Type-specific and indicator taxa of phytoplankton as a quality criterion for assessing the ecological status of Finnish boreal lakes

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Abstract

Key issues in the implementation of the Water Framework Directive are classification of lakes using biological quality parameters and type-specific reference conditions. This work is one of three studies considering different metrics of phytoplankton in the classification of ecological status. Phytoplankton was studied in a total of 55 Finnish boreal lakes, including 32 reference lakes. We tested the suitability of taxonomic composition and abundance of phytoplankton groups for biological classification. We also preliminarily determined the type-specific taxa for the studied lakes. The type-specific taxa for reference conditions are coincidently the indicator species/taxa for high ecological status. Interestingly, some taxa type-specific for impacted oligo-humic lakes proved to be the type-specific taxa for humic reference lakes. The pressure of human impact was observed not only as increase of biomass but also as changes in the species composition. The phytoplankton composition indicated the ecological status of impacted lakes moderately well. There was some variation in the indications given by different algal groups, probably due to the preliminary class boundaries used. However, the preliminary combination of indicative parameters to estimate the ecological status of the studied impacted lakes was in general in accordance with earlier classification of water quality in Finnish lakes.


Introduction

Phytoplankton is known to react sensitively to differences in catchment-derived chemical characteristics (ROSEN 1981; ARVOLA et al. 1999). Indicator species for different nutritional levels have been presented for oligotrophic waters as well as for waters with increased anthropogenic pollution (JARNFELDT 1952; BRETTUM 1989). WILLÉN (2000) pointed out that knowledge of the structure (taxa, abundances and biomass) and function (response to the environmental conditions) of phytoplankton is important when assessing the links between phytoplankton and the environment.

Diverse phytoplankton assemblages occur in natural waters spatially and temporally (HUTCHINSON 1967; HOLOPAINEN et al. 2003). This is based on the abundance of a species as “inoculum” or on the ability of a species to increase at a greater rate than its competitors.

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Phytoplankton assemblages may be designated by the name of one or more dominant species. However, according to Hutchinson (1967) and Reynolds (1986), enumeration of rare, characteristic species can in some cases provide more information about the lake. When looking for type-specific taxa for different lake types, it is important to distinguish the indifferent taxa occurring only in each lake type of reference or impacted conditions.

The taxonomic composition and abundance of phytoplankton is one of the biological metrics in the normative definitions of ecological status classification in the Water Framework Directive, Annex 1.2 (European Union 2000).

The aim of this study was to consider (i) whether the type-specific taxa for different ecological status of lakes, and (ii) the indicator taxa for high ecological status, i.e. reference conditions, assumed by the Water Framework Directive can be determined. We also discuss (iii) how anthropogenic impact manifested as eutrophication is reflected as changes in phytoplankton assemblages and in type-specific taxa composition and (iv) how the percentage and the biomass of some algal groups determine the ecological status of the studied impacted lakes.

Material and Methods

Characteristics of the study lakes

We selected a total of 55 lakes for our study. These lakes belong to the national water-quality monitoring network, and were sampled for phytoplankton and water chemistry in July 2002. The study lakes were mostly located in southern Finland, with some lakes in eastern and northern parts of the country (Fig. 1). The estimated mean depth of the lakes varied from 0.5 to 21 metres. The area of the lakes (or main basins) varied from 0.04 to 1040 km².

The complete set of lakes was divided in two parts: reference lakes with no or only very minor anthropogenic alterations, and impacted lakes. In this study the term “impacted” is used to refer to non-reference lakes reaching at best the ecological status of good. The division was based mainly on expert judgment in the Finnish Environment Institute. A total of 32 reference lakes were selected and phytoplankton assemblages in lake groups (Fig. 2) were compared to those of 23 impacted lakes with typology characteristics corresponding rather closely to those of the reference lake groups.

In this paper we use the appellations:
- “oligo-humic” for lakes with water colour <60 mg l⁻¹ Pt;
- “humic” for lakes with water colour 60–120 mg l⁻¹ Pt;
- “dystrophic” for lakes with water colour >120 mg l⁻¹ Pt.

