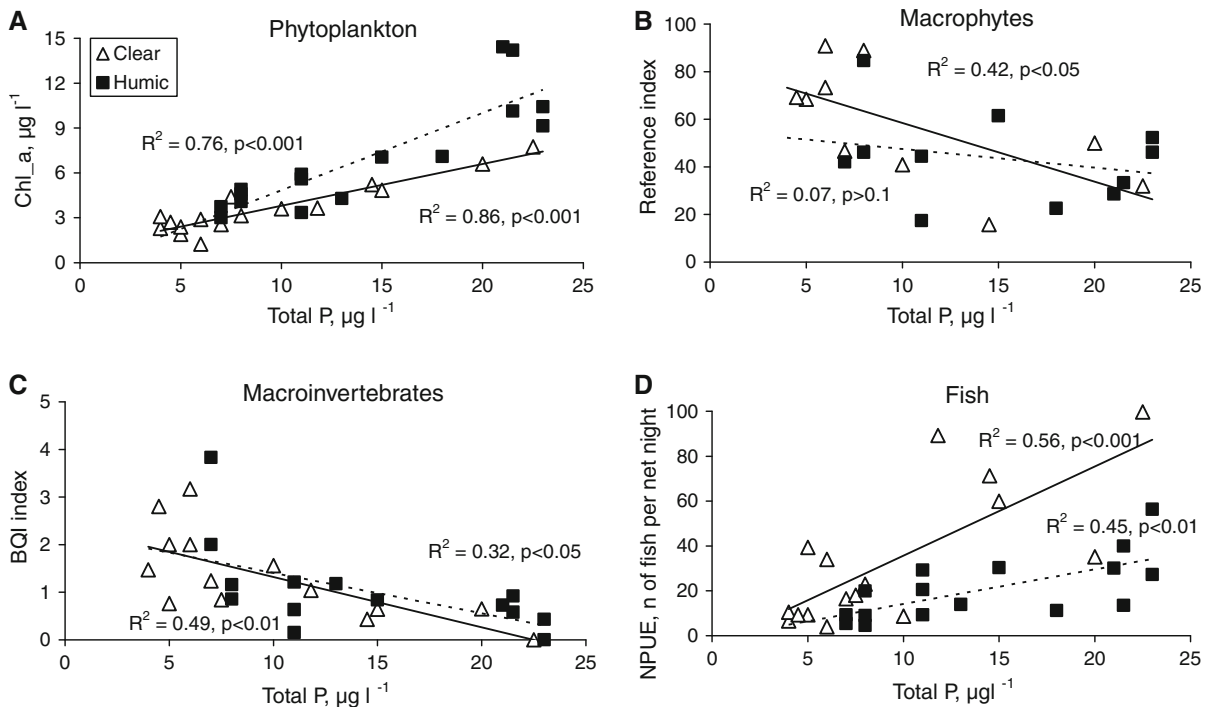


Fig. 2 Examples of parameters of each biological quality element related to the total phosphorus concentration in oligohumic (clear, solid line) and humic (dotted line) study lakes. R^2 and P values for both lake types are given in the graphs. Regression parameters for the whole data set were as

follows: phytoplankton: d.f. = 31, $R^2 = 0.82$, $P < 0.001$, macroinvertebrates: d.f. = 27, $R^2 = 0.51$, $P = 0.001$, macrophytes: d.f. = 20, $R^2 = 0.39$, $P = 0.035$ and fish: d.f. = 31, $R^2 = 0.52$, $P < 0.001$

