# Assessing relations among multiple environmental gradients for shallow lakes in Old Crow Flats, Yukon, using hydrological, limnological and community-collaborative research approaches

by

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The following served on the Examining Committee for this thesis. The decision of the Examining Committee is by majority vote.

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# *Author's Declaration*

This thesis consists of material all of which I authored or co-authored: see Statement of Contributions included in the thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.I understand that my thesis will be made electronically available to the public.

## *Statement of Contributions:*

Chapter 1: General Introduction

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Chapter 2: Source water inputs and catchment characteristics regulate limnological conditions of shallow subarctic lakes (Old Crow Flats, Yukon, Canada).

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Laboratory Analysis: A.M. Balasubramaniam generated T.S.S. and Chl-a data and worked with X. Wang to organize water chemistry analyses submitted to NLET (Environment Canada's National Laboratory for Environmental Testing; Burlington ON).

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Chapter 4: Community-based research, youth outdoor education and other highlights of a northern research internship experience in Old Crow, Yukon Territory.

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# *Abstract*

Shallow freshwater ecosystems are undergoing marked hydrological changes associated with a warming Arctic, which causes concern for remote northern communities that access these regions to maintain their traditional lifestyles. Variation in precipitation patterns (snow and rain), due to changing climate conditions has been found to strongly influence lake water balances. However, knowledge of how such changes in precipitation affect limnology and biotic community structure within lakes is lacking. Working collaboratively with the Vuntut Gwitchin First Nation (VGFN), this thesis examines the influence of hydrology on the limnology of shallow lakes in the Old Crow Flats, Yukon. Relations among source-water composition (snow vs. rain), catchment characteristics, limnology, and sediment properties are assessed and their influence on benthic biota are quantified.

Results from 56 lakes, sampled during the early, mid-, and late ice-free season of 2007, identify that catchment mediated differences in source waters (snowmelt-dominated, intermediate and rainfall –dominated) are associated with different limnological characteristics and divergent seasonal trajectories. Snowmelt-dominated lakes, which occur in catchments with tall shrubs and trees, have significantly higher concentrations of dissolved phosphorus and organic carbon, relative to the other categories. These lakes exhibit the least amount of seasonal variation in water chemistry variables. In contrast, rainfall-dominated lakes, which are located in catchments with dwarf shrub and sparse vegetation, have significantly higher concentrations of major ions and higher pH. The rainfall-dominated lakes experience the greatest amount of seasonal variation in water chemistry and tend to be more similar to intermediate lakes in mid- and late-season. Interestingly, seasonal analysis of intermediate lakes highlights sensitivity of these lakes to transitioning sources of input water. As the ice-free season progresses, the water chemistry of intermediate lakes changes from resembling snowmelt-dominated to that of rainfall-dominated lakes. The strength of these catchment-mediated hydro-limnological associations is demonstrated by their persistence among years (2007- 2009).

Analyses of diatom and chironomid assemblages within surface sediments of a subset of ~49 lakes identifies a cascading influence of input-water sources, on limnology and sediment properties, as mediated by catchment characteristics to affect compositions via direct and indirect pathways. Notably, variance partitioning analyses (VPA) of diatom and chironomid assemblages, identify a substantial amount of shared variation among limnology, sediment properties and catchment characteristics. Given that hydrological processes are the main mechanisms that link catchment characteristics with limnological conditions and sediment properties of lakes, the shared variation is likely primarily attributable to variation in source-water inputs. VPA analyses for both diatoms and chironomids explained less than 50% of variation, which draws attention to the limitations of point-in-time measurements in describing dynamic processes regulating biotic communities. Thus, when describing biotic responses to environmental change within northern aquatic ecosystems, results presented here discourage linking variation in biota to direct effects of any single factor, and rather encourage use of multi-factor analyses that include hydrological processes.

As northern communities undergo unprecedented environmental changes associated with climatic and socio-economic stressors, there is an increased impetus for knowledge generation to be focused on community needs to guide policies and adaptation strategies. In response, natural science research in Canada’s North is shifting towards a framework that is collaborative, interdisciplinary and reflective of Northern people’s priorities. The final sections of this thesis explore effective methods for early career researchers (ECRs) to use when engaging in community-collaborative research. A NSERC Northern Research internship, which allowed for an extended stay in the community of Old Crow, is highlighted as it enabled a partnership to be established with the Vuntut Gwitchin Government's Natural Resource Department (NRD). The discussions among ECRs regarding methods for developing true partnerships with northern communities, which occurred at the 2012 IPY conference, are also highlighted and analyzed. The prevailing themes - dedicating time, being present, communicating in plain-language, listening, respecting and understanding local customs as well as building trust for collaborative efforts and knowledge exchange with communities- are presented along with a list of resources and recommendations to assist ECRs interested in undertaking collaborative research methodology that goes beyond the standard permitting process.

Ultimately, by integrating hydrological, limnological, and community-collaborative research approaches, the results presented here improves understanding of the complex ways in which shallow lakes may respond to future hydro-climatic changes, and provides key insights and recommendations to natural scientists interested in pursuing community-based research in Canada's North.

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## *Dedication*

This thesis is dedicated to my father, Kandavanam Balasubramaniam, and my mother, Saraswathy Balasubramaniam. My father's passion for, and knowledge of, biological sciences captured my interest from a young age, and it was his support that led me to pursue a doctorate degree. My mother's unwavering confidence in me and her lessons in achieving a work-life balance continue to guide me today.

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# *Chapter 1. General Introduction*

## *1.1. Outline*

Freshwater features are an important component of Arctic and sub-arctic regions. The numerous lakes, ponds, streams, rivers and wetlands are estimated to cover over 16% of the northern permafrost landmass (Vonk et al. 2015). Despite arid conditions, freshwater ecosystems are typically abundant in Arctic and subarctic landscapes because of cool air temperatures and presence of a permafrost barrier that impedes vertical drainage (Woo 2012). Shallow lakes and ponds are particularly prolific in lowland regions and occupy 15% -50% of Canadian western Arctic, Alaska and Siberia (Mackay 1992; Zimov et al. 1997; Burn 2002; Frohn et al. 2005; Grosse et al. 2013). Most lowland shallow lakes are thermokarst in origin and initiate when there is a disruption of a thermal equilibrium of ground ice within permafrost that causes thaw and subsidence (Burn 1992; van Everdingen 1998). These thaw lakes are "hot-spots" of biological activity and provide essential food and habitat to resident and migrating populations of fish and wildlife, which are a key component of northern inland community diets.

In recent decades, an increasing amount of evidence suggests that aquatic ecosystems across the north are undergoing pronounced hydrological change triggered by warming air temperatures (Smol and Douglas 2007; Rawlins et al. 2010; CliC/AMAP/IASC 2016). In the absence of long-term hydrological monitoring data, assessments of temporal variation in the hydrology of shallow lakes using remote sensing reveals divergent trends in lake areal extent in response to a warming climate (Christensen et al. 2004; Smith et al. 2005; Riordan et al. 2006; Labrecque et al. 2009; Corcoran et al. 2009; Carroll et al. 2011; Jones et al. 2011; Chen et al.

2014).While some studies stress that warming and resulting increase of evaporation are causing widespread lake area decrease (Riordan et al. 2006; Corcoran et al. 2009), others find warming air temperatures to prompt permafrost disturbances leading to either increased areal extent of lakes and wetlands (Christensen et al. 2004), or compromised integrity of lake basin and subsequent drainage (Yoshikawa and Hinzman 2003; Jones et al. 2011). The lack of uniformity in lake area change within regions suggests that drivers other than atmospheric temperature are asserting influence on northern lake hydrology. Studies have reported precipitation (Plug et al. 2008; Lebrecque et al. 2009; Tarasenko 2013), evaporation (Riordan et al. 2006; Smol and Douglas 2007; Labrecque et al. 2009), lake drainage (Yokishawa and Hinzman 2003; Marsh et al. 2009), terrestrialization (Roach et al. 2011), ice jam flooding (Chen *et al.* 2014), and variation in permafrost characteristics (Karlsson et al. 2012) ro be triggering hydrological change among northern lakes. While it is likely that several of these mechanisms assert influence on lake area, in-depth assessments of seasonal lake hydrology highlight the important role of precipitation (i.e., snowmelt and rainfall) in regulation of lake water balances (Woo and Guan 2006, Turner et al. 2010; Bouchard et al. 2013). Snowmelt triggers widespread hydrological connectivity in the early ice-free season and recharges lake water deficits caused by the previous season's evaporative losses (Rovansek et al. 1996; Boike et al., 2008). In northern regions, snowmelt source waters are essential for maintaining positive lake water balances (Bouchard et al. 2013b). Unlike snowmelt, which occurs after months of snow accumulation that can be augmented by dense snow entrapping catchment vegetation (Pomeroy et al. 2006), the delivery of rain to lakes is more direct. Rainfall directly affects lake water balances when lakes possess larger surface area to depth ratios and act as efficient sinks (Turner et al. 2010), or when rain events of adequate intensity occur and initiate surface flow to lakes by offsetting evaporative deficits in soil moisture content (Koch 2016; Woo 2012).While the role of rainfall and snowmelt, as mediated by catchment characteristics, in the regulation of shallow lake water-balances has been investigated (Rovansek et al. 1996; Turner et al. 2010; 2014; Bouchard et al. 2013b), the concomitant influence of these inputs on chemical and biological lake conditions is currently understudied. Given that precipitation patterns are changing in northern regions (Zhang et al.2000; Trenberth 2011), it will be useful to evaluate how differences in input water sources influence limnological conditions and biota of shallow lakes. This knowledge is essential to understanding northern lake responses to hydro-climatic drivers, and will enable a better comprehension of the cumulative effects of regional warming on freshwater ecosystems in continuous permafrost regions. Moreover, as freshwater bodies have been described as the grocery store, bank and church of northern indigenous communities (Frost 2007), providing food-security, economic resources, and lands to maintain spiritual and cultural practices, quantification of changes in lake ecosystems can provide key information to northern decision makers as they face the challenges of environmental change.

### *1.2. Chemistry of snow and rain in northern regions*

Snowmelt and rainfall, the main source-waters refilling shallow lake basins, can differ in their chemical composition (Treloar 1993) and thus, have the potential to affect shallow lake water chemistry.During nucleation, snow incorporates ions from aerosols and gases (Pomeroy et al. 1993). Percipitated snow can continue to increase in ion concentrations due to a combination of direct atmospheric deposition of aerosols onto snowpack and the further concentration of ions in snowpack via sublimation of windblown snow (Pomeroy et al. 1993; Woo et al. 2000). Notably, during snowmelt, the chemical composition of snow can be further altered via interaction with the active-layer and contact with organic and mineral soils (Quinton and  Pomeroy 2006; Woo et al. 2000). Similar to snow, rainwater inputs can also bring in marine salts or industrial pollutants via incorporation of atmospheric aerosols and gases

(Krawczyket al. 2008). However, as timing of peak aerosol levels vary between spring, summer, and winter, the chemistry of rain can be quite different from snow (Barrie 1995). Additionally, rainwater runoff can bring in catchment-sourced ions and nutrients in regions with a hydraulic gradient, (Quinton & Pomeroy 2006) and the chemical composition of these allochthonous inputs can differ from those of snowmelt due to increases in active layer thaw depths. While there is broad recognition of the influence of hydrological inputs on lake water chemistry, quantification of these hydrolimnological relations reamins lacking.

### *1.3. Limnology of shallow lakes in northern Canada*

The majority of limnological assessments conducted on shallow subarctic lakes are done over large spatial, ecozonal and sometimes climatic gradients (Pienitz et al. 1997; Duff et al. 1999; Gregory-Eaves et al. 2000), which limits the ability to delineate the influence of any one driver. Generally, such regional studies associate variation in concentrations of dissolved organic carbon (DOC) and nutrients (TP, TN) to catchment vegetation (e.g., Pienitz et al. 1997; Duff et al.1999; Gregory-Eaves et al. 2000), whereas variations in ion concentrations are largely attributed to catchment geology and proximity of study lakes to oceans (Pienitz et al. 1997; Duff et al.1999). While hydrology is broadly recognized for its role as a conduit for allochthonous inputs to lakes in these studies, the seasonality and relative importance of input water source has not been addressed. Additionally, because most northern limnological studies typically collect a single water sample near mid-summer, when lakes can be relatively closed to lateral flow after the snowmelt period (Woo and Guan 2006), the influence of snowmelt inputs on lake water chemistry may be underappreciated. Instead, repeated sampling over the course of the ice-free season may more effectively assess the influence of different input water sources on water chemistry. Indeed, because water chemistry is deterministic for organisms at the base of lake food-webs, a stronger knowledge ofhow hydrological processes, as mediated by catchment characteristics, affect the chemical composition of nutrients and ions is vital to understanding the potential for bottom-up changes to lake ecology.

### *1.4. The Old Crow Flats: geography, geology and climate*

The Old Crow Flats (OCF) [68.1°N, 139.7°W], located 175 km north of the Arctic Circle, is a wetland spanning 5,600 $km^2$ and is an internationally recognized wetland under the 1982 Ramsar Convention.This low lying area (<600 m a.s.l.) is in the taiga cordillera and transitions from boreal spruce forest in the south-western region to arctic tundra in the north-eastern regions. It is estimated that there are more than 2,700 shallow thermokarst lakes and ponds embedded in a region of continuous permafrost (Yukon Ecoregions Working Group 2004). The permafrost is visibly ice-rich and numerous ice-wedge polygons, thermokarst lakes, active layer detachment slides and river bank thaw slumps can be seen. The average permafrost depth in Old Crow Flats is unknown but based on depths taken in the town of Old Crow and the Yukon Coastal Plain, respectively, could be between 63 m and 240 m (EBA Engineering Consultants Ltd. 1982 and Yukon Ecoregions Working Group 2004). The depth of the seasonally thawing active layer is likely to vary due to factors such as insulating vegetation, water saturation and proximity to lakes (Bursey et. al. 1990), but can be estimated to be between 40-60 cm deep (Ovenden and Brassard 1989).

The geomorphology of OCF is largely attributed to the region's unique glacial history. During the last glacial period, the eastward flowing Paleo-Porcupine River was blocked by the Laurentide Ice Sheet at the east flank of the Richardson Mountain range, which caused the region to flood and form glacial Lake Old Crow (Hughes 1972). Subsequently, the glacial lake drained westward at approximately 15,000 yr B.P., establishing the new flow path of the Porcupine River and incising flow channels that are the present day rivers (Hughes 1972;

Zazula et al. 2004). Although the majority of glacial lake water was likely lost in a rapid drainage event, macrofossil analysis from a peat core suggests a hydrosere, in which remaining remnant shallow waters dominated by aquatic species gradually drained or dried over the next 5,000 years and were replaced by *Sphagnum*-dominated wetlands (Ovenden 1982). The onset of present-day permafrost terrain is estimated to have occurred after the lake drained around 9,600 yr B.P. due to shifts in vegetation (Ovenden 1982).The initial thermokarst lake likely formed between 11,290 and 6,730 yrs BP, a period inferred to be warm and wet, that had a dominance of species that are similar in composition to contemporary boreal-tundra species (Lauriol 2010; Viau et al. 2008).

The NW/SE orientation of OCF lakes is likely driven by shoreline erosion caused by wave action initiated by prevailing winds from the northeast (Livingstone 1954; Mackay 1956; Roy-Léveillée and Burn 2010). The sediments at the lake bottom are composed of unconsolidated glaciolacustrine clays, alluvial sediments, silt and sand, and can have deposits of peat or organic rich detritus above (Hughes 1972; Ovenden 1982). Most of the present-day lakes in OCF are thermokarst lakes, formed due to thawing of ground ice, which tend to be shallow, flat-bottomed, quadrangular lakes (Allenby 1989). Due to the high thermal capacity of water, the majority of the lakes that have depths exceeding maximum ice thickness are likely underlain by unfrozen mud, known as taliks (Livingstone 1954; Mackay 1997; Yoshikawa and Hinzman 2003). However, in OCF, taliks have been reported to exist even in the shallowest of conditions where lakes freeze to bottom (Roy-Léveillée and Burn 2017). Smaller subsets of OCF lakes are oxbows, which are found adjacent to rivers, and do not have NW-SE orientation. Oxbow lakes tend to be curvilinear in shape, are surrounded by slight shoreline relief and have a deeper average depth and a differing bathymetry to those of thermokarst lakes. Visual observation suggests that the majority of the lakes in OCF are connected by ephemeral creeks and fens that are prevalent during the early ice-free seasons. Lakes close to mountain ranges seem to be hydrologically connected for a longer period of time.

Ice break-up occurs between late-May and late-June, and varies in timing across OCF (Gledsetzer et al. 2010). Freeze-up occurs mid- to late-September (Parks Canada unpublished data). During most of the ice-off season, lakes are exposed to 24-hour sunlight. Average annual air temperature (1971 -2000 climate normal) is -9 °C +/- 6.1°C, and peak average monthly air temperature occurs in July (14.6 °C +/- 1.4 °C), as reported by the meteorological station in Old Crow (Environment Canada 2007). Annual average precipitation is reported to be 265.5 mm, of which 53% is rainfall (Environment Canada 2007). The total precipitation amount is comparable to desert regions in North Africa (e.g. Sudan = 250 mm, World Bank 2015).

### *1.5. The need for community collaborative research in Arctic science*

As Arctic communities and governing institutions face a number of social, environmental, economic and political pressures, the demand for research and knowledge intensifies. The need for natural science research is particularly acute given the influence of changing climate and warming temperatures on northern ecosystems and wildlife, and the potential for adverse effects on northern diets (Ford and Smit 2004; Wenzel 2009). Additionally, because indigenous communities have both the mandate and legal authority to manage their lands, due to self-government and the land-claims process, there is increased need for scientific information at a local level. As a result, northern communities, governing organizations, and federal funders increasingly encourage research to be conducted in partnership with northerners to allow local organizations and decision makers to benefit from the process (Graham and Fortier 2005; Inuit Tapiriit Kanatami and Nunavut Research Institute 2007; Polar Knowledge Canada 2017; Government of Northwest Territories 2017). Indeed, in consideration of the complicated history of northern indigenous communities and scientists, consultation, inclusion of local perspectives in the research process, and dissemination of research findings is not only a part of an evolving research paradigm but is also be seen as an ethical responsibility (Castellano 2004).

Despite the clear incentive for a new collaborative northern research model, there is little evidence to support a widespread adoption of these techniques in Arctic natural science research (Brunet et al. 2014).While a number of authors describe successful engagement with local stakeholders to both improve research approaches and interpretation of science results (Hinkel et al. 2007; Eisner et al. 2009; Kokelj et al. 2012), others have experienced obstacles that inhibited community partnerships due to researchers' inability to meet community needs and a resultant lack of trust (Gearheard and Shirley 2007). As natural scientists are not often trained in participatory methods, collaborative research can be difficult to undertake in light of rigorous field schedules, fiscal restraints, and tight timelines (Gearheard and Shirley 2007). For many natural scientists methodological innovation will be necessary for incorporating community collaborative techniques into research projects (Brunet et al. 2014; Gearheard and Shirley 2007). Researchers will need to find time to foster personal relationships to build a foundation of trust (Gearheard and Shirley 2007) as this will improve working relationships in communities. Further discourse regarding effective methodology for community collaborative research is needed to continue to modernize northern science approaches so that critically-needed knowledge can be provided while respecting community needs and cultural differences.

## *1.6. Thesis overview:*

This thesis is part of a larger multi-disciplinary study intiated during the 2007 International Polar Year entitled: *Yeendoo Nanh Nakhweenjit K'atr'ahanahtyaa* (YNNK): Environmental

Change and Traditional Use of the Old Crow Flats in Northern Canada. The YNNK, led by the Vuntut Gwitchin Government, focuses on using a wide range of scientific methods to quantify complex climate-driven changes observed on the landscape by the VGFN. A major concern for the Vuntut Gwithin, which translates to "people of the lakes," is the state of the freshwater ecosystems within their traditional territory. Several members of the community reported rapidly changing hydrological conditions and some were concerned about the reciprocal effects on lake water quality and biota. Using an integrated hydrolimnological approach, the primary objective of this thesis is to present new data and insight into the influence of hydrology on water chemistry and the distribution and abundance of benthic aquatic biota (e.g. diatoms and chironomids) in shallow lakes in OCF.

