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# Changes of the plankton community composition during chemical neutralisation of the Bockwitz pit lake

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ABSTRACT

Lake Bockwitz, a pit lake in a former lignite open-cast mine south of Leipzig (Germany), was neutralised (from pH 2.65 to pH 7.1) by addition of soda ash (14,620 t) from 2004 to 2007. The additions had to be continued due to ongoing inflows of acid ground and surface water. This paper reports on the changes in the plankton community accompanying the neutralisation.

At the beginning, the community composition and biomass was comparable to other acidic pit lakes, i.e. the pigmented flagellates *Chlamydomonas* and *Ochromonas* dominated the autotrophs, and ciliates and rotifers were the top predators. The biomass was small (maximum 2 mg fresh weight per litre) and decreased until the end of 2008. With increasing pH, the autotrophic community became more diverse, whereby diatoms, chrysophyceans and blue greens contributed significantly to biomass. Although neutral pH conditions were achieved in autumn 2007, picocyanobacteria were not present until the end of 2008. In addition, crustaceans were under-represented in terms of biomass and diversity. Daphnids were not found. We attributed this to short-term changes of the ionic composition of the water and to the limited time available for non-acido-tolerant organisms to colonise the system.


## Introduction

Pit lakes often have acid water as a result of pyrite oxidation caused by aeration of the surrounding underground during mining. Environmental standards and potential use of the pit lakes for recreation, fishing or water storage require, however, neutral conditions. In the past, various methods of neutralisation have been tested and applied in pit lakes (Castro and Moore, 2000; Castendyk and Eary, 2009; Schultze et al., 2009). The extensive experiences from neutralisation of lakes which were acidified by acid atmospheric deposition (AAD) (e.g. Olem, 1991; Henrikson and Brodin, 1995) cannot simply be transferred to the neutralisation of acid pit lakes. The major reasons are the usually much higher acidity and concentrations of nearly all dissolved solids in acid pit lakes (Geller and Schultze, 2009).

Since 1990, about 120 new pit lakes have formed in former lignite open-cast mines in the eastern part of Germany or are currently in filling (Krüger et al., 2002). About 50% of these lakes would be acidic when filling is completed without any preventive measure. The main way of neutralisation has been the filling of the lakes with neutral, well-buffered water diverted from rivers or provided by dewatering operations of mines still operating (Jolas, 1998; Schultze et al., 2009). In some cases, however, there is not enough water available from these sources. Under such conditions, chemical neutralisation or waiting for natural neutralisation are the alternative options. Waiting for natural neutralisation requires periods ranging from a few years to several decades depending on local conditions. Due to national and EU water quality standards, this option is not accepted by regional authorities for new lakes and lakes having an outflow (Schultze et al., 2009). Here we report about a chemical neutralisation performed in Lake Bockwitz. Soda ash ($Na_2CO_3$) was applied after filling of Lake Bockwitz by groundwater, local surface runoff and – in the final period of filling – inflow from other pit lakes located upstream.

Changes of aquatic life caused by AAD and subsequent neutralisation have been widely investigated (e.g. Gunn and Keller, 1990; Stenson et al., 1993; Henrikson and Brodin, 1995; Hogsden et al., 2009). Typical structure and diversity of plank tonic communities of acid pit lakes are also known (e.g. Wollmann et al., 2000; Gaedke and Kamjunke, 2006). However, there is a lack of studies describing changes in planktonic community caused by neutralisation of such acid pit lakes. While mining lakes filled with river water receive a wide variety and substantial numbers of planktonic organisms which potentially colonise the system, the situation may be different in lakes that are neutralised exclusively by addition of alkaline substances. This paper reports on the changes of the plankton community of

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Lake Bockwitz during neutralisation. The results are discussed with respect to the plankton community composition of natural lakes and to the sensitivity of planktonic organisms to chemical perturbation.

## Study site and methods

Lake Bockwitz is located about 25 km south to the city of Leipzig (Fig. 1). It was formed as the result of the operation of the former lignite open-cast mine Bockwitz from 1982 to 1991. This mine was an extension of the mine Borna-Ost. The initial mine Borna-Ost was mined out at the beginning of the 1980s and resulted in Lake Harthsee. The mined lignite was of Tertiary age. The overburden consisted of Quaternary loess, sand and gravel as well as Tertiary clay and sand. The Tertiary layers contained pyrite. The overburden was mainly dumped west of Lake Bockwitz within the mined area.

