BOREAL ENVIRONMENT RESEARCH 10: 31–43 ISSN 1239-6095
Helsinki 25 February 2005 

# Hindcasting baseline values for water colour and total phosphorus concentration in lakes using sedimentary diatoms — implications for lake typology in Finland

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Miettinen, J. O., Kukkonen, M. & Simola, H. 2005: Hindcasting baseline values for water colour and total phosphorus concentration in lakes using sedimentary diatoms — implications for lake typology in Finland. *Boreal Env. Res.* 10: 31–43.

Background and present total phosphorus (TP) concentrations and water colour have been assessed with palaeolimnological methods in 27 lakes in eastern Finland. Sediment samples from core bottoms (sediment depth 29–185 cm) and core tops (sediment depth 0–1 cm) were analysed for diatom assemblages, and TP and water colour were estimated by weighted averaging methods. Changes in DI-TP and water colour between the core bottom and top samples were used for identification of potential reference lakes, as defined by the EU Water Framework Directive. In addition, implications for lake typology in Finland are discussed. Our results suggest that naturally eutrophic lakes may be more common in Finland than previously thought. Water colour, as well as TP, seems to have been subject to considerable changes in many lakes. According to our results, oligotrophic clearwater lakes appear to be little changed from their pre-disturbance conditions, but most of the presently highly coloured lakes have developed towards increasing water colour.

## Introduction

Knowledge of the natural ecological state of waters is essential for rational management of water bodies. While human impact on most water bodies has started much earlier than any monitoring activities, palaeolimnology is often the only means for obtaining reliable information about pre-disturbance conditions. Modern palaeolimnological methods enable quantitative hindcasting of e.g. acidity and total phosphorus (TP) in lakes, providing error estimates to indicate the reliability of the assessments (Birks 1995).

The natural baseline or reference conditions in water bodies are presently of particular interest, since the EU Water Framework directive (WFD; European Parliament 2000), effective since 2000, demands the natural ecological state of freshwater bodies to be determined, as this is taken as a basis for typification and classification of waters. Pilke *et al.* (2002) presented a draft for a Finnish lake typology, which allots lakes to types according to colour (oligohumic lakes < 30 mg Pt $l^{-1}$, mesohumic 30–90 mg Pt $l^{-1}$, and polyhumic > 90 mg Pt $l^{-1}$), surface area (< 5, 5–40, > 40 $km^2$), and existence of temperature stratification. In addition, the rare categories of mountain lakes, naturally eutrophic lakes (winter turbidity > 5 FNU), and lakes with high Ca, are proposed as separate types.

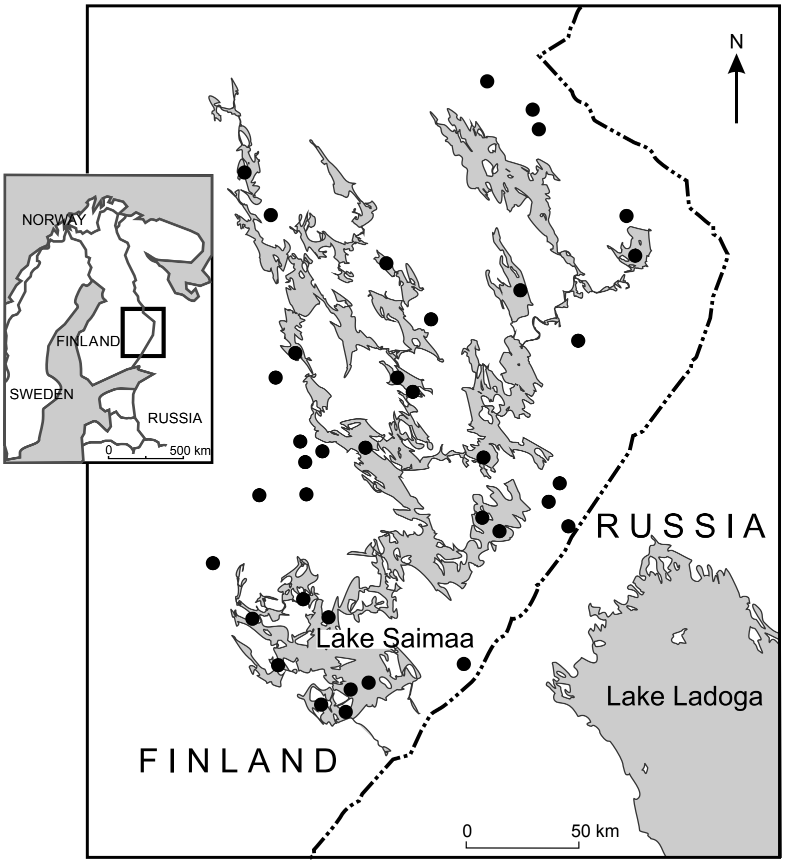


**Fig. 1**. Distribution of the studied lakes and basins (Lake Ladoga and the largest lakes in eastern Finland are outlined and shaded). Dotted line marks the border between Finland and Russia.

In this study, water quality is reconstructed by biological inference models, that assess the relationship between biological assemblages and water quality parameters. We use weighted averaging (WA) transfer functions (ter Braak & Van Dam 1989), that estimate optimum values of environmental parameters for each taxon in a calibration data set. The optimum value for a taxon is the average value of the parameter in sites where the taxa is found, weighted by its abundance in the sites. These optimum values are used to derive estimates for parameter values pertaining to fossil (sedimentary) samples by calculating the average of the respective abundance-weighted optimum values of the taxa found in the sample.