In Chapter 2, information gained from water isotope tracers reported in Turner et al. (2010), which identifed input waters composition to strongly regulate lake water balances, was used to create hydrological categories (snowmelt-, intermideiate and rainfall-dominated lakes) to assess the physical and chemical properties of 56 study lakes during the ice-free season of 2007. Main aims were to: 1) test whether water chemistry differs among lakes receiving differing relative amounts of input waters (rainfall vs. snowmelt); 2) identify relations among hydrological categories, catchments characteristics, and lake water chemistry; and, 3) assess if seasonal patterns of variation in lake water chemistry differ among hydrological categories.

In Chapter 3, the influence of hydrology on aquatic biota is investigated using a set of multivariate techniques that assess the relations among hydrology, catchment characteristics, limnology, and sediment properties on composition of diatom and chironomid assemblages within surface sediments of study lakes. Specifically, building upon prior hydrological (Turner et al. 2010; 2014) and limnological (Chapter 2; published as Balasubramaniam et al. 2015) studies, variation in benthic communities is assessed using catchment land-cover classification, lake-water isotope and chemistry data, and surface sediment properties obtained from 49 lakes in 2008. Aims were to: 1) test if lakes receiving differing relative proportions of snowmelt versus rainfall inputs have distinct diatom and chironomid assemblages in surficial sediments; 2) determine relations between assemblage composition and limnological variables, sediment properties, and catchment characteristics; and, 3) quantify the amount of unique and shared variation in assemblage composition explained by measured environmental variables.

The YNNK project, developed in close consultation with the VGFN, was designed to provide researchers with the opportunity to embrace collaborative research techniques and honour the spirit of the evolving northern research paradigm. This new paradigm calls upon researchers to advance northern scholarship while addressing the needs of local communities, building capacity, and informing local decision makers (Ford and Smit, 2004). Adopting a collaborative model may be appealing to some researchers, however, training, mentorship and institutional knowledge regarding collaborative research methods within natural sciences is limited. Thus, developing new techniques or altering existing methodology to effectively engage community members in research can be challenging. For northern limnologists who perform large spatial surveys within tight timelines, and conduct lab work that is highly technical in nature, the opportunity to collaborate with communities is not obvious. Indeed, even results of analysis can be difficult to portray to community members in an engaging format. However, Brunet et al. (2014) asserts that collaborative methods require a level of innovation in to reduce the scientist-community divide. Thus, the secondary objective of this thesis was to develop methods to engage the community of Old Crow to leave a legacy of knowledge with the VGFN, a key mandate of the IPY project. Specifically, in Chapter 4, methods used to engage the community, while expanding this thesis research program in the summer of 2008 are presented. The narrative description provided in this chapter provides key insights on how the former NSERC Northern Research Internship program, which funded an extended stay in the North, was critical for building relationships with community organizations.

Chapter 5 builds on methods presented in Chapter 4, and reports on comments regarding techniques researchers employed to engage communities in collaborative research provided by 46 early career researchers from 28 different institutions in 10 countries. In this chapter, key themes for community engagement are established, resources for funding options and information to conduct community collaborative research are listed, and recommendations to early career researchers interested in engaging in community-based research are provided. This chapter, intended to provide early career researchers a guide to collaborative research techniques, is co-written with several early career researchers and was aimed at intiating discussion among natural science researchers about how best to engage northern communities.

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Laboratory Analysis: A.M. Balasubramaniam generated T.S.S. and Chl-*a* data and worked with X. Wang to organize water chemistry analyses submitted to NLET (Environment Canada’s National Laboratory for Environmental Testing; Burlington ON).

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# *Chapter 2. Source-water inputs and catchment characteristics regulate limnological conditions of shallow subarctic lakes (Old Crow Flats, Yukon, Canada)*

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## *2.1. Outline*

Climate variations exert rapid and strong control on the hydrology of shallow lake-rich subarctic landscapes, but knowledge of the associated effects on limnological conditions remains limited. Based on analysis of water isotope compositions and water chemistry at 56 lakes across Old Crow Flats (Yukon), a large thermokarst landscape, we assess if differences in source water inputs (snowmelt versus rainfall) affect limnological conditions during the ice-free season of 2007 and explore influences of catchment features. Results demonstrate that lakes with snowmelt-dominated source waters, situated in catchments that support tall shrub and woodland vegetation, possess significantly higher ($p < 0.05$) nutrient (N, P, $SiO_2$) and dissolved organic carbon concentrations than lakes with rainfall-dominated source waters. Conversely, rainfall-dominated lakes, located in catchments dominated by dwarf shrubs and sparse vegetation, have significantly higher concentrations of major ions ($Mg^{2+}$, $Na^{+}$, $SO_4^{2-}$) and pH. These limnological differences persisted throughout the ice-free season. We suggest that interaction of snowmelt with organic-rich detritus raises nutrient concentrations in snowmelt-dominated lakes and that evaporative-concentration, shoreline erosion and possibly rainfall runoff are processes that raise the ionic content of lakes with rainfall-dominated source waters. Knowledge of these relations improves the ability to anticipate limnological responses to ongoing and future climate and hydrological change in Arctic and subarctic regions.

## *2.2. Introduction*

Shallow lakes, a dominant feature in northern regions, are undergoing pronounced hydrological changes consistent with a rapidly warming Arctic (Smith et al. 2005; White et al. 2007; Marsh et al. 2009). Due to their small water volumes, these lakes are particularly responsive to meteorological variations and rely primarily on inputs of snowmelt (Bouchard et al. 2013b; Woo and Young 2014) and intense rainfall (Woo and Guan 2006) to maintain positive water balances. For example, remote sensing analyses of shallow thermokarst lakes, formed due to thawing of permafrost, identified widespread decline in lake levels caused by evaporation in warm-dry years, and mass water gain in cool-wet years (West and Plug 2008; Boike et al. 2008; Labrecque et al. 2009). Catchment characteristics also influence precipitation storage and runoff. Catchments with dense stands of trees and tall shrubs promote increased snowmelt inputs to lakes by trapping winter snowfall (Walker et al. 2003; Winkler et al. 2005; Pomeroy et al. 2006) and prolonging hydrological connectivity (Turner et al. 2014). In contrast, shallow lakes situated in sparsely vegetated low-relief terrain are especially vulnerable to desiccation when snowmelt runoff is low and hydrological connectivity is reduced (Bouchard et al. 2013b). In such low-land ecosystems, prolonged intense rainfall events were found to increase hydrological connectivity and recharge ponds (Woo and Guan 2006; Boike et al. 2008). Thus, climate-driven changes in precipitation, as well as catchment characteristics, are known to exert strong influence on the hydrology of shallow Arctic lakes (Prowse et al. 2011). However, an understanding of limnological responses to varying inputs of snowmelt and rainfall remain less clear for Arctic landscapes (Spence et al. 2015).

In Arctic and sub-arctic regions, variation in seasonality and magnitude of precipitation and associated runoff exert different influences on the chemistry of rivers (McNamara et al.

2008; Townsend- Small et al. 2011; Olefeldt et al. 2013). For example, research conducted at the Cape Bounty Arctic Watershed Observatory, Melville Island, has shown that differences in the timing and intensity of snowmelt and rainfall runoff are associated with distinct differences in river water chemistry (Lewis et al. 2011). Snowmelt runoff was found to deliver dissolved organic nutrients (C and N) to rivers because peak snowmelt occurred when the active layer was shallow and hydrologic connectivity was high, thus limiting infiltration (Lewis et al. 2011). Later in the summer, high-intensity rain events exceeded catchment soil-water deficits, penetrated the mineral horizon of the active-layer and flushed solutes into rivers, thus raising the concentration and altering the composition of dissolved ions in the river water (Dugan et al. 2009; Lewis et al. 2011). We hypothesize that differences in relative contributions of snowmelt and rainfall source waters, and their interaction with landscape features, also account for measureable differences in water chemistry of shallow Arctic lakes. Due to the longer residence times of lakes than rivers, it is likely that such water chemistry differences will be more profound in shallow lakes (Essington and Carpenter 2000). Indeed the influence of catchment hydrology on lake water chemistry may describe variation observed in shallow Arctic lakes that cannot be described by landscape vegetation alone (Umbanhowar et al. 2014).

Here, we assess the influence of variations in hydrological processes on spatial and seasonal patterns of limnological conditions of shallow, mainly thermokarst lakes in Old Crow Flats (OCF), Yukon Territory (Canada), and their association with catchment characteristics. This research was conducted in collaboration with the Vuntut Gwitchin First Nation to address their concerns regarding the effects of climate change on OCF landscape (Wolfe et al. 2011). We combined use of isotope-inferred classification of lakes into snowmelt-dominated and rainfall-dominated categories and quantitative characterization of catchment land-cover characteristics from Turner et al. (2010, 2014) with measurements of a suite of limnological variables to: 1) test whether water chemistry differs among lakes receiving differing sources of input waters during the ice-free season; 2) to identify relations among source water inputs, catchments characteristics and lake water chemistry; and, 3) assess if seasonal patterns of variation in lake water chemistry differ among hydrological categories. The study is based on limnological measurements obtained concurrently with hydrological investigations conducted by Turner et al. (2010). The study aims to improve our ability to anticipate responses of shallow Arctic lakes to ongoing and future climate variations and demonstrate the utility of landscape-scale, integrated hydrological and limnological assessments.

## *2.3. Materials and methods*

### *2.3.1. Study area*

Old Crow Flats is a large (5,600 km$^2$), lake-rich (~2,700 lakes), lowland (<600 m a.s.l.), wetland landscape rimmed by mountain ranges (Yukon Ecoregions Working Group 2004; Figure 2.1). OCF is recognized as a Ramsar Wetland of International Importance because it provides vital habitat to numerous migrating and resident wildlife and waterfowl, and it is the traditional territory of the Vuntut Gwitchin First Nation. It is located within a region of continuous permafrost and the active-layer depth is estimated to be 18-56 cm (Ovenden and Brassard 1989). The mainly flat unglaciated terrain is underlain by relatively uniform unconsolidated glaciolacustrine sediment, consisting of clay, silt, sand and gravel, and patches of intermixed alluvial sediments, covered by deposits of peat and organic detritus (Hughes 1972; Ovenden 1981). Thus, surficial geology is relatively consistent across the landscape and is not likely to be a major cause of limnological variation among lakes. However, there is one small outcrop of carboniferous shale in the north-central region called Timber Hill (Morell and Dietrich 1993), which could exert influence on water chemistry of lakes OCF 46 - 48. The Old

Crow, British, Barn and Richardson mountain ranges flank the southwest, west, north and east margins of OCF, respectively, (Hughes 1972) and runoff was observed to run downslope towards lakes along the periphery during spring water sampling trips. Ice-wedge polygons, active-layer detachment slides, and river-bank thaw-slumps occur in the northern and eastern portions of OCF. Thermokarst lakes dominate the landscape and tend to be shallow, flat-bottomed and quadrangular in shape (Allenby 1989). All thermokarst lakes are elevated above the incised streams and rivers, which ultimately flow southward to the Porcupine River. Oxbow lakes are also present, adjacent to rivers, and are generally deeper than thermokarst lakes.

Terrestrial vegetation cover varies across OCF and spans boreal-taiga forest to tundra. Using remote sensing data, a Landsat 5 TM mosaic land-cover map and oblique aerial photos of lake catchments and digital elevation models of 30-m resolution, Turner et al. (2014) quantified the percent cover of five land-cover classes for 56 lake catchments. The five land-cover classes include: 1) woodland / forest vegetation consisting of black spruce (*Picea mariana*), white spruce (*Picea glauca*) and birch trees (*Betula* spp.); 2) tall shrubs consisting predominantly of willows (*Salix* spp.); 3) dwarf shrub / herbaceous vegetation consisting of low shrub thickets (e.g., *Betula*, *Alnus* and *Salix* spp.*)*, ericaceous shrubs (e.g., *Vaccinium* and *Ledium species*) and vascular (e.g., *Eriophorum* spp.) and non-vascular plants (e.g., *Sphagnum* spp.); 4) sparse vegetation with abundant areas of exposed rock, sand patches and barrens; and, 5) surface water (lakes, rivers and wetlands). Turner et al. (2014) showed that lakes with snowmelt-dominated input water possess catchments covered mainly by woodland/forest and tall shrub vegetation (~60%), and are located mainly in southern and western portions of OCF. And, that catchments of the rainfall-dominated lakes are covered mainly by sparse vegetation, dwarf shrub/herbaceous, and surface water (≥65%), and are located mainly in central and eastern parts of OCF.

Ice break-up on lakes occurs between late-May and mid-June, and freeze-up occurs mid- to late-September. Lakes are exposed to 24-hour sunlight during most of the ice-free season. We compared meteorological data from 2007 with the 1971-2000 climate normal to assess how representative the year of sampling was of climatic and hydrological conditions (Figure 2.2). Average annual air temperature (1971-2000) is -9°C ± 6.1°C, as measured by the meteorological station in Old Crow (Station ID 2100200, Evironment Canada 2007). Monthly mean air temperatures during 2007 were similar to the climate normal, but were above average in June and July and below average in February and March (Figure 2.2). Annual average precipitation is 265.5 mm, with 53% as rainfall (Station ID 2100200, Environment Canada 2007). In 2007, the cumulative snowfall from January until May was 120 mm, which is greater than the 30-year climate normal of 104 mm (Station ID 2100200, Environment Canada, 2007; Figure 2.2). Cumulative rainfall from May to September (90.1 mm) was well below the climate normal (141.8 mm).

### *2.3.2. Hydrological categorization of study lakes based on the dominant source of input waters*

Hydrological assessments were conducted by Turner et al. (2010) for each lake using water isotope tracers. For this, a water sample was collected from each lake, three times over the ice-free season, in an air-tight 30 mL HDPE container and transported to the Environmental Isotope Laboratory at University of Waterloo to determine hydrogen and oxygen isotope composition using conventional techniques (Epstein and Mayeda 1953; Morrison et al. 2001). To assess influence of the main sources of input water to lakes (i.e., snowmelt versus rainfall) on seasonal variations in limnological conditions, we used the estimated isotope composition of input waters ($\delta_I$) for each lake in mid-summer as calculated by Turner et al. (2010). Here, we categorize lakes based on mid-summer values of $\delta_I$ because they represent average ice-free season conditions, and values from early- and late-season may be strongly influenced by spring snowmelt and late-summer rainfall events, respectively. Lakes were placed into the categories based on the isotopic framework reported in Turner et al. (2010), as illustrated in Figure 2.3. Turner et al. (2010), assigned all lakes into one of two dominant source-water categories: *snowmelt-* or *rainfall-dominated* (see Fig. 6 in Turner et al. 2010), using the estimated isotope composition of mean annual precipitation ($\delta_P$) (which lies at the intersection of the Local Evaporation Line (LEL) and the Global Meteoric Water Line (GMWL) as a threshold value to differentiate *snowmelt-* from *rainfall-dominated*. Consistent with Turner et al. (2010), lakes with $\delta_I$ values remaining higher than $\delta_P$ during all sampling episodes of the ice-free season were identified to have water balances dominated by rainfall source water. And, lakes with $\delta_I$ values remaining lower than $\delta_P$ throughout the ice-free season were identified to have water balances dominated by snowmelt source water. To account for lakes that experienced variation in source-water dominance over the ice free season we included a third 'intermediate' category, because we realized that seasonal variations in source water dominance could potentially influence limnological conditions. In order to do this, lakes with $\delta_I$ values situated very close to $\delta_P$, which tended to fluctuate above and below $\delta_P$ during the ice-free season, were identified to receive nearly equal proportions of rainfall and snowmelt and experience transitions in relative dominance of input water. To assign the lakes uniquely into one of the three hydrological categories, we calculated the sample mean and standard deviation (SD) of the $\delta_I$ values for the 56 study lakes in July 2007 and placed lakes that had $\delta_I$ values within 0.5 SD units of the sample mean into the intermediate category (Figure 2.3). Lakes with $\delta_I$ values >0.5 SD below the sample mean were placed in the snowmelt-dominated category. And, lakes with $\delta_I$ values >0.5 SD above the sample mean were placed in the rainfall-dominated category. This method appears to distinguish effectively differences in the input waters among the study lakes. For example, most of the lakes that were placed in the snowmelt- and rainfall-dominated categories consistently remained within their category during the course of the ice-free season. And, all of the transitional lakes were captured by the intermediate category (Figure 2.3). Placing each lake into one of the three hydrological categories provides an ability to assess if, and how, limnological conditions vary due to differences in sources of input water (see Numerical analyses below).

### *2.3.3. Water chemistry sample collection and laboratory analysis*

We sampled the same set of 56 lakes as described in Turner et al. (2010). The lakes varied in several characteristics (e.g., surface area, catchment vegetation, water colour) and captured a broad range of hydrological conditions. Lakes were sampled from a helicopter at a central area of each lake. Surface water (~15 cm below surface) was collected from each lake in mid-June (12th-17th), late-July (23rd-24th) and in late-September (29th) of 2007. Due to adverse weather, fewer lakes (26) were sampled in September. We refer, hereafter, to the three sampling episodes as early-, mid- and late-season, respectively. Fifty-one of the 56 study lakes are thermokarst in origin (OCF1-50, 56). The other five lakes are oxbows (OCF51-55). The oxbow lakes were included in our sample set because they are a common feature in OCF landscape.

*In situ* measurements of water temperature (Temp), specific conductivity (SpCond) and dissolved oxygen (DO) concentration (as percent saturation) were recorded at ~30 cm below the water surface using a YSI 600QS multi-meter. Water depth and Secchi depth were also measured at the same sampling location.

Water samples for chemical analyses were collected from ~15-cm water depth and were stored at 4°C in the dark until processed at the field base in the town of Old Crow. Water was pre-screened through a coarse Nitex mesh screen (200-μm) to remove large particulates (e.g. plant fragments, zooplankton, etc.) before determining concentrations of total phosphorus (TP), total nitrogen (TN), nitrite+nitrate ($NO_2$+$NO_3$), ammonia ($NH_3$), silica ($SiO_2$), major ions ($Ca^{2+}$, $Cl^-$, $Mg^{2+}$, $Na^+$, $K^+$, $SO_4^{2-}$), and pH and alkalinity (Alk). To determine the concentrations of total dissolved phosphorus (TDP), dissolved inorganic carbon (DIC) and dissolved organic carbon (DOC), water was filtered through a 0.45-μm cellulose acetate filter. For TP and TDP, samples were acidified with 1 ml of 30% $H_2SO_4$. All samples were kept cool and dark prior to and during shipment to the Environment Canada's National Laboratory for Environmental Testing (NLET) in Burlington, Ontario, for analysis following standard protocols (Environment Canada 1996). Samples collected in June from lakes OCF 20, 21, 27, 45 and 55 were not analysed because sample integrity was compromised during shipping.

Chlorophyll *a* (Chl *a*) concentration of the lake water, an estimate of phytoplankton biomass, was determined by passing a measured volume of coarse-screened (200 μm) water from each lake through a Whatman GF-F filter (pore size = 0.7 μm). The filters were wrapped in foil, kept frozen and dark until analysis at the University of Waterloo. Chl *a* was extracted from the filters in a measured volume of 90% acetone solution for approximately 18 hours at -20°C, and Chl *a* concentrations were determined using standard fluorescence techniques (Stainton et al. 1977).

Water samples collected in July 2007 from each lake were measured for the concentration of total suspended solids (TSS). A measured volume of lake water was passed through a pre-ashed (at 550°C) and pre-weighed Whatman GF-C filter (pore size = 1.2 μm).

The concentration of TSS was determined as the mass of particles on the filter after drying the filter and sample at 90°C for 24 hours.

### *2.3.4. Numerical analyses*

Secchi depth was not included in numerical analyses because it was visible to bottom in >50% of the study lakes. Concentration of $NO_2$+$NO_3$ was also removed from numerical analyses because values were below detection limits in >30% of the lakes. For the remaining variables, the value of the detection limit was used when reported values fell below the detection limit (following methods of Kumke et al. 2007). This criterion only affected measurements of $SO_4$ in three lakes. Prior to numerical and statistical analyses, all limnological variables were assessed for normality using Shapiro-Wilk normality tests and visual assessments using normal-quantile (Q-Q) plots. Most of the variables had skewed distributions. To improve normality and equality of variances, all variables (except pH) were transformed using $\ln(x+b)$, where b = half of the minimum non-zero value in the dataset.