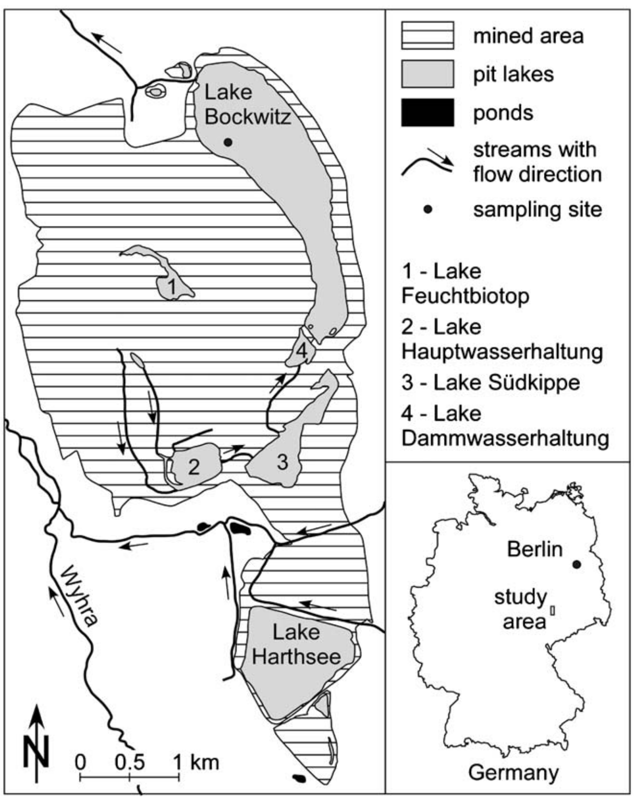


**Fig. 1.** Location of Lake Bockwitz and the sampling site.

The filling of Lake Bockwitz started in summer 1993. The final water level of Lake Bockwitz (146 m a.s.l.) lies about 15–20 m below the groundwater level east, north and west of the lake. A small valley to the north-west is used for the overflow of Lake Bockwitz. Groundwater from unworked underground was the main contributor to the filling of Lake Bockwitz (about 63%). The hydrological conductivity of the dumped overburden is low as a result of mixing various materials of aquifers and aquitards during excavation and dumping. Only about 2% of inflow came from groundwater of the dump during filling. Local surface runoff (from all directions) contributed about 8% of filling water. Inflow from the pit lakes located upstream started in 2000, contributing about 27% to the filling (IBGW, 2002).

Due to acidification, Lake Bockwitz water was not allowed by the regional authorities to be discharged into the local river system before 2007. Therefore, the water level rose temporarily up to 147.4 m a.s.l., i.e. 1.4 m above the anticipated final water level, which was reached in autumn 2004 and again in summer 2008. The morphometric data of Lake Bockwitz at its final water level are $1.68 \times 10^6$ m$^2$ lake surface, $18.4 \times 10^6$ m$^3$ lake volume, 10.4 m mean depth, 19.5 m maximal depth and 7.9 km length of shoreline. The sampling site for the monitoring of plankton and water chemistry (Fig. 1) was located at the deepest site of the lake.

Neutralisation with soda ash ($Na_2CO_3$) started in March 2004 at a water level of 145.7 m a.s.l. The powdered soda ash was blown into the lake just below its surface via a floating pipeline at a single site in the southern part of the lake. Fig. 2 shows the amount of soda ash applied until the end of 2008 when this study was finished. Calcite formed in the vicinity of the addition site in 2004 as a consequence of the locally elevated pH, the availability of carbonate in the form of the soda ash and the concentration of calcium in the lake water. The calcite settled to the lake bottom near the addition site and was buried without exploiting its neutralisation potential. Consequently, the rate of soda addition was lowered in 2005 in order to prevent further losses due to calcite precipitation. Thereafter, formation of calcite was no longer observed (Neumann et al., 2007). An alkalinity balance showed that calcite precipitation consumed about 5% of the added alkalinity; 65% of the added alkalinity neutralised the acidity which was present in the lake water when the neutralisation started; about 20% of the added alkalinity was consumed by the neutralisation of the upper centimetres of the lake sediment (mainly by cation exchange) and about 10% by the permanent inflow of acidity from aerated parts of the underground east of Lake Bockwitz, from the dumped overburden and from pit lakes located upstream (20–30 kmoleq/d) (Neumann et al., 2007). Due to ongoing acidity inflows, frequent applications of soda ash are also expected to be necessary in future.

This paper reports results of a study conducted by the UFZ Department of Lake Research from September 2004 to December

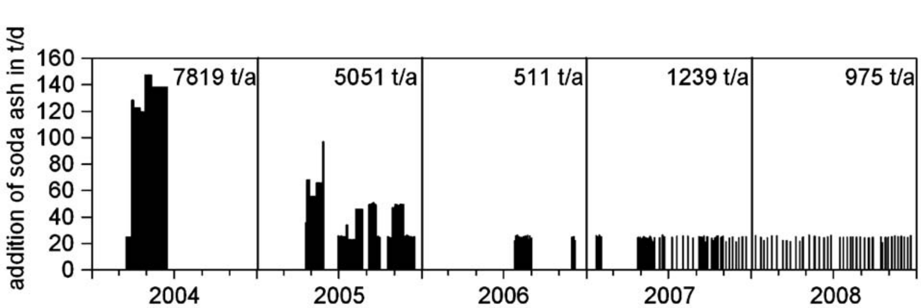


**Fig. 2.** Application of soda ash to Lake Bockwitz. Each column represents the amount of soda ash added within one day. The numbers in the upper part of the diagram show the annual sums of added soda ash in tonnes per year.