For this study we analysed diatoms in top and bottom samples from 37 sediment cores (sites), representing 27 lakes in eastern Finland (Fig. 1), in order to assess the lakes' baseline and modern water colour and TP concentrations. The WA calibration data set (Miettinen 2003) consists of 78 lakes in eastern Finland.

## Material and methods

### Sampling and analysis of sedimentary diatom assemblages

The material consists of 37 sediment cores, out of which 25 are single cores of individual lakes, three are from Karelian Pyhäjärvi, and nine are from five different basins of the complex of Lake Saimaa. The sediments were cored during January–March 2001, except Karelian Pyhäjärvi sites 2 and 3 in late summer 2002, and three basins of Lake Saimaa (Haukivesi, Paasivesi and Puruvesi) in summer 1990. All the samples were obtained from profundal area of the lakes, in most cases from a site with water depth near the maximum depth of the basin.

The water chemistry for the lakes was sampled in September–November in 1999 or 2000, except for Saimaa Lappeenranta 1–4 in November 1997, and Paasivesi, Haukivesi and Puruvesi in autumn 1990. The water chemistry data (Table 1) was provided by the Regional Environment Centres.

The simplest approach for palaeolimnological analyses is the core-top-and-bottom analysis (Hall and Smol 1995). It involves analysing the surface of the sediment, and at least one sediment level that is considered to represent pre-disturbance conditions. The depth of the latter depends on sediment accumulation rate and history; in Finland, where human interference is relatively recent (industrialisation and modern agriculture developed during the 20th century), we find 30 cm sufficient for oligotrophic lakes and ca. 1 m for eutrophic ones. For example, according to Simola *et al*. (1996), sediment accumulation rate in Lake Saimaa varies from 0.2 mm yr$^{-1}$ in the deep, unpolluted areas of Puruvesi, to 3–4 mm yr$^{-1}$ within the uppermost sulphide mud in polluted Haukivesi basin. These 30 cm or 1 m

**Table 1**. Studied sites: coordinates, TP, colour, surface area, and Water Framework Directive type drafted by Pilke *et al*. (2002).

| Site no. | Site | Code | Lat. N | Long. E | TP (µg l$^{-1}$) | Colour (mg Pt l$^{-1}$) | Area (km$^2$) | Draft type |
|---|---|---|---|---|---|---|---|---|
| 1 | Höytiäinen | Hoytiain | 62°44´ | 29°46´ | 5 | 30 | 283 | 8 |
| 2 | Iso-Hietajärvi | Iso-Hiet | 63°10´ | 30°43´ | 5 | 20 | 0.82 | 4 |
| 3 | Iso-Lyly | Iso-Lyly | 63°00´ | 28°32´ | 13 | 30 | 0.84 | 4 |
| 4 | Jamalinjärvi | Jamalinj | 63°24´ | 29°57´ | 14 | 100 | 1.2 | 9 |
| 5 | Kangasjärvi | Kangasja | 62°00´ | 35°20´ | 41 | 150 | 22 | 10 |
| 6 | Kermajärvi | Kermajar | 62°27´ | 28°40´ | 6 | 20 | 86 | 5 |
| 7 | Koirusjärvi | Koirusja | 62°36´ | 27°32´ | 6 | 25 | 4.3 | 4 |
| 8 | Koitere | Koitere | 62°27´ | 30°39´ | 8 | 70 | 164 | 8 |
| 9 | Korpijärvi | Korpijar | 61°14´ | 27°07´ | 4 | 20 | 31 | 4 |
| 10 | Kuolimo | Kuolimo | 61°21´ | 27°24´ | 6 | 10 | 79 | 5 |
| 11 | Kuusjärvi | Kuusjarv | 62°41´ | 28°56´ | 37 | 160 | 1.0 | 9 |
| 12 | Löytöjärvi | Loytojar | 62°34´ | 30°19´ | 8 | 40 | 1.3 | 6 |
| 13 | Luonteri | Luonteri | 61°38´ | 27°47´ | 4 | 10 | 150 | 5 |
| 14 | Muntsurinjärvi | Muntsuri | 63°32´ | 29°59´ | 23 | 210 | 0.83 | 9 |
| 15 | Nurmijärvi | Nurmijar | 61°23´ | 29°10´ | 5 | 10 | 9.8 | 4 |
| 16 | Onkivesi | Onkivesi | 63°15´ | 27°22´ | 60 | 80 | 114 | 2 |
| 17 | Oravilahti | Oravilah | 62°35´ | 27°38´ | 10 | 15 | 42 | 4 |
| 18 | Pyhäjärvi1 | Pyhajar1 | 62°02´ | 29°55´ | 5 | 10 | 248 | 5 |
| 19 | Pyhäjärvi2 | Pyhajar2 | 61°54´ | 29°55´ | 9 | 10 | 248 | 5 |
| 20 | Pyhäjärvi3 | Pyhajar3 | 62°02´ | 29°55´ | 5 | 10 | 248 | 5 |
| 21 | Ruokojärvi | Ruokojar | 61°38´ | 28°23´ | 10 | 50 | 1.6 | 6 |
| 22 | Saimaa Haukivesi | S-Haukiv | 62°10´ | 28°19´ | 16 | 35 | 514 | 8 |
| 23 | Saimaa Lappeenranta1 | S-Lapp1 | 61°06´ | 28°10´ | 10 | 25 | 80 | 8 |
| 24 | Saimaa Lappeenranta2 | S-Lapp2 | 61°05´ | 28°16´ | 14 | 50 | 80 | 8 |
| 25 | Saimaa Lappeenranta3 | S-Lapp3 | 61°08´ | 28°17´ | 50 | 50 | 80 | 8 |
| 26 | Saimaa Lappeenranta4 | S-Lapp4 | 61°10´ | 28°25´ | 25 | 35 | 80 | 8 |
| 27 | Saimaa Lietvesi | S-Lietve | 61°30´ | 28°00´ | 6 | 30 | 91 | 8 |
| 28 | Saimaa Paasivesi | S-Paasiv | 62°08´ | 29°27´ | 7 | 45 | 108 | 8 |
| 29 | Saimaa Puruvesi1 | S-Puruv1 | 61°59´ | 29°30´ | 7 | 10 | 440 | 5 |
| 30 | Saimaa Puruvesi2 | S-Puruv2 | 61°56´ | 29°35´ | 9 | 10 | 440 | 5 |
| 31 | Sorsavesi | Sorsaves | 62°32´ | 27°32´ | 4 | 20 | 55 | 5 |
| 32 | Suomujärvi | Suomujar | 63°08´ | 30°45´ | 5 | 50 | 6.6 | 7 |
| 33 | Suurijärvi | Suurijar | 60°41´ | 27°54´ | 6 | 30 | 16 | 7 |
| 34 | Syvänsi Lahnankuttava | SyvansiL | 62°27´ | 27°25´ | 23 | 120 | 15 | 10 |
| 35 | Sääksjärvi | Saaksjar | 62°04´ | 27°56´ | 31 | 80 | 2.7 | 6 |
| 36 | Valvatus | Valvatus | 62°13´ | 27°50´ | 38 | 70 | 5.5 | 7 |
| 37 | Ätäskö | Atasko | 62°01´ | 30°01´ | 23 | 60 | 14 | 7 |

