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CO_2 fixation in Lake Brienz and Lake Lugano

Carbon dioxide (CO_2) is removed from the natural global cycle and sequestered in lake sediments in the form of organic carbon. But how is CO_2 fixation affected by nutrient concentrations and oxygen availability in lake water? To answer this question, Eawag explored the depths of two lakes, carrying out analyses at the molecular level.

Lakes generally act as carbon sinks: as plant biomass accumulates, CO_2 is removed from the atmosphere. Biomass is either produced in the lake itself – e.g. as phytoplankton, algae and reeds – or enters surface waters from the surrounding area. The resulting organic matter provides the basis for the lake food web. Standing in contrast to accumulation processes are degradation processes, in which part of the biomass is converted back to CO_2 by microorganisms as it passes through the water column. However, the part which is not broken down can be permanently sequestered in sediment.

By fixing CO_2 in this manner, lakes can counteract the greenhouse effect [1–3]. Accordingly, assessments of lakes' effectiveness as carbon sinks are important inputs for modelling the future impacts of climate change. We therefore wished to find out what internal parameters influence the process of CO_2 fixation in lakes. Specifically, we were interested in nutrient concentrations and the associated primary productivity (amount of biomass produced), as well as oxygen availability in lake water. In our research project, we compared two lakes of different trophic levels.

Organic matter production and degradation revealed by lipid biomarkers. The efficiency of sequestration of organic matter in sediment is described by the ratio of organic carbon available in the lake to carbon actually sequestered in sediment. It is thus partly influenced by the amount of biomass present: the higher the content of nutrients – especially phosphate and nitrate [4] – the greater the production of biomass in the lake. However, sequestration efficiency is also determined by the intensity of microbial degradation processes in the water column: if sufficient oxygen is available even in deeper layers, the organic matter may be almost completely mineralized to CO_2 in the water column, with only a small amount entering the sediment. We therefore selected two quite different lakes for our study: the oligotrophic Lake Brienz in the Bernese Oberland – characterized by relatively low levels of nutrients (phosphate <5 µg/l) and biomass and a high oxygen content – and the eutrophic Lake Lugano in Canton Ticino, with substantially higher concentrations of nutrients (phosphate 50–60 µg/l) and biomass, and anoxic deep-water conditions (Fig. 1A).

The aim was to analyse the lipid composition of particulate organic matter collected from different water depths (10, 40, 70, 100, 150 and 200 or 250 m). Lipid biomarkers provide an indication of the sources of organic matter and thus the contributions of different organisms to the biomass [5–7]. More important for us, however, was the fact that we could use biomarkers to track degradation processes in the water column. The samples of suspended matter collected in the spring (June) and autumn

Eawag researcher Carsten Schubert prepares the mass spectrometer for measurement of samples, adding liquid nitrogen.