Phytoplankton data

Phytoplankton samples were collected from a depth of 0–2 metres, and preserved using acidic Lugol’s solution. Simultaneously, samples for water chemistry were taken from a depth of one metre. Phytoplankton biomass was estimated by microscopy using a Nordic variant of the Utermöhl technique (Utermöhl 1958; Olrik et al. 1998), and phase-contrast illumination at x200 and x800–1200 magnifications by a trained group of investigators. Cell counts were converted to biovolumes using the cell volumes of the phytoplankton database of the Finnish Environment Institute. The analysis produced a list with biovolumes of observed species/taxa, the biomass of different algal groups, and the total phytoplankton biomass given as fresh weight, mg l⁻¹ (Tables 1 and 2). Chemical water quality was analysed according to standard methods (Niemi et al. 2000). Of these phosphorus and nitrogen concentrations, water colour, pH and chlorophyll a concentrations were used in this study (Tables 1 and 2).

Statistical analysis

To discriminate the reference lakes the correlations between phytoplankton assemblages using the algal taxa biomass and water quality were examined by detrended correspondence analysis (DCA) using the CANOCO computer program (Ter Braak 1987, 1990). Cumulative distribution function was used when setting the class boundary between high and good ecological status for the type-specific indicator species in the studied lake groups.

Determination of type-specific and indicator taxa, and ecological status of impacted lakes

The Water Framework Directive (European Union 2000) assumes nomination of type-specific taxa. Phytoplankton species/taxa were discriminated with the DCA-analysis. Taxa, which were observed only in a particular reference lake type, were nominated as type-specific taxa. Furthermore, cumulative distribution function was used to select the 90th percentile as a class boundary for indicator species/taxa between high and good ecological status. Furthermore, taxa, which were observed only in impacted lakes of a particular type were nominated type-specific for impacted lakes.

The ecological quality ratio EQR (median value in the reference lake group/observed value in impacted lakes) of the biomass and the percentage of cyanobacteria and diatoms were applied for preliminary determination of the ecological status of 23 impacted oligo-humic and humic lakes. The ecological status was assessed on the basis of the scale presented in the Refcond Guidance
Fig. 1. The observation sites in July 2002.

**Reference lakes (grey dots):** 1 = Haukkajärvi; 2 = Hormajärvi; 3 = Pihlajavesi; 4 = Ääntti; 5 = Unarinjärvi; 6 = Valkea-Kotinen; 7 = Karjalan Pyhäjärvi; 8 = Iso-Hietajärvi; 9 = Lika-Pyöree; 10 = Inarijärvi; 11 = Iso-Löytöne; 12 = Iso-Arajärvi; 13 = Iso-Hanhijärvi; 14 = Iso-Haukivesi; 15 = Iso-Helvetinjärvi; 16 = Kalliojärvi; 17 = Kattilajärvi; 18 = Kukkia; 19 = Kuolimo; 20 = Pielinen; 21 = Punella; 22 = Puujärvi; 23 = Päijänne 78; 24 = Saimaa, Ilkonselkä; 25 = Saimaa, Riutanselkä; 26 = Silkajärvi; 27 = Sääksjärvi; 28 = Vehkajärvi; 29 = Vuohijärvi; 30 = Mallasvesi; 31 = Yli-Kittikä; 32 = Näsijärvi.

**Impacted lakes (black dots):** 33 = Iso-Roine; 34 = Roine; 35 = Katumajärvi; 36 = Kemaalanjärvi; 37 = Tarjannevesi; 38 = Kyrösjärvi; 39 = Lappajärvi; 40 = Päijänne 71; 41 = Längelmävesi; 42 = Haukkajärvi; 43 = Mäyhäjärvi; 44 = Oulujärvi; 45 = Houhajärvi; 46 = P-Kallavesi; 47 = Porttipahta; 48 = Vanajanselkä; 49 = Vanaja; 50 = Vesijärvi; 51 = Pyhäjärvi 93; 52 = Pyhäjärvi, Sorvanselkä; 53 = Pääjärvi; 54 = Rehtijärvi; 55 = Tolsvesi.
Table 1. Some characteristics of the studied reference lakes. The biomass and proportions of cyanobacteria (Cyanob), Cryptophyceae (Crypto), Chrysophyceae (Chryso), Diatomophyceae (Diatoms), Raphidophyceae (Raphi), total biomass and chlorophyll a concentration (Chlor.a) are shown.
Lake No. = number of the lake in Fig. 1. Drainage basin numbers are given according to ERIKUM (1993).
Description of lake groups: Lake group 1 = oligo-humic large lakes; lake group 2 = oligo-humic moderately large lakes; lake group 3 = humic lakes; lake group 4 = dystrophic lakes; lake group 5 = dystrophic acidic lakes.