we consider generally safe levels for background conditions, even though the lakes may have not been pristine, owing to slight impacts of early agriculture (e.g. Taavitsainen *et al*. 1994, Grönlund 1995, Miettinen *et al*. 2002).

Oligotrophic lakes were cored with a Kajak gravity corer, obtaining 29–55 cm long sediment cores. Meso-eutrophic lakes (TP > 20 $\mu$g $l^{-1}$) were cored with piston corers (modifications of Livingstone 1955), obtaining cores 100–185 cm long. 1-cm-thick slices from each of the core top and bottom were used for analysing the diatom compositions. In some cases, identifiable marker horizons (e.g. Simola *et al*. 1987) or clear sediment texture change in the upper part of the core aided in selection of proper sediment level to represent pre-disturbance conditions.

## Diatom identification

The sediment samples were treated using standard methods (Battarbee 1986). At least 500 diatom frustules were identified from the core-top and -bottom samples. An exception is Lake Ätäskö, where only 200 frustules were counted, due to low concentration of frustules in the clay sediment. Leitz Dialux 20 EB and Leica DMLB microscopes were used in the identification, with 1000× magnification and phase contrast optics.

## Ordinations

The sites were ordinated by detrended correspondence analysis (DCA; ter Braak 1995), to assess the grouping of the samples according to their core-bottom diatom assemblages. Program CANOCO 4.0 (ter Braak and Šmilauer 1998) was used for the ordinations, with square-root transformation of the species data. Only planktonic species were used in the final ordination, since it was observed that the proportion of epiphytic and benthic taxa in the sediment is greatly variable and dependent on the sampling site, and so appeared to hamper the comparison between lakes. In the ordination, the sites are presented by the types in the Finnish draft for typology (Pilke *et al*. 2002), based on the monitoring data of the lakes. Owing to lack of information about eventual temperature stratification in some of the lakes, we did not use stratification as a grouping factor for the sites.

**Table 2**. Transfer functions used for the TP and colour reconstructions: root mean squared error of prediction (RMSEp) and squared correlation ($R^2$) between observed and WA-modelled TP and colour values in the calibration set of 78 lakes (Miettinen 2003).

| Model | RMSEp | $R^2$ |
|---|---|---|
| log TP | 0.193 | 0.73 |
| log colour | 0.248 | 0.59 |

## Total phosphorus and colour calibration and reconstruction

The calibration data set consists of 78 lakes in eastern Finland, having an autumnal TP range 3–125 $\mu$g $l^{-1}$ and colour range 5–260 mg Pt $l^{-1}$. The diatom-TP transfer function has been validated by cross-validation using an independent 30-lake test set (Miettinen 2003). In the calibration data, TP and colour were used as the sole environmental variables in canonical correspondence analyses (CCA; ter Braak 1995), with a Monte Carlo test to evaluate the significance of the variables in explaining the variance of diatom data. The measured variables used in the calibration set as covariables were conductivity, pH, surface area and water depth, in addition to TP and colour.

All the chemistry values were log-transformed before the modelling, because of their skewed distributions in the calibration set. The diatom inferred (DI) values were derived from log-transformed data, and then back-transformed to linear scale ($\mu$g P $l^{-1}$ and mg Pt $l^{-1}$). The reconstructions are considered accurate enough for the sites, where the observed TP and water colour value is in the range of DI value ± root mean squared error of prediction (RMSEp; Table 2). As the error estimates are derived on a logarithmic scale, and are then backtransformed to linear scale, this results in confidence limits of 64%–155% of the observed TP and 57%–177% of the observed colour for the DI values.