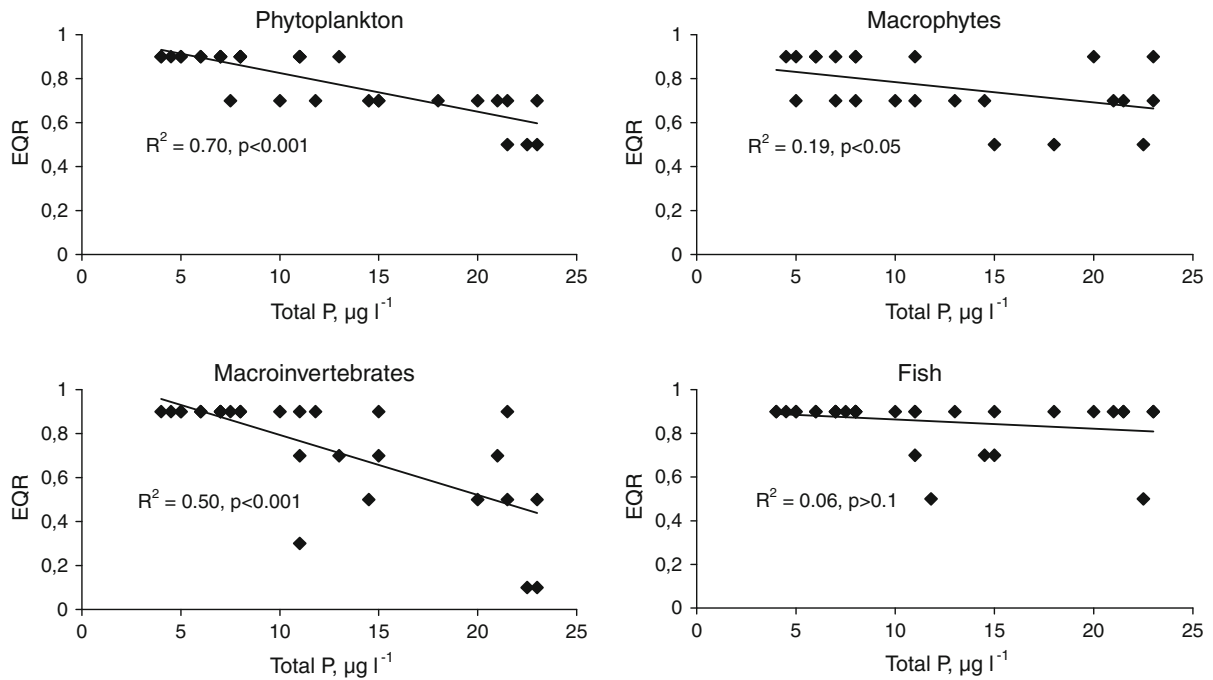


Fig. 3 Ecological quality ratio (EQR) scores for different biological quality elements (BQE) related to the total phosphorus concentrations of the lakes

the correlation was not significant (Fig. 2B). The relationship of macroinvertebrate BQI to total P was apparently independent of lake type (Fig. 2C). The NPUE of fish seemed to increase more steeply in oligohumic than humic lakes along the total P gradient (Fig. 2D), although the difference in the regression coefficients was not significant ($P = 0.741$). The relation of the EQR scores of the BQEs to the total P concentrations indicated highly significant correlations for phytoplankton and macroinvertebrates but was not significant for fish (Fig. 3).

Among the biological quality elements, the phytoplankton-based classification suggested high status for 18 of the 32 lakes (Fig. 4). Based on macrophytes and macroinvertebrates, the proportion of high status lakes would be somewhat smaller (10/23 and 13/28 lakes, respectively), whereas according to fish-based classification most of the lakes (27/32) would be of high ecological status. Profundal macroinvertebrates was the only biological element which classified some lakes as poor or bad status (Fig. 4).

Hydromorphological status was determined from 24 lakes for which the status was high or good for 18, whereas the water quality status was high or good in 28/32 lakes (Fig. 5). The output of biological

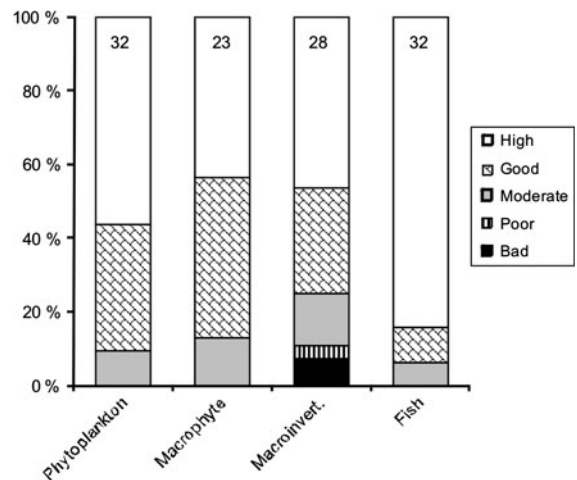


Fig. 4 The distribution of ecological status of the large lakes of the present study according to the four biological quality elements (BQE) separately. Number of lakes with data for each BQE is given on the bars