**Table 1**
Changes of concentrations of selected substances in water of Lake Bockwitz (6 m depth).

| Sampling LMBV | 16.03.04 | 25.11.04 | 30.11.05 | 15.03.07 | 21.11.07 | 12.12.08 |
|---|---|---|---|---|---|---|
| Sampling UFZ | – | 23.11.04[a] | 06.12.05[a] | 05.12.06[a] | 04.12.07[a] | 25.11.08[a] |
| SRP | < 0.002 | < 0.003[a] | < 0.003[a] | < 0.003[a] | < 0.003[a] | < 0.003[a] |
| TP | < 0.01 | < 0.006[a] | < 0.006[a] | < 0.006[a] | < 0.006[a] | < 0.006[a] |
| $NH_4^+$–N | 0.77 | 0.75 | 1.3 | 0.93 | 0.85 | 0.70 |
| $NO_3^-$–N | 0.19 | 0.20 | 0.23 | 0.20 | 0.25 | 0.37 |
| Si | n. d. | 9.3[a] | 8.5[a] | 9.3[a] | 8.3[a] | 8.0[a] |
| TIC | < 0.5 | < 0.5[a] | < 0.5[a] | < 0.5[a] | 0.8[a] | 3.1[a] |
| DOC | n. d. | < 0.5[a] | < 0.5[a] | < 0.5[a] | < 0.5[a] | < 0.5[a] |
| $SO_4^{2-}$ | 1260 | 1350 | 1330 | 1360 | 1270 | 1380 |
| Fe | 55.3 | 8.7 | 0.28 | 0.43 | 0.31 | 0.49 |
| Al | 19.4 | 9.7 | 1.60 | 1.53[a] | < 0.06[a] | < 0.05[a] |
| Ca | 363 | 278 | 251 | 247 | 233 | 223 |
| Na | 12 | 202 | 302 | 302 | 301 | 267 |

SRP—soluble reactive phosphorus, TP—total phosphorus, TIC—total inorganic carbon, DOC—dissolved organic carbon, units: mg $L^{-1}$, n. d.—no data.

[a] Data from UFZ sampling, other data from monitoring program of the LMBV. For overturn in autumn 2006, no data from LMBV monitoring were available. Therefore, data from the following spring overturn 2007 were used.

2008. Data from monitoring performed by the Lausitzer und Mitteldeutsche Bergbau-Verwaltungsgesellschaft (LMBV) for the first eight month of 2004 were included to complement the observation period. In addition, monitoring data from the LMBV were included for a number of chemical parameters (Table 1, Fig. 2). Wherever possible, the chemical data considered were taken from samplings which were also used for plankton analyses, i.e. data from the UFZ.

The following description of methods refers to those applied by the UFZ. The other data were, however, collected in a comparable way and analysed in accordance with German standards.

Water samples for chemical and biological analysis were taken monthly as far as possible according to weather conditions. Temperature, electrical conductivity, oxygen concentration and pH-value were measured with a multi-parameter probe (IDRONAUT Ocean Seven, Milano, Italy) from the lake surface to the lake bottom in 20 cm steps. Water samples were taken from 6 m and from 16 m depth. From each depth, 17.5 L of water were collected using a 3.5 L sampler (Limnos, Finland). The samples from each depth were mixed and sub-samples were taken for chemical and plankton investigations. Samples for analysis of iron and other metals were filtered using 0.45 μm pore size PVDF filters (Minisart High-Flow) and preserved with nitric acid. Samples for soluble reactive phosphorus (SRP) were filtered using 0.2 μm pore size PVDF filters; samples for dissolved organic carbon (DOC) were processed using Millex-HV (0.45 μm pore size). Ammonium, nitrate, silicon, total phosphorus (TP), total organic and inorganic carbon (TOC, TIC), acidity and alkalinity were analysed from unfiltered samples. Samples for chlorophyll *a* were filtered using Whatman GF/F.

Ammonium, nitrate, soluble reactive phosphorus, total phosphorus (after digestion) and silicon were analysed photometrically by continuous flow analysis (Skalar, The Netherlands). A HighToc-analyser (Elementar, Germany) was used for detecting TIC, TOC and DOC. Sulphate and chloride concentrations were determined by ion chromatography (GAT Analysentechnik, Germany). Metals were analysed by ICP-OES (Perkin Elmer, USA).