Principal components analysis (PCA) was used to explore patterns of variation in limnological conditions (water chemistry variables, temperature, and concentrations of DO and Chl *a*) among the study lakes. A single PCA was performed on the combined limnological dataset from all three sampling episodes (early-, mid- and late-season), and separate ordination plots were generated for each sampling episode to explore how the limnological variables differ among the hydrological categories based on their primary source of input water. To achieve this, sample scores were coded according to each lake's hydrological category. Lakes with missing values of water chemistry variables (OCF 20, 21, 27, 45 and 55 in June) were eliminated from the PCA and subsequent multivariate analyses. Also, OCF 51 (one of the oxbow lakes) was detected as an outlier, based on anomalously high concentrations of nutrients and ions, and was removed from the PCA (and other statistical and graphical analyses involving the water chemistry data). In the PCA, scaling focused on inter-sample distances, and variables were centered and standardized (divided by their standard deviation) prior to ordination.

Multivariate Analysis of Similarities (ANOSIM) tests were performed on the measurements of water chemistry variables, water temperature and concentrations of DO and Chl *a* obtained during each of the three sampling episodes in 2007 to test if, and determine when, limnological conditions differ significantly among the hydrological categories. Limnological variables were normalized prior to calculating the dissimilarity matrix (Euclidean distances between samples) used in the ANOSIM tests. The ANOSIM test statistic (global R) reflects the observed differences in the limnological variables among hydrological categories contrasted with the differences among replicates within each category, and it ranges from 0 to 1. A value of 0 indicates that the similarity between and within hydrological categories is the same on average. A value of 1 indicates that replicates within a category are more similar to each other than to all other replicates of other categories (Clarke and Warwick 2001). A *p*-value was computed by comparing the distribution of within- and across-group rank Euclidean distance similarities (99,999 random permutations) to the initial rank similarity, as reported by the global R value (Clarke and Warwick 2001; Clarke and Gorley 2006). For all ANOSIM tests that resulted in a significant global R value ($p \leq 0.05$), we used a series of univariate Kruskal-Wallis tests to identify which of the limnological variables differ significantly among the hydrological categories. We also used Tukey post-hoc tests to determine pairwise differences among hydrological categories. Boxplots were used to visualize differences in distributions of selected limnological variables among hydrological categories.

To explore relations among limnological conditions, input water sources and catchment characteristics, we used redundancy analysis (RDA) with the mid-season values of the lake-water chemistry variables as the response variables and the catchment land-cover variables as the explanatory variables, and with the lakes (sample scores) coded by their hydrological category in the resulting ordination plot. The catchment land-cover variables were expressed as percentage of each lake catchment, as reported in Turner et al. (2014).

To explore if and how temporal variation of limnological conditions differed among the three hydrological categories during the 2007 ice-free season, we plotted seasonal water chemistry trajectories of the PCA sample scores along axes 1 and 2 for all sampling periods, following approaches similar to those used by Engstrom et al. (2000) and White et al. (2014). This seasonal-trajectory analysis was limited to only lakes that were sampled during all three sampling episodes (n = 21). For each hydrological category, average changes in sample scores along PCA axes 1 and 2 were also assessed using bar graphs for the same set of lakes.

For all significance tests, we set alpha = 0.05. Ordinations by PCA and RDA were performed using the software CANOCO version 4.5 (ter Braak and Šmilauer 2002). ANOSIM tests were performed using the software PRIMER version 6.1.5 (Clarke and Warwick 2001; Clarke and Gorley 2006). The univariate tests (Shapiro-Wilks, Kruskal-Wallis, Tukey post-hoc) and normal-quantile plots were performed using the software SPSS version 16.0.

## *2.4. Results*

### *2.4.1. Physical characteristics*

Based on Kruskal-Wallis tests, lake surface area ($\chi^2 = 22.28$, $p = 1.4\text{x}10^{-5}$, d.f. = 2) and water temperature ($\chi^2 = 15.67$, $p = 4.0\text{x}10^{-4}$, d.f. = 2) differ significantly among the hydrological categories (Figure 2.4a, b; Table 2.1). Lakes with snowmelt-dominated input waters have the smallest surface area (range = 0.2 - 122.0 ha; mean = 23.4 ha; SD = 35.8 ha), whereas lakes with rainfall-dominated input waters have the largest surface area and span the broadest range of values (range = 11.6 - 1318.1 ha; mean = 439.9 ha; SD = 409.6 ha). Mean surface area of lakes in the intermediate category (range = 4.4 - 983.0 ha; mean = 135.2 ha; SD = 265.6 ha) falls mid-range between snowmelt- and rainfall-dominated lakes, but differs significantly from them. Pairwise tests identify that mean water temperature is significantly ($p<0.05$) warmer for snowmelt-dominated lakes than for lakes in the other categories (Figure 2.4b; Table 2.1). Nearly 80% of the study lakes had depths shallower than 2 m (range = 0.4 - 6.2 m; mean = 1.5 m; SD = 1.2 m), and lake depth does not differ significantly among hydrological categories (Kruskal-Wallis test; $\chi^2 = 1.05$, $p = 0.59$, d.f. = 2) (Figure 2.4c; Table 2.1). However, several lakes in the snowmelt-dominated and intermediate categories are deeper than 2 m (Figure 2.4c). TSS concentration in July does not differ significantly among the three hydrological categories (Kruskal-Wallis test, $\chi^2 = 1.01$ $p = 0.60$, d.f. = 2; Figure 2.4d; Table 2.1). Except for two rainfall-dominated lakes with TSS >100 $mg \cdot L^{-1}$ (OCF 38, OCF 43) and one intermediate lake with TSS = 22 $mg \cdot L^{-1}$ (OCF 7), TSS values are typically low in the study lakes (<10 $mg \cdot L^{-1}$), but span a larger range in the rainfall-dominated lakes.

### *2.4.2. Water chemistry*

Collectively, the study lakes are circum-neutral to alkaline and span a broad range of pH and concentrations of nutrients and ions (Table 2.2). Lakes experience a mid-season peak in concentrations of TP, TDP and DOC. Based on phytoplankton biomass at mid-season, 47.3% of study lakes are ultra-oligotrophic, 36.3% are oligotrophic and 16.4% are mesotrophic (*sensu* Padisak 2004). Specific conductivity ranges from 18.60 to 329.00 $\mu S \cdot cm^{-1}$, and corresponds to low concentrations of major ions. Relative concentrations of anions are DIC>$SO_4$>Cl, whereas relative concentrations of cations are generally Ca>Mg>Na>K.

Ordination by PCA identifies systematic differences among the three hydrological categories in the distribution of water chemistry variables and temperature during the ice-free season (Figure 2.5). The first two PCA axes ($\lambda_1 = 0.346$, $\lambda_2 = 0.161$) explain 50.7% of the variation in the dataset. Sample scores for lakes in the snowmelt-dominated category are generally positioned to the right along PCA axis 1 and slightly lower along PCA axis 2 compared to lakes in the other categories. Snowmelt-dominated lakes are associated with relatively high concentrations of major nutrients (N, P), DOC, $SiO_2$ and Chl *a*, relatively low concentrations of major ions, and low alkalinity, specific conductivity and pH (Figure 2.5; Table 2.3). In contrast, sample scores for lakes in the rainfall-dominated category are positioned to the left along PCA axis 1, associated with relatively low concentrations of major nutrients (N, P), DOC, $SiO_2$ and Chl *a*, and relatively high concentrations of major ions, and high alkalinity, specific conductivity and pH (Table 2.3). Sample scores for lakes in the intermediate category span the full range along axes 1 and 2, indicating high variability of water-chemistry values, which overlap with sample scores for lakes in the other hydrological categories. Interestingly, however, mid- and late-season sample scores for lakes in the intermediate category appear to overlap more extensively with lakes in the rainfall-dominated category than those in the snowmelt-dominated category (Figure 2.5c, d). Oxbow lakes classified as snowmelt-dominated (OCF 52, 54, 55) plot within the range of sample scores for the thermokarst lakes with snowmelt-dominated input waters, indicating similar limnological conditions during the ice-free season.

Results of the one-way ANOSIM tests demonstrate that limnological conditions differ significantly among the three hydrological categories during all of the sampling episodes of the 2007 ice-free season ($p<0.05$, Table 2.4). In early-season, shortly after snowmelt, all pairwise comparisons among the hydrological categories resulted in significant differences. Similar results were obtained during the mid- and late-season except for pairwise comparison between the rainfall-dominated and intermediate hydrological categories. This finding indicates that limnological conditions in the intermediate category tend to converge towards those of the rainfall-dominated lakes as the ice-free season progresses. Consistent with patterns evident in the PCA ordination plot, the greatest differences in limnological conditions occur between snowmelt- versus rainfall-dominated lakes for all three sampling periods, as identified by values of the global R for pairwise comparisons between the hydrological categories (Table 2.4).

Kruskal-Wallis tests on the individual limnological variables identify that the distributions of nine variables (pH, specific conductivity, alkalinity, temperature, and concentrations of $SO_4$, DOC, DIC, Mg and Na) differ significantly among the hydrological categories during all three sampling periods ($p<0.05$; Table 2.1). TDP concentration differs significantly among the hydrological categories in early- and mid-season, but not in late-season. Concentration of Ca differs among hydrological categories in mid- and late-season, but not in early-season. Concentrations of $SiO_2$, TN, TP and Chl *a* differ significantly among the hydrological categories in early-season, but not in mid- or late-season. Concentrations of Cl, K and $NH_3$ do not differ significantly among the hydrological categories during any of the sampling episodes.

Boxplots and Tukey post-hoc tests of samples collected in mid-season, when peak biological productivity occurs (based on maximum Chl *a* concentration; see Table 2.2), reveal distinct differences in several water chemistry variables among the hydrological categories (Figure 2.6). For example, rainfall-dominated lakes possess significantly higher pH, alkalinity and specific conductivity, and higher concentrations of Ca, $SO_4$, DIC and Mg than snowmelt-dominated lakes. In contrast, snowmelt-dominated lakes have significantly higher concentrations of DOC and TDP than rainfall-dominated lakes. For water chemistry of the intermediate lakes, Tukey's post-hoc tests reveal a less distinctive pattern. For example, they indicate that intermediate lakes possess intermediate values of Ca, $SO_4$, DIC and TDP concentrations, which do not differ significantly from the snowmelt- and rainfall-dominated lakes categories. But, intermediate lakes possess significantly higher pH, alkalinity, specific conductivity and Mg concentration than the snowmelt-dominated lakes, and do not differ significantly from values for the rainfall-dominated lakes. An exception is DOC concentrations, which differ significantly among all three hydrological categories. Concentrations of TN, $SiO_2$ and Chl *a* do not differ significantly among the hydrological categories (Figure 2.6).

### *2.4.3. Relations among catchment land cover, hydrology and water chemistry*

RDA analysis identifies strong ($p<0.005$) and predictable relations among catchment land-cover, source water inputs and water chemistry of the study lakes (Figure 2.7). For example, vectors for percent cover of tall shrubs and woodland vegetation are negatively correlated with RDA axis 1 and are strongly associated with relatively high concentrations of nutrients ($SiO_2$, TDP, TP, $NH_3$), DOC and Chl *a*, and warmer temperature, but relatively low concentrations of major ions (Mg, $SO_4$, Ca, Na, Cl), DIC and dissolved oxygen, and low specific conductivity, pH and alkalinity. Lakes with snowmelt-dominated source water are positioned to the left along RDA axis 1, suggesting that catchments dominated by woodland and tall shrub vegetation supply relatively high amounts of nutrients to lakes. In contrast, vectors for percent cover by dwarf shrubs, sparse vegetation and surface water are positively correlated with RDA axis 1, and are associated with relatively high lake-water pH, alkalinity, conductivity and high concentrations of major ions, DIC and dissolved oxygen, but relatively low concentrations of nutrients, DOC, and Chl *a* and lower temperatures. Rainfall-dominated and intermediate lakes are positioned to the right along RDA axis 1, suggesting that catchments dominated by dwarf shrub and sparse vegetation supply relatively low amounts of nutrients.

### *2.4.4. Comparison of seasonal water-chemistry variation among hydrological categories*

To explore the influence of differences in source water input on seasonal patterns of limnological change, we plotted the seasonal trajectories of PCA axis 1 and 2 sample scores of the study lakes for each of the hydrological categories (Figure 2.8a-c). Also, to summarize the total amount of change between sampling episodes, we present the average change in PCA axis 1 and 2 scores for each hydrological category (Figure 2.8e). These analyses illustrate differences among the hydrological categories in the magnitude and direction of seasonal changes in limnological variables from the initial conditions in early-season.

During early-season, PCA sample scores for most lakes in the snowmelt-dominated category are positioned farther to the right along axis 1 compared to the lakes in the other categories, indicating they possess the highest concentrations of DOC and major nutrients, and the lowest specific conductivity and pH (Figure 2.8a, d). In fact, concentrations of TDP, TP, $SiO_2$ and DOC are nearly double those for rainfall-dominated lakes (Table 2.3). Compared to the other hydrological categories, sample scores for the snowmelt-dominated lakes moved relatively little along PCA axis 1 between early- and mid-season, but increased markedly on average along axis 2. This pattern suggests that nutrient content declines while concentrations of major ions did not change markedly (Figure 2.8a, e). Between mid- and late-season, sample scores of the snowmelt-dominated lakes tend to decrease along PCA axis 1 and 2 (Figure 2.8e), reflecting increases in nutrient concentration (mainly the N species), and decreases in pH, alkalinity and DIC concentration. During the ice-free season, sample scores for the lakes in the snowmelt-dominated category moved a shorter distance along PCA axes 1 and 2 when compared to lakes in the other categories, indicating that they possess the least varying water chemistry.

PCA sample scores for the rainfall-dominated lakes are typically positioned farthest to the left along PCA axis 1 in early-season when compared to lakes within the other categories, indicating they have higher initial concentrations of major ions and lower initial concentration of $SiO_2$ relative to lakes in the other categories (Figure 2.8c, d; Table 2.3). Between early- and mid-season, sample scores of the rainfall-dominated lakes tend to decline along PCA axes 1 and 2, due to a net increase in alkalinity, pH and concentrations of major ions, nutrients and Chl *a*. Between mid- and late-season, they continue to decline along axis 1 but increase along axis 2, associated with increases in DIC concentration and decreases in concentrations of $SiO_2$, major nutrients and Chl *a* (Figure 2.8d, e). Overall, the patterns indicate that rainfall-dominated lakes experience greater seasonal change in water chemistry variables during the ice-free season compared to snowmelt-dominated lakes.

Sample scores for lakes in the intermediate category occupy an intermediate position along axis 1 relative to those for the snowmelt- and rainfall-dominated categories (Figure 2.8b). Similar to lakes in the rainfall-dominated category, sample scores for the intermediate lakes decline along PCA axes 1 during the ice-free season, associated with net increases in alkalinity, pH, specific conductivity and concentrations of major ions (Table 2.3). Samples scores increase along PCA axis 2 in the rainfall-dominated and intermediate lakes between mid- and late season, reflecting mainly declines in concentrations of major nutrients. But, patterns of movement along axis 2 differ for lakes from these two categories between early- and mid-season. Specifically, rainfall-dominated lakes decrease markedly along PCA axis 2, whereas intermediate lakes move slightly upwards along PCA axis 2 in the same direction as the snowmelt-dominated lakes. This signifies a decrease in concentrations of some major nutrients (mainly $SiO_2$ and TP) in the intermediate lakes.

## *2.5. Discussion*

Despite predictions formulated nearly two decades ago that variations in climatic conditions exert important influence on limnological conditions of shallow Arctic lakes via regulation of hydrological processes (Rouse et al. 1997), few well-integrated hydro-limnological studies have been conducted to test them over large spatial scales in lake-rich landscapes. Here, we employed spatial surveys across broad environmental gradients in a lake-rich landscape of ecological and cultural importance, and integrated the use of water isotope tracers and remote sensing with physico-chemical measurements, to quantitatively assess the limnological conditions of shallow lakes in OCF. Our analyses identify that differences in the dominant sources of input water (snowmelt versus rainfall) and related catchment characteristics (morphology, vegetation cover), as identified by Turner et al. (2010, 2014), result in significant and predictable variations in physical and chemical conditions of lakes in OCF.

In early spring, lakes throughout OCF experience widespread hydrological connectivity with their surrounding catchment and are replenished by meltwater from the winter snowpack (Turner et al. 2010), but water chemistry conditions differ significantly among the hydrological categories despite this common water source. For example, lakes classified as snowmelt-dominated, based on mid-season water isotope values, possess significantly higher concentrations of nutrients (i.e., N, P, $SiO_2$), DOC and Chl *a* in the early ice-free season, and significantly lower pH, alkalinity and concentrations of major ions (Figure 2.5; Table 2.1; Table 2.3) compared to lakes in the other categories. The catchments of these snowmelt-dominated lakes tend to possess a high proportion of woodland forest and tall-shrub vegetation (Figure 2.7), and often are located near the base of hillslopes along the south and west margins of OCF (Turner et al. 2014) which facilitate an increased inflow of snowmelt during melt period. These results compare well with broad limnological patterns reported in other spatial surveys in western Canada, Alaska and Siberia that show higher nutrient and DOC concentrations in lakes within forested catchments compared to those of sparsely-vegetated tundra catchments (Pienitz et al. 1997; Duff et al. 1998; Gregory-Eaves et al. 2000), and highlight the importance of snowmelt runoff as a key vector delivering catchment-detrived nutrients to lakes. Since snow is not usually rich in nutrients (Treloar 1993), the elevated nutrients found in snowmelt-dominated lakes likely accumulate in the meltwater as it travels downslope through densely vegetated catchments reportedly rich in organic detritus (Ovenden and Brassard 1989; Roy-Léveillée et al. 2014). We suggest that enhanced contact of the meltwater with organic detritus in snowmelt-dominated lake catchments lead to accumulation and transport of nutrients (N, P) and DOC via runoff. Additionally, the relatively high concentration of nutrients in the snowmelt-dominated lakes are associated with significantly higher biomass of phytoplankton (as inferred from Chl *a*) in early-season, suggesting that interaction of catchment features and hydrological processes exert influence on lake ecology (Table 2.1; Table 2.3).