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Results

There was a wide variation in total phytoplankton biomass, concentrations of nutrients and water colour in the whole dataset (Tables 1 and 2). Phytoplankton biomass in the studied 55 lakes varied from 0.12 mg $\text{l}^{-1}$, measured in the reference Lake Iso-Hietajärvi (lake No. 8), to 5.71 mg $\text{l}^{-1}$ in the impacted Lake Houhajärvi (lake No. 45).

Groups of reference lakes

Reference lakes were clustered on the axis 1 into four distinct groups on the basis of phytoplankton assemblages in the DCA ordination analysis. The main part of the study reference lakes, i.e. the oligo-humic lakes with water colour $\leq 60$ mg $\text{l}^{-1}$ Pt, were grouped together. However, mainly large lakes were clustered at the upper end of the axis 2, and oligo-humic moderately large lakes were clustered at the opposite end. One small lake (lake No. 27) with a low water colour of 8 mg $\text{l}^{-1}$ Pt was an outlier (Tables 1 and 2, Fig. 2).

Humic lakes formed a separate group on the axis 1. Furthermore, two dystrophic lakes and two acidic (pH 5.3–5.5) small lakes, one humic and one dystrophic (100–160 mg $\text{l}^{-1}$ Pt) were grouped at opposite ends of the axis 1 (Fig. 2).

Algal groups, type-specific and indicator taxa in the study lakes

- Oligo-humic lakes

In oligo-humic large reference lakes (lake group 1 in Table 1) the median of total phytoplankton biomass was 0.44 mg $\text{l}^{-1}$ (Fig. 3) and the chlorophyll $a$ median 2.9 $\mu \text{g}$ $\text{l}^{-1}$. Cyanobacteria contributed 6% to the total biomass.

Table 2. Some characteristics of the studied impacted lakes. Lake No. = number of the lake in Fig. 1. Drainage basin numbers are given according to EK HOLM (1993). Description of lake groups: Lake group 1 = impacted oligo-humic large lakes; lake group 2 = impacted oligo-humic moderately large lakes; lake group 3 = impacted humic lakes. For further information, see the legend to Table 1.
and cryptomonads (Cryptophyceae) 14% as median values. The proportion of diatoms (Diatomophyceae) was 22% and that of chrysomonads (Chrysophyceae) 26%.

Chloromonads (Raphidophyceae) were observed only occasionally and the maximum percentage was 2% of the total biomass (Table 1). Altogether 15 taxa were statistically selected as type-specific indicator taxa for high ecological status (90th percentile) when using the cumulative distribution function. Such algae as the cyanobacterium *Merismopedia warmingiana* and *Anabaena lemmermannii* and the small chrysomonad *Chrysoykos planctonica*, *Dinobryon borgei*, *D. crenulatum* and *D. suecicum*, and the dinoflagellate *Peridinium umbonatum* belonged to these taxa (Fig. 4, Table 3).

In impacted oligo-humic large lakes (lake group 1 in Table 2) the median biomass was 1.25 mg l⁻¹ (Fig. 3) and the chlorophyll a concentration was 8.6 μg l⁻¹. Cyanobacteria contributed 8% (median value) to the total biomass, cryptomonads 16% and diatoms 31% (Table 2). The proportion of chrysomonads was 19% and that of chloromonads (*Gonyostomum semen*) 2% at the highest, if present. Cyanobacterium *Microcystis viridis* and the diatoms *Aulacoseira granulata* v. *angustissima* and *Rhizosolenia euriensis* were type-specific. In all studied oligo-humic large lakes, irrespective of their ecological status, the cyanobacteria *Aphanotoce minutissima*, *Snowella atomus* and *Woronichinia naegelian*, and the medium-large (cell length 26 μm) cryptomonad *Cryptomonas* sp., diatoms *Asterionella formosa* and *Tabellaria flocculosa* and the green algae *Polyta* spp. and *Botryococcus terribilis* were frequently observed (Fig. 4, Table 3).

In oligo-humic, moderately large reference lakes (lake group 2 in Table 1) the total median biomass was 0.5 mg l⁻¹ and median chlorophyll a concentration was 3.2 μg l⁻¹. The total phytoplankton biomass included 7% cyanobacteria, 19% cryptomonads, 7% diatoms and 25% chrysomonads. Altogether 14 taxa were statistically selected as type-specific indicator taxa for high ecological status (90th percentile) when using the cumulative distribution function (Fig. 5, Table 3). The cyanobacteria *Aphanotoce clathrata*, *Chroococcus minutus* and *Radiocystis geminata*, the chrysomonads *Dinobryon borgei*, *D. crenulatum* and *Kephyrion boreale* and the green algae *Monoraphidium komarkovae* and *Oocystis rhomboidea* belonged to these taxa (Fig. 5, Table 3).