The differences between the core-top and core-bottom samples were assessed by the DI-TP and DI-colour values, to detect potential

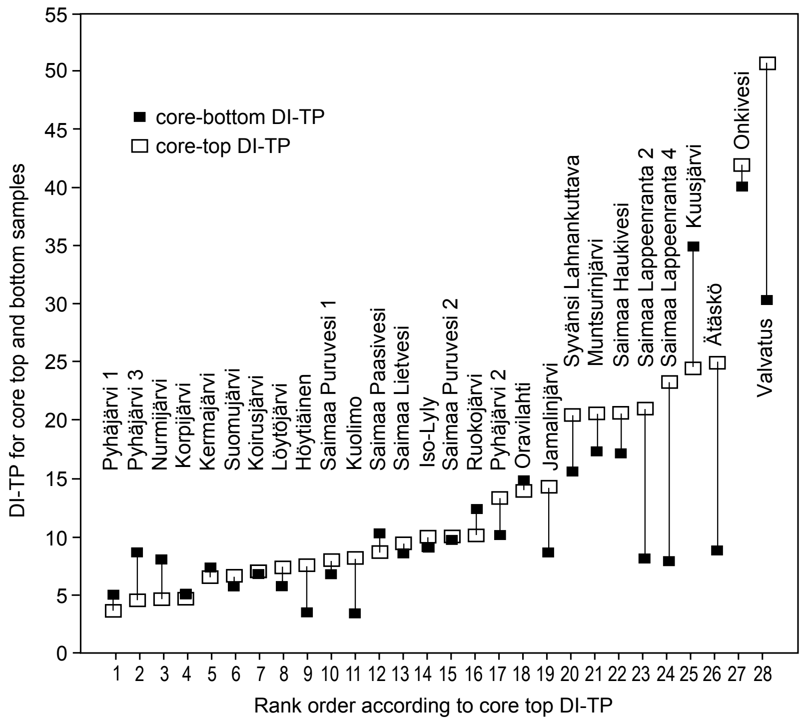


**Fig. 2**. Diatom-inferred total phosphorus in 28 sites. Open squares = sediment surface (present) DI-TP; black squares = core-bottom (background) DI-TP. The lakes are arranged along the *x*-axis according to their present DI-TP.

reference lakes for the WFD classification. In the absence of guidelines for assessment of change, we decided that differences smaller than 20% in both DI-TP and DI-colour between the core-bottom and top samples would indicate a site sufficiently close to its natural condition, so as to qualify as a potential reference site.

## Results

### TP and colour reconstructions

The sedimentary diatom assemblages are mostly dominated by planktonic taxa (genera *Asterionella*, *Aulacoseira*, *Cyclostephanos*, *Cyclotella*, *Stephanodiscus* and *Tabellaria*, and species *Fragilaria capucina*, *F. crotonensis*, *F. tenera* and *F. ulna*). The average proportion of these taxa in all the samples is 74%. Maximum amount of planktonic taxa was counted in the surface sediment of Lake Onkivesi (98%), and minimum in Lake Syvänsi, sediment depth 154–155 cm (24%).

In the CCA of the calibration data, TP gained a highly significant, and colour a significant axis 1 when the other measured variables were as covariables ($p = 0.002$ for TP, and $p = 0.018$ for colour; Monte Carlo test with 499 unrestricted permutations under full model). TP alone explained 7.8% of the variance in the species data, and 4.6% when the other variables were entered as covariables. Colour explained 6.7% and 2.3% of the variance in the species data, respectively.

With the terms of acceptability, presented in Material and methods, the obtained TP reconstructions are accepted for 28 sites. For nine sites the observed water column TP was outside the confidence limits of the core-top DI-TP. In Fig. 2, showing the core-top and -bottom DI-TP's for the accepted sites, the lakes are arranged according to the core-top DI-TP. It appears that among the most oligotrophic lakes there are many with no evidence of change, and some with a history of decreasing TP, while among the most eutrophic ones eutrophication is more common. There are six sites in the dataset with observed TP > 30 $\mu$g $^{-1}$, reflecting eutrophy according to Wetzel (1983), and of these three have very clearly been subject to eutrophication. However, there are also lakes that appear to have

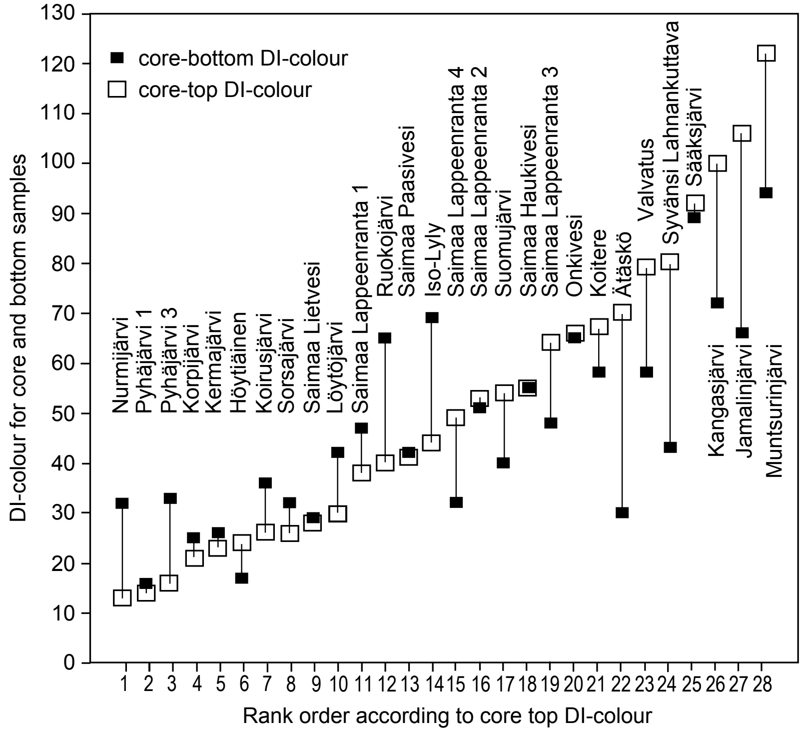


**Fig. 3**. Diatom-inferred total phosphorus in 28 sites. Open squares = sediment surface (present) DI-colour; black squares = core-bottom (background) DI-colour. The lakes are arranged along the *x*-axis according to their present DI-colour.

been naturally eutrophic. Three lakes have their core-bottom DI-TP > 30 $\mu$g l$^{-1}$ (sediment depths 100–185 cm).