classification based on integrated (median) BQEs was fairly close to the water quality based status (Fig. 5). According to the decision on ecological status based on the WoE approach, the number of high status lakes was lower and good status lakes higher compared to

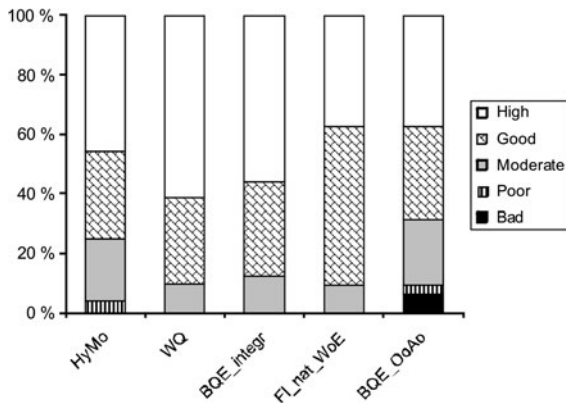


Fig. 5 The status of the 32 large lakes included in the present study. Finnish national status decision (FI_nat_WoE) is based on the expert judgement assessing the weight-of-evidence from hydromorphological status (HyMo, available from 24 lakes), water quality status (WQ), median-based biological classification (BQE_integr) and lake-specific pressures. The classification output from all BQEs according to the OoAo approach is given for comparison

the distribution of hydromorphological, water quality or integrated median-based biological status (Fig. 5).

Compared to the OoAo classification of BQEs, the national WoE approach gave similar, downgraded or upgraded status classes. Downgrading from high to good took place in three lakes due to higher weight given to water quality and eutrophication pressures. Upgrading from bad/poor to moderate/good or poor/moderate to moderate/good (10 lakes) was mainly due to lower weight being given to a single macro-invertebrate metric with poorly represented data. This can be seen in Fig. 5 with the poorest status classes of OoAo omitted in the national WoE classes.

Discussion

The differences between the trends of some biological BQE parameters along the gradient of total phosphorus concentration suggest that dividing the large Finnish lakes into two types, clearwater or oligohumic and humic (Pilke et al., 2002), is justified. The modified reference index of macrophytes correlated with total P concentration more strongly in oligohumic than in humic lakes. The reason for this is that most of the oligotrophy indicators decrease both with increasing eutrophication and with increasing

humic content of water which produces a worsening underwater light climate (Penning et al., 2008). The higher fish catches from clearwater than from humic lakes are in line with earlier observations from Nordic countries (Rask et al., 1999).

The classification of the ecological status of large Finnish lakes using biological data supports recent recognition of the generally good status of the lakes (with respect to eutrophication) following effective reductions of nutrient loads from point sources during the last 40 years (Niemi et al., 2004). Moreover, a recent European comparison of chlorophyll *a* values indicated that the proportion of high and good status lakes was 71%, the majority of those (25/37) from Finland, whereas among the lakes of less than good status only 3 of 16 were found from Finland (Poikane et al., 2009). For status assessment of Estonian large lakes, see Nõges & Nõges (2006).

