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Spatio-temporal distribution of cell-bound and dissolved geosmin in Wahnbach Reservoir: Causes and potential odour nuisances in raw water

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ABSTRACT

In many lakes and reservoirs, problems caused by off-flavours are known to be particularly associated with the occurrence of planktonic and benthic cyanobacteria. Frequently observed objectionable taste and odorous products of cyanobacteria are geosmin and 2-methylisoborneol.

Investigations focused on the littoral zone of Wahnbach Reservoir (Germany) revealed that benthic cyanobacteria were present in this oligotrophic drinking water reservoir. Benthic cyanobacteria were found in the depth horizon between 1.75 m and 11 m, particularly on south-exposed slopes. This spatial distribution indicates a possible key role of the underwater light climate. Moreover, cell-bound and dissolved geosmin were detected in corresponding littoral samples. Both fractions were subjected to spatial and primarily temporal variations with maximum concentrations at the end of summer. However, a substantial lowering of the water level caused a diminution of cyanobacterial growth. Due to the drawdown of the water level concentrations of cell-bound geosmin and pigments (as a proxy of cyanobacterial biomass) were remarkably reduced, and dissolved geosmin was never detected during this phase. Except for the influence of water level fluctuation no other abiotic variables had a significant influence on pigment and geosmin concentrations. From geosmin concentrations detected in the littoral zone, the probability of serious episodes of odour events in the raw water of the Wahnbach Reservoir was estimated. Hence, the probability that the raw water was affected by geosmin was minor, which was supported by routine flavour profiles. Nevertheless, the study shows that odorous episodes caused by benthic cyanobacteria are likely to develop even in an oligotrophic lake or reservoir when these cyanobacteria, and consequently odorous production, proliferate. In principle, such a proliferation cannot be excluded as nutrients are available from the sediment pore water, and underwater light at the sediment surface in the sublittoral is sufficiently high due to very low phytoplankton-induced turbidity under oligotrophic conditions. Thus, management-induced fluctuations of the water level seem to be the main control variable to generate light conditions at the sediment surface fluctuating in a given depth horizon faster than cyanobacteria can develop there.

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1. Introduction

Episodes of taste and odour nuisance of water bodies have been reported throughout the world (for summary see Jüttner and Watson, 2007; Krishnani et al., 2008). Among the multitude of compounds causing water quality problems the most prominent ones are the earthy–muddy–musty smelling terpenoids geosmin and 2-methylisoborneol (MIB). Odour threshold concentrations of geosmin and MIB are very low, thus concentrations at parts per trillion levels can already be detected by human olfactory sense. Geosmin and MIB are produced by planktonic and benthic aquatic cyanobacteria, and these metabolites may also originate from aquatic filamentous actinomycete bacteria (Watson, 2003; Smith et al., 2008). For a long time the odorous potential of benthic cyanobacteria has been underestimated (Izaguirre and Taylor, 2004; Watson, 2004), mainly due to the methodology of routine sampling in lakes and reservoirs (Wood et al., 2001). However, if the potential of several benthic and pelagic cyanobacterial taxa to produce geosmin or MIB was compared, it became obvious that the majority of the identified producers were benthic species (Watson, 2003; Jüttner and Watson, 2007; Smith et al., 2008). Thus, it can be concluded that odorous problems in lakes and reservoirs may be mainly caused by these organisms. However, besides the taxonomical affiliation the environmental conditions also exert a strong (indirect) influence on the production of geosmin or MIB by controlling the cyanobacterial growth. The proliferation of benthic cyanobacteria in lakes and reservoirs depends primarily on the underwater light climate which is governed by incident solar radiation and turbidity in the water column. Besides sediment resuspension, turbidity is mainly caused by phytoplankton abundance which, in turn, is controlled by dissolved nutrients. Consequently, the littoral of oligotrophic lakes with ample light conditions was assigned to be the preferred habitat of benthic cyanobacteria (Lowe, 1996), and benthic contribution to total primary production was found to be highest in such clear-water lakes (Pouličková et al., 2008). More eutrophic and turbid conditions impede phytobenthic primary production mainly due to the shading by the phytoplankton (Lowe, 1996; Liboriussen and Jeppesen, 2003). Thus, whereas pelagic geosmin production resulted in higher concentrations in a eutrophic lake compared to meso- and oligotrophic ones (Peter et al., 2009), benthic cyanobacteria were considered to be the primary source of water odour problems in a mesotrophic system (Watson and Ridal, 2004).