Lake Onkivesi has the highest core-bottom DI-TP (40 $\mu$g l$^{-1}$). It is an exceptionally large (114 km$^2$) and at the same time shallow (mean depth 3.3 m) lake, situated in the bedrock zone of Karelidic schists, which includes apatite minerals. High phosphate levels in the mineral soils in this area are evident in geochemical mapping (Lahermo *et al.* 1996). Onkivesi has been lowered twice, in the 1840s and again in the 1950s, decreasing the mean water depth by 0.4 m (Tanskanen 2002).

The eutrophicated sites of Saimaa Lappeenranta are situated in southern Saimaa in an area impacted by wood processing industry effluents (J. Kukkonen *et al.* 1996, Manninen *et al.* 2003). The other eutrophication cases, Valvatus and Ätäskö are smaller lakes influenced by agriculture and forestry practices (Anonymous 2003, M. Kukkonen *et al.* 2003a, respectively). Water level in both of these lakes was lowered markedly in the 1800s (Anttila 1967); our reference levels represent the pre-lowering conditions. Kuusjärvi is a shallow lake (max. depth < 4 m), lowered around 1820 (Anttila 1967). The core-bottom DI-TP for Kuusjärvi (sediment depth 140–141 cm) is higher than the core-top DI-TP.

In the large oligotrophic Pyhäjärvi, the diatom assemblage reflects slightly higher nutrient levels at one sampling point, Pyhäjärvi 2 near the mouth of Mustolanjoki, than at the other two sites. DI-TP has remained consistently high at this sampling site, which has been sampled for surface sediment in 1985, 1990 and 2002 (M. Kukkonen *et al.* 2003b; site 18 therein). The drainage area consists largely of peat bogs, which were drained in the 1970s. In addition, effluents of the local municipal waste water treatment plant have affected the site since 1977 (M. Kukkonen *et al.* 2003a).

Colour reconstructions (Fig. 3) are also accepted for 28 out of 37 of the sites. According to the reconstructions, some lakes have changed towards decreasing water colour. These are all relatively low-coloured lakes. Of the presently high-coloured lakes (> 90 mg Pt l$^{-1}$), only Sääksjärvi has remained about the same (from 89 to

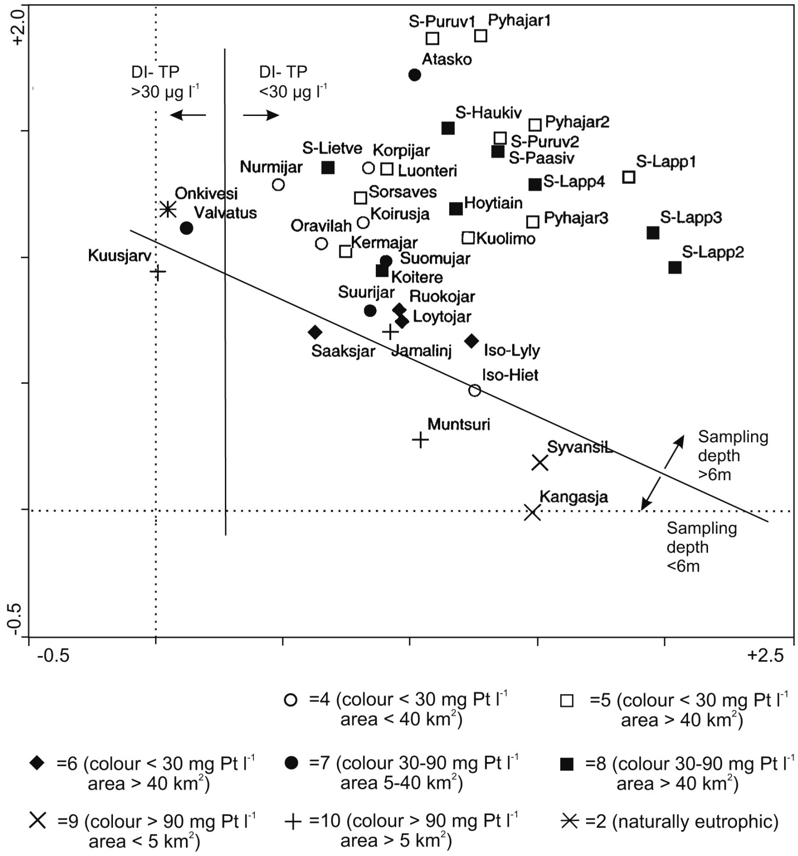


**Fig. 4**. DCA-ordination for the core-bottom samples, showing site affinities in the background conditions. The sedimentary diatom assemblages are different in eutrophic lakes, shallow dystrophic lakes, and large clearwater lakes. Lakes and basins are marked according to the draft types of Pilke *et al*. (2002).