The assessment tools developed thus far in Finland are mainly targeted at detecting the pressure of eutrophication. Among single BQEs, this was reflected as significant correlations with the total P concentration of water. However, for fish the correlation was weak and the EQR4 index clearly gives too high ecological status values for large lakes. This may be due to many reasons. One is that the fish fauna of Finnish lakes is composed of a relatively low number of species with a wide range of environmental tolerances (Tonn et al., 1990). Thus, it may be that in a narrow eutrophication gradient of lakes, as in the present study, the fish community response to eutrophication is not as detectable as in lakes of a higher degree of eutrophy (Olin et al., 2002). Furthermore, the reference data used in this study includes only a small number of lakes. In humic lake types, joint class boundaries for the parameters have been used for large and moderate size lakes, which may result in too high reference values for fish variables. One problem may be the difficulty of sampling huge water areas or volumes in a reliable way and with acceptable effort by means of gill netting. In the future, the possibilities of including sampling of littoral fish by electrofishing (Sutela et al., 2008) and pelagic sampling with echo counting (Jurvelius & Auvinen, 1989) have to be considered. The former method is likely to be better in assessing the effects of hydromorphological changes (Sutela & Vehanen, 2008; Sutela et al., 2008). Diekmann et al. (2005) recommended fish sampling in different habitats with complementing methods to

fulfil the requirements of the Water Framework Directive. A picture of fish status covering all main habitats in lakes would also give more useful information for fisheries management.

The poorest status of lakes according to BQEs was suggested by the benthic invertebrates. The lakes with the poorest BQI scores are known to have been suffering from eutrophication, especially during former decades. In the light of decreased nutrient concentrations and improved hypolimnetic oxygen conditions in these lakes during recent years, the classification result from BQI appears to be too strict. Low BQI values may result from narrow, restricted profundal areas dominated by a single BQI-species, such as *Chironomus plumosus*. Given the low overall abundance and of BQI-species especially, the low number of replicates may yield unreliable estimates for the BQI metric. This was the case in our data for the bad/poor status classes in a couple of lakes. Further, the subtraction of 1 from the original BQI values appeared to artificially downgrade the status class. Use of the OoAo principle in such cases may not be justified, at least when all other elements indicate moderate or good status. On the other hand, these observations may indicate a slow recovery of profundal benthic habitats and biota, their partial decoupling from other compartments of the lake and hence their value in holistic lake assessment (e.g. Little et al., 1999).

The national Finnish decision on the status of the lakes, which is based on the weight-of-evidence from hydrological and morphological status, water quality status, biological classification, lake-specific pressures and expert judgement, clearly lowered the proportion of lakes in high status class compared to the distribution of hydromorphological, water quality, or integrated median-based biological status. This is well justified considering that some of these lakes have good water quality but are hydromorphologically altered due to regulation (Keto et al., 2008) or have been previously subject to heavy nutrient loading (Niemi et al., 2004). The hydromorphological changes are not adequately detected in the Finnish BQE-based classification and more sensitive metrics should be developed for this common pressure (Sutela & Vehanen, 2008).

Because of the substantial variability in the classification results of the different BQEs, it seems

that classifications based on a single quality element representing a single habitat may not adequately represent the overall quality status of a lake (see also Nöges & Nöges, 2006; Søndergaard et al., 2005). This is why the integrated WoE approach was applied in Finland rather than the OoAo principle (Alahuhta et al., 2009; Vuori et al., 2009). We believe that this approach results in more credible classifications. Nevertheless, in practical lake management the evidence from the strictest BQE does need to be thoroughly considered.

To develop the BQE-based ecological classification of surface waters, studies are clearly needed to examine how different biotic groups respond to multiple environmental pressures and whether the responses are concordant among different habitats. Furthermore, and given that aquatic macrophytes are the only quality element representing the lake littoral in the current classification system, more attention should be paid to other shoreline communities such as littoral macroinvertebrates and fish.

Concluding remarks

The first classification of the ecological status of the large Finnish lakes using biological data supports the recent recognition of the generally good current status of the lakes following effective reductions of nutrient loads from the point sources. Different classification approaches yielded different status class distributions. Compared to the One-out-all-out approach of classifying lakes according to the strictest biological element, the national approach using weight-of-evidence justification gave similar, downgraded or upgraded status classes. We suggest that this approach is optimal for ecological status assessments, which always face problems with the quality, quantity and representativeness of monitoring data. This approach also seems to be well justified during the early implementation of WFD, when monitoring programs have just started and classification criteria are deficient for several water body types. The present study highlights the need for high-frequency and high-quality monitoring data for BQEs, for further research into the responses of biological communities to different pressures in different habitats, and for further development of methods for status assessment.

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