Lakes with rainfall-dominated input waters possess lower concentrations of nutrients, DOC, and Chl *a* than the snowmelt-dominated lakes in the early ice-free season, and significantly higher pH, alkalinity, specific conductivity and concentrations of major ions (Figure 2.5; Table 2.3). The rainfall-dominated lakes tend to occupy catchments in the low-relief regions of central and eastern OCF, which contain dwarf-shrub and sparsely-vegetated tundra vegetation (Turner et al. 2014). Relatively higher ion concentration in rainfall-dominated lakes is unlikely to originate from rain itself, because low $Cl^-$ concentrations in the lakes suggest minimal marine influence (Lim et al. 2001) across OCF. Thus, ionic content of rainfall-dominated lakes is more likely elevated by processes occurring within the lake and surrounding catchment, rather than spatial gradients of rainfall. On average, the surface area of rainfall-dominated lakes is 19 times larger than the snowmelt-dominated lakes (Figure 2.4a), and consequently their water balance experiences relatively higher influence of evaporative water loss compared to smaller lakes receiving more snowmelt inflow from surrounding catchment (Turner et al. 2010). Thus, we suggest evaporative concentration is an important mechanism that consistently influences ionic content of the lakes with rainfall-dominated source waters. Higher rates of shoreline erosion may also account for the relatively higher ionic content of rainfall-dominated lakes. Ice-wedge polygons and ice-lenses are abundant in sparsely-vegetated and dwarf shrub tundra areas of OCF (Roy-Léveillée et al. 2014), where rainfall-dominated lakes are situated. Because presence of ground ice and orthogonal ice-wedges facilitate the lateral expansion of lakes due to thermo-mechanical erosion of shorelines (Roy-Léveillée and Burn 2010), and thermokarst lakes in ice-rich areas of OCF have been reported to erode by as much as $3.5\ m \cdot year^{-1}$ (Roy-Léveillée and Burn 2010), we suggest that resulting shoreline slumps can transport ion-rich water into lakes. This process is well documented near Inuvik (NWT), where input of massive volumes of shoreline soil and water following thermokarst thaw-slump events elevated ion concentrations in shallow tundra lakes (Kokelj et al. 2005, 2009). Interestingly, these studies report that $SO_4$ concentrations are orders of magnitude higher in lakes affected by thaw slumps compared to undisturbed control lakes. In our study, average $SO_4$ concentration of the rainfall-dominated lakes is 3 - 9 times greater than the snowmelt-dominated lakes (Figure 2.6; Table 2.3). Presence of woodland and tall-shrub vegetation along the perimeter of snowmelt-dominated lakes, in contrast, likely reduces rates of shoreline erosion, which is consistent with their smaller size and field-based observations of stable shorelines. Runoff generated from rain events could provide a third mechanism driving higher ionic content in sparsely vegetated low-relief tundra regions, which reportedly have shallower organic horizons in the permafrost profile (Roy-Léveillée et al. 2014). When the active layer develops beyond the organic horizon in these regions, it is possible that intense rain events, which replenish catchment soil-moisture levels, would induce ephemeral hydrologic connectivity and allow subsurface runoff of rain to flush solute-rich water of the mineral horizon into lakes, as observed elsewhere (Dugan et al. 2009). Further research measuring active layer depths and flow paths after large rain events in OCF are needed to assess the importance of this mechanism.

Early-season differences in water chemistry among lakes in the hydrological categories persisted throughout the ice-free season. Lake-water pH, alkalinity, conductivity and concentrations of DOC, DIC and several major ions (Ca, Mg, Na, $SO_4$) continue to differ significantly among the hydrological categories in mid- and late-season (Table 2.1). And, differences in TDP concentration continued to mid-season. Above average snowfall in the preceding winter, positioning of lakes in well-drained densely-vegetated catchments, and a lower relative influence of evaporation (Turner et al. 2010; 2014) likely caused the persistent higher concentration of dissolved nutrients (TDP, DOC) and relatively smaller increases in ionic concentrations in the snowmelt-dominated lakes during the ice-free season (Figure 2.8a, Table 2.3). In contrast, the continued influence of evaporation and possible influence of shoreline erosion, likely account for higher and seasonally-rising ion concentrations in the rainfall-dominated lakes. Interestingly, mid-season Chl *a* values, which did not differ significantly among lake categories but were higher in rainfall-dominated lakes on average (Table 2.3), suggest that other processes such as light limitation were controlling lake productivity in mid-season. Overall, seasonal variation of water chemistry conditions is lowest in the snowmelt-dominated lakes because snowmelt inputs offset evaporation effects and replenish nutrients, whereas rainfall-dominated lakes experience marked seasonal increases in ion concentrations and greater fluctuations in nutrient concentrations (Figure 2.8).

The seasonal pattern of water chemistry variation for the intermediate lakes is broadly comparable to that of the rainfall-dominated lakes, except that intermediate lakes possess lower ionic content in early-season. Thus, water chemistry of intermediate lakes share similarity with the snowmelt-dominated lakes in early-season, and subsequently mimics the pattern of change observed for rainfall-dominated lakes as the influence of snowmelt wanes. This seasonal pattern of variation in water chemistry highlights the sensitivity of intermediate lakes to transitioning sources of input water.

## *2.6.Implications*

Hydrologists and limnologists focus on understanding processes that influence lakes, but rarely integrate their expertise to generate a comprehensive understanding of how hydrological processes regulate physical, chemical and biological dynamics of lakes (Hodkinson et al. 1999; Brooks et al. 2014). For shallow Arctic lakes, hydrologists have tended to focus on understanding how hydrological processes are affected by climatic variations to better anticipate responses of water balance to future warming (Hinzman et al. 2005; Smith et al. 2005; Rawlins et al. 2010; Karlsson et al. 2012). Limnologists, on the other hand, typically focus on improving understanding of how water chemistry and biological communities respond to rising air temperatures and related disturbances (Smol and Douglas 2007; Corcoran et al. 2009; Thienpont et al. 2013; Rühland et al. 2014), but lack measurements of hydrological processes that may mediate the changes. As a consequence, limnologists often remain unable to account for important amounts of variation in physical and chemical characteristics of shallow Arctic lakes over space and time (Medeiros et al. 2012), which ultimately impedes our ability to anticipate how lakes and lake-rich landscapes will become altered as the climate continues to warm and seasonality and magnitude of precipitation change.

Here, we demonstrate how coupled analyses of water isotope tracers and limnological measurements, collected during the 2007 ice-free season from 56 lakes in a lake-rich lowland thermokarst landscape, can overcome some of these limitations. Results from our study demonstrate that differences in sources of input water to lakes (snow versus rain), in combination with evaporation and shoreline erosion of lakes account for significant variation in pH, conductivity and concentrations of nutrients and major ions. Catchment characteristics, including vegetation cover and topography, appear to be important determinants of the observed directional relations between dominant sources of input water and limnological conditions. Similar to studies of Arctic river systems (Lewis et al. 2011), we found that lakes receiving greater snowmelt input possessed higher concentrations of nutrients (i.e., DOC and TN). Notably, the differences among lake categories are greater than those reported by Lewis et al. (2011) for the rivers, and they persisted throughout the ice-free season, possibly due to longer residence times for lakes. This knowledge provides a foundation to anticipate limnological responses to hydro-climatic change in lakes of OCF, and perhaps elsewhere.

As the ice-free season lengthens due to warmer air-temperatures and precipitation patterns change (AMAP 2012), water chemistry in thermokarst lakes will also shift. Longer duration of the ice-free season will lead to greater evaporative lake water losses and elevated ionic content in all lakes. Also, vegetation can be expected to grow taller and denser with warming (Myers-Smith et al. 2011), thus increasing entrapment of snow in OCF affecting delivery of snowmelt to adjacent lakes. In these areas, intermediate lakes could shift to snowmelt-dominated with associated increases in concentration of major nutrients and DOC. Conversely, if increased air temperatures trigger a rapid snowmelt over a short period, nutrient delivery to snowmelt-dominated lakes may become short-lived and lead to clearer water (i.e., lower DOC), lower nutrient availability (N, P) over the ice-free season and earlier shift to conditions typical of lakes with intermediate or rainfall-dominated hydrology. However, such a reduction of nutrients in snowmelt-dominated lakes may not reduce phytoplankton production since rainfall-dominated lakes support similarly high biomass of phytoplankton in mid-season. But, if snowfall declines or becomes more variable as duration of the ice-free season increases, the shallow, rainfall-dominated lakes located in sparsely-vegetated catchments in central OCF will become more prone to evaporative drawdown or periodic desiccation (e.g., Bouchard et al. 2013b), increase in conductivity, pH and ion concentrations.

## *2.7.Acknowledgements*

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## *2.8.Figures and Tables*

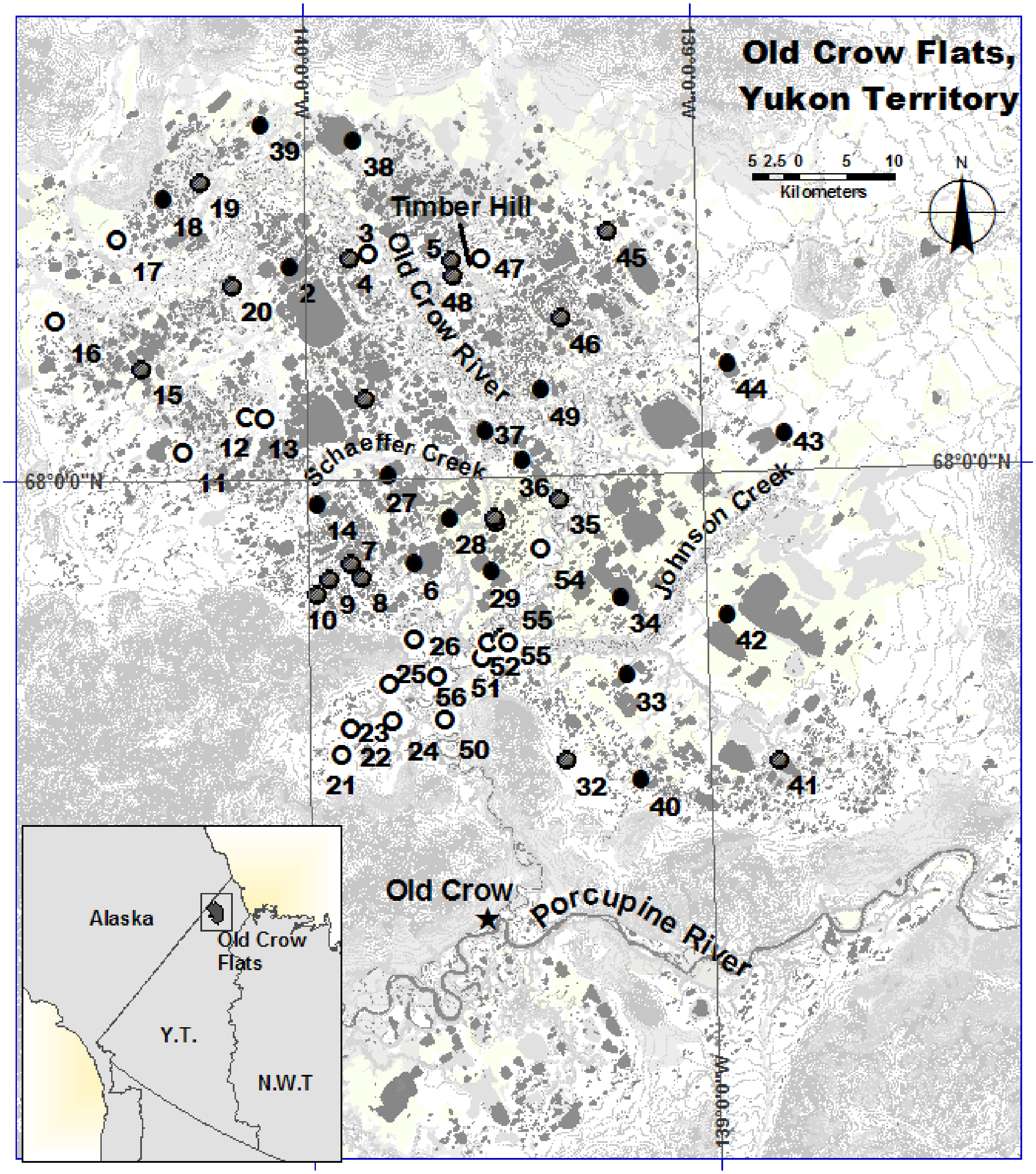

Figure 2.1: Maps showing locations of Old Crow Flats (OCF), YT and study lakes. Lakes are classified into three hydrological categories based on differences in the dominant sources of input water, as indicated by the different symbols (rainfall-dominated lakes = solid black circles, snowmelt-dominated lakes = white circles, intermediate lakes = grey circles).

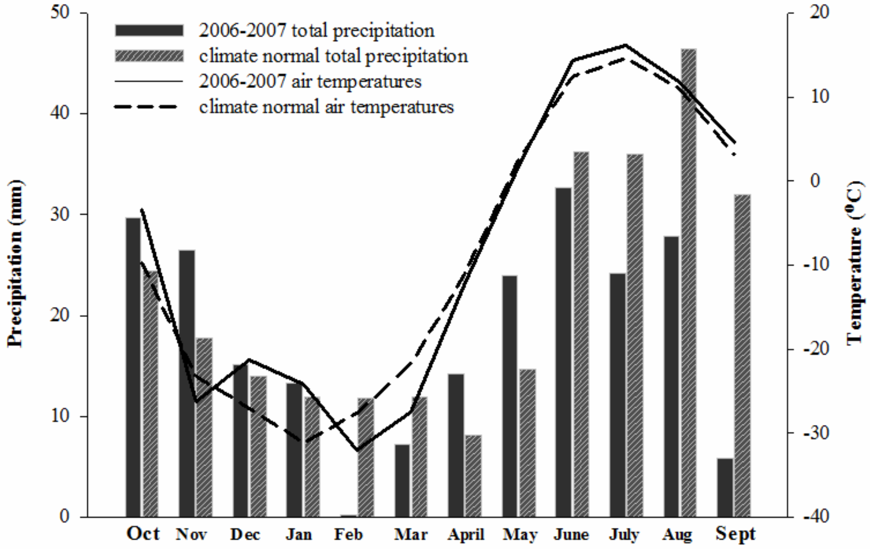

Figure 2.2: Graph showing mean monthly air temperatures (lines) and monthly precipitation (vertical bars) at Old Crow, YT based on data recorded at Old Crow airport (Station ID 2100200; Environment Canada (2007)). Values are shown for the climate normal (1971-2000) and for the hydrological year spanning October 2006 – September 2007.

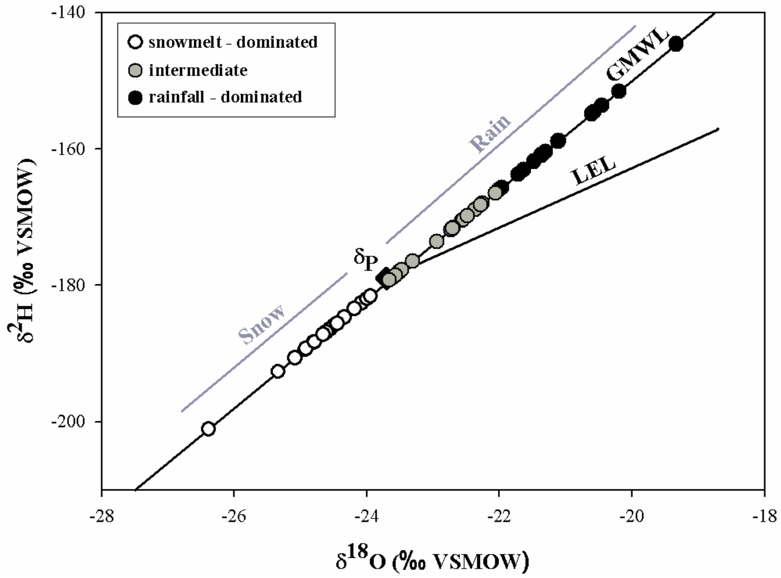

Figure 2.3: Isotope framework adapted from Turner et al. (2010) to show hydrological categorization of lakes based on calculated values of lake specific input ($\delta_I$) values (represented by circles). For each lake, Turner et al. (2010) calculated $\delta_I$ from measured hydrogen and oxygen isotope composition of water from the study lakes (late-July, 2007) and using the coupled-isotope tracer method developed by Yi et al. (2008). Values of $\delta_I$ are assumed to plot on the Global Meteoric Water Line (GMWL; $\delta^2H = 8\delta^{18}O + 10$; Craig, 1961). The estimated mean annual isotope composition of precipitation ($\delta_P$) is indicated with a black solid square (Turner et al. 2010) and anchors the Local Evaporation Line (LEL). The “Rain” and “Snow” labels are positioned to identify approximate isotopic ranges of these source waters along the GMWL.

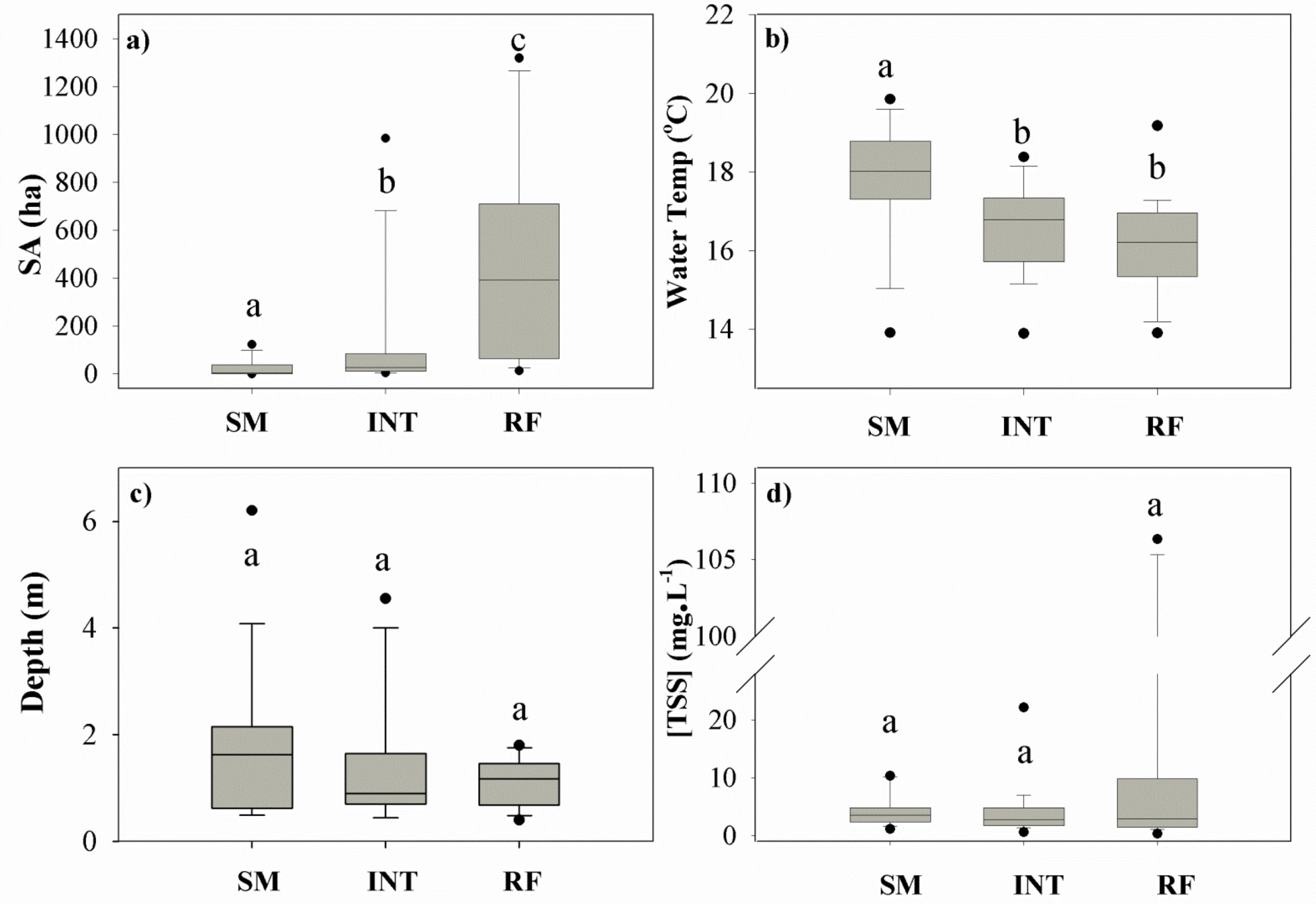

Figure 2.4: Boxplots comparing the distributions of selected physical variables among lakes in the snowmelt-dominated (SM; n=18), intermediate (INT; n=19) and rainfall-dominated (RF; n=18) hydrological categories, based on data obtained in mid-season (late-July) of 2007. Whiskers represent the 10th and 90th percentiles, and values beyond them are represented by black dots. Panels are as follows: a) surface area (SA), b) water temperature, c) depth and d) concentration of total suspended solids (TSS). Different lowercase letters (a, b, c) indicate that the distribution of the variable differs significantly ($p \leq 0.05$) among hydrological categories based on a Kruskal-Wallis test and subsequent Tukey post-hoc tests of that variable (see text for further details).

