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Concentrations of particulate and dissolved cylindrospermopsin in 21 *Aphanizomenon*-dominated temperate lakes☆

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Abstract

The cyanobacterial toxin cylindrospermopsin (CYN) is widely distributed in German lakes, but volumetric data for risk assessment are lacking and it is unclear which cyanobacterial species produce CYN in Europe. We therefore analyzed CYN concentration and cyanobacterial composition of 21 German lakes in 2005. CYN was detected in 19 lakes (102 of 115 samples). In total, 45 samples contained particulate CYN only, and 57 contained both dissolved and particulate CYN. The concentrations were 0.002–0.484 μg L^{-1} for particulate CYN and 0.08–11.75 μg L^{-1} for dissolved CYN with a maximum of 12.1 μg L^{-1} total CYN. A drinking water guideline value of 1 μg L^{-1} proposed by Humpage and Falconer [2003. Oral toxicity of the cyanobacterial toxin CYN in male Swiss albino mice: determination of no observed adverse effect level for deriving a drinking water guideline value. Environ. Toxicol. 18, 94–103] was exceeded in 18 samples from eight lakes due to high concentrations of dissolved CYN. CYN occurrence in the German lakes could not be ascribed to the three known CYN-producing species *Cylindrospermopsis raciborskii, Anabaena bergii* and *Aphanizomenon flos-aquae*, which were detected in some lakes in low abundances. The highest correlation coefficients were observed between particulate CYN and the native *Aphanizomenon gracile*. It occurred in 98 CYN-positive samples, was the most abundant Nostocales and was the only Nostocales in five samples. This indicates that *A. gracile* is a potential CYN producer in German lakes.

Keywords: Freshwater ecology; Phytoplankton; Toxic cyanobacteria; Nostocales; *Cylindrospermopsis raciborskii*; *Anabaena bergii*

1. Introduction

Cyanobacteria can produce a wide range of bioactive and toxic substances which can be harmful to wildlife and humans (e.g. Carmichael and Falconer, 1993; Chorus and Bartram, 1999). One of these toxins is cylindrospermopsin (CYN), a

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tricyclic alkaloid that was first detected in an Australian strain of *Cylindrospermopsis raciborskii* (Ohtani et al., 1992). CYN is a potent hepatotoxin; it can cause damage to the kidney, lungs and heart and is genotoxic. CYN is also suspected to be carcinogenic, as recently reviewed by Falconer and Humpage (2006). The toxicity of CYN to humans first became evident in the "Palm Island Mystery Disease" in Queensland, Australia in 1979. In this incident, local inhabitants supplied with drinking water from a reservoir where CYN-producing *C. raciborskii* bloomed contracted hepatoenteritis (Bourke et al., 1983; Hawkins et al., 1985). Combined effects of CYN and microcystin were implicated in the Brazilian dialysis clinic tragedy (Carmichael et al., 2001). Due to the toxicity of CYN, a drinking water guideline value of $1\,\mu g\,L^{-1}$ has been proposed by Humpage and Falconer (2003).

CYN is widely distributed in tropical and subtropical freshwaters, e.g., in Australia (McGregor and Fabbro, 2000) and Florida (Burns et al., 2002), but is also found in temperate regions such as Europe (Fastner et al., 2003, 2007; Manti et al., 2005; Quesada et al., 2006). Species from at least six genera of freshwater cyanobacteria are known to produce CYN. Beside *C. raciborskii*, these are *Anabaena bergii* from Australia (Schembri et al., 2001), *Aphanizomenon ovalisporum* from Australia, Israel and Spain (Shaw et al., 1999; Banker et al., 1997; Quesada et al., 2006), *Umezakia natans* from Japan (Harada et al., 1994) and *Raphidiopsis curvata* from China (Li et al., 2001). *Aphanizomenon flos-aquae* from Germany (Preußel et al., 2006) and *Anabaena lapponica* from Finland (Spoof et al., 2006) were recently identified as CYN producers from northern European habitats. All of these species except *U. natans* (Stigonematales) belong to the order Nostocales.

The ability of cyanobacterial strains isolated from the temperate zone to produce CYN and the northwards spread of tropical CYN-producing species like *C. raciborskii* (Padisák, 1997) or *A. bergii* (Stüken et al., 2006) creates the necessity to conduct toxin screening in the northern hemisphere. Although CYN production by European strains of *C. raciborskii* could not be proved (Fastner et al., 2003; Saker et al., 2003; Neilan et al., 2003; Bernard et al., 2003, etc.) and has not been tested in German *A. bergii* isolates so far, these species must be considered as potential CYN producers here, since the co-occurrence of toxin-producing and non-producing genotypes within a given population occurs with other cyanotoxins. Until now, only two large-scale qualitative screening studies on the distribution of CYN in natural waters of northern Europe have been published. Whereas Spoof et al. (2006) did not find CYN in 51 Finnish freshwater sites or in the Baltic; Fastner et al. (2007) found the cyanotoxin in 63 out of 127 German lakes but not at the four Baltic coastal sites studied. Thus, CYN is widely distributed in German lakes but volumetric data for risk assessment of CYN are lacking.

The aims of our study were: (i) to collect the first data on CYN concentrations (dissolved and particulate fractions) in German freshwaters, (ii) to analyze environmental conditions under which CYN is likely to occur and (iii) to identify the CYN-producing species in these waters. For this purpose, CYN, abiotic and morphometric parameters as well as cyanobacterial abundance and composition were studied in 21 lakes during summer 2005.

2. Materials and methods

2.1. Study site

Twenty-one lakes were chosen based on their seston dry-weight-related CYN concentrations (Fastner et al., 2007) and cyanobacterial composition (Stüken et al., 2006) as determined in a preliminary study conducted at 142 lakes in 2004. The selected lakes contained CYN and known CYN producers (at that time *C. raciborskii* and *A. bergii*) and differed with respect to lake morphometry (maximum depth, volume and surface area) and mixing regime (di- and polymictic). Limnological characteristics of the lakes are given in Table 1. The lakes studied are located in the lowlands of North-east Germany, between 52°07′17″N and 53°27′07″N latitude and 12°48′09″E and 13°59′41″E longitude and are mainly used for recreation and fishery.

2.2. Sampling and analyses

The lakes were sampled fortnightly at their deepest point between June and September 2005 for a minimum 6-week period. Quantitative data collected in 2004 were additionally used for two lakes, Melangsee and Langer See. On each sampling date, we determined the Secchi depth (SD) and vertical profiles of water temperature, pH and oxygen saturation of the lakes at 0.5 m intervals using a multi-parameter probe (Hydrolab H20).