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Environmental changes in an alpine lake (Gossenköllesee, Austria) over the last two centuries – the influence of air temperature on biological parameters

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Abstract

Changes in microfossils (diatoms, chrysophytes, chironomids and cladocera remains), geochemistry and deposition of atmospheric pollutants have been investigated in the sediment records of the alpine lake Gossenköllesee (Tyrol, Austria) spanning the last two centuries. The sediment records were compared with seasonal and annual air temperature trends calculated for the elevation (2417 m a.s.l.) and the geographical position (47°13′46′′N, 11°00′51′′E) of the lake, and with precipitation records available since 1866 from Innsbruck. Temperature trends followed a 20–30 year oscillation between cold and warm periods. Regarding long-term changes, temperature trends showed a U-shaped trend between 1780 and 1950, followed by a steep increase since 1975.

Physical, geochemical, and organic parameters were not controlled by air temperature. Among the biological records only diatoms and chrysophytes reacted to air temperature changes: the relative abundance of planktonic diatoms increased during warm periods and changes in mean annual alpine air temperature explained 36.5% of their variation. The relation between abundance of seasonal stomatocyst types and air temperature varied on two different time scales: while summer stomatocysts were influenced by short term temperature fluctuations, the autumn stomatocysts were affected only by the long term changes. Other biological parameters exhibited a constant

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species composition (chironomids, pigments) or changes were small and independent of temperature (cladocera). Spheroidal carbonaceous fly-ash particles, and trends in Pb and Cr indicated increasing deposition of atmospheric pollutants but had no detectable effects on the biological parameters either. In respect to temperature variations over the last 200 years, this alpine lake is much less sensitive than expected and has thus to be regarded as a well buffered site. However, temperature alone is not sufficient to understand changes in species composition and other biogeochemical processes with unknown historical patterns might have affected species composition more strongly.

Introduction

The impact of climate change on lakes is still not fully understood. Some reactions are restricted to specific catchment characteristics, such as geochemistry of the bedrock, and type and amount of vegetation cover. For example, increasing pH during warmer periods has been reported for alpine lakes in the Austrian and Italian Alps (Psenner & Schmidt, 1992; Marchetto et al., 1993; Sommaruga et al., 1998; Koinig et al., 1998b). However, the opposite relationship was described for boreal lakes in Canada (Schindler et al., 1990, 1996). Furthermore, even within the same region, lakes may react distinctly differently (Koinig et al., 1998a). In order to gain a better understanding of possible reactions to temperature change, several alpine lakes have been studied within the EC MOLAR project (Battarbee et al., this issue).

Remote, alpine lake ecosystems are particularly sensitive to climate change as small differences between warm and cold periods will strongly affect the duration of the ice- and snow-cover and in consequence the limnochemistry and the growing period within lakes. Biological remains preserved in sediments offer a useful tool to study the impact of temperature change on lakes in a historical perspective (Smol, 1988; Battarbee, 1991). Furthermore, the impact of human activities on remote, alpine lakes is small and largely comprises the deposition of atmospheric pollutants and the use of alpine pastures.

Here we carry out a multi-parameter sediment investigation of a remote alpine lake for comparison with temperature data retrodicted for the lake site for the period 1781–1997. Sediment profiles of diatoms, chrysophytes, cladocera, chironomids, pigments, and organic parameters (organic carbon, organic nitrogen, C:N ratios, and loss on ignition) were investigated. To discuss possible effects of atmospheric pollutants, stratigraphies of spheroidal carbonaceous fly-ash particles, lead (Pb), and chromium (Cr) were included. We address the questions: (a) do climate trends correlate with changes in the species compositions or with the occurrence of individual taxa; (b) are these changes caused by direct temperature influences (water temperature, duration of ice-cover); and (c) is there a detectable influence of alterations in atmospheric deposition or organic parameters, on the biological records?

Study site and material

Gossenköllesee (GKS) is a remote alpine soft water lake located at 2417 m a.s.l. in the Stubaier Alps, Austria (47°13′46″N, 11°00′51″E). The lake is regarded as moderately sensitive to acidification (pH 6.74, alkalinity 93.6 μeq/l). Concentrations of dissolved organic carbon (DOC) are relatively low with an average of 0.45 mg DOC/l (min. 0.25, max. 1.10). Wögrath (1995) and Thies et al. (2000) have described the limnochemical characteristics of this lake in greater detail. The basin of the lake is 9.9 m deep and consists mainly of large boulders in the west and smaller rocks in the east. Only 5.8% of the lake area (17179 m²) is covered with soft sediment which is approximately equivalent to the area deeper than 9 m (Zaderer, 1982). Fish have been introduced into the lake about 500 years ago. The catchment (ca. 30 ha) consists mainly of moraines and crystalline boulders (mica schist, granite, amphibolite) and only 10% are covered with soils and vegetation (alpine grass, heather; Hiesberger, 1988). The lake has neither surface inflows nor outflows but a subsurface outflow can be observed 50 m below the lake. There are no direct human impacts occurring in the catchment. However, in summer sheep graze in the area. Since 1975, a limnological research station has been located at the lakeshore. The station was heated with fossil fuel until 1994 and since then has been heated with electricity to diminish local atmospheric pollution.

Due to the high water content of the GKS sediment (99.6–89.3%, mean 94%), seven sediment cores were taken with a modified Kajak corer (diameter 90 mm) from the deepest part of the lake between 1995 and 1998. The cores were cut immediately in the field into 0.25 cm layers except for GKS4 and GKS98 which were divided into 0.5 cm layers because of the high amount of material needed for some analyses. A sum-