Organisms were fixed using Lugol's solution. Bacteria and protozoans were processed as described in Tittel and Kamjunke (2004). Briefly, bacteria were harvested onto black polycarbonate membranes and stained with acridine-orange. For epifluorescence microscopy, the Lugol's colour was removed by adding a few drops of 0.1 N sodium thiosulphate. Cells were counted and measured using epifluorescence microscopy and biovolumes were calculated by applying simple geometric formulas best fitted to cell shape. The occurrence of heterotrophic flagellates, picocyanobacteria and eukaryotic autotrophic picoplankton was checked after staining with DAPI. Phytoplankton and ciliates were counted in an inverted microscope. Phytoplankton biovolumes were estimated using published taxon-specific cell volumes, while those of ciliates were derived from individual measurements of cell size. Rotifers and crustaceans were harvested from a volume of 10 L onto 40 μm steel mesh and counted and measured with an inverted microscope. Biovolumes were calculated as described in Tittel et al. (1998).

## Results

Lake Bockwitz showed a thermal stratification during summer every year. In winter 2005/06, it was ice-covered (clear ice without a blanket of snow) from January to March. In 2004, the pH of the hypolimnion rose above that of the epilimnion (Fig. 3). In the following years, temporarily elevated pH-values ( > 9) of the metalimnion were observed. A lateral decrease in pH of up to 0.5 units was found from North to South on some sampling occasions in 2007 and 2008. Fig. 3 shows the changes in pH, acidity, alkalinity, Secchi-depth and concentration of chlorophyll *a* from 2004 to 2008. Table 1 summarises the changes in the concentrations of additional substances. The first sampling in Table 1 (16th March, 2004) represents the water quality immediately before the start of soda ash addition. All other data describe the water quality after overturn was completed and vertical differences of water quality were removed in autumn of the respective years.

The autotrophic biomass was low in Lake Bockwitz throughout the investigation and did not exceed 0.7 mg $L^{-1}$ fresh weight, except for autumn 2004 and spring 2005 when biomass values of up to 2.1 mg $L^{-1}$ were achieved by flagellates of the genus *Chlamydomonas* and *Ochromonas* (Fig. 4). Concentrations of chlorophyll *a* were also low and decreased from maximum values of about 3 μg $L^{-1}$ in 2005 and 2006 to 1 μg $L^{-1}$ in 2008 (Fig. 2). In the first acidic phase (2004–2005), chlorophycean and chrysophycean flagellates (*Chlamydomonas*, *Ochromonas*, *Chrysococcus*) dominated. *Chlamydomonas, Ochromonas* and *Chrysococcus* occurred also in the following years. *Chromulina* was the third genus considerably contributing to the chrysophycean biomass from 2006 to 2008. However, diatoms (*Synedra acus*, *Nitzschia acicularioides*, *Eunotia exigua*), cryptomonads (*Cryptomonas ovata*, *Rhodomonas minuta*) as well as dinoflagellates (*Peridinium umbonatum*) were also found

