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Quantitative screening level assessment of human risk from PCBs released in glacial meltwater: Silvretta Glacier, Swiss Alps

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ABSTRACT

Persistent organic pollutants (POPs) are entrained within glaciers globally, reemerging in many alpine ecosystems. Despite available data on POP flux from glaciers, a study of human health risk caused by POPs released in glacial meltwater has never been attempted. Glaciers in the European Alps house the largest known quantity of POPs in the Northern Hemisphere, presenting an opportunity for identification of potential risk in an end-member scenario case study. With methodology developed by the US Environmental Protection Agency (EPA), we provide a regional screening level human risk analysis of one class of POPs, polychlorinated-biphenyls (PCB) that have been measured in melt waters from the Silvretta Glacier in the Swiss Alps. Our model suggests the potential for both cancer and non-cancer impacts in residents with lifetime exposure to current levels of PCB in glacial meltwater and average consumption of local fish. For residents with an abbreviated 30-year exposure timeframe, the risk for cancer and non-cancer impacts is low. Populations that consume higher quantities of local fish are predicted to be at a greater risk, with risk to lifetime consumers higher by an order of magnitude. Based on the results of our screening study, we suggest that local government move to the next step within the risk assessment framework: local monitoring and management. Within the Alps, other glacial watersheds of a similar size and latitude may see comparable risk and our model framework can be adapted for further implementation therein.

1. Introduction

Despite being banned by the multinational Stockholm Convention agreement in 2004, long-range atmospheric transport has made some persistent organic pollutants (POPs) ubiquitous in the environment (Bogdal et al., 2009; Simonich and Hites, 1995; Villa et al., 2001).

In Arctic and high alpine environments, POP sorption to snow crystals leads to deposition and entrainment in glaciers, resulting in the long term storage of legacy chemicals in glacial ice (Blais et al., 2001; Miner et al., 2018, 2017; Pavlova et al., 2016). POPs also accumulate at enhanced rates in high-altitude, high-snowfall alpine environments proximal to areas of use (Daly and Wania, 2004; Dong et al., 2017, 2015; Pavlova et al., 2014). Glacial entrainment of POPs has been documented in mountain ranges within China, Svalbard, Canada, Switzerland and Italy, with the highest concentrations found in the European Alps due to a latitudinal atmospheric gradient (Lafrenière et al., 2006; Miner et al., 2017; Wang et al., 2008). The central location and high altitude of the Swiss Alps concentrates pollution input from both local and distal sources, with glacial POP and PCB concentrations the highest of any sampled to date in Europe or the Arctic (Ferrario et al., 2017; Miner, 2018).

Though POPs have been identified in glaciers globally, long-term human risk from uptake of fish and meltwater from the glacial watershed is unknown. Even at low concentrations, POPs in the environment have the potential to create health problems in downstream populations with long term exposure (Iszatt et al., 2015; Jaacks and Staimez, 2015; Ngwa et al., 2015).

Since 1975, the U.S. Environmental Protection Agency (EPA) has developed protocols for screening human cancer and non-cancer risk from chemicals at varying scales (EPA, 2017, 2003, 2001a; EPA et al., 2009). Applying a regional, multi-variable linear tool that utilizes both a conceptual and quantitative framework is the most comprehensive way to survey the potential for human toxicological risk within a larger glacial watershed. To establish a risk baseline we use observed

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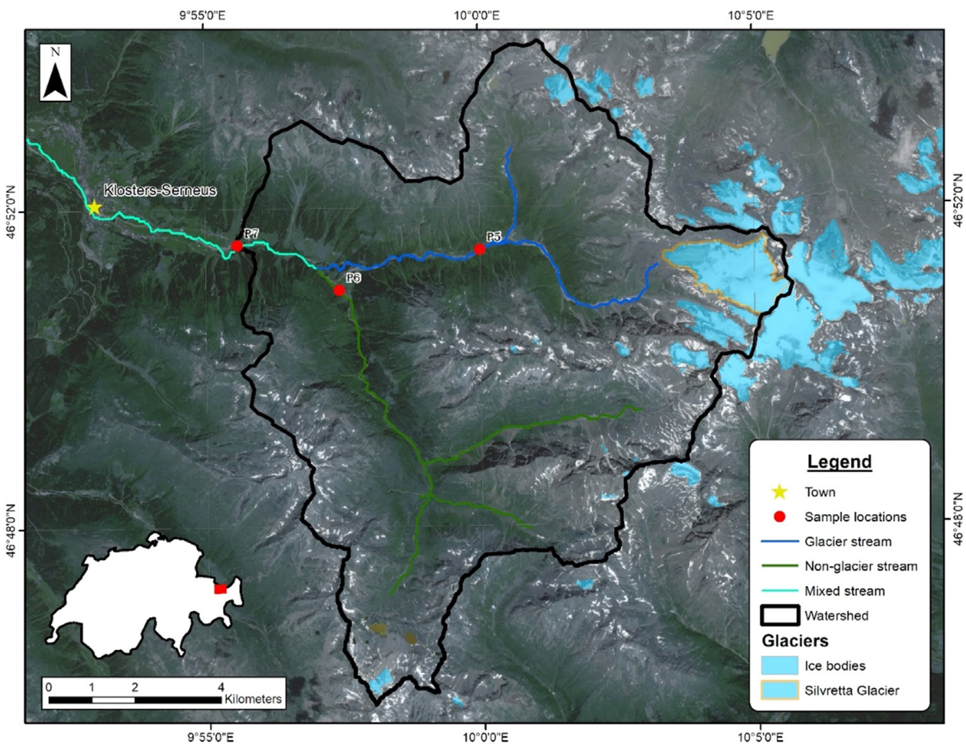

