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Isotopic and geochemical surveys of lakes in coastal B.C.: Insights into regional water balance and water quality controls

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ABSTRACT

Study region: This study was conducted within a 100,000 km^2 area of British Columbia, (B.C.) Canada including Vancouver Island, the Georgia Basin, and the Pacific and Kitimat mountain ranges rising from the Pacific Ocean.

Study focus: A stable isotope mass balance method is applied to estimate evaporation loss and water yield from a remote network of 560 lakes on Vancouver Island and coastal B.C., based on helicopter sampling surveys conducted between 2008 and 2015. Spatial patterns in derived hydrological parameters are compared to water quality indicators and watershed characteristics to provide insight into water quantity and water quality relationships in the region, to be incorporated within a future critical loads assessment.

New hydrological insights for the region: Regional trends in lake water balance, underlying physical drivers, and geochemical processes potentially influencing critical loads of acidity are described. Dominant non-anthropogenic regional drivers of geochemistry include sea spray, lithology, weathering and elevation. Significant contrast is noted in alkalinity between the sedimentary and volcanic substrates on Vancouver Island and igneous intrusive substrates of the Pacific and Kitimat ranges. A positive correlation is found between elevation and water yield to lakes, while the opposite is observed for rivers, which is interpreted to reflect disconnection of low elevation lakes from regional drainage networks. This may invalidate use of river gauge data for critical loads assessment in this or similar regions.

1. Introduction

Lakes are an important element of the landscape in coastal B.C. accounting for close to 10% of the land area, although relatively few studies have described the hydrology and water quality of these lakes. While a limited number of local studies have been conducted to characterize specific lakes and water supply reservoirs on southern Vancouver Island (Nowlin et al., 2004; Werner et al., 2015), and selected lake types such as proglacial lakes (Richards et al., 2012), fjord-type lakes (Petticrew et al., 2015) or sub-alpine lakes (Dunnington et al., 2016), no studies have previously investigated regional patterns in lake water balance parameters across the region. In fact, most hydrological interest in B.C. has been focused on the Okanagan valley due to water scarcity in this region (see Wassenaar et al., 2011). While many areas of coastal B.C. are still considered pristine and undeveloped, dominance of base-poor geologies with poor weathering capacity and potential for rapid growth in emissions due to expansion of shipping, industry and

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urbanization in the south coastal mainland, indicate that soils and lakes in some areas may be at risk of acidification (Mongeon et al., 2010).

Here, we report on a systematic survey of lakes in coastal B.C. designed to provide a regional assessment of critical loads of acidity to lakes as part of Canada's National Acid Rain Program. Acid sensitivity studies within the program have mainly focused on eastern Canada over the past several decades, largely owing to proximity to emissions from intensive industrial activity in eastern Canada and the United States. Only a few studies have been carried out recently in western Canada (Jeffries et al., 2010). In a national assessment preceding initiation of this study, Jeffries et al. (2005) concluded that the information available for evaluating the regional acidification status of lakes in many parts of western Canada was too old, too sparse or too unrepresentative to permit meaningful analysis, and new and representative surveys were recommended. As a result, new surveys were initiated in Alberta, Saskatchewan and Manitoba see Gibson et al. (2010a,b), Jeffries et al. (2010)). An additional study was initiated in coastal B.C., an area potentially sensitive to local, marine and transboundary acidifying emissions (Environment Canada and U.S. Environmental Protection Agency, 2014).

The purpose of this paper is to provide an introduction to the B.C. survey results describing some of the major regional hydrologic patterns across the region and their relation to climatic and physical characteristics of the selected lakes and watersheds, and the lake water geochemistry. The hydrologic assessment applies an isotope mass balance approach relying on measurement of the stable isotopes of water, $\delta^{18}O$ and $\delta^{2}H$, in lakewater, which has been previously tested across other regions of Canada and the US. (Gibson et al., 2010a,b; Gibson et al., 2017; Brooks et al., 2014). The stable isotopes, which are contained within the water molecule, are used to estimate water yield to the lakes based on a steady-state isotope mass balance model (Gibson et al., 2015a), and provide a new perspective of hydrologic variability of a large number of lakes and contributing watersheds that have not previously been studied in detail. In addition, this study provides an initial evaluation of the main drivers of water chemistry of the lakes including physical characteristics of the watersheds and water balance parameters. This analysis will underpin an assessment of critical loads of acidity for lakes in the region using the Henriksen et al. (2002) model and isotope-based estimates of water yield.

1.1. Study area

The study area lies in coastal B.C. between 48°N and 58°N and 124°W and 138°W, including Vancouver Island and coastal regions of B.C. between the Alaska State border to the north and the Washington State border to the south. 560 lakes were sampled in total (Fig. 1), ranging in size from less than 0.1–124 km^2, situated at elevations ranging from 18 to 2003 m above sea level (m.a.s.l.) The watersheds of the study lakes ranged in size up to 1534 km^2, averaging 15 km^2.

The study area occurs predominantly on the windward (westward) slopes of the coastal mountains, and has a cool mesothermal climate with cool summers and mild winters (Pojar et al., 1991a). Mean annual temperature ranges from 0.5 to 14 °C, averaging 9.1 °C as interpolated from the gridded North American Regional Reanalysis (Mesinger et al., 2006). Precipitation has strong inland and northward gradients, ranging from 600 mm in areas of the Georgia Basin with significant rainshadow effects to 3400 mm in the

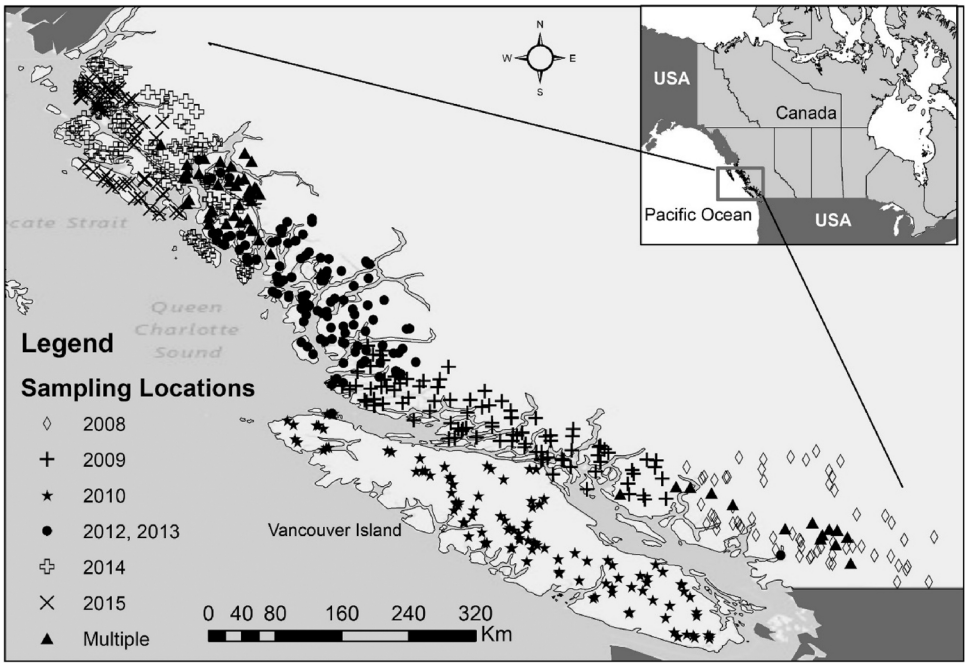

Fig. 1. Map of coastal B.C. showing lakes sampled in this study, as differentiated by year of first sampling. Lakes sampled multiple times are also identified.