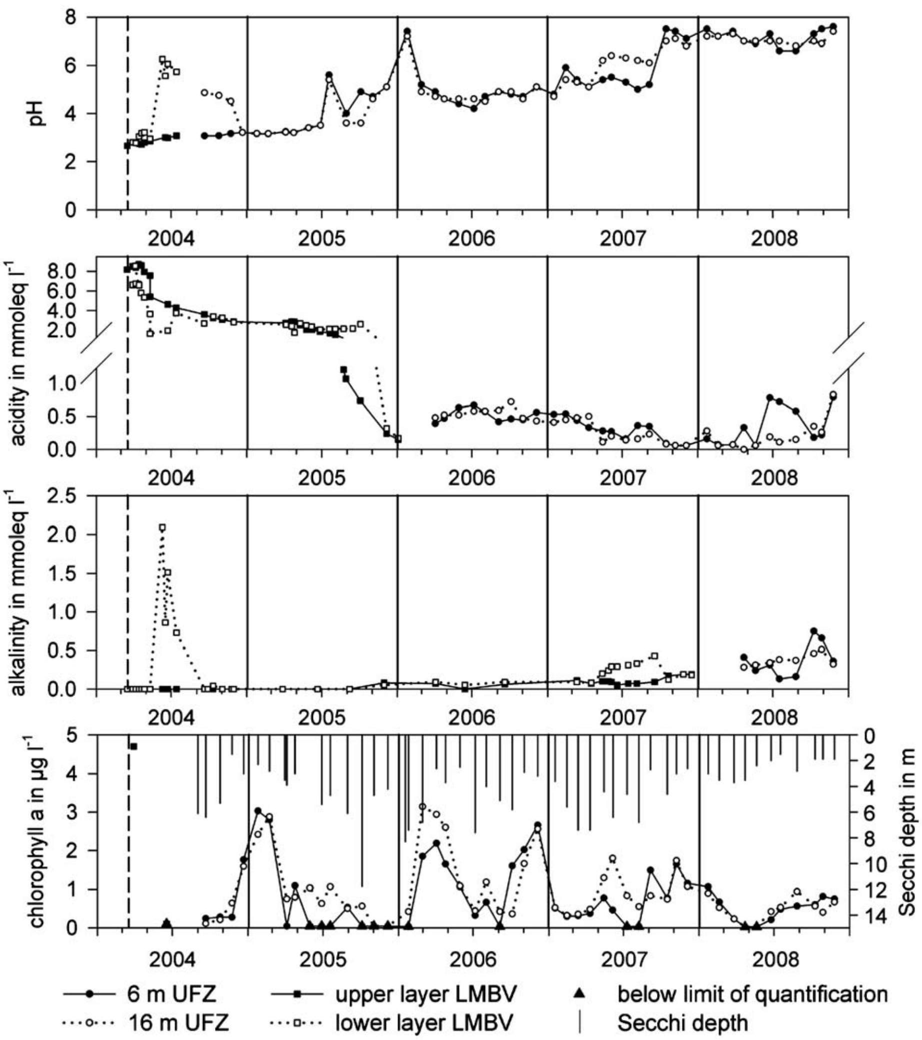


**Fig. 3.** Changes of pH, acidity, alkalinity, concentration of chlorophyll *a* and Secchi depth from 2004 to 2008 in Lake Bockwitz. Where the sampling depth of LMBV monitoring differed from that of the UFZ, the data from depths closest to 6 or 16 m depth, respectively, were used.

(Fig. 5). In the next 2 years (2006–2007), the number of phytoplankton species increased. When pH conditions came close to neutrality in November 2007, the first cyanobacteria appeared; they persisted in the plankton afterwards (*Limnothrix redekei*, *Pseudanabaena catenata*, *Geitlerinema* sp., *Myxobaktron* sp.). Moreover, an increase in the number of species of diatoms and chlorophyceans was observed (*Nitzschia* c.f. *flexa*, *N.* c.f. *palea*, *Fragilaria crotonensis*, *Pinnularia subcapitata* and *Monoraphidium convolutum*, *M. contortum*, *Scourfieldia cordiformis*, *Schroederia setigera*, *Choricystis* sp., respectively). There were no systematic differences between the samples from 6 and 16 m depth.

The biovolume of bacteria ranged between 0.002 and 0.1 $mm^3$ $L^{-1}$, except for two higher values in 2007 (Fig. 4). Ciliates occurred in about 60% of all samples (Fig. 4). In winter 2004 and spring 2005, they achieved comparatively high biovolumes of up to 0.15 $mm^3\,L^{-1}$, represented almost exclusively by Hypotrichida of the genus *Oxytricha*. Abundances remained low in the following years. Rotifers were found in low numbers and biomass throughout the whole study; where their biovolume only exceeded 0.1 $mm^3\,L^{-1}$ in one sample. Most identified rotifers were *Brachionus urceolaris, Cephalodella hoodi* and *Elosa worallii*, which were found throughout the study. In 2007 and even more in 2008, the common rotifers *Keratella quadrata*, *K. cochlearis*, *Kellicottia longispina* and *Polyarthra* sp. also occurred. Crustaceans were first observed in 2007. The small cladocerans *Bosmina longirostris* and a few individuals of *Chydorus spaericus* were found. In addition, cyclopoid copepods occurred in most samples, although in very low numbers and only with naplius instars or non-adult copepodit stages. In the next year, 2008, the small cladocerans disappeared. Daphnids were not yet found in Lake Bockwitz.

The overall plankton biomass decreased during the study. This decrease was based on lower biovolumes of phytoplankton and also of ciliates in 2006 and 2007 compared to 2005 and in 2008 compared to all previous years (Fig. 4). Biovolumes in the epilimnion were not generally higher than in the hypolimnion, except for the last year when higher phytoplankton numbers were monitored in the surface strata. There was no marked seasonal variation in any of the sampled groups, although it must be noted that with the low sampling frequency short-term changes or peaks may have been overlooked.

At the beginning of the study, until summer 2005, the composition of the plankton community was characterised by the dominance of phytoplankton, while bacteria contributed only 6% to total biomass (Fig. 6). Ciliates achieved a relative biomass of more than 25% on two occasions. With the decrease of autotrophic biomass, bacteria became more prominent from autumn 2005 onwards (28%), while the relative importance of ciliates and metazoan grazers was low (5%).

