Characterizing Hydro-Limnological Relationships in the Shallow Thermokarst Lakes of the Old Crow Flats, Yukon Territory

by Ann M. Balasubramaniam

INTRODUCTION

THE VULNERABILITY OF ARCTIC WETLANDS to a changing climate is an increasing concern of northern Aboriginal communities, parks managers, and conservation authorities because these lake-rich areas provide food and habitat for a myriad of wildlife populations. For more than a decade, researchers have recognized that both the hydrology and the ecology of lakes and ponds within regions of permafrost will be altered significantly by climatic warming (Rouse et al., 1997). Shallow thermokarst lakes, formed in lowland regions by thawing of ice-rich permafrost, are particularly susceptible to hydro-climatic change because they lack sufficient storage and depend predominantly on seasonal input waters to offset evaporation (Woo and Guan, 2006). Annual precipitation is especially important in thermokarst lake water budgets because snowmelt in spring and rainfall in the ice-free season replenish water supplies and sustain lake water levels (Boike et al., 2008; Plug et al., 2008). In northwestern Canada, research in regions of continuous permafrost has shown that thermokarst lakes experience net water losses from evaporation in warm, dry years and net water gains in cool, wet years (Labrecque et al., 2009). Changes to either the timing and quantity of snowmelt or the frequency and amount of rainfall will likely cause major shifts in lake hydrology throughout the Arctic. It is also likely that such shifts in hydrology will initiate changes in lake water chemistry and biota. However, the specific relationships between hydrological processes and limnological characteristics in Arctic freshwaters are generally underinvestigated and remain poorly understood. Integrated hydro-ecological evaluations of thermokarst lake responses to seasonal variations in hydrology (i.e., snowmelt, rainfall, and evaporation) are needed in order to better understand the overall effects of a changing hydrology on Arctic freshwater ecosystems. This knowledge will help park managers, Aboriginal governments, and conservation authorities develop the predictive capacity to anticipate and monitor future climate-driven changes in Arctic wetlands.

The primary objective of my research is to investigate linkages among climate, hydrology, and limnology in thermokarst lakes of Old Crow Flats, a dynamic lake-rich landscape in northern Yukon Territory designated by the Ramsar Convention as a Wetland of International Importance (Fig. 1). Old Crow Flats is the traditional territory of the Vuntut Gwitchin First Nation (VGFN) and is one of northwestern Canada's largest wetlands within a region of continuous permafrost. Over the past few decades, the Vuntut Gwitchin have witnessed unprecedented changes in

FIG. 1. Aerial photo of thermokarst lakes in the Old Crow Flats, Yukon Territory. Photo by Ann Balasubramaniam.

hydrology within Old Crow Flats, which they feel threaten their traditional livelihoods. They report that shifts in water levels associated with draining and drying lakes have greatly reduced the overall accessibility to their traditional territory. They also fear that a changing wetland hydrology will negatively affect lake water quality and associated wildlife habitat. In order to characterize the hydrological variation in the ecosystem, Turner et al. (2010, 2012) used water isotope tracers to assess lake water balances within the region. They found distinct spatial, seasonal, and interannual patterns in the hydrology of the landscape. Analysis of input water composition suggested that snowmelt and rainfall were the dominant inputs responsible for maintaining positive water balances in the majority of the studied lakes (Turner et al., 2010). Lakes dominated by snowmelt source waters were spatially correlated with boreal-taiga catchment vegetation that entraps winter snowfall. In contrast, lakes dominated by rainfall source waters were spatially correlated with open tundra. Additionally, it was found that all lakes experienced seasonal evaporative drawdown and that the amount of evaporation was intensified in warm, dry years (Turner et al., 2012).

My research aims to assess the effect of varying hydrology on lake water chemistry and biota using the information gained from water isotope tracers as reported in Turner et al. (2010, 2012). Specifically, I am evaluating the response of various water chemistry variables and algal communities to different sources of input waters (i.e., snowmelt and rainfall), as well as evaporation over seasonal and interannual timescales, to answer the following questions: 1) Do physical and chemical conditions differ predictably between

lakes that receive water input mainly from snowmelt and lakes fed mainly by rainfall? 2) If there are limnological differences between snowmelt input lakes and rainfall input lakes, do these trends persist throughout the ice-free season and between years? 3) What are the limnological effects of evaporation and do they equally affect lakes with different source waters? 4) Which physical and chemical variables within lake basins, if any, are most affected by hydrological processes? Answering these questions will elucidate key relationships between hydrology and limnology in thermokarst lakes of Old Crow Flats.

The secondary objective of my research is to develop innovative tools that can efficiently and systematically measure the limnological responses of thermokarst lakes to hydrologic stressors over time. Traditional limnological sampling methods, which require multiple trips to lake sites, can be a resource-intensive undertaking in Arctic wetlands, where the majority of thermokarst lakes are not easily accessible and researchers often require helicopter transport. Consequently, continuous records of historical lake conditions for the majority of these shallow lake ecosystems do not exist. However, understanding how lake water chemistry and biota have responded and continue to respond to hydroclimatic drivers is crucial to understanding the extent of change occurring in these lakes because of climate forcing. Diatoms, unicellular siliceous algae, are increasingly used as biological indicators of site-related water quality because of their rapid response to changes in pH, nutrients, and ionic concentrations (Hall and Smol, 1996; Douglas and Smol, 1999; Fritz et al., 1999). An analysis of a single sample of diatoms effectively captures useful information about the environmental conditions and status of the lake because the community composition represents the integrated sum of lake conditions that have occurred during the organisms' growth period. By studying the relationships between lake hydrology, water chemistry, and the composition of diatom communities, I aim to establish innovative methods to assess changes in the ecological integrity of the shallow thermokarst lakes in the Old Crow Flats. Specifically, I will identify linkages between diatom taxa and hydro-limnological characteristics by answering the following questions: 1) Does the composition of diatom communities in recently deposited surface sediments vary significantly among thermokarst lakes? 2) How much of this variation can be explained by differences in lake hydrology and water chemistry? 3) Which taxa, if any, are most highly associated with snowmelt-sourced, rainfall-sourced, and evaporation-dominated lakes? This knowledge will be useful in creating new approaches for ecological monitoring that can be used by future researchers who wish to track limnological responses to hydro-climatic drivers.