### Table 2. (Continued)

<table>
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<tr>
<td>0.12</td>
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<td>0.36</td>
<td>4.7</td>
<td>poor</td>
<td>good</td>
<td>good</td>
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</table>
Fig. 2. Dedrended correspondence analysis (DCA) of phytoplankton sampling sites. Eigen values for axis 1 = 0.55, and for axis 2 = 0.3. Lake group 1 = oligo-humic large lakes; lake group 2 = oligo-humic moderately large lakes; lake group 3 = humic lakes; lake group 4 = dystrophic lakes; lake group 5 = dystrophic acidic lakes.

The median biomass in impacted moderately large lakes (lake group 2 in Table 2) was 1.24 mg l⁻¹ and median chlorophyll a 6.3 μg l⁻¹. Cyanobacteria contributed 7% (median value), cryptomonads 9% and diatoms 28% to the total biomass. The proportion of chrysomonads was 27%. The maximum percentage of chloromonads was 60%. The cyanobacterium *Aphanocapsa holsatica*, and the diatoms *Acamthoceras zachariasii*, *Aulacoseira ambiguа*, *A. granulata*, *A. italica*, *A. italica* var. *tenuissima* and *A. tenella* represented type-specific taxa. Furthermore, the green alga *Dictyosphaerium subsolitarium* was also type-specific in impacted lakes. Indifferent taxa, occurring in both reference and impacted lakes, were the medium-large *Cryptomonas* spp., *Ceratium hirundinella*, *Mallomonas akrokomos* and *Botryococcus terribilis* (Fig. 5, Table 3).

Fig. 3. The total phytoplankton biomass in reference and impacted lakes as box-plot figures. The minimum, maximum, median and deviation values are given. N = the number of observations; reference = reference lakes; impacted = impacted lakes.
• Humic lakes

In humic reference lakes (lake group 3 in Table 1) the median biomass was 0.95 mg l\(^{-1}\) and the median of chlorophyll \(\alpha\) was 8.2 \(\mu\)g l\(^{-1}\). Cyanobacteria contributed 1% to the total biomass and cryptomonads 7%. The median proportion of diatoms was 25% and chloromonads 31% of the total biomass. Chrysomonads contributed 11% (Table 1). Altogether 9 taxa were selected as type-specific indicator taxa for high ecological status (90th percentile) when using the cumulative distribution function (Fig. 6, Table 3). No cyanobacteria were selected as type-specific indicator taxa for high ecological status (90th percentile) when using the cumulative distribution function (Fig. 6, Table 3). No cyanobacteria were selected as type-specific indicator taxa for high ecological status (90th percentile) when using the cumulative distribution function (Fig. 6, Table 3). No cyanobacteria were selected as type-specific indicator taxa for high ecological status (90th percentile) when using the cumulative distribution function (Fig. 6, Table 3). No cyanobacteria were selected as type-specific indicator taxa for high ecological status (90th percentile) when using the cumulative distribution function (Fig. 6, Table 3).

In the impacted humic lakes (lake group 3 in Table 2) the median biomass was 3.34 mg l\(^{-1}\) and chlorophyll \(\alpha\) concentration was 12 \(\mu\)g l\(^{-1}\). The median proportion of cyanobacteria was 8%, of cryptomonads 11% and of diatoms 52%. Chrysomonads contributed 6% and chloromonads a maximum of 2% to the total biomass. The cyanobacteria Anabaena minutissima and Anabaena spp. (twisted) and the diatom Rhizosolenia eriensis were type-specific. Indifferent were the frequently observed chrysomonads Dinobryon bavaricum and Mallomonas caudata and the diatoms Asterionella formosa and Tabellaria flocculosa. The chloromonad Gonystomum semen was moderately frequently observed (Fig. 6, Table 3).

Two dystrophic, extreme lakes, Lake Lika-Pyöree (lake No. 9), a small, shallow and “naturally eutrophic”

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Table 3. Alphabetic list of type-specific species presented in Figs. 4–6 by RUBIN codes (ZETTERBERG 1986).