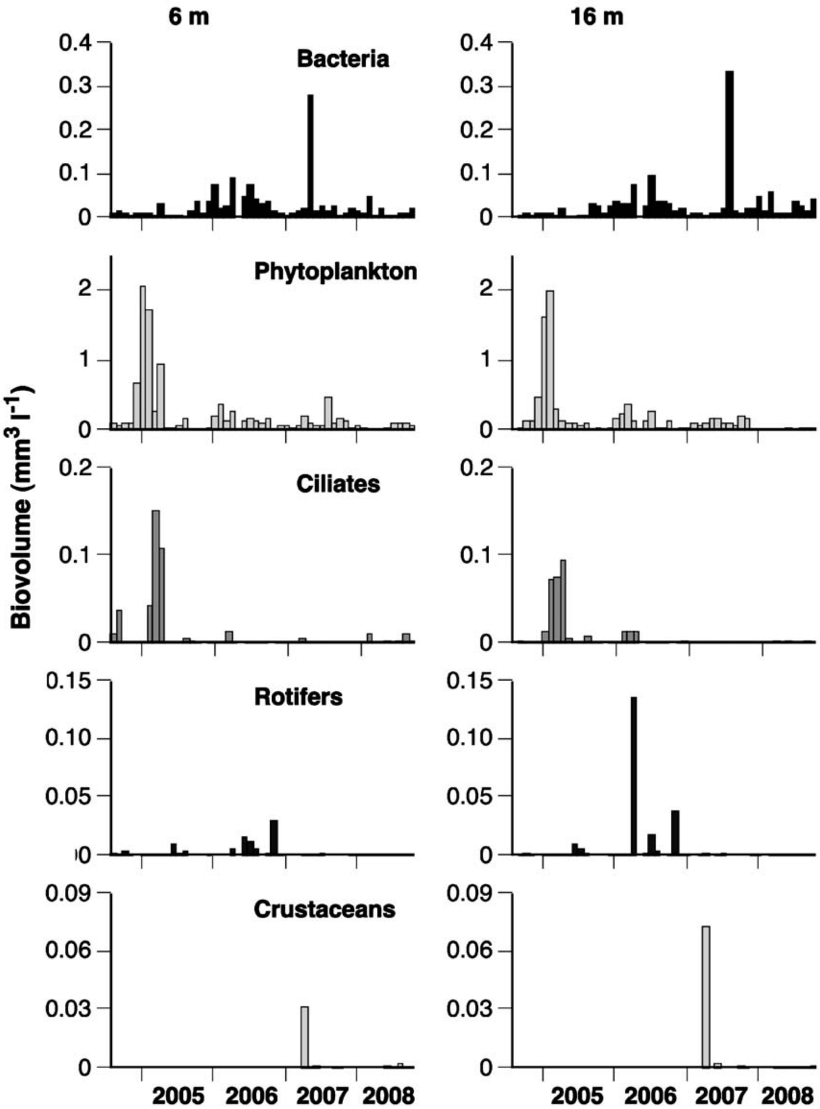


**Fig. 4.** The biovolume of planktonic organisms in the surface layer (6 m) and in the hypolimnion (16 m) of Lake Bockwitz. Phytoplankton encompasses all pigmented organisms including cyanobacteria and genera with a known mixotrophic mode of nutrition (e.g. *Ochromonas*).

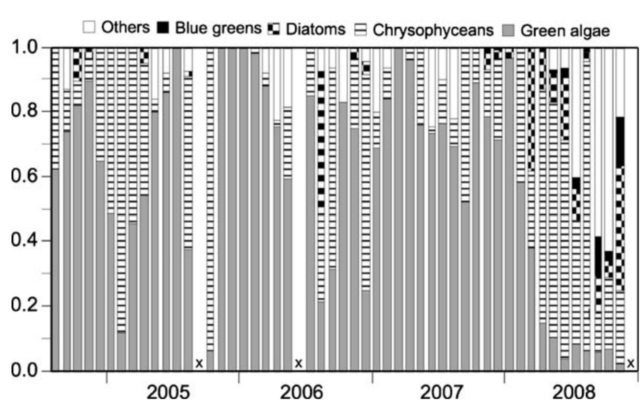


**Fig. 5.** Taxonomic composition of the phytoplankton community. Data of individual samples from 6 m depth in Lake Bockwitz are shown. "Others" were mainly *Trachelomonas* sp., *Peridinium umbonatum* and *Gymnodinium* sp. An "x" at the bottom of an entirely white column indicates a month without data.

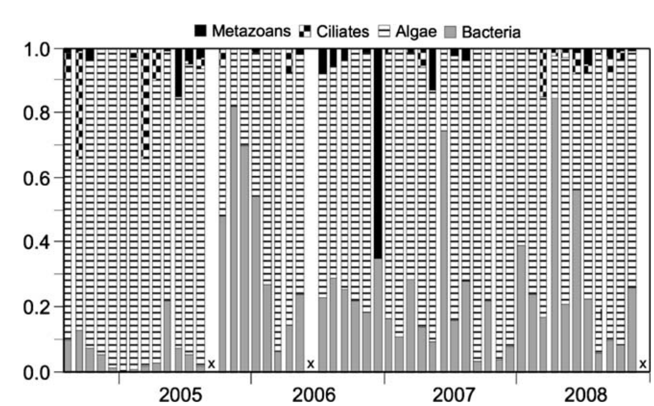


**Fig. 6.** The contribution of planktonic groups to total plankton biomass in surface samples (6 m depth) in Lake Bockwitz. Metazoans represent rotifers plus crustaceans. The occurrence of heliozoans and of non-pigmented (heterotrophic) flagellates was checked regularly in samples using inverted microscopy and epifluorescence microscopy, respectively. Only a very small number of cells were found. Their biomass was negligible and was not considered here. An "x" at the bottom of an entirely white column indicates a month without data.