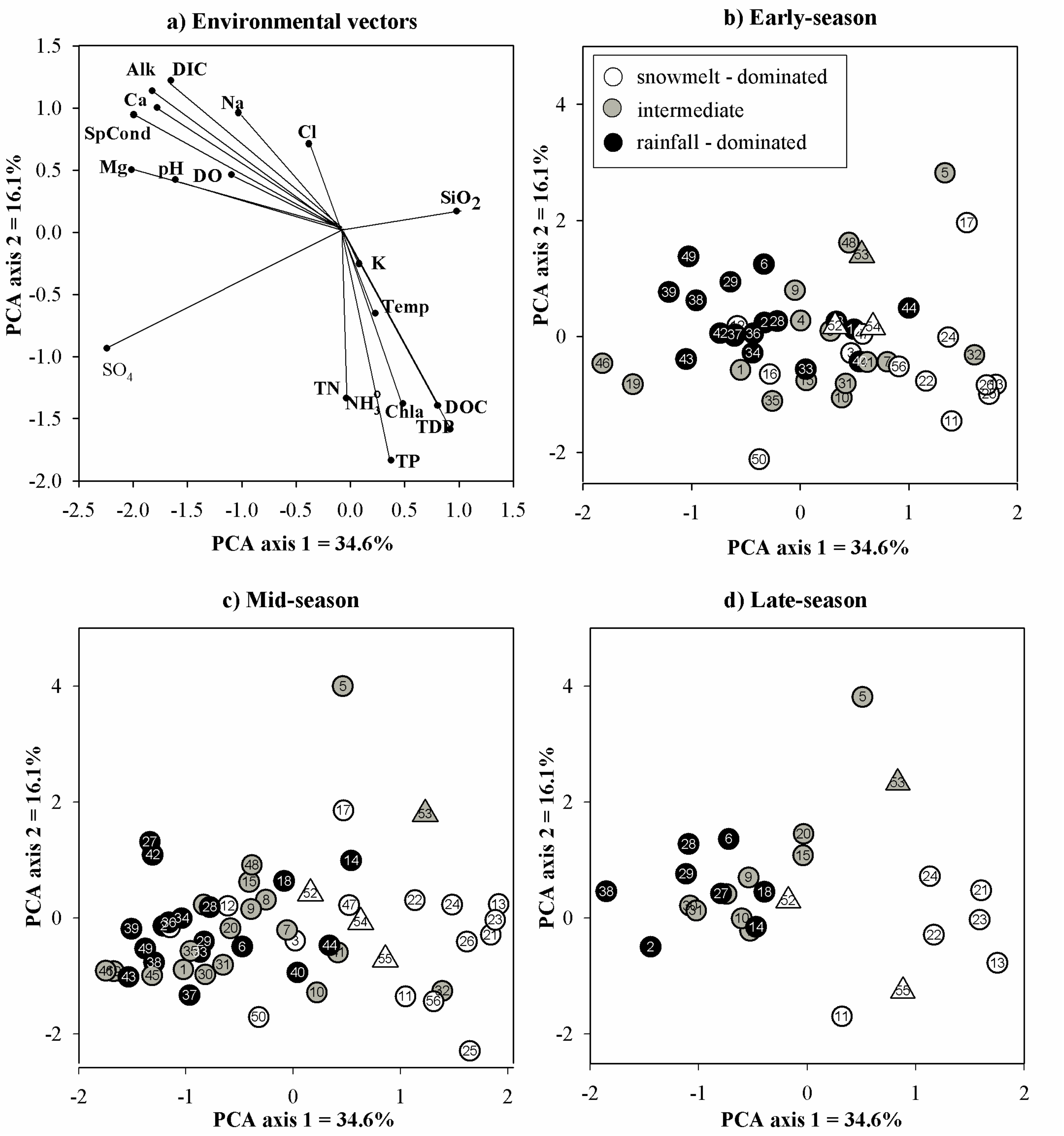

Figure 2.5: Principal components analysis (PCA) ordination plots showing the variation in limnological conditions for lakes in the three hydrological categories. Panel a) shows vectors for the limnological variables. Sample scores for the study lakes are shown in panels b) through d) for early-season, mid-season and late-season, respectively. Sample scores are coded by their hydrological category. The oxbow lakes included in analysis, OCF 52-55, and are represented by triangles. All other lakes are thermokarst and are represented by circles.

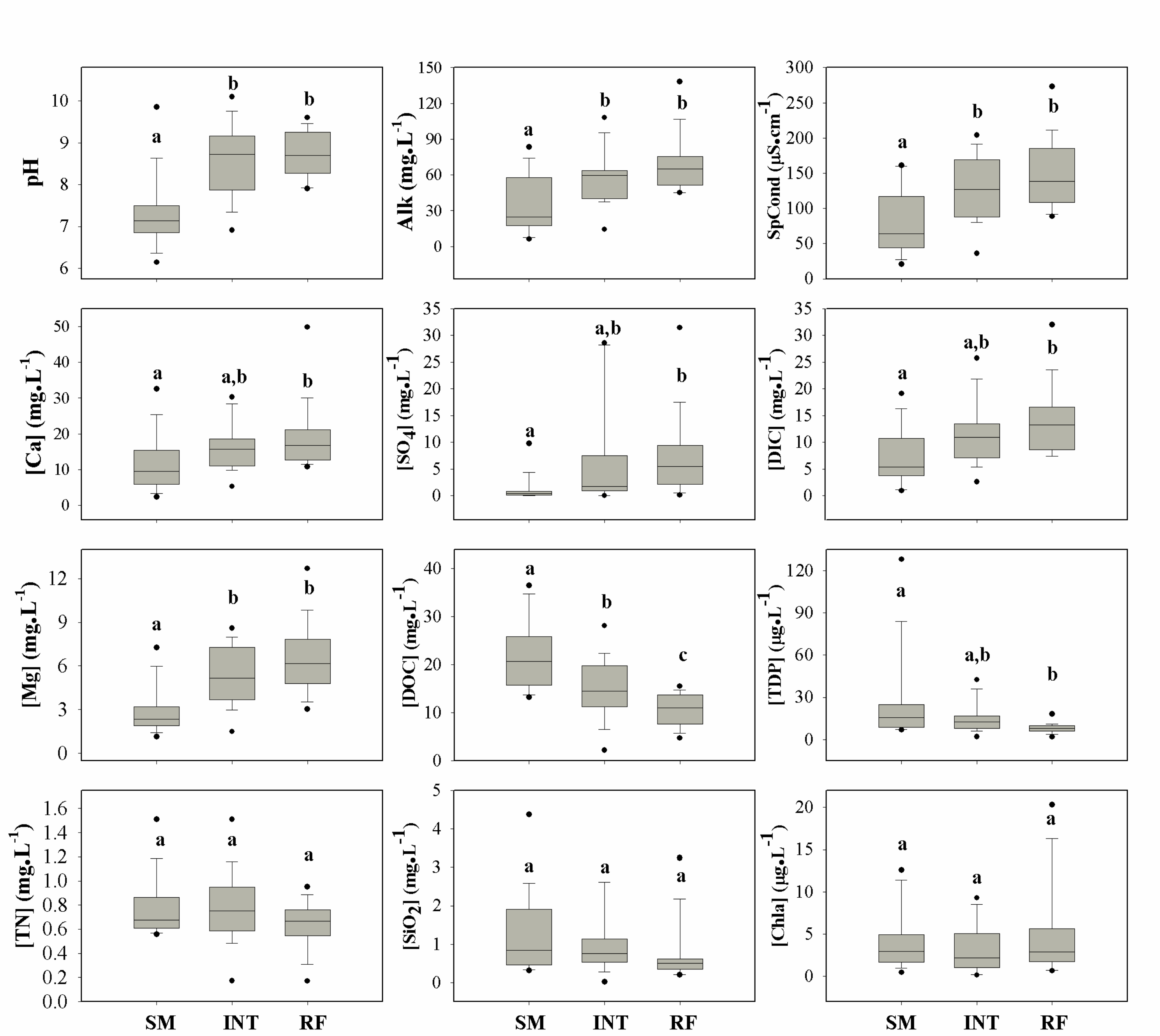

Figure 2.6: Boxplots comparing the distributions of selected water chemistry variables among the snowmelt-dominated (SM; n=18), intermediate (INT; n=19) and rainfall-dominated (RF; n=18) hydrological categories, based on data obtained in mid-season (late-July) of 2007. Whiskers represent the 10th and 90th percentiles, and values beyond them are represented by black dots. Different lowercase letters (a, b, c) indicate that the distribution of the presented variable differs significantly ($p \leq 0.05$) among hydrological categories based on a Kruskal-Wallis test and subsequent Tukey post-hoc tests of that variable (see text for further details).

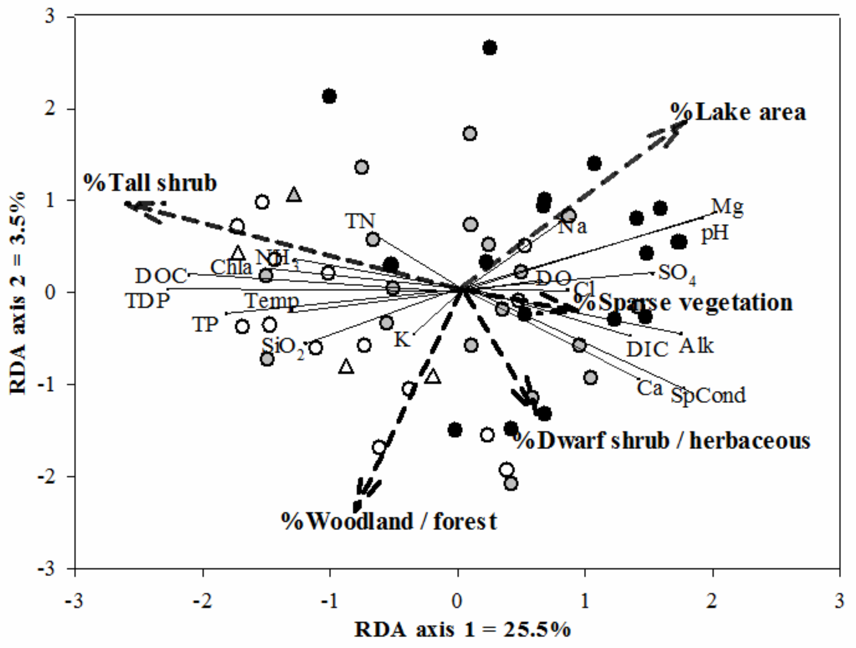

Figure 2.7: Redundancy analysis (RDA) ordination plot showing relations between the distribution of water chemistry variables, based on values obtained in mid-season of 2007 (as response variables; indicated as vectors with solid lines), and catchment vegetation-cover (included as explanatory variables; indicated as vectors with dotted lines). Sample scores for the lakes are coded by their hydrological category (rainfall-dominated (black circles), intermediate (grey circles) and snowmelt-dominated (white circles)).

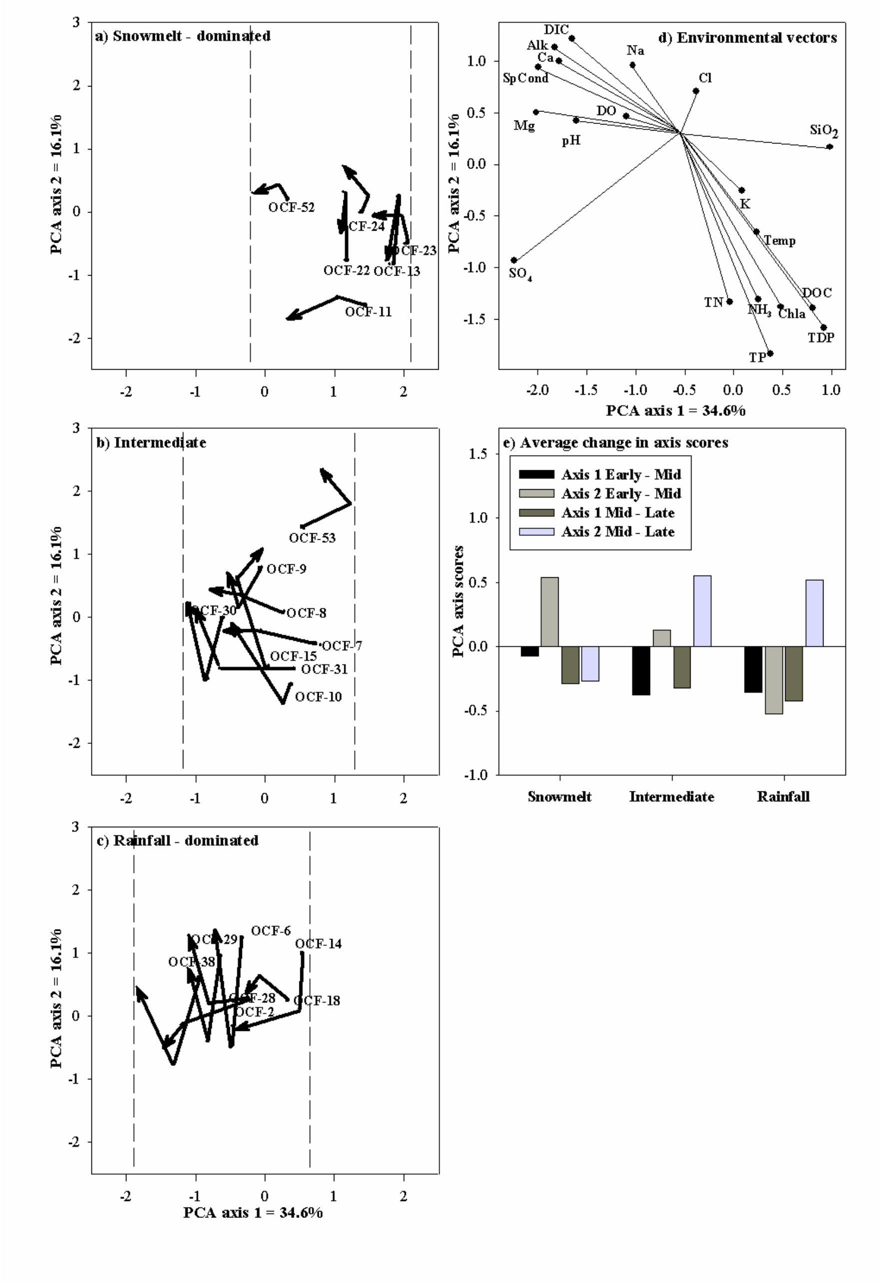

Figure 2.8: Principal components analysis (PCA) ordinations showing seasonal variation of limnological conditions for lakes in each of the three hydrological categories (snowmelt-dominated, intermediate, rainfall-dominated; panels a) through c), respectively). Seasonal trajectories of lakes are based on sequential sample scores for each lake along PCA axes 1 and 2 in early-, mid- and late-seasons. Sample scores from early-season are at the beginning of the arrow, mid-season scores are at the centre point of the arrow and late-season scores are at the end of the arrow. Only the lakes that were sampled during all three sampling episodes are shown (n = 21). Note that OCF 52 and OCF 53 are oxbow lakes, while all others are thermokarst. Panel d) displays the vectors for the limnological variables. Bar graph in panel e) displays the average amount of change in sample scores along PCA axes 1 and 2 for each hydrological category from early- to mid-season, and from mid- to late-season.

Table 2.1:P-values from a series of Kruskal-Wallis tests used to assess which of the limnological variables differ significantly among the three hydrological categories (snowmelt-dominated, rainfall-dominated, intermediate) during the early-, mid- and late-season in 2007. The results are based on 50 lakes analyzed in early-season (16 snowmelt-dominated, 17 intermediate, 17 rainfall-dominated), 55 lakes in mid-season (18 snowmelt-dominated, 19 intermediate, 18 rainfall-dominated) and 26 lakes in late-season (8 snowmelt-dominated, 10 intermediate, 8 rainfall-dominated). P-values in **bold** are significant at alpha = 0.05.

| Variable | Early-season | Mid-season | Late-season |
|---|---:|---:|---:|
| pH | **0.004** | **$2.9 \times 10^{-5}$** | **$8.5 \times 10^{-4}$** |
| SpCond ($\mu S \cdot cm^{-1}$) | **0.036** | **$4.5 \times 10^{-4}$** | **0.001** |
| Alk ($mEq \cdot L^{-1}$) | **0.032** | **0.001** | **0.001** |
| Temp (°C) | **0.003** | **$4.0 \times 10^{-4}$** | **0.003** |
| $SO_4$ ($mg \cdot L^{-1}$) | **0.008** | **$2.9 \times 10^{-4}$** | **0.010** |
| DOC ($mg \cdot L^{-1}$) | **$6.3 \times 10^{-6}$** | **$7.3 \times 10^{-6}$** | **0.004** |
| DIC ($mg \cdot L^{-1}$) | **0.012** | **0.007** | **$9.6 \times 10^{-4}$** |
| Cl ($mg \cdot L^{-1}$) | 0.089 | 0.145 | 0.166 |
| Ca ($mg \cdot L^{-1}$) | 0.140 | **0.019** | **0.005** |
| Mg ($mg \cdot L^{-1}$) | **0.016** | **$2.5 \times 10^{-5}$** | **$4.8 \times 10^{-4}$** |
| K ($mg \cdot L^{-1}$) | 0.527 | 0.649 | 0.100 |
| Na ($mg \cdot L^{-1}$) | **$4.4 \times 10^{-4}$** | **$3.5 \times 10^{-4}$** | **0.020** |
| $SiO_2$ ($mg \cdot L^{-1}$) | **0.005** | 0.072 | 0.137 |
| TN ($mg \cdot L^{-1}$) | **0.025** | 0.304 | 0.259 |
| $NH_3$ ($\mu g \cdot L^{-1}$) | 0.754 | 0.429 | 0.716 |
| TDP ($\mu g \cdot L^{-1}$) | **$2.1 \times 10^{-5}$** | **$9.6 \times 10^{-4}$** | 0.101 |
| TP ($\mu g \cdot L^{-1}$) | **0.013** | 0.829 | 0.405 |
| Chl *a* ($\mu g \cdot L^{-1}$) | **0.033** | 0.526 | 0.078 |
| DO (% saturation) | 0.102 | **$4.2 \times 10^{-5}$** | **0.011** |

Table 2.2: Summary of seasonal data for limnological variables (early-season, n = 50; mid-season, n = 55; and late-season, n = 26).

| Variable | **Early-season** | | | | **Mid-season** | | | | **Late-season** | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Avg | s.d. | Max | Min | Avg | s.d. | Max | Min | Avg | s.d. | Max | Min |
| Temp (°C) | 8.60 | 4.08 | 17.2 | 2.4 | 16.83 | 1.43 | 19.9 | 13.9 | 3.29 | 1.11 | 6.3 | 1.5 |
| pH | 6.99 | 0.40 | 7.7 | 5.7 | 8.20 | 1.00 | 10.1 | 6.1 | 7.63 | 0.70 | 9.1 | 6.3 |
| SpCond ($\mu S \cdot cm^{-1}$) | 98.28 | 57.82 | 329 | 18.6 | 117.3 | 53.73 | 273.0 | 20.7 | 107.9 | 51.5 | 228 | 21.1 |
| Alk ($mEq \cdot L^{-1}$) | 44.32 | 27.55 | 137.0 | 4.1 | 53.68 | 26.43 | 138.0 | 6.3 | 51.69 | 26.80 | 120.0 | 6.5 |
| Cl ($mg \cdot L^{-1}$) | 0.45 | 0.29 | 1.8 | 0.2 | 0.24 | 0.16 | 0.6 | 0.1 | 0.24 | 0.18 | 0.8 | 0.1 |
| $SO_4$ ($mg \cdot L^{-1}$) | 3.59 | 6.74 | 34.0 | <DL | 4.83 | 7.34 | 31.4 | <DL | 3.09 | 4.32 | 19.7 | 1.5 |
| Ca ($mg \cdot L^{-1}$) | 13.32 | 8.71 | 53.7 | 1.8 | 15.69 | 8.52 | 49.8 | 2.4 | 14.09 | 7.81 | 35.6 | 2.3 |
| Mg ($mg \cdot L^{-1}$) | 3.24 | 2.03 | 10.7 | 0.8 | 4.88 | 2.49 | 12.7 | 1.2 | 4.66 | 2.06 | 8.0 | 1.1 |
| K ($mg \cdot L^{-1}$) | 1.52 | 0.79 | 4.4 | 0.6 | 1.22 | 0.82 | 4.5 | 0.1 | 0.75 | 0.66 | 2.4 | 0.01 |
| Na ($mg \cdot L^{-1}$) | 1.04 | 1.02 | 5.9 | 0.3 | 1.56 | 1.95 | 12.1 | 0.3 | 1.45 | 1.41 | 7.7 | 0.4 |
| DOC ($mg \cdot L^{-1}$) | 12.57 | 7.43 | 35.4 | 2.8 | 15.89 | 7.27 | 36.5 | 2.2 | 13.9 | 5.6 | 27.3 | 1.9 |
| DIC ($mg \cdot L^{-1}$) | 10.63 | 6.51 | 30.8 | 0.9 | 10.78 | 6.21 | 32.0 | 0.9 | 11.2 | 6.1 | 27.6 | 1.6 |
| $SiO_2$ ($mg \cdot L^{-1}$) | 1.16 | 0.95 | 4.0 | 0.03 | 1.06 | 1.28 | 8.1 | 0.02 | 0.75 | 1.87 | 9.5 | <DL |
| $NO_3$+ $NO_2$ ($\mu g \cdot L^{-1}$) | 7.86 | 6.63 | 42.0 | <DL | 12.00 | 4.75 | 29.0 | <DL | 57.00 | 49.43 | 230.0 | 9.0 |
| $NH_3$ ($\mu g \cdot L^{-1}$) | 80.06 | 59.44 | 270.0 | 6.0 | 63.15 | 34.76 | 171.00 | 5.0 | 35.50 | 39.06 | 153.0 | <DL |
| TN ($\mu g \cdot L^{-1}$) | 609.36 | 236.41 | 1500.0 | 140 | 730.11 | 252.18 | 1510.0 | 171.0 | 721.2 | 205.9 | 1190.0 | 201.0 |
| TDP ($\mu g \cdot L^{-1}$) | 14.76 | 11.29 | 59.7 | 3.3 | 16.76 | 20.74 | 128.0 | 1.8 | 12.4 | 8.5 | 34.8 | 2.8 |
| TP ($\mu g \cdot L^{-1}$) | 34.89 | 19.81 | 94.6 | 9.6 | 34.90 | 31.57 | 196.0 | 4.2 | 24.28 | 14.1 | 58.8 | 5.8 |
| N:P | 20.53 | 8.97 | 53.9 | 9.1 | 29.86 | 13.45 | 63.1 | 3.1 | 35.94 | 15.07 | 64.9 | 15.4 |
| Chl *a* ($\mu g \cdot L^{-1}$) | 1.97 | 1.67 | 7.6 | 0.03 | 4.12 | 4.11 | 20.3 | 0.1 | 2.83 | 1.98 | 6.8 | 0.2 |

Note: <DL means lower than detection limit.