92 mg Pt $l^{-1}$), but Jamalinjärvi, Muntsurinjärvi and Kangasjärvi have experienced considerable increase in water colour. Overall, the range of water colour in our lake set seems to have been more narrow in the past (DI-TP 16–94 mg Pt $l^{-1}$) than at present (DI-TP 13–122 mg Pt $l^{-1}$).

## Ordination

DCA ordination for the core-bottom samples resulted in gradient length of 2.05 for the first ordination axis (square-root transformation of species data, no downweighting of rare species), suggesting that both linear- and unimodal-based ordination methods would be appropriate (ter Braak and Prentice 1988). Eigenvalues in the DCA-ordination are 0.231 for the first ordination axis, and 0.157 for the second axis.

In the ordination (Fig. 4), the eutrophic lakes Onkivesi, Kuusjärvi and Valvatus are grouped at the low end of the ordination axis 1. The diatom assemblages in these lakes are dominated by *Aulacoseira ambigua* and *A. subarctica*, in both the top and the bottom core samples.

All the studied basins of Lake Saimaa are situated among the oligotrophic lakes in the ordination of the core-bottom samples. Also, the diatom composition in the core-bottom (140–141 cm) of the mesotrophic, mesohumic Lake Ätäskö is very similar to the diatom composition in the connected oligotrophic Pyhäjärvi.

The most humic lakes (types 9 and 10 in the draft typology of Pilke *et al*. 2002), are positioned at the low end of axis 2. Small oligotrophic, clearwater lakes are situated in and around the center of the biplot field. Large oligotrophic lakes (types 5 and 8) score high axis 2 values. Small and mid-sized mesohumic lakes (types 6 and 7) tend to ordinate between the clearwater and polyhumic lakes, as expected. The assemblages of the large clearwater lakes (type 5) are dominated mainly by the genus *Cyclotella*, whereas most of the other lakes are dominated by *Aulacoseira*.

## Potential reference lakes for WFD implementation

Lakes potentially suitable for reference lakes in the WFD implementation are indicated in Table 3. We find 9 lakes out of the 27, or 11 basins out of the 31, as suitable reference sites, when using the fairly strict exclusion limit of 20% change in either DI-TP or DI-colour. According to our data, lakes near their natural condition are abundant among the oligotrophic clearwater type of lakes. On the other hand, out of the five polyhumic lakes in our data set (types 9 and 10 according to Pilke *et al*. 2002), none fulfills our reference lake criteria.

**Table 3**. Reconstruction results for the core top and bottom samples, and the lengths of the sediment cores. Not accepted results (*see* Material and methods) are marked with an asterisk. Potential reference lakes (differences between top and bottom samples < 20%) are shaded.

| Site no. | Site | Bottom TP (µg l$^{-1}$) | Top TP (µg l$^{-1}$) | Bottom colour (mg Pt l$^{-1}$) | Top colour (mg Pt l$^{-1}$) | Core (cm) |
|---|---|---|---|---|---|---|
| 1 | Höytiäinen | 3 | 7 | 17 | 24 | 31 |
| 2 | Iso-Hietajärvi | 10* | 11* | 40* | 56* | 41 |
| 3 | Iso-Lyly | 9 | 10 | 69 | 44 | 32 |
| 4 | Jamalinjärvi | 9 | 14 | 66 | 106 | 32 |
| 5 | Kangasjärvi | 13* | 19* | 72 | 100 | 150 |
| 6 | Kermajärvi | 7 | 7 | 26 | 23 | 45 |
| 7 | Koirusjärvi | 7 | 7 | 36 | 26 | 38 |
| 8 | Koitere | 12* | 13* | 58 | 67 | 32 |
| 9 | Korpijärvi | 5 | 5 | 25 | 21 | 38 |
| 10 | Kuolimo | 3 | 8 | 11* | 35* | 144 |
| 11 | Kuusjärvi | 35 | 24 | 103* | 90* | 140 |
| 12 | Löytöjärvi | 6 | 7 | 42 | 30 | 37 |
| 13 | Luonteri | 6* | 6* | 27* | 23* | 32 |
| 14 | Muntsurinjärvi | 17 | 20 | 94 | 122 | 179 |
| 15 | Nurmijärvi | 8 | 5 | 32 | 13 | 42 |
| 16 | Onkivesi | 40 | 42 | 65 | 66 | 100 |
| 17 | Oravilahti | 15 | 14 | 60* | 36* | 44 |
| 18 | Pyhäjärvi1 | 5 | 4 | 16 | 14 | 30 |
| 19 | Pyhäjärvi2 | 10 | 13 | 46* | 46* | 35 |
| 20 | Pyhäjärvi3 | 9 | 5 | 33 | 16 | 35 |
| 21 | Ruokojärvi | 12 | 10 | 65 | 40 | 31 |
| 22 | Saimaa Haukivesi | 17 | 20 | 55 | 55 | 40 |
| 23 | Saimaa Lappeenranta1 | 11* | 16* | 47 | 38 | 41 |
| 24 | Saimaa Lappeenranta2 | 8 | 21 | 51 | 53 | 46 |
| 25 | Saimaa Lappeenranta3 | 10* | 32* | 48 | 64 | 51 |
| 26 | Saimaa Lappeenranta4 | 8 | 23 | 32 | 49 | 31 |
| 27 | Saimaa Lietvesi | 9 | 9 | 29 | 28 | 32 |
| 28 | Saimaa Paasivesi | 10 | 9 | 42 | 41 | 29 |
| 29 | Saimaa Puruvesi1 | 7 | 8 | 23* | 22* | 40 |
| 30 | Saimaa Puruvesi2 | 10 | 10 | 29* | 30* | 45 |
| 31 | Sorsavesi | 6* | 7* | 32 | 26 | 42 |
| 32 | Suomujärvi | 6 | 7 | 40 | 54 | 38 |
| 33 | Suurijärvi | 8* | 14* | 61* | 84* | 33 |
| 34 | Syvänsi Lahnankuttava | 15 | 20 | 43 | 80 | 155 |
| 35 | Sääksjärvi | 24* | 20* | 89 | 92 | 182 |
| 36 | Valvatus | 30 | 50 | 58 | 79 | 185 |
| 37 | Ätäskö | 9 | 25 | 30 | 70 | 141 |