## Discussion

Due to its relatively high density, the soda ash solution moved downwards through the epilimnetic water layers and increased the pH primarily in the hypolimnion during 2004 (Fig. 3). In the following years, the temporarily elevated pH values of the metalimnion (not shown in Fig. 3) indicated that the same process occurred again without reaching the hypolimnion. The lateral differences in pH observed in 2007 and 2008 resulted from acid interflow, groundwater and inflow from the pit lakes located upstream of the southern end of Lake Bockwitz.

The changes of pH, acidity, and concentrations of total inorganic carbon (TIC), iron and aluminium reflect the progress of neutralisation. Neutral conditions were reached at the end of 2007. In 2008, circumneutral conditions were stabilised by repeated additions of soda ash. As indicated by alkalinity and TIC, the carbonate buffering system was established under the neutral conditions. The soda ash increased the sodium concentrations above natural levels (about 12 $mg\,L^{-1}$, as indicated by the data of March 16, 2004). The decrease in 2008 reflects the decrease of addition rate and the dilution by natural flushing. The sulphate concentration remained nearly unchanged during neutralisation as a result of ongoing inputs of sulphate via interflow, groundwater, local surface runoff and inflow from the pit lakes located upstream. One reason for the decrease of the calcium concentration was the above-mentioned calcite precipitation due to locally elevated pH. Another reason was the cation exchange in the upper part of the lake sediment, as also mentioned above.

The considerable decrease of the Secchi-depth in 2008 (maximum 2008: 3.7 m; maxima 2004–2007: 6.4–11.8 m; Fig. 3) probably resulted from a change of particle size of iron precipitates. During neutralisation, larger particles could form due to higher iron concentrations in the lake water and due to the still acid conditions. After neutralisation, the iron was precipitated under neutral conditions immediately when entering the lake, resulting in smaller particles. Smaller particles cause a more intense light-scattering, i.e. more turbidity and smaller Secchi depth, than the same mass of larger particles. Plankton blooms can be excluded as a reason for the decrease of the Secchi depth in 2008 based on the results for chlorophyll *a* and plankton biomass (Figs. 3 and 4). However, no investigations were made regarding quantity and quality of the seston and its abiotic components. Therefore, the explanation presented above is only a hypothesis.

Typical sources of nutrients such as waste water inflows or intensive agricultural land use in the vicinity are not present at Lake Bockwitz and, therefore, not relevant. The majority of the lake is part of a nature protection area (southern and central 70% of the lake area; mainly for waterfowl). The northern 30% are open for recreation (e.g. swimming, fishing). However, only a small degree of recreational use is expected because of many more attractive alternatives at a distance of 25 km or less (Linke and Schiffer, 2002). Therefore, the very low concentration of phosphorus is probably the result of ongoing inputs and precipitation of iron, as known from other pit lakes (Kleeberg and Grüneberg, 2005). The ongoing precipitation of iron may also explain the low concentrations of DOC. The concentrations of ammonium were relatively high under the initial acid conditions. Such elevated ammonium concentrations are common in acid pit lakes. They result from an inhibition of nitrification under acid conditions (Klapper and Schultze, 1995). The decrease of ammonium concentration in 2008 was smaller than expected. Possibly, the further supply of acidity via groundwater may have inhibited nitrification in parts of the lake sediment. Consequently, the nitrate concentration in the lake water was low during the whole study period. The relatively high concentrations of silicon are also common for acid pit lakes (Geller and Schultze, 2009). As known from other neutralised pit lakes, the silicon concentration usually decreases over a period of some years after neutralisation as a consequence of uptake by diatoms. Oxygen concentrations were close to saturation due to the low potential for consumption (data not shown).

Compared to acidic lakes and to lakes having a moderate or low mineral nutrient availability, the numbers of bacteria, algae and ciliates were roughly in the range in which organisms of these groups typically occur. The low abundance of autotrophs and the predominance of *Chlamydomonas* and *Ochromonas* were in agreement with earlier observations in Lake Bockwitz (Roth and Biermann, 2003). Both flagellates are commonly found and typically contribute 90% to pigmented biomass in acidic mining lakes (Lessmann et al., 2000; Kamjunke et al., 2004). Other autotrophs that were observed in 2004 and 2005 were also found in lakes and streams under acidic conditions (e.g. *Eunotia exigua*, *Synedra acus*, *Nitzschia acicularioides*, *Rhodomonas minuta*, *Cryptomonas ovata*) (Douglas et al., 1998; Lessmann et al., 2000). The absence of cyanobacteria below pH 6 was in accordance with earlier observations (Brock, 1973).