Table 2.3: Seasonal averages and standard deviations of limnological variables for the three hydrological categories. Values were calculated using: 16 snowmelt-dominated, 17 intermediate, 17 rainfall-dominated in early-season; 18 snowmelt-dominated, 19 intermediate, 18 rainfall-dominated in mid-season; and 8 snowmelt-dominated, 10 intermediate, 8 rainfall-dominated in late-season.

| | **Snowmelt-dominated** | | | **Intermediate** | | | **Rainfall-dominated** | | |
|---|---|---|---|---|---|---|---|---|---|
| Variable | Early- Avg (s.d.) | Mid- Avg (s.d.) | Late- Avg (s.d.) | Early- Avg (s.d.) | Mid- Avg (s.d.) | Late- Avg (s.d.) | Early- Avg (s.d.) | Mid- Avg (s.d.) | Late- Avg (s.d.) |
| Depth (m) | 2.0 (1.5) | 1.8 (1.5) | - - | 1.5 (0.9) | 1.4 (1.3) | - - | 1.1 (0.4) | 1.1 (0.4) | - - |
| Temp (°C) | 11.07 (3.68) | 17.74 (1.48) | 4.39 (1.01) | 8.50 (4.06) | 16.56 (1.09) | 2.94 (0.70) | 6.38 (3.22) | 16.17 (1.23) | 2.61 (0.82) |
| pH | 6.70 (0.48) | 7.32 (0.87) | 6.89 (0.37) | 7.08 (0.31) | 8.56 (0.92) | 7.93 (0.62) | 7.19 (0.18) | 8.72 (0.54) | 7.99 (0.48) |
| SpCond ($\mu$S•cm$^{-1}$) | 61.5 (37.1) | 78.4 (46.1) | 54.5 (28.3) | 116.4 (73.9) | 126.8(44.2) | 124.2 (36.9) | 108.6 (43.5) | 146.3 (48.9) | 140.8 (45.4) |
| Alk (mEq•L$^{-1}$) | 0.59 (0.42) | 0.71 (0.48) | 0.48 (0.31) | 1.05 (0.64) | 1.14 (0.43) | 1.22 (1.11) | 1.00 (0.46) | 1.37 (0.47) | 1.35 (0.39) |
| Cl (mg•L$^{-1}$) | 0.37 (0.19) | 0.18 (0.09) | 0.19 (0.09) | 0.53 (0.43) | 0.27 (0.19) | 0.25 (0.21) | 0.45 (0.15) | 0.28 (0.17) | 0.26 (0.22) |
| SO$_4$ (mg•L$^{-1}$) | 1.52 (3.23) | 1.20 (2.36) | 0.63 (1.02) | 5.18 (10.17) | 6.09 (9.19) | 2.63 (2.78) | 3.95 (4.35) | 7.14 (7.39) | 6.14 (6.16) |
| Ca (mg•L$^{-1}$) | 9.75 (6.50) | 11.72 (8.11) | 7.20 (4.96) | 15.62 (12.02) | 16.33 (6.64) | 16.26 (6.03) | 14.37 (5.37) | 19.00 (9.44) | 18.26 (8.11) |
| Mg (mg•L$^{-1}$) | 2.15 (1.26) | 2.91 (1.69) | 2.33 (1.03) | 3.53 (1.90) | 5.28 (1.99) | 5.21 (0.91) | 3.97 (2.37) | 6.43 (2.42) | 6.32 (1.81) |
| K (mg•L$^{-1}$) | 1.57 (0.89) | 1.04 (0.46) | 0.85 (0.42) | 1.67 (0.93) | 1.44 (1.06) | 0.81 (0.79) | 1.32 (0.49) | 1.18 (0.80) | 0.58 (0.72) |
| Na (mg•L$^{-1}$) | 0.74 (0.94) | 1.03 (1.66) | 0.73 (0.45) | 1.41 (1.35) | 2.27 (2.75) | 2.17 (2.04) | 0.94 (0.55) | 1.34 (0.60) | 1.28 (0.42) |
| DOC (mg•L$^{-1}$) | 19.2 (8.0) | 21.8 (7.1) | 18.5 (4.8) | 11.5 (5.2) | 15.4 (6.1) | 13.7 (5.5) | 7.4 (2.8) | 10.5 (3.3) | 9.5 (2.3) |
| DIC (mg•L$^{-1}$) | 6.8 (4.8) | 7.5 (5.2) | 5.3 (3.3) | 12.3 (7.2) | 11.1 (5.7) | 12.7 (5.7) | 5.3 (3.3) | 13.7 (6.3) | 15.1 (4.4) |
| SiO$_2$ (mg•L$^{-1}$) | 1.46 (0.86) | 1.21 (1.05) | 0.74 (0.94) | 1.41 (1.20) | 1.25 (1.78) | 1.18 (2.92) | 0.62 (0.42) | 0.70 (0.76) | 0.21 (0.27) |
| NO$_3$+NO$_2$($\mu$g•L$^{-1}$) | 10.75 (8.59) | 12.28 (2.37) | 53.63 (47.06) | 6.06 (6.05) | 11.00 (5.06) | 51.70 (25.74) | 6.94 (3.99) | 12.64 (5.91) | 67.00 (74.11) |
| NH$_3$($\mu$g•L$^{-1}$) | 67.63 (44.76) | 60.00 (36.83) | 70.50 (47.92) | 79.41 (46.69) | 71.26 (39.60) | 17.30 (17.00) | 92.41 (80.27) | 57.72 (26.55) | 23.25 (27.16) |
| TN ($\mu$g•L$^{-1}$) | 706.2 (253.9) | 763.6(240.7) | 824.1 (182.7) | 622.6 (254.6) | 788.9 (288.0) | 667.3(212.1) | 504.9(181.7) | 634.6 (203.8) | 685.6(206.1) |
| TDP ($\mu$g•L$^{-1}$) | 23.80 (14.47) | 27.64 (32.19) | 19.08 (11.73) | 13.47 (7.00) | 14.64 (10.13) | 10.60 (5.29) | 7.54 (2.55) | 8.11 (3.43) | 7.89 (1.63) |
| TP ($\mu$g•L$^{-1}$) | 44.03 (23.73) | 40.71(44.52) | 32.68 (19.64) | 37.08 (18.86) | 30.23 (16.18) | 21.52 (11.06) | 24.10 (10.27) | 34.03 (29.09) | 19.33 (6.14) |
| N:P | 20.78 (12.38) | 30.00 (15.71) | 34.35 (19.67) | 18.58 (7.77) | 30.42 (11.18) | 35.36 (12.76) | 22.26 (5.92) | 29.12 (13.94) | 38.27 (14.33) |
| Chl *a* ($\mu$g•L$^{-1}$) | 2.601 (1.894) | 3.965 (3.558) | 4.294 (2.198) | 2.057 (1.582) | 3.274 (2.962) | 1.875 (1.398) | 1.283 (1.331) | 5.168 (5.461) | 2.552 (1.658) |

Table 2.4: Results of one-way ANOSIM tests on the measured water chemistry variables, water temperature and concentrations of dissolved oxygen (percent saturation) and chlorophyll a during early- (n = 50), mid- (n = 55) and late-season (n = 26). The ANOSIM tests assess if limnological conditions differ among the three hydrological categories (snowmelt-dominated, intermediate and rainfall-dominated) during each of the sampling episodes. For all comparisons, 99,999 random permutations were performed for Monte-Carlo tests of significance. P-values in bold are significant at alpha = 0.05.

| Season | Comparison | R statistic | P-value | # ≥Observed |
|---|---|---|---|---|
| Early-season | Overall | 0.197 | **$1.0x10^{-5}$** | 0 |
| Early-season | Snowmelt, Rainfall | 0.413 | **$1.0x10^{-5}$** | 0 |
| Early-season | Snowmelt, Intermediate | 0.097 | **0.018** | 1834 |
| Early-season | Rainfall, Intermediate | 0.096 | **0.010** | 949 |
| | | | | |
| Mid-season | Overall | 0.225 | **$1.0x10^{-5}$** | 0 |
| Mid-season | Snowmelt, Rainfall | 0.417 | **$1.0x10^{-5}$** | 0 |
| Mid-season | Snowmelt, Intermediate | 0.235 | **$2.0x10^{-4}$** | 21 |
| Mid-season | Rainfall, Intermediate | 0.022 | 0.188 | 18,804 |
| | | | | |
| Late-season | Overall | 0.348 | **$3.0x10^{-5}$** | 2 |
| Late-season | Snowmelt, Rainfall | 0.713 | **$3.0x10^{-4}$** | 2 |
| Late-season | Snowmelt, Intermediate | 0.460 | **$3.0x10^{-4}$** | 13 |
| Late-season | Rainfall, Intermediate | -0.024 | 0.591 | 25,865 |

# *Chapter 3. Biotic responses to multiple aquatic and terrestrial gradients in shallow subarctic lakes (Old Crow Flats, Yukon, Canada).*

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### 3.1. Outline

Biotic communities in shallow northern lakes are frequently used to assess environmental change, however, the influence of complex interactions among multiple factors on biota remain understudied. Here, we present analysis of a comprehensive data set that evaluates the influence of input waters, catchment characteristics, limnology, and sediment properties on diatom and chironomid assemblages in surface sediments of ~49 shallow mainly thermokarst lakes in Old Crow Flats, Yukon. Multivariate analyses and ANOSIM tests identified that composition of diatom (119 taxa) and chironomid (68 taxa) assemblages differ significantly ($p<0.05$) between lakes with snowmelt- versus rainfall-dominated input water. Redundancy analysis revealed strong correlation of limnological, sediment, and catchment variables with input waters. Variation partitioning analysis showed that unique effects of limnological variables account for the largest proportion of variation in diatom and chironomid assemblages (17.2, 12.6 %, respectively). Important independent roles of sediment properties (8.5, 9.5 %) and catchment characteristics (4.9, 5.1 %) were also identified. We suggest that the substantial variation shared among these classes (6.1, 7.9 %) is largely attributable to hydrological processes. Our study demonstrates the utility of multi-factor analysis in northern aquatic research and draws attention to the limitations of one-dimensional comparisons and their interpretations when modelling biotic responses to environmental change.

## *3.2.Introduction*

In northern regions, climate warming of recent decades has led to earlier onset of snowmelt (Stone et al. 2002), shorter ice-cover duration (Brown and Duguay 2011), expansion of snow-trapping shrub vegetation (Sturm et al. 2001; Myers-Smith et al. 2011a, b), permafrost degradation (Osterkamp 2005; White et al. 2007), and changes in precipitation and evaporation (Kattsov and Walsh 2000; Derksen and Brown 2012; Bintanja and Selten 2014). The numerous shallow lakes, including those of thermokarst origin, are highly responsive to the effects of climate warming due to their large surface area to volume ratios (Hinzman et al. 2005) and catchment characteristics (Turner et al. 2014; Medeiros et al. 2014). Indeed, marked hydrological changes have already occurred, but the directions of change have varied among regions and individual lakes. These include increased incidence of lake-drainage (Smith et al. 2005; Pohl et al. 2009; Lantz and Turner 2015) and desiccation events (Smol and Douglas 2007; Bouchard et al. 2013b) that have been linked to changes in precipitation and evaporation. Hydrologic changes are expected to exert strong control on the limnology and biotic community structure of northern lakes, potentially causing cascading effects in food-webs (Quinlan et al. 2005; Wrona et al. 2006). While, there is growing evidence that climate warming leads to alteration of biotic community structure of northern lakes (Smol et al. 2005; Medeiros and Quinlan 2011; Rühland et al. 2015), few studies have explored indirect climate-mediated effects (Anderson 2000). A clearer understanding of the complex interactions among multiple, climate-mediated landscape processes may elucidate mechanisms underlying biotic responses to climate warming.

The lack of long-term datasets for lakes and ponds in remote northern regions challenges our ability to understand the direct and indirect effects of climate change on freshwater biota, despite recognition that climate variation is an overarching driver of limnological conditions (Rouse et al. 1997; Keller 2007). Recent research demonstrates that variation of lake water chemistry is driven by inter-related gradients of catchment characteristics and hydrology (Stewart and Lamoureux 2011;

Herzschuh et al. 2013; Balasubramaniam et al. 2015), which are strongly associated with climate conditions. For example, warming is increasing the density of shrub vegetation, which traps more snow (Pomeroy et al. 2006). This leads to greater snowmelt input (Turner et al. 2010; 2014) and increased supply of allochthonous nutrients (e.g., N, P) and dissolved organic carbon (DOC) to downstream lakes and rivers (Finlay et al. 2006; Townsend-Small et al. 2011; Lapierre et al. 2015). Increased lake-water concentration of nutrients and DOC has also been associated with climate warming, via stimulation of terrestrial production and microbial decomposition within the catchment, and release of elements from previously-frozen ground (Frey and Smith 2005). Elevated frequency and intensity of rainfall events sufficiently large to exceed soil moisture deficits leads to greater hydrologic connectivity (Bowling et al. 2003; Woo and Guan 2006) and delivery of catchment-derived solutes to lakes (Herzschuh et al. 2013). Higher rates of lake evaporation, when not offset by the diluting effects of precipitation (Turner et al. 2010; 2014), are associated with increased concentration of ions in lake water during the ice-free season (Corcoran et al. 2009; Balasubramaniam et al. 2015). Clearly, the complex interplay among catchment characteristics and hydrology, driven by climate, influences water chemistry of northern lakes.

Shallow northern lakes tend to have food-webs dominated by benthic biota, which are often responsive to changes in environmental processes (Sierszen et al. 2003; Rautio and Vincent 2007; Cazzanelli et al. 2012). Diatoms, a group of mainly single-celled algae with siliceous cell walls (Chromista: Bacillariophyta), and chironomids, non-biting midges with chitinous exoskeletons (Insecta: Diptera: Chironomidae), are well represented in lake sediments (Birks 1998; Douglas and Smol 1999; Brodersen and Quinlan 2006) because taxonomically diagnostic components are relatively resistant to post-depositional degradation processes (Battarbee 2000; Axford et al. 2009). Importantly, they respond sensitively and rapidly to changes in water chemistry (Hall and Smol 1996; Medeiros and Quinlan 2011), climate (Smol et al. 2005; Fortin et al. 2015), and catchment-mediated processes

(Thienpont et al. 2013; Medeiros et al. 2014). Thus, analysis of diatoms and chironomids in lake sediments can serve to improve knowledge of how climate-driven interactions amongst catchment characteristics, hydrology, and limnology affect aquatic biota of shallow northern lakes.

Old Crow Flats (OCF; Yukon, Canada) is a remote, undeveloped, subarctic, lake-rich lowland landscape that provides exceptional opportunity to quantitatively assess effects of multiple environmental gradients on benthic biota. Previous analyses of lakes sampled across OCF have demonstrated strong relations among catchment features, water balance, and limnology (Turner et al. 2010; 2014; Balasubramaniam et al. 2015). Water balances of lakes are influenced mainly by snowmelt, rainfall, and evaporation, whose relative roles are associated with catchment features (Turner et al. 2010; 2014). For example, Turner et al. (2014) demonstrated that input waters to lakes with abundant tall shrubs and trees in the catchment, which entrap wind re-distributed snow, tend to be dominated by snowmelt, whereas lakes situated in catchments dominated by tundra vegetation possess water balances dominated by rainfall input. An investigation of water chemistry in the same lake set by Balasubramaniam et al. (2015) found that the lakes dominated by snowmelt input possess higher concentrations of nutrients (N, P) and DOC than lakes dominated by rainfall inputs, likely due to enhanced interaction of snowmelt with organic matter in densely vegetated catchments. The snowmelt-dominated lakes are often situated closer to the fringe of OCF where they experience enhanced hydrologic connectivity to the surrounding hill slopes (Turner et al. 2014; Balasubramaniam et al. 2015). Balasubramaniam et al. (2015) found that lakes dominated by rainfall inputs possess relatively higher conductivity, alkalinity and ion content than lakes dominated by snowmelt inputs. They attributed these differences to the stronger influence of evaporation on lake water balance of the rainfall-dominated lakes (due to their large surface area to volume ratios; Turner et al., 2010). However, input of ions from shoreline erosion, which occurs more rapidly in lakes within tundra catchments that have higher density of rectangular ice-wedge networks, and stormwater runoff events, delivering solutes from mineral-rich soils, are also suggested as possible mechanisms affecting ionic content of the rainfall-dominated lakes (Balasubramaniam et al. 2015).Based on analysis of seasonal water samples (spring, mid-summer, fall), Balasubramaniam et al. (2015) also identified existence of a subset of lakes whose water balances were dominated by snowmelt inputs in spring and transitioned to dominance by rainfall inputs later in the ice-free season. These “intermediate” lakes possess water chemistry values in between those of the snowmelt- and rainfall-dominated lakes in spring, and values often converge towards those typical of the rainfall-dominated lakes by mid-summer (Balasubramaniam et al. 2015).

Here, we build on prior hydrological (Turner et al. 2010; 2014) and limnological (Balasubramaniam et al. 2015) studies to assess the variation in benthic communities using catchment land-cover classification, lake-water isotope and chemistry data from July 2007 and 2008, and surface sediment properties obtained from 49 lakes in 2008. Our aims were to: 1) test if the composition of recently deposited diatom and chironomid assemblages in surficial sediments differs in lakes fed predominantly by snowmelt versus rainfall inputs; 2) determine relations between assemblage composition and limnological variables, sediment properties, and catchment characteristics; and, 3) quantify the amount of unique and shared variation in assemblage composition explained by classes of measured environmental variables. For the third objective, we used variation partitioning analysis (VPA; Borcard et al. 1992; Hall et al. 1999) to quantify unique and combined effects of limnological, sediment, and catchment classes on composition of diatom and chironomid assemblages, and assess the importance of hydrological processes. If hydrological processes exert strong influence on biotic assemblages, we expect that substantial amounts of variation will be explained by covariation of two or more of the classes in the VPA. Recent reviews have alluded to relations between changing hydrology and community composition in Arctic and subarctic freshwater ecosystems (Anderson 2014; Wrona et al. 2016) but to our knowledge the complex interplay among landscape-mediated factors and their influence on aquatic biota has not been described in a quantitative manner.Such knowledge is key to improve our understanding of the cumulative effects of multiple interacting processes on aquatic biota in a lake-rich subarctic landscape experiencing warming.

