HISTORY REPEATS ITSELF: PERSISTENT ORGANIC POLLUTANTS IN THE GLACIER-FED LAKE OBERAAR, SWITZERLAND

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Abstract

A dated sediment core from a high-Alpine lake (Lake Oberaar, Switzerland), which is directly fed by glacier meltwater has been analyzed for polychlorinated dibenzo-*p*-dioxins and dibenzofurans (PCDD/Fs) and polychlorinated biphenyls (PCBs). Concentrations of PCDD/Fs and PCBs peaked in the 1960s-1970s, reflecting their higher emissions and their use at that time. Since the late 1990s concentrations of PCDD/Fs and PCBs have sharply increased, pointing towards a considerable release of these compounds from melting glaciers.

Introduction

Global warming is recognized as a major global issue nowadays, with potentially drastic environmental impacts[1]. The ongoing climate change is expected to affect pollutant dynamics, which are closely linked to climate conditions. In the present study the impact of global warming on the occurrence of persistent organic pollutants (POPs) in remote Alpine areas is investigated. To this end, we analyzed polychlorinated dibenzo-*p*-dioxins and dibenzofurans (PCDD/Fs) and polychlorinated biphenyls (PCBs) in a dated sediment core from the high-Alpine Lake Oberaar, Switzerland, which is mainly fed by glacier meltwater.

Materials and Methods

Sampling Site
Lake Oberaar is a proglacial reservoir lake located at 2303 m a.s.l. in the Bernese Alps in Central Switzerland. Its surface area is 1.47 km² and its maximal depth is 80 m. The dam was constructed in 1953 for electric power generation. The lake is fed by meltwater from the Oberaar Glacier, which is a valley glacier with a tongue length of 5 km. The glacier peak is at 3463 m a.s.l., its average width is 800 m and its surface area is around 5 km². Figure 1 shows Lake Oberaar with its dam and in the background the Oberaar Glacier.

Figure 1. Picture of the hydroelectric proglacial reservoir Lake Oberaar and the Oberaar Glacier. (Picture V.Raz)

Sampling and Dating
Sediment cores were sampled in 2006. After sampling, the cores were split and dated with annual varves counting. The clear identification of annual varves and the recognition of the 1953-layer, when the dam was constructed, enabled a very precise and reliable dating. Two sediment cores were combined to obtain samples covering the entire period 1953-2005. Sediment sections representing 2-5 years of sediment deposition were prepared.

Sediment analysis
Homogenized and freeze-dried sediment was Soxhlet extracted. Aliquots of the extracts were spiked with isotope labeled internal standards ($^{13}C_{12}$-labeled PCDD/Fs and $^{13}C_{12}$-labeled PCBs), purified and fractionated. Detection and quantification was performed with gas-chromatography coupled to high resolution mass spectrometry. Target analytes included all 17 2,3,7,8-chlorosubstituted PCDD/Fs and the coplanar dioxin-like PCBs (congeners number 77, 81, 105, 114, 118, 123, 126, 156, 157, 167, 169, and 189). Quality assurance included analysis of blank samples (most concentrated blank represented 25% of PCDD/Fs and 11% of PCBs in comparison to the least concentrated sediment sample) and check for recovery of internal standards (48%-92% for PCDD/Fs and 60%-98% for PCBs).

Results

The historical record of PCDD/Fs and PCBs in sediment from the High-Alpine Lake Oberaar is presented in Figure 2. For comparison, Figures 2 also includes trends in Lake Greifen, Lake Constance, and Lake Thun, which are representative of low-altitude lakes situated in urbanized areas from the Swiss plateau and which have previously been investigated[2,3,4].