Due to the absence of larger grazers, ciliates (*Oxytricha*) and heliozoans (*Actinophrys*) are the dominant consumers in acidic mining lakes (Packroff and Woelfl, 2000; Woelfl, 2000; Kamjunke et al., 2004). This also applied to Lake Bockwitz until spring 2005 (Figs. 4 and 6) when pH values were still low (Fig. 3). In contrast, abundances of rotifers and (if present at all) crustaceans remained low even when the pH rose in 2007 and 2008. Only a few individuals per litre were monitored. In many non-acidic lakes with a comparably low phosphorus concentration and phytoplankton biomass, rotifers are present with higher abundances, e.g. about 20–150 individuals per litre in Lake Königssee (Barthelmeß, 1995). Some of the monitored rotifers (*Brachionus urceolaris, Cephalodella hoodi, Elosa worallii*) often occur in acidic lakes (Deneke, 2000; Weithoff, 2005) but are not restricted to them, while all other rotifer species found here occur exclusively in circumneutral waters.

Compared to other plankton organisms, crustaceans have longer and more complex life cycles and, therefore, are expected to be more sensitive to episodic changes of proton concentration. While some copepods can tolerate a moderately low pH (Steinberg et al., 1998), daphnids require pH values $\geq 6$, depending on the availability of other ions such as $Ca^{2+}$ (Hooper et al., 2008). Daphnids grow and reproduce fast, but environmental parameters must fit within relatively narrow limits. They are, for example, susceptible to changes of water chemistry as their iono- and osmoregulation (e.g. $Na^+$, $Ca^{2+}$) critically depends on pH and on the presence of metal toxicants (Bianchini and Wood, 2008; Clifford and McGeer, 2009), which could be relevant in phases of soda application. In addition, high concentrations of abioseston as observed in the form of iron flocs (see above) are especially unfavourable for non-selective filter feeders such as daphnids (Kirk, 1991). This may explain the absence of *Daphnia* in Lake Bockwitz. Autotrophic picoplankton was not found, neither picocyanobacteria nor eukaryotic algae smaller than 2 μm cell size. Especially the absence of picocyanobacteria appears remarkable, as this group contributes substantially to autotrophic biomass in many nutrient-poor lakes (Petersen, 1991). It is known that picocyanobacteria respond sensitively to chemical stress and environmental perturbation (Munawar et al., 1994). Weisse and Mindl (2002) reported significant reductions of growth rate in one out of three tested *Synechococcus* strains exposed to industrial soda wastewater.

We observed a community in transition. Therefore, it may be less comparable to older lakes, irrespective of whether they are acidic or not. However, the ratio of bacterial to phytoplankton biomass in Lake Bockwitz (Fig. 6) illustrates the structural changes that occurred during the process of neutralisation: the median ratio in surface samples amounted to 1:30 from September 2004 until April 2005 and decreased to 1:3.5 from May 2005 until November 2008. For comparison, the biomass ratio varied in a much smaller range (from 1:3 to 1:7) in four lakes, representing a large gradient of pH and productivity (oligo-mesotrophic Lake Constance, eutrophic Lake Müggelsee, acidic Mining Lakes 111 and 117) (Gaedke and Kamjunke, 2006).

We conclude that after neutralisation of Lake Bockwitz, many components of plankton of natural non-acidic lakes were present. However, picocyanobacteria and *Daphnia*-species were still missing. Metazoan grazers were found to be under-represented in terms of biomass and taxonomic diversity. Low abundances of phytoplankton, ciliates and bacteria together with the absence of a seasonal variation of these groups are typical for a lake having a low availability of mineral nutrients.

The neutralisation of Lake Bockwitz shows that addition of alkaline substances, in this case soda ash, can be a successful approach to treat (pit) lakes (Schultze et al., 2009). The amount of alkalinity applied to Lake Bockwitz for reaching neutral conditions, i.e. until the end of 2007 ($281 \times 10^6$ moleq, i.e. 14,620 t soda ash), was larger than the amount of alkalinity added to Lake Orta ($218 \times 10^6$ moleq alkalinity, i.e. 14,800 t of powdered limestone), which was the largest previously reported liming action in a single lake (Calderoni and Tartari, 2001). The course of the neutralisation of Lake Bockwitz showed that acidity import via cation exchange in the upper part of the lake sediment, interflow, erosion and inflow from pit lakes located upstream was not known exactly and, therefore, underestimated (Neumann et al., 2008). As already mentioned above, frequent additions of soda ash are also expected to be necessary for the coming years in order to maintain neutral conditions. A prediction of the future soda ash requirements is currently in preparation. Future neutralisations of other pit lakes should be based on more detailed and complete investigations of local conditions. Addition of soda ash or other alkaline substances may be performed not only at one site but widespread over the lake surface in order to prevent formation of solutions or suspensions of high density, resulting in incomplete mixing of the applied agents with the lake water and consequent losses of neutralisation capacity.

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