



## Lake morphometry and wind exposure may shape the plankton community structure in acidic mining lakes

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### ABSTRACT

Acidic mining lakes (pH < 3) are specific habitats exhibiting particular chemical and biological characteristics. The species richness is low and mixotrophy and omnivory are common features of the plankton food web in such lakes. The plankton community structure of mining lakes of different morphometry and mixing type but similar chemical characteristics (Lake 130, Germany and Lake Langau, Austria) was investigated. The focus was laid on the species composition, the trophic relationship between the phago-mixotrophic flagellate *Ochromonas* sp. and bacteria and the formation of a deep chlorophyll maximum along a vertical pH-gradient. The shallow wind-exposed Lake 130 exhibited a higher species richness than Lake Langau. This increase in species richness was made up mainly by mero-planktic species, suggesting a strong benthic/littoral – pelagic coupling. Based on the field data from both lakes, a nonlinear, negative relation between bacteria and *Ochromonas* biomass was found, suggesting that at an *Ochromonas* biomass below 50 µg C L<sup>-1</sup>, the grazing pressure on bacteria is low and with increasing *Ochromonas* biomass bacteria decline. Furthermore, in Lake Langau, a prominent deep chlorophyll maximum was found with chlorophyll concentrations ca. 50 times higher than in the epilimnion which was build up by the euglenophyte *Lepocinclis* sp. We conclude that lake morphometry, and specific abiotic characteristics such as mixing behaviour influence the community structure in these mining lakes.

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### Introduction

Acidic mining lakes that originate from ceased open-cast lignite mining activities, are very specific habitats which are often characterised by extreme chemical conditions. The key process is the weathering of pyrite and markasite resulting in the generation of high amount of acidity (Friese et al., 1998). Besides the low pH, high concentrations of sulphate, aluminium, iron and other heavy metals which are several orders of magnitude higher than in circum-neutral lakes are typical. In such extreme habitats, only a limited number of species is able to survive and, consequently, a low diversity of plankton organisms is found (Wollmann et al., 2000; Kamjunke et al., 2004). The plankton community consists typically of heterotrophic bacteria, mixotrophic flagellates and a limited number of other algae (Nixdorf et al., 1998; Lessmann et al., 2000; Beulker et al., 2003) and very few heterotrophic protist and rotifer species (Packroff, 2000; Deneke, 2000). Despite the extreme chemical forcing factors, other environmental (e.g.

lake morphology, turbulence, etc.) and biological factors (e.g. competition and predation) may shape the plankton community structure in such lakes. For example, bacteria compete with the osmo-mixotrophic *Chlamydomonas acidophila* (Tittel et al., 2005) for dissolved organic carbon (DOC) (Kamjunke et al., 2008), and bacteria are consumed by the phago-mixotrophic *Ochromonas* sp. (Schmidtke et al., 2006). In low productive mining lakes (e.g. in Lake 111) consumers such as rotifers are resource limited (Weithoff, 2004). These biotic interactions as well as physical forces such as sediment resuspension and transport of the biota from the benthos/littoral are important processes for structuring the plankton community. The aim of this study was to investigate the effect of lake morphometry and wind exposure (and mixing behaviour) on the plankton communities in two differing mining lakes that are similar in their chemical characteristics. Lake 130 in the Lusatian mining district (Germany) is shallow and wind-exposed with extensive macrophyte beds. The larger part of the lake is polymictic and only at a few deeper areas a thermal stratification establishes in summer. Lake Langau (Lake LG, Austria) is less wind-exposed due to its location and surrounding trees, and stable stratified during summer. Accordingly, the chances of colonizing the pelagial by littoral/benthic (micro-) organisms and by wind-dispersed invaders should be higher in Lake 130 than in Lake LG. Our hypothesis was that higher

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probability of colonization would result in a more complex food web in Lake 130.

## Material and methods

The two mining lakes studied are located in the Lusatian mining area in Eastern Germany (Lake 130, ca. 51°33'N, 13°43'E, ca. 34 ha area, 5 m depth), and in North-East Austria (Lake LG, ca. 48°51'N, 15°44'E, 10 ha area, 10 m depth). Both lakes are ca. 330 km apart; Lake 130 arose ca. 10 years ago, Lake LG is ca. 40 years old.

In 2008, Lake 130 was sampled five times on April 24, May 27, July 3, August 4 and October 17. Samples were taken at 6 depths, at 0, 1, 2, 3, 4 and ca. 5 m using a vertical water sampler. Additionally, physical and chemical parameters (pH, temperature and oxygen) were recorded using a multiparameter probe (Idronaut, Brugheri, Italy). The underwater light intensity as photosynthetic active radiation was recorded with spherical light sensors (Li-Cor 193, Li-Cor, Lincoln, Nebraska, USA).

Subsamples for the analysis of bacteria and phytoplankton were fixed with Lugol's iodine (1 mL 100 mL<sup>-1</sup>) and 1 mL 24% sulphuric acid was added to avoid iron precipitation. Phytoplankton was analysed using the Utermöhl procedure (Utermöhl, 1958) using an inverted microscope (Zeiss, Jena, Germany). The cell sizes were measured with video-aided software (Thalheim, Pulsnitz, Germany). From these measurements the cell volume of phytoplankton cells was calculated assuming a regular geometric shape, and converted into carbon content based on previously established conversion factors (Kamjunke et al., 2004).