## Discussion

### Lake typology

In the DCA-ordination, the lakes fall partly into groups that comply with the types proposed in the Finnish draft for lake typology. Lakes Valvatus and Kuusjärvi are ordinated with lake Onkivesi (the only lake with winter turbidity > 5 FNU). These three lakes have background TP values of at least 30 $\mu$g l$^{-1}$, and can be considered naturally eutrophic. According to the DCA ordination, diatom assemblages are different in lakes with water depth less than 6 meters, than in lakes with water depth more than 6 m (we used water depth at the sampling sites, which is in most cases near the maximum depth of the lakes).

According to the ordination of the core-bottom samples, all the studied basins of Lake Saimaa have been oligotrophic in the past, although the sites Paasivesi, Puruvesi, Haukivesi and Lappeenranta today present a gradient from clean to polluted waters. Simola *et al.* (1996) have earlier demonstrated that the pre-industrial fossil assemblages of both diatoms and chironomids of the polluted Haukivesi correspond closely with those of the unpolluted Paasivesi. Ätäskö and Pyhäjärvi form another pair of connected sites with similar diatom assemblages in the core-bottom samples. It seems that the analysed core-bottom sediment from Lake Ätäskö predates the 1830s lowering event (Anttila 1967). Before the lowering , the presently narrow strait between the lakes was more open, and the water quality presumably more similar in both basins. Since Lake Ätäskö presently is an independent water body belonging to the mesohumic, medium-sized type, whereas Pyhäjärvi is a large clearwater lake, in Lake Ätäskö a sediment level representing the time after its lowering would be preferable for the purpose of assessing the reference conditions.

The lakes cannot be divided into oligohumic and mesohumic types by their diatom assemblages: oligohumic and mesohumic lakes are mixed in the ordination, regardless whether the observed colour or core-bottom DI-colour is used for grouping the lakes. Lakes with colour > 90 mg Pt l$^{-1}$ (polyhumic) are distinctly grouped apart from the other lakes by their diatoms. Based on these data, water colour, at least the 30 mg Pt l$^{-1}$ level, appears not to be an ecologically decisive typification factor for surface waters. Tolonen *et al.* (2003) obtained similar results with littoral and profundal macroinvertebrate communities within the Vuoksi catchment area: their DCA ordination did not make any distinction between mesohumic (type 7) and oligohumic (type 4) lakes.

Most of the presently highly coloured lakes in this study have significantly lower background DI-colour values, implying that the high colour in lakes in eastern Finland is at least partly due to human influences. This appears to be a common feature, and it makes water colour a rather questionable factor for lake typologies. The same problem exists also with TP and may exist with other water chemistry variables, too. The factors that will be used in the ecological classification of the quality of lakes should not be the same ones that are employed for defining the types of lakes. This supports the notion that water chemistry variables should be ignored in the lake typology applied for the WFD implementation. Pilke *et al.* (2002) gives an option of using a more direct measure of catchment geology instead of the water colour.

### Value of palaeolimnological reconstructions for determining reference conditions

In earlier studies, empirical models have resulted in lower estimates of lake background TP than diatom inference models, although the models give similar estimates for the present day TP concentrations (Hall and Smol 1999). In studies where sediment-stratigraphic DI-TP concentrations have been compared to historical records (occasionally available since the 1970s), the paleolimnological methods have been shown to be reliable in revealing the trends, but not always the true values, in the TP concentrations in lakes (Bennion *et al.* 1995, Bradshaw and Anderson 2001, Kauppila *et al.* 2002).

In this study, the observed values of TP and colour fell outside the confidence limits of the surface sediment DI values in nine cases. Some of the errors between the observed and DI values may partly be due to unrepresentative water analysis results, since we have only one autumnal TP and colour measurement for comparison with each DI value. Deep, highly compacted sediment levels contain material sedimented over several, in many cases dozens of years in one centimeter, and can be considered more reliable on representing long-term diatom assemglages (and long-term water chemistry), than the surface, or near surface, sediment levels. Based on this, the reliability of the inferred reference values is likely to be as good or better than the inferred values for surface sediments.

Based on the RMSEp and $R^2$ between the observed and estimated colour, the precision and accuracy of the colour estimates are not as high as for TP. Clearly, water colour is not as important a factor for diatom distributions as TP, and the differences in colour optima for the diatom taxa may result from some other ecological factor linked to the water colour. However, we have tried to hindcast water colour, since humic substances causing water colour have a profound effect on the limnology of lakes (Keskitalo and Eloranta 1999). Already Järnefelt (1952, 1956) divided Finnish lakes into four categories according to trophy and dystrophy: oligohumic-oligotrophic, meso- to polyhumic oligotrophic, eutrophic and dyseutrophic.