METHODS

A set of 58 lakes spanning broad hydrological gradients were sampled three times during the ice-free seasons

FIG. 2. Ann (left) collecting water samples with Robert Kyikavichik of the Vuntut Gwitchin Government's Natural Resource Department at Mary Netro Lake. Photo by Brandon Kyikavichik.

of 2007–09 to assess seasonal and interannual relationships between water chemistry conditions and the hydrological processes of snowmelt, rainfall, and evaporation. These lakes were selected in collaboration with the Vuntut Gwitchin First Nation and Parks Canada in order to include lakes within specific management areas (Fig. 2). Water was collected 5–10 cm below the lake surface and was analyzed for nutrients (TP, TDP, TN, NH_3, DOC, DIC, and SiO_2), major ions (Ca^{2+}, Mg^{2+}, K^+, Na^+, Cl^-, SO_4^{2-}), pH, and alkalinity, as well as for biomass of phytoplankton (Chl-a). Water chemistry analysis was conducted at Environment Canada's National Laboratory for Environmental Testing in Burlington, Ontario, using methods outlined in Environment Canada (1996). Phytoplankton samples were filtered onto a 0.7 μm GF/F filter and frozen for later extraction of chl-a, which was done using a 90% acetone aqueous solution over a period of 18 to 20 hours. Chl-a concentrations were determined using a Turner Designs 10 AU florometer. In September 2008, surface sediments (0–1 cm) of each lake were collected using a mini-Glew gravity corer (Glew, 1991). Samples were stored in Whirl-pak® bags at 4°C until acid digestion was initiated using a mixture of H_2SO_4/HNO_3 (1:1 by volume) at 85°C for 5 h (Fig. 3). Samples were left to settle and then washed until neutralized. The cleaned diatom slurries were dried onto microscope coverslips and mounted onto slides using standard methods outlined in Sokal et al. (2008). For each sample, at least 400 valves were enumerated and identified to the lowest taxonomic level possible, following Krammer and Lange-Bertalot (1986–91). Results were analyzed using hydrological groupings that were based on modeled water isotope data reported in Turner et al. (2010). Principal components analysis and non-parametric data analysis were used to identify and test significance of trends between hydrological processes and measured limnological variables. Multivariate analyses (i.e., ANOSIM and SIMPER) will be used

FIG. 3. Ann holding a sample of surface sediments taken using a gravity corer. Photo by Roland Hall.

to determine whether the composition of diatom communities differs among the three hydrological lake categories and to identify taxa that best discriminate between the hydro-limnological categories.

PRELIMINARY RESULTS

Results suggest that hydrological processes, specifically snowmelt and rainfall, play a significant role in thaw-lake water chemistry and distribution of diatoms. Analysis of seasonal water chemistry data from the years 2007–09 revealed that assigned hydrological categories consistently and accurately described the majority of seasonal and inter-annual variation of limnological parameters. Therefore, much of the seasonal variation in water chemistry of shallow thermokarst lakes is caused by variation in input water sources. Lakes that receive a greater portion of input water from snowmelt are characterized by significantly higher concentrations of dissolved phosphorus, silica, and dissolved organic carbon. In contrast, lakes that receive a greater input of rainfall tended to have lower concentrations of nutrients, higher pH, and substantially higher concentrations of major ions. A third intermediate category of lakes, which seasonally transition in dominance from snowmelt to rainfall, also had distinct limnological characteristics with measured values that fall between those of snowmelt- and rainfall-dominated lakes. The effect of evaporation was confounded by its correlation to rainfall-dominated lakes; however, evaporative concentration of nutrients and ions was evident during warm, dry years. Overall, these data highlight the influence of hydrology on water chemistry throughout the ice-free season. Snowmelt water is an important source of nutrient delivery to thermokarst lakes, and its influence lasts throughout the ice-free season. Preliminary results from diatom analysis indicate substantial differences in community structure between lakes and among hydrological categories. However, future numerical analyses are required to elucidate the significance of these differences and identify indicator taxa for each hydro-limnological category.

Relevance of Research

Results of my research are intended to fill an important knowledge gap that exists in Arctic freshwater science while providing new baseline data and a useful tool for future researchers and monitoring agencies. My results provide the basis for predicting limnological responses to ongoing changes in hydro-climatic conditions in the Old Crow Flats. For instance, a decrease in winter snowfall will not only decrease spring meltwater inputs to lakes, but also reduce nutrient delivery to lakes and potentially affect the structure and function of algal communities. As algae are the foundation of the food web, such shifts would likely affect populations of fish and wildlife that use the lake for food and habitat. These data will be important for ongoing studies and future monitoring programs that aim to understand limnological responses to hydrological changes. Knowledge gained from this study has already enabled the development and testing of new bio-monitoring protocols, which are being implemented in partnership with Parks Canada.

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Ann Balasubramaniam is the 2012 recipient of the Lorraine Allison Scholarship. She is currently a doctoral candidate in the Department of Biology, University of Waterloo.
E-mail: annbala@gmail.com.