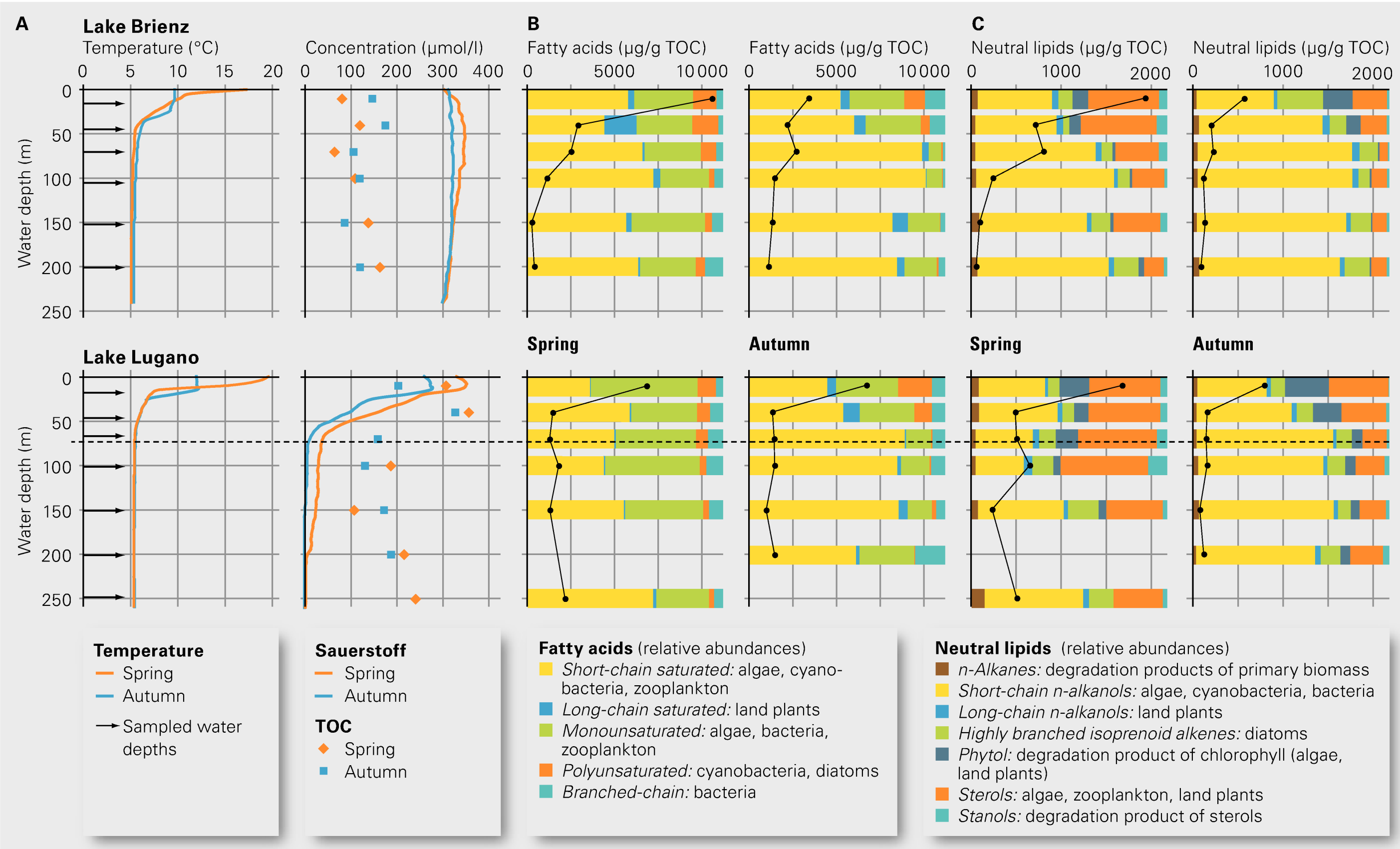

Fig. 1: Parameters studied at various depths in Lake Brienz and Lake Lugano (spring and autumn sampling campaigns).
A) Bioproductivity (expressed as total organic carbon concentration [TOC]) and oxygen content.
B) Total fatty acid concentrations (curves) and relative abundances of fatty acid groups (bars).
C) Total neutral lipid concentrations (curves) and relative abundances of neutral lipid groups (bars).
The dashed line indicates the oxic-anoxic interface in the water column of Lake Lugano

(October/November) of 2007 were therefore separated into fatty acid and neutral lipid fractions, and the molecular composition was then analysed.

Detailed analysis of fatty acids. As a first step, we analysed in detail the fatty acid compositions and concentrations for both lakes. The following conclusions can be drawn from our data:

► Both lakes show roughly comparable fatty acid concentrations, if these are normalized to total organic carbon (TOC; cf. curves in Fig. 1B). However, the absolute fatty acid concentrations in micrograms per litre of water filtered are approx. 4 times higher in Lake Lugano. This clearly reflects the differences in primary productivity resulting from the different nutrient concentrations in the two lakes.

► In deeper water layers, fatty acid concentrations decline (curves in Fig. 1B). At the same time, there is an increase in the proportion of unsaturated as against saturated fatty acids (bars in Fig. 1B). The biomass available in the lake is thus reduced as water depth increases. However, fatty acid concentrations tend to rise again in the deep waters of Lake Lugano – here, degradation appears to proceed more slowly.

► In both lakes, the fatty acid fractions mainly consist of short-chain, saturated and monounsaturated substances, indicating the predominant contribution of phytoplankton to the biomass. For example, monounsaturated fatty acids with 16 carbon atoms are markers for diatoms. We detected a high relative abundance of these compounds in the euphotic zone of Lake Brienz in the spring and autumn. The euphotic zone is the well-illuminated upper layer of water, where photosynthesis can occur. Only a small proportion of the organic matter is attributable to land plants – identifiable by the long-chain fatty acids which are components of waxes (bars in Fig. 1B).