<table>
<thead>
<tr>
<th>RUBIN code</th>
<th>Scientific name</th>
<th>RUBIN code</th>
<th>Scientific name</th>
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<tr>
<td>Acan lem</td>
<td>Anacanthoceras zachariasii (BRUN.) SIMONSEN</td>
<td>Gloe sp</td>
<td>Gloeobots limneticus (G.M. SMITH PASCHER</td>
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<tr>
<td>Anaouana</td>
<td>Anabaena lemermannii P. RICHTER</td>
<td>Gony sp</td>
<td>Gonyostomum semen (EHR.) DESING</td>
</tr>
<tr>
<td>Anabaz</td>
<td>Anabaena spp. (twisted)</td>
<td>Keph sp</td>
<td>Kephyron boreale SKUJA</td>
</tr>
<tr>
<td>Anky lan</td>
<td>Ankyra lanceolata (KORSH.) FOTT</td>
<td>Keph cup</td>
<td>Kephyion cupuliforme CONRAD</td>
</tr>
<tr>
<td>Apha hol</td>
<td>Aphanocapsa holbatica (LEMMEN, CRONBERG &amp; KOMAREK)</td>
<td>Keph nva</td>
<td>Kephyion ovale (LACK.) HUBER-PESTALOZZI</td>
</tr>
<tr>
<td>Apha cla</td>
<td>Aphanothece clathrata W. et G.S. WEST</td>
<td>Keph sku</td>
<td>Kephyion skjai ETTL</td>
</tr>
<tr>
<td>Apha min</td>
<td>Aphanothece minutissima KOM.-LEG. &amp; CRONBERG</td>
<td>Mal akr</td>
<td>Mallomonas akrokonomus RUTHNER</td>
</tr>
<tr>
<td>Aphaniz</td>
<td>Aphaniizomenon spp.</td>
<td>Mal cau</td>
<td>Mallomonas caudata VANOK VIT. KRIEGER</td>
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<td>Aula amb</td>
<td>Aulacoseira ambigua (GRUNOW) SIMONSEN</td>
<td>Meri war</td>
<td>Merismopedia warmingiana LAGERHEIM</td>
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<td>Aula gra</td>
<td>Aulacoseira granulata (EHR.) SIMONSEN</td>
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<td>Aula it; te</td>
<td>Aulacoseira italicata v. tenissima (GRUNOW) SIMONSEN</td>
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<td>Aula ten</td>
<td>Aulacoseira tenella (NYGAARD) SIMONSEN</td>
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<td>Monoraphidium dybowskii (WOL.) HIND. &amp; KOM.-LEG.</td>
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<td>Ast ffor</td>
<td>Asterionella formosa HASSALL</td>
<td>Mono kom</td>
<td>Monoraphidium komarkovae NYGAARD</td>
</tr>
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<td>Bicosoez</td>
<td>Bicosoeca sp.</td>
<td>Nitz ac</td>
<td>Nitzschia circularis W. SMITH</td>
</tr>
<tr>
<td>Bico mit</td>
<td>Bicosoeca mitra FOTT</td>
<td>Oocy rho</td>
<td>Oocystis rhomboidae FOTT</td>
</tr>
<tr>
<td>Bott ter</td>
<td>Bottbycococcus terribilis KOMAREK &amp; MARIAN</td>
<td>Peri umb</td>
<td>Peridinium umbonatum STEIN</td>
</tr>
<tr>
<td>Cera hir</td>
<td>Ceratium hirundinella (O.F.M.) SCHRECK</td>
<td>Polytomz</td>
<td>Polytomaz spp.</td>
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<tr>
<td>Cera for</td>
<td>Ceratium furcoides (LEVANDER) LANGHANS</td>
<td>Pse lac</td>
<td>Pseudosphaerocystis lacustris (LEMMEN) NOVAKOVA</td>
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<tr>
<td>Chro mts</td>
<td>Chroococcus minutus (KOTTING) NAGELI</td>
<td>Pse ennt</td>