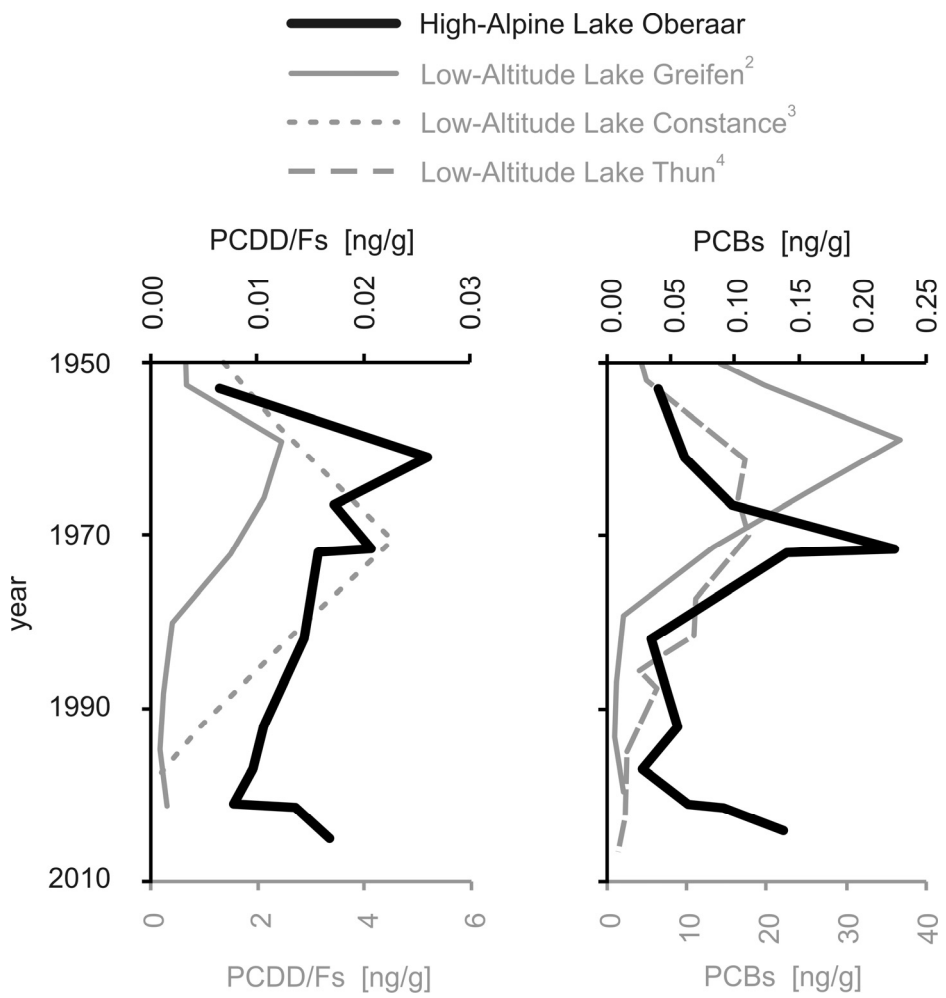

Figure 2. Concentrations of PCDD/Fs and PCBs in dated sediment cores from the High-Alpine Lake Oberaar (black curve, upper scales) and the low-altitude Lake Greifen[2], Lake Constance[3], and Lake Thun[4] (gray curves, lower scales).

Concentrations of PCDD/Fs and PCBs increased in the 1950s and peaked in the 1960s-1970s in the glacier-fed Lake Oberaar, as well as in the urban Lake Greifen[2], Lake Constance[3], and Lake Thun[4]. In the 1970s-1990s, concentrations of PCDD/Fs and PCBs in all the lakes steadily decreased to low levels. After the late 1990s trends in Lake Oberaar are remarkably different from the trends in low-altitude lakes. In the glacier-fed lake a second distinctive peak of PCDD/Fs and PCBs is observed.

Discussion

Historical peak of PCDD/Fs and PCBs

The first peak of PCDD/Fs and PCBs in Lake Oberaar closely follows the global production, usage, emission, and regulatory history of these compounds. Anthropogenic emissions of PCDD/Fs in Switzerland considerably increased at the beginning of the 20th century in parallel to industrialization. Since the early 1980s, emissions of PCDD/Fs in Switzerland have sharply decreased as a result of improved solid waste incineration technologies[5].

The global production of PCBs started in the 1930s and gradually increased until the 1960s-1970s[6]. PCBs were banned in Switzerland in open applications in 1972, followed by a complete ban and mandatory disposal in 1986[7]. Worldwide, the Stockholm Convention, which includes PCDD/Fs and PCBs, has been in force since 2004[8].
Due to the regulatory actions taken for PCDD/Fs and PCBs, and due to the phase-out of PCBs some decades ago, their residues in sediment from Lake Oberaar considerably decreased until the 1990s. This is in line with previous studies from different low-altitude lakes in the region. Maximum PCDD/F concentrations in sediment in the 1960s were reported for urban lakes in Switzerland, such as Lake Greifen[2] and Lake Constance[3] (Figure 2). High PCB concentrations in sediments from the 1960s-1970s were also reported in the urban Lake Greifen[2], as well as in the Pre-Alpine Lake Thun[4] (Figure 2), which is a low-altitude lake situated in a distance of only 45 km from Lake Oberaar.

Current peak of PCBs
The sharply increasing concentrations of PCDD/Fs and PCBs in Lake Oberaar since the late 1990s are in strong contrast to dated sediment cores from low-altitude lakes, such as Lake Greifen[2], Lake Constance[3], and Lake Thun[4]. Considering the emission and usage history of PCDD/Fs and PCBs in Switzerland[5-8], direct input through atmospheric deposition as a source of these rising trends is very unlikely. Our data suggest that a pulse effect from the melting Oberaar Glacier feeding Lake Oberaar is a possible cause. Thus, according to this hypothesis, the glacier plays a key role, as it trapped and accumulated the atmospherically-derived POPs in the 1960s-1970s and is now releasing these chemicals at high rates. The Oberaar Glacier has been monitored for the last century; in the recent years, it has decreased significantly in size[9]. During the last 80 years the glacier tongue shrunk by 1.6 km. Currently, the concentrations of PCDD/Fs (0.01 ng/g) and PCBs (0.14 ng/g) in the lake sediment are similar to their historical peaks (0.03 and 0.23 ng/g for PCDD/Fs and PCBs, respectively) and no signs of decreasing or stabilizing concentrations are noticeable.

As a conclusion, our study provides indications that glaciers may represent an important secondary source for POPs and the re-cycling of these compounds in remote areas. The latter finding is of relevance regarding possible consequences of the predicted massive glacier melting due to the ongoing climate change in the future.

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