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Chlorophyll *a* concentration across a trophic gradient of lakes: An estimator of phytoplankton biomass?

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Dedicated to Prof. Jürgen Benndorf on the occasion of his 65th birthday.

Abstract

Chlorophyll *a* (chl*a*) concentration was evaluated as a predictor of phytoplankton biomass across a broad trophic gradient of lakes (oligotrophic – highly eutrophic). First, a literature survey was conducted to collect information on the proportion of chl*a* in phytoplankton biomass. As a result of this study ($n = 21$) a mean value of $0.505\% \pm 0.197$ S.D. chl*a* per unit wet weight of phytoplankton was calculated. Second, analyses were performed on 756 paired measurements from an unpublished database where the specific chl*a* content of phytoplankton biomass was regressed against phytoplankton standing stocks and chl*a* concentration. Within an interval of $0.1–50\,g\,m^{-3}$ of phytoplankton wet weight, a substantial decrease in chl*a* proportion from approximately 2.5% to 0.18% was found. Likewise, the proportion in phytoplankton wet weight decreased from 0.7% to 0.15% across a chl*a* concentration interval of $0.001–0.150\,g\,m^{-3}$. These results had a significant impact both on chl*a*-based biomass calculations and the subsequent comparison with phytoplankton biomasses resulting from microscopic counts. Assuming the microscopic method was a measure of the ‘‘true’’ phytoplankton standing stocks, then the precision by which phytoplankton biomass might be predicted based on chl*a* measurements is clearly better when using variable proportions as compared to a constant conversion factor. The same holds for temporal coherence between annual records of phytoplankton biomass. The temporal fit was apparently better when relating the results of microscopic counts and biomass estimation based on variable proportions of chl*a* in phytoplankton biomass. Nevertheless, this effect diminished as the tropic status of the lakes increased. Because of their variable specific chl*a* content, separate taxonomic groups of phytoplankton differently affected the proportion of chl*a* in total

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phytoplankton wet weight. Chlorophyceae, Cryptophyceae and cyanobacteria had a high impact, while Bacillariophyceae, Dinophyceae and Chrysophyceae were of lesser importance.

Keywords: Phytoplankton; Biomass estimation; Comparison of methods; Microscopic counts; Specific chlorophyll *a* proportion; Conversion factors; Lakes; Trophic gradient

Introduction

Estimating phytoplankton biomass is one of the most useful measurements in limnology and oceanography. Although frequently performed, the approach is not trivial and the results are sometimes hard to interpret (Tolstoy, 1977; Wasmund, 1984; Stich and Brinker, 2005). This is especially true if information from various methods is being compared (Hallegraeff, 1977; Halfson, 1984; Schmid et al., 1998).

Methods to determine phytoplankton standing crops have been developed for quite some time and can be categorised into two general groups: (1) particle counting (Utermöhl, 1923, 1958), and (2) measurement of chemical constituents (Richards and Thompson, 1952; Strickland and Parsons, 1960) with flow-cytometry being a combination of both (Töpel et al., 2004). Over the past decades both approaches were heavily refined and modified. Nevertheless, some of the basic methodological problems have not been resolved (Padisák et al., 1999; Wright et al., 1997). The most important are: (i) methodological flaws, (ii) variable chl*a* proportions per unit phytoplankton biomass, (iii) the taxonomic composition of the phytoplankton community and finally (iv) seasonal aspects.

Microscopic examination and counting of phytoplankton species in collected samples is time-consuming and requires extensive taxonomic experience by the investigator (Banse, 1977; Krienitz et al., 1996). Chemical preservation of the samples can alter the size frequency distribution of the phytoplankton cells (Verity et al., 1992). Moreover, autotrophic picoplankton (APP) may sometimes contribute significantly to total phytoplankton biomass but are not often recorded (Padisák et al., 1997). To overcome these problems, particle counters and image analysis systems have been utilised, but their performance in estimating phytoplankton biomass as compared to microscopic methods is still questioned (Hillebrand et al., 1999).

Concerning chl*a* extraction and the subsequent photometric or HPLC measurements, several authors have shown that there is no ideal protocol (Pápista et al., 2002; Stich and Brinker, 2005). Depending on the taxonomic structure of the phytoplankton sample being analysed, different extraction solvents may have different extraction efficiencies (Vollenweider, 1974; Wright et al., 1997).

Finally, various studies have found that chl*a* content per unit of phytoplankton biomass decreases as phytoplankton standing stocks increase (Desortova, 1981; Ahlgren, 1983; Wojciechowska, 1989; Watson et al., 1992; Talling, 1993; Chow-Fraser et al., 1994; Schmid et al., 1998; Felip and Catalan, 2000; Sandu et al., 2003; Kiss et al., 2006). This phenomenon may be influenced by lake trophic status (Harris, 1986), phytoplankton community structure (Bursche, 1961; Nusch and Palme, 1975), the size frequency distribution of the algal cells (Watson and McCauley, 1988), and by seasonal shifts within the plankton community (Loth, 1985; Vanni et al., 1993).

Notwithstanding these problems and limitations, we examined whether chl*a* concentration across a trophic gradient of lakes (oligotrophic – eutrophic) can be used as a predictor of phytoplankton biomass. Chl*a*-based calculations of phytoplankton biomass were performed by applying constant conversion factors as determined from the literature and by using variable ratios gained from a comprehensive database of the Leibniz-Institute of Freshwater Ecology & Inland Fisheries (IGB, Neuglobsow, Germany). Moreover, we tested the precision and temporal coherence by which time series of phytoplankton biomass of various lakes can be predicted using these conversion factors as compared to the results of microscopic counts.

Material and methods

Investigation sites

The five lakes included in this study are located within the eastern part of Germany's glacial Baltic lake region (53°15′N, 13°10′E) approximately 100 km north of Berlin. They are seepage lakes with ground water and rainfall being the major sources of water. The lakes thermally stratify from May until at least September. Mean temperature of the mixed layer varies between 4 °C (January) and 20 °C (August). Global radiation ranges between 200 J cm^{-2} d^{-1} (December) and 1700 J cm^{-2} d^{-1} (June; German Weather Service, unpublished results). The lakes have significantly different morphometric and chemical characteristics. Their trophic status spans from oligotrophic to highly eutrophic (cf. Table 1). For more information about the five study lakes see Casper (1985), Kasprzak et al.