## *3.3.Site Description*

Covering an area of 5,600 km$^2$, OCF is an unglaciated low-lying wetland landscape (~290 m a.s.l.) located within a region of continuous permafrost (Yukon Ecoregions Working Group, 2004; Figure 3.1). OCF is situated within the Taiga Cordillera Ecozone (Yukon Ecoregions Working Group 2004) and the terrestrial vegetation broadly transitions from boreal-taiga to tundra. OCF is underlain by relatively uniform unconsolidated glaciolacustrine sediment, consisting of clay, silt, sand, and gravel, with patches of intermixed alluvial sediments covered by deposits of peat and organic detritus (Hughes 1972; Ovenden 1981). The abundant thermokarst lakes are typically shallow and macrophyte-rich (Balasubramaniam et al. 2015). Average annual air temperature is -9.0 °C and annual precipitation is 265.5 mm with 54.3 % falling as rainfall (1971-2000 climate normal, station ID 2100800, Environment Canada 2007). According to dendroclimatological analysis, OCF has been experiencing marked warming in recent decades (Porter and Pisaric 2011).

## *3.4.Methods*

### *3.4.1. Determination of Catchment Land-Cover*

The 49 lake catchments were delineated using a 2007 SPOT 5 (Système Pour l'Observation de la Terre) image, a 30-m resolution digital elevation model, oblique aerial photographs and field observations (Turner et al. 2014). Land cover for these catchments was quantified by performing a supervised classification of a Landsat 5 TM mosaic (Turner et al. 2014). Five broad land-cover classes were identified: 1) woodland/forest vegetation consisting mainly of black spruce (*Picea mariana*), white spruce (*Picea glauca*), and birch trees (*Betula* spp.); 2) tall shrub vegetation consisting predominantly of willows (*Salix* spp.); 3) dwarf shrub/herbaceous vegetation consisting mainly of low shrub thickets (e.g., *Betula*, *Alnus*, and *Salix* spp.), ericaceous shrubs (e.g., *Vaccinium* and *Ledium* species), and vascular (e.g., *Eriophorum* spp.) and non-vascular (e.g., *Sphagnum* spp.) plants; 4) sparse low-growing vegetation with abundant areas of dry or wet barrens, exposed rock, and sand patches; and, 5) surface water (lakes, rivers, and wetlands).

### *3.4.2. Field Methods*

Fifty–six lakes were selected from across OCF landscape to capture the large spatial gradients in basin hydrology and limnological characteristics (e.g., colour, aquatic vegetation, and morphometry) based on consultation with local community members who attended a mapping workshop and observations made during helicopter flights, as described in Wolfe et al. (2011). From the floats of a helicopter, water samples were collected at a central location (or, at least 200-300 m from shore) at all 56 lakes three times (June, July, and September) during the ice-free season of 2007, as described in Balasubramaniam et al. (2015). Sampling was repeated again during the ice-free season of 2008 and 2009. In this study, we use the averaged values of water chemistry variables from July 2007 and July 2008 for a subset of 49 lakes from which we obtained surface sediments in September 2008. *In situ* measurements were recorded for temperature (Temp), pH, specific conductivity (Cond), and dissolved oxygen concentration (as percent saturation; DO%) using a YSI 600QS multi-meter (YSI Ltd., 1700/1725 Brannum Lane, Yellow Springs, Ohio). These measurements were recorded consistently at 30 cm below surface, the depth required to fully immerse the YSI sonde while ensuring maximum depth of lakes were not exceeded. Water samples for chemistry analyses were collected from 15 cm water depth, after sample bottles were pre-rinsed three times using lake water. Water samples were kept cool (4 °C) and dark until processed. Consistent with Balasubramaniam et al. (2015), water was pre-screened using a 200-µm Nitex mesh to remove coarse particles prior to measuring chemical concentrations of the lake water. A portion of the water was filtered through a 0.45-µm cellulose acetate filter, and the filtrate was used to determine the concentrations of total dissolved phosphorus (TDP), dissolved inorganic carbon (DIC), and dissolved organic carbon (DOC). Remaining water was bottled without filtering for analyses of total phosphorus (TP), total nitrogen (TN), nitrite+nitrate ($NO_2NO_3$), ammonia ($NH_3$), silica ($SiO_2$), major ions ($Ca^{2+}$, $Cl^-$, $Mg^{2+}$, $Na^+$, $K^+$, $SO_4^{2-}$), and alkalinity (Alk). Samples for phosphorus analyses (TP, TDP) were preserved by adding 1 ml of 30 % $H_2SO_4$ to each 125 ml bottle of sample water. Additional samples of water (30 ml) were collected for isotope ($^{18}O$, $^{2}H$) analyses.

Surface sediments were collected from the same central location as the water samples in 49 of the 56 lakes in early September 2008 using a mini-Glew gravity corer (Glew 1991). The top ~1 cm of 4-5 replicate sediment cores were placed into a single Whirl-Pak® bag and stored at 4$^{o}$C in the dark until subsequent analyses.

### *3.4.3. Laboratory Methods*

#### *3.4.3.1. Water Chemistry and Isotope Composition*

Chemical analyses were performed by Environment Canada's National Laboratory for Environmental Testing (NLET) in Burlington, Ontario, following standard methods (Environment Canada 1996). Water chemistry data for 2007 were reported in Balasubramaniam et al. (2015). Water samples for determination of oxygen and hydrogen isotope composition were transported in 30 ml high-density polyethylene bottles for analysis at the University of Waterloo – Environmental Isotope Laboratory (UW-EIL). Isotope data used here have been reported in Turner et al. (2010; 2014). To assess the influence of variation in water chemistry variables on surface-sediment diatom and chironomid assemblage composition, we averaged the mid-season (July) values obtained in 2007 and 2008, as this period represents typical growth-season conditions and precedes collection of the surface sediment samples. A two-year average was used because sampled lake surface sediments likely represent more than one year of deposition.

The oxygen isotope composition of input waters ($\delta^{18}O_I$) was estimated to assess the relative contribution of snowmelt versus rainfall for each lake, following methods as described by Turner et al. (2014). Consistent with analysis of the water chemistry data, we calculated the mid-season (July) average of $\delta^{18}O_I$ in 2007 and 2008 for each lake, and used the average values to divide lakes into the three input-water categories (snowmelt-dominated = -26.0 to -24.2 ‰ (n=15), intermediate = -24.1 to -22.9 ‰ (n=14), and rainfall-dominated = -22.8 to -18.5 ‰ (n=20)) using methods described in Balasubramaniam et al. (2015). The placement of each lake into these three input-water categories allowed for assessment of whether water chemistry variables, sediment properties, and composition of biotic assemblages vary due to differences in input water sources (see *Numerical Analyses* below).

#### *3.4.3.2. Sediment Properties*

Sediment sub-samples were analyzed for bulk content (expressed per dry sediment mass) of organic matter (%OM) and mineral matter (%MM) using loss-on-ignition (LOI) methods (Heiri et al. 2001). To determine the organic carbon ($\%C_{org}$) and nitrogen (%N) content and isotope composition ($\delta^{13}C_{org}$ and $\delta^{15}N$), sub-samples of wet sediment were treated with a 10 % HCl solution in a 60 °C water bath to remove carbonates, and then rinsed with de-ionized water repeatedly until a neutral pH was reached. Coarse sediment was then removed using a 500-µm sieve, and the fine fraction was analyzed using an elemental analyzer interfaced with a continuous flow isotope ratio mass spectrometer at the UW-EIL. Results are reported in δ notation, as per mil (‰) relative to Vienna Pee Dee Belemnite (VPDB) standard for carbon isotope composition, and atmospheric nitrogen (AIR) for nitrogen isotope composition. Analytical uncertainties were ±0.07 ‰ for carbon isotope composition and ±0.06 ‰ for nitrogen isotope composition based on repeated analyses of samples. We calculated carbon-to-nitrogen (C/N) ratios using percent dry weight of organic carbon and nitrogen.

#### *3.4.3.3. Biological Analysis*

Diatom analysis was conducted on surface sediments from the 49 OCF lakes. Microscope slides were prepared from sub-samples of wet sediment by acid digestion following standard methods (Hall and Smol 1996). For each sample, a minimum of 400 diatom valves were identified and enumerated along transects using a Zeiss Axioskop II Plus compound microscope (Carl Zeiss Light Microscopy, Göttingen, Germany) with differential interference contrast optics (1000x magnification, numerical aperture = 1.30). Diatom taxonomy followed Krammer and Lange-Bertalot (1986–1991) and Lavoie et al. (2008). Diatom nomenclature for *Fragilariforma virescens* and *Navicula aitchelbee* followed Morales and Spaulding (2011) and Bahls (2012). Data were expressed as taxon relative abundances (percent of the total sum of diatom valves in each sample). An analysis of outliers was conducted, where 95 % confidence limits were calculated for the sample scores on the first two axes of a detrended correspondence analysis (DCA) of diatom data (Gauch 1982). No sites were identified as outliers.

Sediment samples for 44 of the 49 OCF lakes were processed for subfossil chironomid head capsules, following Medeiros and Quinlan (2011). Due to a lack of available sediment, chironomids were not processed for lakes OCF 3, 9, 14, 15, and 53. A minimum of 50 head capsules (Quinlan and Smol 2001) were extracted from sediments washed through nested 212- and 106-μm mesh sieves. Chironomid head capsules were individually mounted onto glass slides and identified at 400-1000× magnification to the best taxonomic resolution possible, as per Medeiros and Quinlan (2011). Specimens were enumerated and the data were expressed as taxon relative abundances (percent of the total sum of identifiable midges). OCF 42 and 43 were identified as outliers, as they exceeded the 95% confidence intervals of the DCA species scores. Consequently, they were removed from subsequent analysis, leaving 42 of the 49 OCF lakes available for numerical analysis of chironomid assemblages.

### *3.4.4. Numerical Analysis*

We determined if composition of recently deposited sedimentary assemblages of diatoms and chironomids within study lakes differ among the three input-water categories (snowmelt-dominated, intermediate, and rainfall-dominated) using statistical tests and exploratory data analyses [Objective 1]. Analysis of Similarities (ANOSIM) tests were conducted to determine if the composition of surface sediment diatom and chironomid assemblages differed among lakes designated by the three input-water categories. Taxon percent abundances were square-root transformed prior to computing Bray-Curtis dissimilarities (with 99999 random permutations), to down-weight influence of highly abundant taxa (Clarke and Warwick 2001; Clarke and Gorley 2006). The global R reflects the observed differences in biotic assemblages among the input-water categories contrasted with the differences among replicates within each category, and ranges from 0 to 1. A value of 0 indicates that the similarity between and within input-water categories is the same on average. A value of 1 indicates that replicates within a category are more similar to each other than to all other replicates of other categories (Clarke and Warwick 2001). Also, detrended correspondence analysis (DCA) was used to assess the spatial variation and compositional turnover (gradient lengths of the first two axes) of square-root transformed diatom and chironomid assemblage percent abundance data (ter Braak and Šmilauer 2002). Sample scores were coded in the ordination plots to explore differences in assemblage composition among the three input-water categories. A non-hierarchical K-means cluster analysis of DCA sample scores for diatom and chironomid assemblages was subsequently performed to objectively assess biotic differences among the input-water categories. Ellipsoids encompassing points within the 95 % confidence interval of detected clusters were added to the DCA plots.

In order to determine if variation in limnological conditions and sediment properties could account for observed differences in diatom and chironomid composition among lakes in the three input water categories (snowmelt-dominated, intermediate, and rainfall-dominated lakes), non-parametric

Kruskal-Wallis tests of significance and subsequent Tukey HSD post-hoc tests examining pairwise differences between input water categories were run. Tukey's post-hoc tests were only run for limnological and sediment variables that generated a significant result ($p \leq 0.05$) in Kruskal-Wallis tests. Concentrations of $NO_2$+$NO_3$ were removed from all numerical analyses as values were below detection limits in >30 % of the lakes.

Direct gradient ordination was used to explore relations between the composition of diatom and chironomid assemblages and the measured environmental variables [Objective 2]. Due to intermediate DCA gradient lengths for diatom assemblages (2.376, 2.180 for axes 1 and 2, respectively), and many zero values (ter Braak 1987), we employed redundancy analysis (RDA) utilizing a chi-square distance-transformation, as suggested in Legendre and Gallagher (2001). This avoided errors associated with Euclidean distances within an RDA linear model, while preserving the weighting of species that could capture taxon-specific gradients. Each variable was assessed for significant correlation with diatom and chironomid assemblage composition (function anova.cca, 9999 permutations). Parsimonious forward selection (hereafter referred to as 'forward selection') was conducted to identify a subset of environmental variables that explain independent and significant ($p \leq 0.05$) directions of variation in assemblage composition among sites (following Blanchet et al. 2008). Results of the RDA were presented as biplots, and sample scores were coded using the a priori input-water categories to assess the role of hydrology on taxon-environment relations. Prior to RDA analysis, variables were checked for normality using Kolmogorov-Smirnov tests, and variables with a non-normal distribution were transformed using square-root or log(x+1) (Table S1).

Variation partitioning analysis (VPA; Borcard et al. 1992; 2011) was performed to quantify the unique and shared variation in composition of diatom and chironomid communities explained by classes of explanatory variables: limnology (L), sediment properties (S), and catchment variables (C)

[Objective 3]. Hydrology, as represented by $\delta^{18}O_I$, was highly collinear with variables in all three classes, and so was not explicitly evaluated by the VPA. Five steps, as outlined in Hall et al. (1999), were required to partition variation in assemblage composition among the three classes. First, a constrained ordination, without covariables, measured the total variation in assemblage composition attributed to all explanatory variables (L+S+C) and the total unexplained variation (100-(L+S+C)). Second, a series of partial ordinations calculated variation explained by the unique effects of each category (L, S, or C). Here, the partial ordinations were run with variables of a single category as the explanatory variables, and variables in the remaining two categories as covariables. Third, a series of partial ordinations calculated the individual effects plus first order covariations for each class (L+LS, L+LC, S+LS, S+SC, C+LC, C+SC). In each partial ordination, one category of explanatory variables was paired with one of the remaining categories as a covariable. Fourth, first-order covariation terms (LS, LC, SC) were calculated by subtracting the effects of each other category (e.g., LS = L-(L+LS)). Finally, the second-order covariation was calculated as the difference between 100% and the sum of the variation of all other steps (LSC = 100–L–S–C–LS–LC–SC–unexplained). If hydrological processes exert strong influence on composition of diatom and chironomid assemblages, a large portion of the explained variation in assemblage composition will be captured by the first- and second-order covariation terms (LS, LC, SC, LSC).

For all analyses of biotic data, we retained taxa with a minimum abundance of 2 % and present in at least two lakes to minimize influence of rare taxa (Quinlan and Smol 2001; Rühland and Smol 2005). All ordinations (DCA, RDA) were conducted using the R statistical language v3.1.1 with the pack for and vegan libraries.

## *3.5. Results*

### *3.5.1. Influence of Source Water on Limnology, Sediment Properties, and Biota*

Approximately 20,650 diatom valves representing 265 different taxa were enumerated in surface sediment samples from the 49 lakes analyzed. Of these, 119 taxa met our criteria for inclusion in numerical analyses (Table S2). On average, lakes contained 51 different diatom taxa (median = 52; range 18-81). Diatom taxa consisted mainly of araphid, monoraphid, and raphid, pennate taxa capable of attaching to substrates. Over 6,300 chironomid head capsules representing 89 taxa were extracted and identified from the 42 lakes analyzed. Of these, 68 taxa met our criteria for inclusion in numerical analyses. On average, lakes contained 29 different chironomid taxa per lake (median = 30; range 10-42) (Table S3).

ANOSIM test results demonstrated that the composition of diatom and chironomid assemblages differ significantly between lakes in the snowmelt- and rainfall-dominated categories (Table 3.1). Diatom assemblage composition also differs significantly between snowmelt-dominated and intermediate lakes, but chironomid assemblage composition does not (Table 3.1). Low values of the R statistic (R= 0.195 and 0.086 for diatoms and chironomids, respectively) suggest that factors other than input water also contribute to variation in assemblage composition.

Composition of diatom and chironomid assemblages differs distinctly between lakes with snowmelt- versus rainfall-dominated input water, as outlined by dispersion of sample scores in the DCA (Figure 3.2; Table 3.2, Tables S2, S3). Cluster analysis identified distinct community composition, as represented by small overlap of the 95 % confidence ellipsoids (Figure 3.2a, b). However, sample scores for lakes in the intermediate category overlap with those for the rainfall- and snowmelt-dominated lakes, and do not form a distinct cluster (Figure 3.2). Taxa that are centrally located on the plot were broadly distributed among the study lakes (e.g., *Achnanthidium minutissimum* [taxon 3 in Figure 3.2c] and *Staurosirella pinnata* [113] for diatoms, and *Polypedilum* [taxon 48 in Figure 3.2d] and *Dicrotendipes* [21] for chironomids (Note: authority names for all taxa are presented in Tables S2, S3). Diatom taxa with higher relative abundance in the snowmelt-dominated lakes include: *Tabellaria flocculosa* [118], *Pinnularia nodosa* [100], *Eunotia bulinaris* [34], *Eunotia implicata* [37], *Eunotia incisa* [38], and *Eunotia spp.* [40], which are positioned on the right of the DCA ordination (Figure 3.2a, c and Figure S1; Table S2). Chironomid taxa with higher relative abundance in the snowmelt-dominated lakes include: *Glyptotendipes barbipes*-type [25], *Corynocera ambigua* [2], and *Psectrocladius monopsectrocladius*-type [53], as well as *Chaoborus* taxa [5] (Figure 3.2b and Figure S2; Table S3). In contrast, diatoms characteristic of rainfall-dominated lakes include: *Gomphonema olivaceum* [53], *Navicula reichardtiana* [80], *Nitzschia* spp. [93], and *Calonies silicula* [14] (Figure 3.2 a, c and Figure S1; Table S2). Chironomid taxa associated with rainfall-dominated lakes include: *Chaetocladius* [4], *Psectrocladius barbipes-type* [51], *Orthocladius type i* [38], and *Corynoneura arctica* [11] (Figure 3.2b,d and Figure S2; Table S3).

Kruskal-Wallis tests performed on water chemistry data averaged for July 2007 and 2008 identified that 12 limnological variables and one sediment variable differ significantly among the input-water categories (Table 3.3; Table S4). The test results were comparable to those obtained previously by Balasubramaniam et al. (2015) for July 2007 data only, with the exception that when data were averaged for 2007 and 2008 temperature did not differ significantly among lakes within the three input-water categories, and $Cl^-$ concentrations did differ significantly among lakes in the three input water categories. Tukey's post-hoc pair-wise comparisons based on the average of July 2007 and 2008 data (not shown here) were also broadly consistent with results reported for mid-season of 2007 alone by Balasubramaniam et al. (2015). These results identify that snowmelt-dominated lakes have significantly higher concentrations of DOC, TP and TDP, but significantly lower specific conductivity, pH, alkalinity, and lower concentrations of dissolved oxygen, major ions ($Cl^-$, $Ca^{2+}$, $Mg^{2+}$, $Na^+$, $SO_4^{2}$)

and DIC than lakes in the rainfall-dominated category. Values for the intermediate category typically fell between those of the snowmelt- and rainfall-dominated lakes. Tukey post-hoc tests identified that rainfall-dominated lakes have significantly higher $\delta^{13}C_{org}$ than lakes in the snowmelt-dominated and intermediate categories (Table 3.3). Surface sediment values of $\delta^{15}N$, %$C_{org}$, %N, C: N, %OM and %MM ratios do not differ significantly among input-water categories).