The correlation coefficient between the log TP optima and log colour optima of the taxa in the calibration set is 0.683. This correlation seems generally to hold for most of the diatom taxa. However, there are exceptions, for example the common species *Cyclotella radiosa* and *Aulacoseira alpigena* have very similar TP optima (13 $\mu$g l$^{-1}$ and 14 $\mu$g l$^{-1}$) but different colour optima (36 and 80 mg Pt l$^{-1}$, respectively). The differences in the DI colour for bottom and top sediment samples are mainly the result of change in the *Aulacoseira*/*Cyclotella* ratio: the increased relative proportion of *Cyclotella* results in decreased DI colour, and vice versa.

According to Järnefelt (1952), the species of the genus *Aulacoseira* prefer dyseutrophic lakes, with the exceptions of *A. islandica* preferring eutrophy, and varieties of *A. distans* preferring humic mesotrophic lakes. The most abundant species in the genus *Cyclotella*, *C. radiosa* (*C. comta*) and *C. rossii* (*C. kützingiana*), prefer clearwater lakes; of these *C. radiosa* more eutrophic and *C. rossii* oligotrophic ones. The TP and colour optima used in this study for the WA estimations agree with the trophy preferences of diatom taxa reported by Järnefelt (1952). The TP optima for *C. rossii* is 8 $\mu$g l$^{-1}$, and for *C. radiosa* and the genus *Aulacoseira* between 13 and 38 $\mu$g l$^{-1}$ in our calibration set (Miettinen 2003). Colour optima for genus *Aulacoseira* is between 49 and 84 mg Pt l$^{-1}$, for *Cyclotella radiosa* 36 mg Pt l$^{-1}$, and for *C. rossii* 27 mg Pt l$^{-1}$.

One may argue that reconstructing two separate variables using one calibration set of lakes is somewhat questionable, and indeed the independent signal of the water colour is weaker than that for TP. However, the changes in the species assemblages behind the reconstructed changes in water colour, and literature (Järnefelt 1952, 1956, Lepistö and Rosenström 1998) supporting the trophy and dystrophy preferences of the taxa, give the reconstructed estimates of the water colour at least qualitative value. The diatom inferences may under- or overestimate especially the water colour systematically for some lakes, but we consider that these methods give quite accurate indications of the trends in the lakes.

This study was undertaken to help define the general reference conditions in eastern Finnish lakes, and also to size up the practical effort required for the paleolimnological assessment. Based on the confusing results obtained from the shallow Kuusjärvi (higher DI-TP for the core-bottom sediment than the top sample), more than two analysed sediment levels and dating of the core may be needed for some shallow lakes to obtain credible results. Exceptional sedimentation conditions in a lake would easily result in more than 1 m of sediment representing the industrial time. Also some special environmental events in the pre-industrial time could result in erroneous paleolimnological interpretations, if only a short sediment section is analysed. For example, many lakes have been lowered in Finland during the 18th and 19th centuries, leading to major sedimentation events and limnological changes in some cases. Among such lowered lakes are the lakes Valvatus and Kuusjärvi (Anttila 1967). This knowledge in fact casts some doubt on our results indicating that these lakes would be naturally eutrophic.

Dating (varves, Pb methods) would allow the use of sediment deposited in predefined years as background samples. Still, there remains the question which point in time to take as the reference. In the UK, pre-1850 (pre-industrial time) has been used as the date against which the impacts to lakes are assessed for the implementation of the WFD (Bennion *et al*. 2003). Individual lakes are known to have been changed by agricultural and forestry activities much earlier than that, for example in Finland from the Iron Age, ca. 400–500 AD (Tolonen *et al*. 1976, Huttunen & Tolonen 1977). Moss *et al*. (2003) proposed that a desirable background condition would be one in which the land use was sustainable, and states that this condition still prevailed in the land use in the early twentieth century, prior to World War II. We find that this definition of background would very well suit most Finnish lakes also, especially while it would circumvent the problems associated with the numerous lake-lowering events of the 18th and 19th centuries.

### Contemporary freshwater monitoring

Sedimentary assemblages provide a powerful tool for assessing the background and reference conditions in lakes. While the present (surface sediment) algal community will be sampled at the same time as the background community, the approach also provides valuable data for the actual classification and monitoring of the sites. Sedimentary diatoms store and integrate information on a time-average basis, thus evading the effects of seasonal variation and weather conditions on single water column samples. Work on benthic invertebrate assemblages suggests that this kind of quantitative modelling approach based on sedimentary assemblages might be useful also for contemporary freshwater monitoring (Hämäläinen 2000).

## Conclusions

We conclude that naturally eutrophic lakes may be more common in Finland than previously thought. Their geographic distribution appears related to the presence of phosphorus rich bedrock. However, datings for the sediment levels used in palaeolimnological studies would be especially useful or even required for eutrophic lakes, because of the high sediment accumulation rates.

This study implies a narrower range of water colours in the past than today: the most highly coloured lakes have been less coloured in the past. These results suggests that present day water colour in lakes, as well as phosphorus concentrations, are partly the result of anthropogenic effects to lakes, and as such inappropriate to be used in lake typologies required by the WFD.

Analysis of sedimentary diatom compositions is an effective method for indication of naturally eutrophic lakes and selection of reference lakes, and can yield improvements to lake typologies. Based on the palaeolimnological studies, reference lakes can be selected for the set of ecological analyses required by the WFD.

*Acknowledgements:* We thank Mrs. Kirsti Kyyrönen for finishing the figures.

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*Received 7 May 2004, accepted 27 October 2004*