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Snowmelt, glacial and atmospheric sources of mercury to a subarctic mountain lake catchment, Yukon, Canada

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Abstract

In montane regions, ongoing and future shrinkage of glacier cover, coupled with a shortening snow cover period, can profoundly alter river hydrology but also lead to the release of long-range contaminants, such as mercury (Hg), deposited and stored in snow and ice. In this study, field data coupled with hydrological and atmospheric models were used to estimate the contributions of atmospherically-deposited Hg released by snow or glacier ice melt, and from direct atmospheric deposition, to Kusawa Lake, in subarctic Yukon, Canada. The estimated net Hg accumulation rate in supraglacial snow obtained from field samples is 0.55 $\mu g\ m^{-2}\ a^{-1}$. The direct annual atmospheric Hg flux to Kusawa Lake, obtained from model simulations, and which includes summertime wet deposition, is ~6 times larger, averaging 3.04 $\mu g\ m^{-2}\ a^{-1}$. The estimated mass of Hg from snow/ice meltwater entering the lake annually is 0.6 kg, while direct atmospheric deposition to the lake may contribute a further 0.4 kg, totaling 1.0 kg a^{-1}. Levels of Hg in cores taken from glaciers in the catchment's headwaters are mostly above expected pre-industrial values, which suggests that some Hg now being released from glaciers is legacy anthropogenic Hg that accumulated in the past 150 years. At present, the delivery of Hg from melting glacial ice is the largest known source to Kusawa Lake, followed by contemporary atmospheric inputs (direct or via runoff). Efforts should be made to quantify other potential sources, such as subglacial meltwater, runoff from wetlands/forest, or melting permafrost, to better constrain the Hg balance in montane lake catchments of this region.

Keywords: Mercury; Snow; Glaciers; Subarctic; Lake; Atmosphere

1. INTRODUCTION

The global dispersion of neurotoxic mercury (Hg) emitted to the atmosphere by human activities is a major environmental issue addressed under the Minamata Convention on Mercury (UNEP, 2013). The volatility of gaseous elemental Hg (Hg^0) allows it to be dispersed very far from emission point sources and to contaminate remote and formerly pristine environments, where it can be biomagnified in the aquatic food chain (Fitzgerald et al., 1998; Driscoll et al., 2013). Lakes in cold mountain regions may be particularly susceptible to this form of contamination owing to potential orographic cold-trapping of

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airborne volatile pollutants (Loewen et al., 2005; Blais et al., 2006; Battarbee et al., 2009).

Another concern associated with Hg pollution is the legacy problem: although Hg levels in the atmosphere now appear to be stable or declining in many regions (Zhang et al., 2016), a large amount of historically-emitted Hg is thought to have accumulated in terrestrial soil reservoirs from which it is being released via revolatilization to air or in runoff (Smith-Downey et al., 2010; Amos et al., 2013; Obrist et al., 2017; Schuster et al., 2018). For mountain lakes in glacier-fed catchments, a related issue is the potential release of accumulated legacy Hg in runoff as a result of global glacier retreat. To properly evaluate ecosystem contamination risks associated with this effect, it is important to quantify the contribution of Hg to mountain lakes from snow and ice meltwater, relative to other inputs (e.g., Zdanowicz et al., 2013; Sun et al., 2017; Vermilyea et al., 2017).

Here, we present an investigation of the sources of Hg to Kusawa Lake, which lies in a protected area in the subarctic montane region of southern Yukon, Canada. This region and neighboring parts of British Columbia (BC) and Alaska have experienced a warming trend since the mid-20th century, which accelerated in recent decades, leading to widespread thinning and recession of glaciers and of perennial mountain ice patches (Farnell et al., 2004; Barrand and Sharp, 2010; Larsen et al., 2007; Arendt et al., 2009). In the Wheaton Basin south of Whitehorse, the glacier-covered area shrank by 17% between 1990 and 2010 (DeBeer et al., 2012). If this trend persists, it could lead to important changes in the supply of water, dissolved and particulate matter to Kusawa Lake in the near future, which could impact the biogeochemical cycle of Hg. The objective of this study is to estimate the magnitude of Hg inputs to Kusawa Lake that result from release of atmospherically-derived Hg by snow and glacier ice melt, and to compare it to direct atmospheric deposition. Atmospherically-derived Hg, in this context, includes various forms of Hg deposited in snow from the atmosphere by wet and dry deposition, with or without particulate matter, but it does not include Hg glacially eroded from local bedrock sources that may be released, for e.g., in proglacial streams. Findings from the present study have immediate relevance for aquatic ecosystem health assessment in the Kusawa Lake region, but are also relevant to the broader issue of potential future Hg exports to the marine environment by the Yukon River, because seasonal snow and/or glacier meltwater contributions dominate the hydrology of most of its major tributary rivers (Brabets et al., 2004; Schuster et al., 2011).