<td>Pseudokephyrion entzi (CONRAD) SCHMID</td>
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<td>Chry pia</td>
<td>Chrysoylosko poloniticus MACK</td>
<td>Quad pfi</td>
<td>Quadrugula piliferi (SCHRÖDER) G.M. SMITH</td>
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<tr>
<td>Clo gral</td>
<td>Closterium gracile BRIESSIN</td>
<td>Radi germ</td>
<td>Radiocystis gernata SKUJA</td>
</tr>
<tr>
<td>Cryptomz</td>
<td>Cryptomonas spp. (cell length &lt;13 (\mu)m; 26 (\mu)m)</td>
<td>Rhab dill</td>
<td>Rhabdoderma lineare SCHMIDLE &amp; LUTERBORN</td>
</tr>
<tr>
<td>Dici sub</td>
<td>Dictysophosarium subsolitarium VAN GOOR</td>
<td>Rhiz eri</td>
<td>Rhizosolenia eriensis H. L. SMITH</td>
</tr>
<tr>
<td>Didymoz</td>
<td>Didymozos spp.</td>
<td>Rhodomoz</td>
<td>Rhodomonas spp./Flagelloisim sp.</td>
</tr>
<tr>
<td>Dino bav</td>
<td>Dinobryon bavaricum IMHOF</td>
<td>Scen arm</td>
<td>Scenedesmus armatus CHODAT</td>
</tr>
<tr>
<td>Dino borg</td>
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<td>Scourfieldia sp.</td>
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<tr>
<td>Dino cre</td>
<td>Dinobryon crenulatum W. &amp; G.S. WEST</td>
<td>Snow ato</td>
<td>Snowella atomus KOMAREK &amp; HINDÁK</td>
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<tr>
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<td>Dinobryon diversus IMHOF</td>
<td>Stepdiss</td>
<td>Stephanodiscus spp.</td>
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<tr>
<td>Dino sue</td>
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<td>Synura spp.</td>
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<td>Frag cro</td>
<td>Fragilaria crotonensis KITTON</td>
<td>Tet jol</td>
<td>Tetraedriella jovetii (BOURRELLY) BOURSÉLY</td>
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<tr>
<td>Frag uln</td>
<td>Fragilaria ulna (NITZSCH) LANGE-BERTALOT</td>
<td>Uroglenz</td>
<td>Uroglena sp.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Woro nae</td>
<td>Woronichinia naegeli (UNGER) ELENKIN</td>
</tr>
</tbody>
</table>
lake, and Lake Kalliojärvi (lake No. 16) with an occasional biomass maximum, formed a separate group (lake group 4 in Table 1). Chloromonads (*Gonyostomum semen*) and diatoms such as *Tabellaria flocculosa* contributed 31–68% and 2–70%, respectively, to the total biomass (Tables 1 and 4). In two lakes (lake group 5 in Table 1) the acidic, humic Lake Valkea-Kotinen (lake No. 6) and the acidic, dystrophic Lake Iso-Hanhijärvi (lake No. 13) the biomasses were 0.30 and 0.88 mg l⁻¹ and the chlorophyll a concentrations were 12 and 4.9 µg l⁻¹, respectively. The main part of the biomass was composed of dinoflagellates. Typical taxa in these lakes are *Gonyostomum semen*, *Gymnodinium* spp., *Peridinium umbonatum*, *Monochrysis* spp. and *Spiniferomonas* spp., as well as *Pseudopedinella* spp. (Table 4). No impacted lakes in this data were comparable to these four lakes, i.e. lakes Lika-Pyöree, Kalliojärvi, Valkea-Kotinen and Iso-Hanhijärvi.