► Branched-chain fatty acids are biomarkers for bacterially derived biomass. Elevated relative abundances of these fatty acids were found in Lake Lugano at the interface between oxic and anoxic water at a depth of around 70 m (spring) and in deep water layers (autumn). The relatively high abundances of branched-chain fatty acids in the anoxic deep waters of Lake Lugano indicate the presence of bacteria which are active in the absence of oxygen.

► Polyunsaturated fatty acids indicate the occurrence of cyanobacteria (i. e. blue-green algae = bacteria capable of photosynthesis) and diatoms. In particular, polyunsaturated fatty acids with

18 carbon atoms are of cyanobacterial origin. These were found, for example, in the euphotic zone of Lake Lugano in the spring. By contrast, polyunsaturated fatty acids occurring in Lake Brienz and in the euphotic zone of Lake Lugano in the autumn derive mainly from diatoms.

► High contents of short-chain saturated fatty acids with 18 carbon atoms in both lakes suggest an increased contribution of zooplankton to the biomass in deeper parts of the water column at the time of sampling in the autumn (bars in Fig. 1B).

Valuable information provided by neutral lipids. Additional insights are also to be gained from the neutral lipid fractions, which include alcohols, alkanes and alkenes. Our findings were as follows:

► As with fatty acids, concentrations of neutral lipids decrease as water depth increases (curves in Fig. 1C), reflecting the degradation of biomass in the water column.

► The predominance of short-chain over long-chain *n*-alkanols (saturated hydrocarbons with one or more hydroxyl groups) confirms the finding – already obtained with reference to fatty acids – that the biomass present in the lake is mainly derived from phytoplankton, with only a small contribution from land plants (bars in Fig. 1C).

► In all the samples, we also detected alkanols of microbial origin (branched-chain *n*-alkanols with 15 or 17 carbon atoms).

► Phytol – a component of chlorophyll – serves as a marker for photosynthetically active organisms. It is therefore not surprising that it mainly occurs in the upper layers of both lakes.

► Sterols are constituents of plant cell membranes, with individual sterols being attributable to specific groups of organisms. Thus, sitosterol is considered to be a marker for land plants, while a particular sterol with 28 carbon atoms is typical of diatoms. Both of these sterols were detected in the samples collected in the spring from Lake Brienz and Lake Lugano. By contrast, the autumn samples contain much lower concentrations of plant sterols. Here, the predominant sterol is cholesterol, which suggests an increase in the relative contribution of zooplankton to the biomass, especially in deeper parts of the water column.

► In deeper water layers, the stanols/sterols ratio increases. This may be regarded as evidence of degradation of organic matter in the water column.

► Also noteworthy is the high relative abundance of highly branched isoprenoid alkenes – another characteristic marker for inputs from diatoms.

Organic matter dynamics and CO_2 fixation. In summary, what can be concluded from our findings? As expected, less organic matter is produced in the oligotrophic Lake Brienz than in the eutrophic Lake Lugano. At the same time, organic matter is more efficiently degraded in Lake Brienz than in Lake Lugano, so that overall more organic carbon is sequestered in the sediment of Lake Lugano. At first glance, therefore, Lake Lugano is the larger carbon sink. However, the other side of the coin shows Lake Lugano as an ecosystem which has undergone major changes since the 1970s. Until the late 1980s, nutrient levels rose continuously as a result of human impacts. Since then, while increased efforts to protect the environment have achieved some initial success, there is still evidence today not only of unnaturally high biomass production but also of changes in the composition of phytoplankton and zooplankton. Our analysis of lipid composition, for example, demonstrates the predominance of cyanobacteria (which can adversely affect water quality) and green algae in Lake Lugano, while diatoms predominate in the oligotrophic Lake Brienz. As a result of the elevated nutrient concentrations, oxygen levels in Lake Lugano are only comparable to Lake Brienz in the uppermost water layers (Fig. 1A). From a depth of around 70 m, there is virtually no oxygen in Lake Lugano, which accounts for the less marked degradation of organic matter. At the same time, however, organic matter is transformed by microorganisms even under these anoxic conditions – producing not CO_2, but methane, which is about ~20 times more potent as a greenhouse gas. The significance of Lake Lugano as a larger carbon sink is thus substantially reduced. Overall, our study shows that nutrient and oxygen levels in water are crucial factors determining carbon turnover and hence also CO_2 fixation in lakes.. ○○○

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