2. STUDY AREA

Kusawa Lake (137 km^2, 7.72 km^3) lies at 670 m a.s.l. in the Yukon-Stikine Highlands ecoregion of Canada, 80 km west of Whitehorse, and 130 km from the Gulf of Alaska (Fig. 1). Much of the lake's ~4200 km^2 catchment lies within the Boundary Ranges, part of the Northern Coast Mountains, with peaks reaching up to 3000 m a.s.l. Kusawa Lake discharges into the Takhini River, which feeds the Yukon River. The catchment is mostly underlain by felsic to intermediate rocks of the Paleocene Ruby Range and

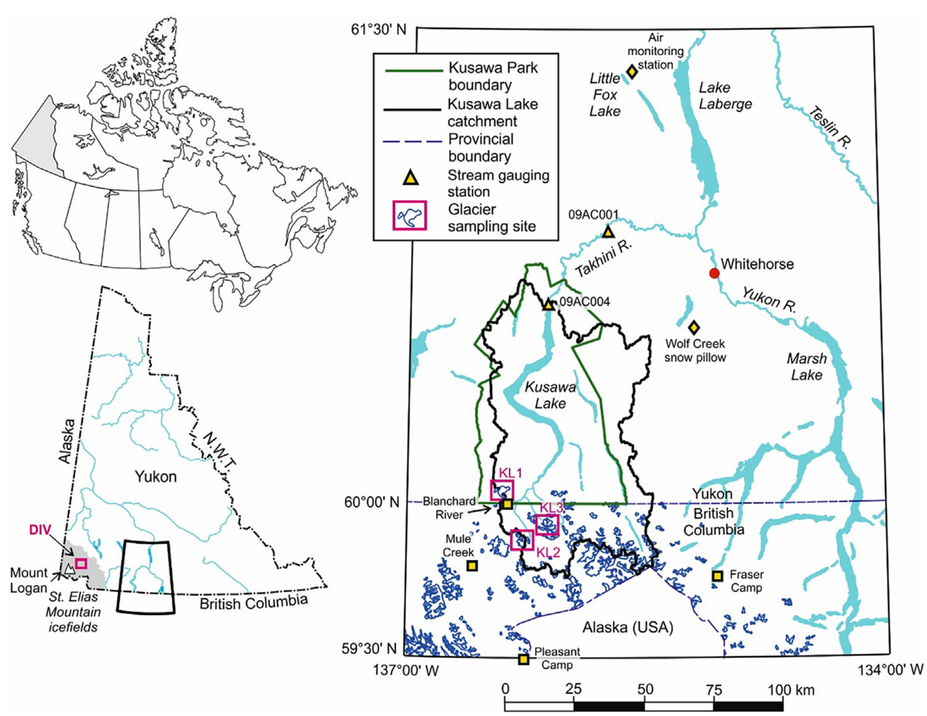

Fig. 1. Location map of the study area, northern British Columbia and southern Yukon, Canada. KL1, KL2 and KL3 are the snow sampling sites in the headwaters of the Kusawa Lake catchment, while DIV ("Divide") is the sampling site in the icefields of the central St. Mountains. Glacier outlines are from the Randolph Glacier Inventory, v. 5.0 (Arendt et al., 2009). Also shown are a stream gauging station (triangle), historical climate stations (squares) and other sites (diamonds) mentioned in the text.