**Fig. 4.** Type-specific and indicator species (taxa) for oligo-humic large reference (left) and impacted lakes (right) are presented as RUBIN codes. Scientific names are given in Table 3. In connection with RUBIN code is indicated the number of observations of the taxon in reference lakes/impacted lakes. Indifferent species (taxa) are situated below. The total number of reference lakes was fifteen and that of impacted lakes nine.

**Fig. 5.** Type-specific and indicator species (taxa) for oligo-humic moderately large reference (left) and impacted lakes (right) are presented as RUBIN codes. Scientific names are given in Table 3. Number of observed taxa in reference lakes/impacted lakes is indicated. Indifferent species (taxa) are situated below. The total number of reference lakes was ten and of impacted lakes nine.

**Fig. 6.** Type-specific and indicator species (taxa) for humic reference (left) and impacted lakes (right) are presented as RUBIN codes. Scientific names are given in Table 3. Number of observed taxa in reference lakes/impacted lakes is indicated. Indifferent species (taxa) are situated below. The total number of reference lakes was three and of impacted lakes five.
Table 4. Typical species (taxa) for dystrophic and dystrophic acidic reference lakes.

<table>
<thead>
<tr>
<th>Dystrophic reference lakes (Lakes Lika-Pyörre and Kalliojärvi)</th>
<th>Dystrophic acidic reference lakes (Lakes Valkea-Kotinen and Iso-Hanhijärvi)</th>
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<tr>
<td>Bitrichia chodatii (Reverdin) Hollande</td>
<td>Gonyostomum semen (Ehr.) Diesing</td>
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<tr>
<td>Dinobryon borgei Lemmermann</td>
<td>Gymnodinium sp.</td>
</tr>
<tr>
<td>Gymnodinium sp.</td>
<td>Peridinium umbonatum Stein</td>
</tr>
<tr>
<td>Peridinium umb. v. goslaviense (Wol.) Popov &amp; Pfet.</td>
<td>Dinobryon bavaricum Imhof</td>
</tr>
<tr>
<td>Gonyostomum semen (Ehr.) Diesing</td>
<td>Monochrysis spp.</td>
</tr>
</tbody>
</table>

Preliminary determination of ecological status

The ecological status of 23 impacted oligo-humic and humic lakes was determined preliminarily using the EQR-ratios of 0.8 for high, 0.6 for good and 0.4 for moderate as boundaries between classes.

- **Cyanobacteria EQR**
  The EQR-ratio based on the median cyanobacteria biomass classified two of the oligo-humic large lakes to high, three to good and four to poor or bad ecological status. The percentage of cyanobacteria, however, reflected high or good status for five of these lakes. In oligo-humic moderately large lakes the cyanobacteria biomass EQR indicated in two lakes high, in one good and in six moderate – bad ecological status but the EQR-ratio on the basis of cyanobacteria percentage indicated high or good ecological status with the exception of one lake with poor status.

  Four humic lakes had poor or bad ecological status and in one lake the cyanobacterial biomass EQR indicated moderate ecological status. The EQR-ratio based on median cyanobacteria percentage indicated bad ecological status in four lakes with the exception of the manmade lake with moderate status (Table 2).

- **Diatom EQR**
  The diatom biomass EQR-ratio classified seven of nine oligo-humic large lakes as bad and two as having high or good ecological status. However, when using the EQR-ratio of the percentage of diatoms, five lakes had high or good ecological status and four lakes had moderate or poor ecological status. In all moderately large oligo-humic lakes the diatom biomass EQR indicated bad ecological status but the EQR-ratio on the basis of diatom percentage indicated high or moderate ecological status in two lakes and poor or bad status in seven lakes (Table 2).

  Two humic lakes had high or good and three lakes had a poor or bad ecological status according to the diatom biomass EQR-ratio. By contrast, the percentage EQR reflected high or good for two lakes and moderate status for three lakes.

Discussion

The total phosphorus concentration, the median biomass and the chlorophyll a concentration indicated oligotrophy in large oligo-humic reference lakes, according to the limits specified by Heinonen (1980) for Finnish lakes and by OECD (1982). This agrees with the national water quality classification in Finland, in which only 4% of the lake area was significantly impacted by local water pollution (Vuoristo 1998). The total phosphorus concentration reflected mesotrophy and the biomass was almost fourfold higher in the impacted lakes. Cyanobacteria increased slightly in impacted lakes whereas chrysomonads slightly decreased. In moderately large reference lakes the median biomass was higher than in large reference lakes, being close to oligo-mesotrophic concentrations, which is in accordance with the observations of Fée et al. (1992). Human impact increased the median biomass twofold in these lakes. The proportion of cryptomonads was reduced clearly but the proportion of diatoms was increased threefold in impacted lakes compared to reference lakes.

The filamentous cyanobacterium Anabaena lemmermannii, considered as typical for oligotrophic waters (Leištö 1999), was clearly type-specific for large oligo-humic reference lakes but was not observed in impacted large lakes in this study. It has not been included in Anabaena spp. identified in the impacted lakes. Several small-celled species, such as Merismopedia warnmgiana, Dinobryon borgei, D. suecicum, and Kephyrion spp. were also type-specific. Radiocystis geminata, Kephyrion boreale and Oocystis rhomboidea were type-specific for moderately large lakes. The species list agrees with the observations of assemblages typical for oligotrophic and oligo-mesotrophic waters (Willén 1992; Leištö 1999; Reynolds et al. 2002). According to the Water Framework Directive (European Union 2000), phytoplankton assemblages in waters with high ecological status should be composed mainly of taxa type-specific for reference conditions and with almost no taxa typical for impacted waters. In the studied oligo-humic lakes type-specific indicator taxa for high ecologi-
cal status, and type-specific taxa for impacted lakes with mainly good or moderate ecological status were determined and several taxa were also found to be indifferent.