For the analysis of bacteria, the samples were bleached with sodium-thiosulfate and stained with acridine orange (Hobbie et al., 1977). The samples were then filtered on black membrane filters (0.2 µm, nuclepore) and analysed with a fluorescence microscope (Zeiss, Jena, Germany). Cell sizes were measured with a porton grid and cell volume and carbon content was calculated according to Simon and Azam (1987).

For zooplankton, depth integrated samples (10.5 L) were taken from the epilimnion and hypolimnion based on the temperature measurements. These samples were filtered through 30 µm mesh size and fixed as described above. Samples were analysed with an inverted microscope (Thalheim, Pulsnitz, Germany). The conversion into carbon was according to Weithoff (2005), Gaedke and Kamjunke (2006) and Weithoff (unpublished results).

For the calculation of the ratio of heterotrophy:autotrophy (H:A) we assumed that the osmo-mixotrophic *C. acidophila* gains 80% of its carbon by photosynthesis and 20% by the uptake of DOC and *Ochromonas* sp. uses to 43% the autotrophic way for carbon acquisition and to 57% the heterotrophic pathway (Gaedke and Kamjunke, 2006). For Lake LG, the algae in the deep chlorophyll maximum (DCM) were not considered in the calculations, because no information on their nutritional strategy was available.

In the laboratory, untreated samples were filtered through GF/F glass fibre filters for the analysis of the soluble reactive phosphorus (SRP), iron and dissolved organic carbon. SRP was measured photometrically using the molybdenum-method, iron using the ferrozine assay (Lovley and Phillips, 1987) and DOC with a carbon analyser (Elementar, Hanau, Germany). From the filters, chlorophyll was extracted overnight with hot ethanol and measured fluorometrically (TD-700, Turner Design, Sunnyvale, California, USA).

The sampling procedure and analyses for Lake LG were similar as for Lake 130 with the following modifications which did not influence our overall results: A total of 9 samples were taken during the growing season in 2005 (September 28 and October 25), 2007 (April 17, June 21, August 29 and November 6) and 2008

(April 1, June 25 and August 1). One or two epilimnetic samples and, if present, one sample from the deep chlorophyll maximum were taken on each occasion. Depth profiles including chlorophyll-fluorescence were measured with a multi parameter probe (YSI Environmental, Yellow Spring, Ohio, USA). Bacterial abundance was determined from epifluorescence cell counts of formalin-fixed (1% final concentration) samples after DAPI staining (Porter and Feig, 1980). The same samples were used to analyse phytoplankton abundance and community composition by flow cytometry (FACS Calibur, Becton Dickinson, San Jose, California, USA) during 2007 and 2008, in addition to cell counts obtained from Lugol fixed samples by the Utermöhl procedure. The agreement between both methods was, on average, within 10% (T. Weisse, unpubl. res.). We report results from the Utermöhl counts to render results from both lakes comparable; however, flow cytometric cell counts were used to assess the phytoplankton abundance close to the lake bottom where high detrital and inorganic particle concentration hindered visual analysis of the samples. Since no size measurements for bacteria are available from Lake LG, constant carbon contents of 15 fg carbon per single cell and 150 fg carbon per filamentous bacteria were assumed.

## Results

### Physical and chemical characteristics

Vertical depth profiles from August 2008 exhibited in both lakes a stable thermal stratification (Fig. 1). The shallow and wind-exposed Lake 130 had a constant temperature up to 3.5 m depth and temperatures decreased downwards to 5 m by ca. 8 °C, whereas in the more sheltered Lake LG, the temperature decreased more gradually over depth with a maximum temperature difference from the surface to the lake bottom of ca. 15 °C; maximum surface temperature was 30.2 °C in June 2007. Due to the high attenuation of the FeS-rich, red-coloured water, light intensity is reduced strongly in both lakes. The 1% surface light intensity was reached at 5–6 m in Lake 130 and at 6–7 m in Lake LG. In the hypolimnion of both lakes, the oxygen concentration decreased towards the lake bottom, but remained above anoxic conditions. A specific feature in the pH profile of Lake LG was that below 5 m, the pH increased to about 5 close to the lake bottom. The stable stratified, low-light, low-oxygen and relatively high pH hypolimnion provided a distinct habitat different from the epilimnion. In Lake 130, the pH was constant over depth except for a slight increase above the sediment.

### Temporal and vertical abundance of plankton organisms

In Lake 130, the bacteria biomass was relatively constant over depth and during the year with a grand mean of  $10 \pm 3$  (SD) µg C L<sup>-1</sup>. The phytoplankton biomass exhibited a much higher variability both at the total biomass level and also at the species level. The depth integrated biomass ranged from 30 to 220 µg C L<sup>-1</sup> (mean  $117 \pm 74$  (SD) µg C L<sup>-1</sup>), however, the individual species biomass varied more strongly (Fig. 2A) suggesting some compensatory dynamics on the community level. Remarkably, compared to some other mining lakes in the Lusatian region, more species contributed to the total phytoplankton biomass in Lake 130: besides the common mixotrophic flagellates *Ochromonas* sp. and *C. acidophila*, two different diatom species (*Eunotia* spp., typical for benthic habitats), one coccal green alga (not identified) and *Euglena* sp. occurred at some sampling dates in considerable abundances (Fig. 2A). The chlorophyll-*a* concentration in the epilimnion was

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