In Wahnbach Reservoir, an oligotrophic water body used for drinking water supply, sporadic episodes of unpleasant odours in drinking water were documented during the last years. However, the origin of the muddy, musty smelling compounds remained unknown. Therefore, the objective of this study was to determine the sources and to analyse the spatio-temporal distribution of off-flavours in Wahnbach Reservoir. Secondly, influences of abiotic variables on the dynamics of the odour compounds will be investigated in order to gain insights to the underlying processes that trigger and modify benthic growth and odour production. Thirdly, the probability of off-flavour impacts on raw water will be estimated from odour concentrations in littoral zone.

2. Methods

2.1. *Study site, sampling*

The investigation was performed in Wahnbach Reservoir (Germany, 50°48′N, 7°17′E), an oligotrophic, dimictic or monomictic water body with a surface area of 2.0 km^2, a volume of $40.9 \cdot 10^6$ m^3 and a maximum depth of 46 m. Samples were collected from the littoral (for locations see Fig. 1) from 2006 through 2009 between May and October. Sampling was performed between 8 am and 1 pm. Every sampling position was located with a GPS navigator (Garmin, Olathe, KS, USA). Phytobenthos were surveyed by diving several transects to a depth of about 10 m. The areal extent of algal mats was estimated visually at each sampling site. Benthic samples were taken from all areas where algal mats grew, otherwise a random sample was selected at a depth of 3 m. At each site, water was collected close to the sediment surface for chemical analyses, including total dissolved phosphorus (TDP), soluble reactive phosphorus (SRP), nitrite (NO_2^-), nitrate (NO_3^-), ammonium (NH_4^+), dissolved iron, and dissolved geosmin and MIB. Furthermore, water temperature, pH, and dissolved oxygen (O_2) were recorded close to the sediment surface by WTW probes (WTW Instruments, Weilheim, Germany). Measurements of light attenuation were performed with a spherical quantum sensor (LiCor, Lincoln, NE, USA). At two pelagic sampling points (PA, PE see Fig. 1) depth profiles of chlorophyll

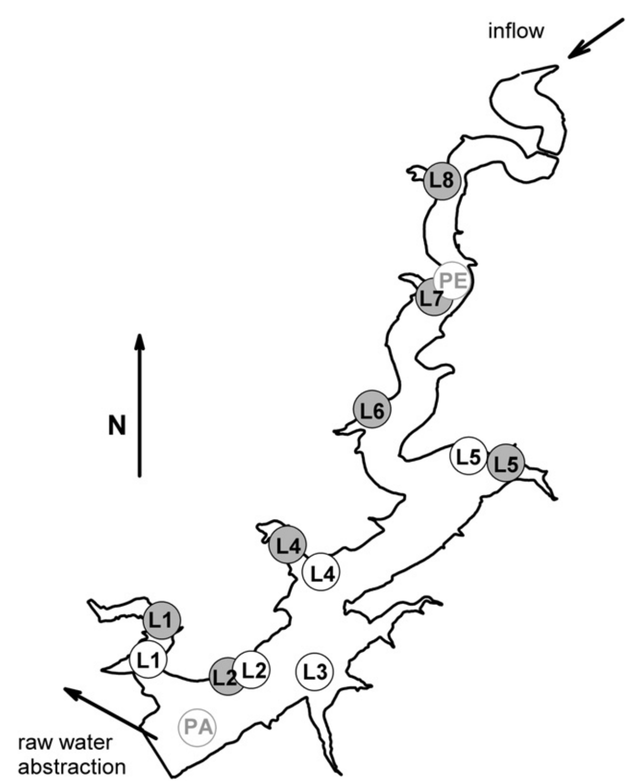

Fig. 1 – Sampling sites in Wahnbach Reservoir. All littoral sampling sites (L) which were investigated from 2006 through 2009 are indicated by a grey circle except for those during low water level phase in 2008 (white circles). Additional sampling sites in the pelagic zone (PA, PE) are shown.