With impairment of the ecological status, the often large-sized, type-specific taxa for impacted waters tend to become dominant. Such an increase of large-sized taxa was reported by Willén (1992) in the Swedish lakes during the process of eutrophication. Microcystis viridis, Aulacoseira granulata v. angustissima and Rhi-
zosolenia eriensis were type-specific in impacted oligo-
humic large lakes whereas in moderately large lakes e.g. Acanthoceras zachariasii, Aulacoseira ambigu a and A. italica v. tenuissima were the type-specific taxa.

The mesotrophy-indicating median biomass, accord-
ing to Heinonen (1980) in humic reference lakes was in accordance with earlier observations from humic lakes with high biomass values produced by cryptomonads, diatoms, and by Gonyostomum semen (Arvola 1984; Salonen et al. 1992; Salonen et al. 2001). In impacted humic lakes the median biomass was three times higher, and the proportion of diatoms was twice as high as in reference conditions. This was the case especially in a man-made lake in which regulation of the water level is reflected in the abundance of diatoms in the overall phy-
toplankton biomass (Lepistö & Pietiläinen 1996), which is however rather low compared to the other im-
 pact ed humic lakes. Interestingly, the diatom Aulaco-
seira ambigu a, which was reported by Brettum (1989) to indicate mesotrophic conditions, was type-specific for impacted oligo-humic lakes, but also for humic reference lakes. The fragile diatom Rhizosolenia eriensis, reported to decrease with increasing eutrophication (Davis 1964), was detected in oligo-humic and in humic impacted lakes as type-specific. Willén (2003) reported this species as a characteristic of humic reference forest lakes in Sweden. In the studied humic lakes indicator species for high ecological status, and for impact-
ed lakes with mainly good or moderate ecological status were determined and several taxa were classified as in-
different.

Lakes Li ka-Pyöree (No. 9) – a small, shallow and “naturally eutrophic” lake – and Kalliojärvi (No. 16) formed a separate group. Gymnodinium spp., Peridinium goslaviense, Bitrichia chodatii, Dinobryon borgei, and the chloromonad Gonyostomum semen were type-spe-
cific but diatoms were also abundant in these lakes. This observation agrees with the main species assemblages from Swedish humic forest lakes (Willén 2003). In dys-
 trophic acidic lakes the biomass values are clearly high-
er compared to those in oligo-humic acidic lakes report-
ed by Kippo-Edlund & Heitto (1990), obviously due to the abundant humic substances (Arvola 1984; Salonen et al. 2001) and to the heterotrophic or mixotrophic be-
aviour of the main part of the type-specific flagellated algae. These organisms are able to ingest both organic particles and bacteria (Salonen & Jokinen 1988; Holén & Boraas 1996). For example, Gonyostomum semen is able to respond to low light conditions and to occasional nutrient depletion by its migrative behavior and by mixotrophy (Salonen et al. 1984; Jansson et al. 1996). In the study lakes this species was observed in dystroph-
irc reference lakes with low pH, which agrees with the observations of Cronberg et al. (1988).

The ecological classification of the study lakes was generally in agreement with earlier information presented by Vuoristo (1998), especially in the case of cyanobacte-
rial biomass but less clearly as cyanobacterial biomass percentage. Neither the biomass nor the percentage of di-
atoms agreed with the earlier water quality classification. This observation should be more carefully considered, as one of the methods to assess the approximate original ecological status of naturally eutrophic lakes are the pale-
ologimological studies based on diatom assemblages. However, the preliminary combination of indicative pa-
rameters by averaging (Ecostat 2003), to estimate the ecological status of the studied impacted lakes was in general in accordance with the water quality classification of Finnish waters presented by Vuoristo (1998).

Finally, we want to underline that the attempt to group the lakes, even those of the same type, in order to find out type-specific species is hazardous and the list of type-specific taxa needs further evaluation. As Round (1981) has demonstrated, no two lakes are alike, and therefore no floras are alike, although there are certain broad categories of lakes with similar basic conditions.

Concluding remarks

The type-specific taxa for reference conditions as indicators for high ecological status in oligo-humic waters were taxa reported to indicate oligotrophic conditions. These taxa should be present at least by 50% in waters having a high ecological status. Some taxa were typical for impacted waters. Furthermore, there are numerous in-
different taxa. Interestingly, some taxa type-specific for impacted oligo-humic lakes proved to be the type-specific taxa for humic reference lakes.

When the lakes are correctly grouped into lake types and into reference and impacted lakes, the taxa list agrees with the observations of phytoplankton assem-
blages in lakes of e.g. various trophic status and water colours. This result is also in accordance with our long-
time observations from phytoplankton assemblages in boreal lakes.

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