Fig. 1. Silvretta Glacier watershed with Silvretta Glacier outlined in orange. P5 is the sample location fed directly by glacial meltwater, P6 is the sample location for non-glacial samples and P7 is the sample location for the mixed stream. Klosters-Serneus is the closest town to the Silvretta Glacier and is indicated by a yellow star.

concentrations in a well-researched, endmember location, the Silvretta Glacier in the Swiss Alps.

The combination of ice cores, water samples, lake cores and glacial flow models from the Silvretta glacier (Fig. 1) makes it a glacier with one of the most complete data sets of glacial POP movement over time, providing a baseline for hazard identification (Pavlova et al., 2016, 2014). Therefore, the goal of this study is to provide the first assessment of population-level human risk from the uptake of PCB pollutants in glacial meltwater. While this study is site specific, the need to understand the potential risk to humans from pollutants in glacial meltwater is broadly applicable to numerous glaciated ranges.

2. Materials and methods

2.1. Silvretta data and exposure assessment

The field of glacial POP toxicology is in its infancy, characterized by a dearth of data. To account for this and to establish a risk baseline, we incorporate published research from the most-studied glacier in the Swiss Alps (Pavlova et al., 2016, 2014; Steinlin et al., 2016). Silvretta glacier, with an area of 3 km^2, is a temperate alpine glacier located in the Central Eastern Range of the Swiss Alps where yearly ice melt begins in April and ends in December (Fig. 1) (Pellicciotti et al., 2010). Fourteen meltwater samples taken at three locations (P5,P6,P7-Fig. 1) in the glacial watershed during the summer months of two years were analyzed for 6 representative PCB congeners, and characterize the peak yearly glacial meltwater contribution to the watershed (Pavlova et al., 2016). While the bulk water sample data for the proglacial stream (P5: 73 pg/L-*Sept. 2013*; 52 pg/L-*Oct. 2013*) and non-glacial stream (P6: 51 pg/L-*Sept. 2013*; 55 pg/L-*Oct. 2013*) are similar, samples from the mixed stream where glacial and non-glacial water sources combine (P7: 100 pg/L-*Sept. 2013*; 100 pg/L-*Oct. 2013*) show an elevated PCB concentration indicative of the mixture of both sources (Pavlova et al., 2016; Steinlin et al., 2016). Though these concentrations are specific to the Silvretta watershed, results are within the observed range for PCB samples taken throughout the Alps within both glacially-fed streams and lake waterbodies over the past 10 years (Bogdal et al., 2010; Quadroni and Bettinetti, 2017; Schmid et al., 2011; Villa et al., 2001).

For this risk assessment, the upper limit PCB water concentration data was derived from the highest sample concentrations in the mixed stream bulk samples (P7–100 pg/L) with the average concentrations determined using the mean of all mixed stream data (P7–57 pg/L, averaged from 4 samples from 2012 and 2013). This allows us to identify the potential for risk under the highest observed concentration, as well as the median concentration that may more closely mirror the below glacier watershed. Though glacial melt peaks during summer months and dwindles during the winter, chemical concentrations in proglacial lakes and streams will continuously reflect the accumulation of multi-year chemical release and environmental partitioning (Grimalt et al., 2001; Mackay, 2001; Schmid et al., 2011). In accordance with standard practice, these concentrations were multiplied by a factor of 5 to account for the 30 representative PCB congeners frequently found in the environment (Glüge et al., 2017; Pavlova et al., 2016, 2014; Steinlin et al., 2015).

The below glacier watershed encompasses a variety of potential PCB exposure routes for humans, including the consumption of glacial water or resident fish, direct contact with the skin and inhalation of volatilized chemicals (Fig. 2a, b) (EPA, 1999; Bettinetti et al., 2008; Czub and McLachlan, 2004a; Czub and McLachlan, 2004b; Ren et al., 2016; Schmid et al., 2007). Compared to some industrial waterways such as the Hudson River, Silvretta Glacier meltwater exhibits relatively low concentrations of PCBs (EPA, 2001b). Accordingly, we identified that exposure through skin contact and inhalation posed extremely low risk during the initial exposure assessment and was thus eliminated from the quantitative screening model.

Within the Swiss Alps, high altitude, proglacial lakes immediately below the glacial terminus often contain fish, increasing the potential for bioaccumulation in fish tissue from waterborne chemicals (EPA, 2015; Mackay et al., 2001; Mackay and Patterson, 1990; Ren et al.,