Similar to the unconstrained DCA ordination, constrained ordination using RDA with forward selection resulted in separation of sample scores (biotic assemblages in lakes) for snowmelt-dominated lakes from those of rainfall-dominated lakes. Forward selection identified that four limnological variables (TDP, $Ca^{2+}$, $Mg^{2+}$, DO %), two sediment variables (%$C_{org}$, %OM), and one catchment variable (%Surface water) explain independent and significant directions of variation in diatom assemblage composition among lakes (Figure 3.3a; Table S5). RDA of the chironomid data identified four limnological variables (TN, Alk, DO, DOC), two sediment variables (%MM, %OM), and one catchment variable (%Sparse vegetation) that explain independent and significant directions of variation in assemblage composition (Figure 3.3b; Table S5). The RDA captured 30.0 % and 33.7 % of the total variation of the diatom and chironomid data, respectively. The species-environment correlations for the first two axes of the RDA were high (0.953 and 0.889 for diatoms; 0.884 and 0.848 for chironomids, respectively) (Table 3.2). In the RDAs, $\delta^{18}O_I$ was not selected because it is highly collinear with the forward-selected environmental variables. Nonetheless, $\delta^{18}O_I$ explains a significant ($p< 0.001$) amount of variation in assemblage composition for both diatoms and chironomids (5.143 and 5.593 %, respectively) in RDAs singularly constrained to $\delta^{18}O_I$. Thus, to visualize the collinear relations between variables and biotic assemblages, we passively projected $\delta^{18}O_I$ in the RDA ordinations. For diatoms, this identifies positive correlation of $\delta^{18}O_I$ with concentrations of ions (Cond, $Ca^{2+}$, $Mg^{2+}$), and negative correlation with TDP, DOC, %$C_{org}$, and %Woodland vegetation (Figure 3.3c). For chironomids, the RDA identified positive correlation of $\delta^{18}O_I$ with Cond, Alk, pH, %MM,

$\delta^{13}C_{org}$, and %Surface water, and negative correlation with %OM, DOC, and %Woodland vegetation (Figure 3.3d). Strong correlation of $\delta^{18}O_I$ with these variables suggests that hydrological processes influence biotic communities via complex interactions among limnological conditions, sediment properties, and catchment characteristics.

### *3.5.2. Partitioning Variation in Biological Community Composition*

Variation partitioning analysis (VPA) for diatoms indicated that limnology alone (L), independent of the other classes of environmental variables, explained the largest portion of variation (17.2 %), followed by sediment alone (S, 8.5 %; Figure 3.4). Shared variation among the three classes of environmental variables (LSC+LS+LC+SC, 6.1 %) explained more variation than catchment alone (C, 4.9 %). Of the shared variation, 2.6 % was explained by covariation among all three classes (LSC), 1.9 % by covariation between limnology and sediment (LS), 0.8 % by covariation between sediment and catchment (SC), and 0.7 % by covariation between limnology and catchment (LC).

Similar to the diatom results, VPA results show that limnology alone (L) captured the largest portion of explained variation (12.6 %) of chironomid assemblages, followed by sediment alone (S, 9.5 %; Figure 3.4). Shared variation among the three classes of environmental variables (LSC+LS+LC+SC, 7.9 %) explained more variation than catchment alone (C, 5.1 %). Of the shared variation, 4.0 % was explained by covariation among all three classes (LSC), 2.4 % by covariation between limnology and sediment (LS), 0.9 % by covariation between limnology and catchment (LC), and 0.6 % by covariation between sediment and catchment (SC). Overall, VPA captured 36.7 and 35.2 % of the total variation of the diatom and chironomid data, respectively, leaving 63.3 % and 64.8 % unexplained by the supplied environmental variables.

## *3.6. Discussion*

Complex interactions among a host of environmental processes and landscape factors are known to influence biotic assemblages in northern and alpine aquatic ecosystems (Kernan et al. 2009; Sweetman et al. 2010; Medeiros et al. 2015). Variation in input waters to alpine streams is associated with differences in physico-chemical conditions, and the diversity and richness of diatom and chironomid communities (Füreder et al. 2001; Robinson and Kawecka 2005; Roy et al. 2011). However, comparable research incorporating knowledge of source-water input and multiple environmental gradients has not yet been undertaken to discriminate their direct and indirect influence on benthic biota in northern lakes and ponds. Admittedly, collecting the data needed to decipher effects of complex interactions among multiple, interrelated environmental factors on the structure of biotic communities in northern lakes and ponds is challenging. At OCF, however, availability of catchment land-cover and water isotope data for 49 lakes across landscape gradients offered unique opportunity to incorporate quantitative hydrological and catchment variables to the analyses of biotic assemblages. Other regional-based studies typically have been restricted to collection and analyses of water chemistry and surface-sediment variables (Rühland and Smol 2002; Porinchu et al. 2009). Here, we utilize the rich dataset from OCF to demonstrate that composition of recently-deposited diatom and chironomid assemblages differs between lakes receiving predominantly snowmelt versus those receiving predominantly rainfall. Our results show that these differences in assemblage composition are regulated by complex interplay of hydrological processes with catchment characteristics and in-lake processes that affect water chemistry and sediment properties.

### *3.6.1. Influence of Source Waters on Limnology, Sediment Properties, and Biota*

As shown by Turner et al. (2010; 2014), lakes in OCF with snowmelt-dominated input possess a greater proportion of woodland and tall shrub vegetation, and thus have greater capacity to entrap wind re-distributed snow compared to rainfall-dominated lakes, which are surrounded by sparse, tundra vegetation (Figure 3.1). Similar to analyses of water chemistry by Balasubramaniam et al. (2015), we find that the snowmelt-dominated lakes in OCF have higher concentrations of nutrients and DOC, lower pH, and lower concentration of ions and DIC than lakes dominated by rainfall input (Table 3.3). Interaction of snowmelt with terrestrial organic-rich detritus and soil was suggested to increase transport of DOC and nutrients to the snowmelt-dominated lakes, which raises lake-water concentrations of DOC and nutrients above values typical of rainfall-dominated lakes (Balasubramaniam et al. 2015). In contrast, the rainfall-dominated lakes have higher pH and ionic content, and lower nutrient concentration than that of the snowmelt-dominated lakes (Table 3.3). Greater surface area of rainfall-dominated lakes and associated evaporative enrichment of dissolved ions, deposition of dissolved mineral matter from shoreline erosion that occurs more rapidly in sparsely vegetated tundra catchments with ice-wedge features, and influx of ion-rich material delivered by storm water runoff have been proposed as possible mechanisms that contribute to higher ionic concentrations (Balasubramaniam et al. 2015). It is also possible that some of the difference in ionic content is caused by snowmelt dilution effects on snowmelt-dominated lakes (Lim et al., 2001a). We show here that the hydro-limnological patterns presented in Balasubramaniam et al. (2015), based on seasonal water samples (spring, summer, and fall) during a single year (2007), remain consistent for July samples spanning two years (2007, 2008; Table 3.3). Thus, they are patterns that persist for more than a single season or single year.

The low C/N ratio of surface sediment in OCF lakes (mean±SD = 11.13±1.36) suggests that the organic matter originates mainly from autochthonous primary production (Meyers and Teranes 2001). However, differences in $\delta^{13}C_{org}$ of the surface sediments between the snowmelt- and rainfall-dominated lakes are consistent with the linkages described above between catchment-influenced hydrological processes and water chemistry. Lower $\delta^{13}C_{org}$ values in surface sediment of snowmelt-dominated lakes, compared to the rainfall-dominated lakes (Table 3.3), is consistent with supply of soil-derived $^{13}C$-

depleted DIC from forested catchments and their greater hydrological connectivity. In contrast, the rainfall-dominated lakes possess higher $\delta^{13}C_{org}$ values, likely because lake water DIC is not replenished as readily, leading to $^{13}$C-enrichment as a consequence of primary production. Interestingly, these spatial patterns are analogous to the interpretation of carbon and oxygen isotope records of sediment cores of treeline lakes in Canada and Siberia that experienced warming and boreal forest expansion in their catchments during the Holocene (Wolfe et al. 1996; MacDonald et al. 2004).

Composition of recently-deposited biotic assemblages in surface sediments differs significantly between lakes dominated by snowfall input versus those dominated by rainfall input, and the differences are consistent with the above cascading effects of catchment characteristics and input water sources on water chemistry and sediment properties. For example, *Tabellaria flocculosa*, *Pinnularia nodosa*, *Eunotia* spp., *E. bulinaris*, *E. implicata*, and *E. incise* are relatively more abundant in snowmelt-dominated lakes than rainfall-dominated lakes (Figure 3.2a, c, S1; Table S2). These taxa often reach high relative abundance in dystrophic lakes and ponds, characterized by acidic waters, low ionic content, and high concentration of nutrients and DOC (Werner 1977; Round et al. 1990; Pienitz 2001; Furey 2010). For chironomids, snowmelt-dominated lakes are characterized by high relative abundance of *Glyptotendipes barbipes*-type, *Corynocera ambigua*, and *Psectrocladius monopsectrocladius*-type, as well as *Chaoborus* taxa (Figure 3.2b, d, Figure S2; Table S3). Gajewski et al. (2005) found that *C. ambigua* is prevalent in lakes with forested catchments and relatively high DOC concentration. High relative abundance of *Glyptotendipes* and *C. ambigua* has also been reported for forested lakes across the central Canadian treeline (Walker and MacDonald 1995). This contrasts with the rainfall-dominated lakes, where diatom assemblages have high relative abundance of *Gomphonema olivaceum*, *Navicula aitchelbee*, *Navicula reichardtiana*, *Nitzschia* spp. and *Calonies silicula*. These taxa tend to be abundant in lakes with relatively high ionic content (Potapova et al. 2005; Bahls 2012). Chironomid taxa commonly found in rainfall-dominated lakes include:

*Chaetocladius*, *Psectrocladius barbipes-type, Orthocladius* type i, and *Corynoneura arctica*. These taxa frequently occur in shallow lakes in tundra landscapes north of treeline (Medeiros and Quinlan 2011).

While hydrological differences among lakes were expected to exert strong control on the limnology and biotic community structure, our findings suggest that cascading effects of catchment vegetation, input water (snow versus rain), limnological conditions and sediment properties influence community composition via direct and indirect pathways. This is highlighted by the RDA of the biotic and environmental data (Figure 3), where $\delta^{18}O_I$ did not explain independent directions of variation in diatom and chironomid assemblage composition. Instead, $\delta^{18}O_I$ was positively correlated with lake-water ionic content, conductivity, pH, alkalinity, DO%, sediment $\delta^{13}$Corg, and the proportion of catchment area covered by surface water (lakes, ponds, wetlands), and negatively correlated with concentrations of TDP, TN, DOC, and woodland vegetation cover within the catchment (Figure 3c,d). As we further develop below, there is substantial covariation of $\delta^{18}O_I$ with these classes of explanatory variables on composition of the biotic assemblages.

### *3.6.2. Partitioning Variation in Biological Community Composition*

Limnological variables, independent of catchment characteristics and sediment properties, account for the largest portion of explained variation in diatom and chironomid assemblage composition (17.2 and 12.6 %, respectively; Figure 3.4), which highlights the importance of the unique influence of water chemistry on community structure. Water chemistry variables such as pH and concentration of nutrients, DOC and ions are well known to have strong influence on diatom assemblages in lakes and ponds across the subarctic (Pienitz et al. 1995; Rühland and Smol 2002) and Arctic (Smol and Douglas 1996; Bouchard et al. 2004). For chironomids, water temperature is often described as the primary factor that governs the community structure of northern and alpine lakes

(Walker et al. 1991; Lotter et al. 1997; Fortin et al. 2015). Water chemistry is also known to have some influence (Gajewski et al. 2005; Medeiros and Quinlan 2011). For example, nutrients enhance aquatic production and lead to change in chironomid community composition via alteration of food supply and habitat availability (Medeiros et al. 2015). These relations are likely a reflection of basin morphology and associated differences in ice-cover duration, light penetration, extent and duration of winter anoxia, nutrient availability, and their subsequent effects on productivity that are independent of catchment or sediment characteristics (Lotter and Bigler 2000) and may confound temperature relationships (Medeiros et al. 2015), given that strong correlations exist between trophic state and temperature (Broderson and Anderson 2002).

Sediment properties, independent of limnology and catchment characteristics, account for the second largest portion of explained variation in diatom and chironomid assemblage composition (8.50 and 9.48 %, respectively; Figure 3.4). Variation in local geology and surficial sediment can be an important factor in determining differences in microhabitat availability within lakes. These habitat differences are known to influence periphytic diatom communities (Lim et al. 2001b), independent of the influence of water chemistry (Michelutti et al. 2003). For example, shallow lakes with abundance of silt and clay bottom sediment are often dominated by epipsammic diatom taxa (Miller et al. 1987), whereas lakes with organic-rich muds often support greater macrophyte growth with associated epiphytic taxa (Sokal et al. 2008; 2010). Also, thermokarst lakes with sediments rich in peat and moss fragments contain abundant *Eunotia* species (Bouchard et al. 2013a). Likewise, chironomids are known to have strong associations with sediment texture (Rae 2004) and aquatic vegetation (Welch 1976; Hershey 1985).

The unique effect of catchment characteristics explained 4.9 and 5.1 % of the variation in diatom and chironomid assemblages, respectively (Figure 3.4). The catchment variables selected for inclusion in the VPA were percentage of surface water in the catchment (i.e., lakes, streams, wetlands) and percentage of woodland vegetation. Mechanisms by which unique effects of these variables influence composition of diatom and chironomid assemblages are more difficult to identify, but may be associated with variation in light penetration and aquatic microhabitat availability. For example, tall and dense trees and shrubs could shade the nearshore region of the snowmelt-dominated lakes. Also, variation in the amount and type of terrestrial debris in the littoral zone of lakes influences the habitat available for colonization, as demonstrated by Pope et al. (1999). Vinke et al. (2015) noted that diversity of chironomids differs substantially between woody debris and leaf-pack habitats. Diatom community composition has also been shown to differ among non-living and living substrates (Gaiser and Johansen 2000; Wiklund et al. 2010).

In the VPAs, first- and second-order shared-variation terms explain 6.1 and 7.9 % of the variation diatom and chironomid assemblages, respectively (Figure 3.4). This represents 16.6 and 22.5 % of the variation explained by the supplied environmental variables, respectively. We attribute the substantial shared variation to the influence of hydrological processes, because they are the main mechanisms that link catchment characteristics with limnological conditions and sediment properties of lakes, as we have demonstrated here and elsewhere (Turner et al. 2010; 2014; Balasubramaniam et al. 2015). Given the importance of hydrological processes on lake biota via cascading and indirect pathways that alter water chemistry and sediment properties, we recommend that measurement of hydrological variables be routinely included in northern landscape-scale freshwater studies.

Limnological variables, while clearly important to biotic community structure, uniquely explain less than 20 % of the variation in diatom and chironomid assemblages in lakes of OCF. This suggests that attempts to link biotic assemblages to direct effects of a single factor (e.g., water chemistry variables such as pH, ions, and nutrients) may be oversimplified. For example, Pienitz et al. (1995)

identified strong control on composition of surface sediment diatom assemblages in lakes spanning treeline in northwestern Canada by lake water chemistry and air temperature. They recognized that differences in catchment vegetation and hydrological processes were likely involved, but did not have the data to quantify their roles. Indeed, such complexities have long been acknowledged (Anderson 2000), and not accounting for them may inflate the importance of test variables. For example, when we constrain the ordinations to just the limnological variables (i.e., without the catchment and sediment variables), the explained variation increases to 22.4 % for diatoms (vs. 17.2 % with catchment and sediment metrics as covariables; Figure 3.4) and almost doubles for chironomids (20.0 % without vs.12.6 % with the covariables). It is unknown if these differences are representative of other northern landscapes. However, studies which measure only water chemistry variables remain unable to evaluate the role of complex interactions mediated by hydrological processes.

Our dataset spans more than 40 lakes and numerous measured variables characterizing catchment characteristics, sediment properties, limnological conditions and hydrology, yet VPA results explain less than 50 % of the variation in diatom and chironomid community composition. Although the explained variation may seem proportionately low, these values are typical when compared to other datasets for which variation has been partitioned (Douglas and Smol 1995; Sweetman et al. 2010). Nonetheless, the unexplained variation highlights the difficulty in describing complex biotic factors, such as predation and interspecific competition, and inability to capture time-lags and other limitations associated with use of point-in-time measurements (Allan and Johnson 1997; Palmer et al. 2000). Likewise, the large amount of variation explained by the inter-play of multiple internal and external processes shown here highlights the need for careful interpretation of how environmental change will affect aquatic ecosystems in dynamic northern landscapes.

### *3.6.3. Implications*

During the past couple of decades, landscape-scale studies have increasingly been used to identify fundamental and inter-related processes that regulate Arctic and sub-arctic lakes (Kernan et al., 2009), which can be especially useful when evaluating lake responses to large-scale environmental shifts (Johnson and Host 2010). For northern landscapes, such studies often relate distributions of biota to measurements of water chemistry and environmental variables in order to evaluate environmental change (e.g., Pienitz et al. 1995; Bigler and Hall 2002; Fallu et al. 2002; Rühland and Smol. 2002; Porinchu et al. 2009). The use of RDAs to analyze spatial environmental gradients has also been applied to temporal gradients for environmental reconstruction (Lotter et al. 1997; Lotter 1998; Anderson et al. 2008). However, a host of internal lake processes and external environmental factors likely simultaneously exert strong influence on aquatic communities (Blenckner 2005). Fritz and Anderson (2013) alluded to the need to recognize biogeochemical linkages between lakes and their catchments, but these can be difficult to quantify and interpret. The examination of abundance and diversity of aquatic organisms that respond directly and indirectly to environmental variables is often used for the inference of their environment (Walker and MacDonald 1995; Weckström and Korhola 2000; Brodersen and Anderson 2002; Anderson et al. 2008; Medeiros and Quinlan 2011). These types of studies typically focus on direct relationships between singular factors, such as temperature and biotic production (Lotter et al. 1997; Rühland et al. 2015), which are predicated on assumptions that large-scale interactions, such as the effects of alterations in climate or water-chemistry, will result in overarching shifts in the distributions of species (Pienitz et al. 1995; Lotter et al. 1999; Battarbee 2000; Fallu et al. 2002; Fritz and Anderson 2013). However, recent work has noted indirect responses exert strong influence on northern diversity (Medeiros et al. 2014; 2015). Likewise, Fritz and Anderson (2013) note that ecosystem structure and function is greatly affected by the relative roles of ecosystem processes in mediating limnological change. Thus, studies focusing on limnological associations alone may miss the interplay of catchment or hydrological factors on limnology and aquatic biota.

### *3.7.Conclusions*

We incorporated quantitative data on multiple factors (catchment characteristics, hydrology, limnology, and sediment properties) to determine their influence on diatom and chironomid assemblages in surface sediments of thermokarst lakes in Old Crow Flats, Yukon. Although unique effects of limnological variables explained the largest proportion of variation in biotic communities, important independent roles of sediment properties and catchment characteristics were also identified. Substantial shared variation among these classes of environmental variables identified cascading effects of input-water sources on water chemistry and sediment properties, as mediated by catchment characteristics. This is consistent with the significant difference in composition of the biotic assemblages between lakes receiving varying proportions of snowmelt and rainfall input. Thus, our study identifies a strong role of hydrology in regulating biotic responses to multiple environmental factors in shallow lakes within a northern thermokarst landscape. Knowledge of direct and indirect effects of multiple factors on community structure is required to anticipate responses of northern aquatic ecosystems to climate warming and other environmental changes.

### *3.8. Acknowledgements*

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Vuntut Gwitchin First Nation for being partners in this research program and Parks Canada for their ongoing collaboration and logistical support of the fieldwork. This research was supported by funding from the Government of Canada IPY program, NSERC, PCSP, NSTP, Parks Canada, and a W. Garfield Weston Foundation postdoctoral fellowship awarded to ASM. Comments from three anonymous reviewers helped improve this manuscript.

### 3.9.Figures and Tables

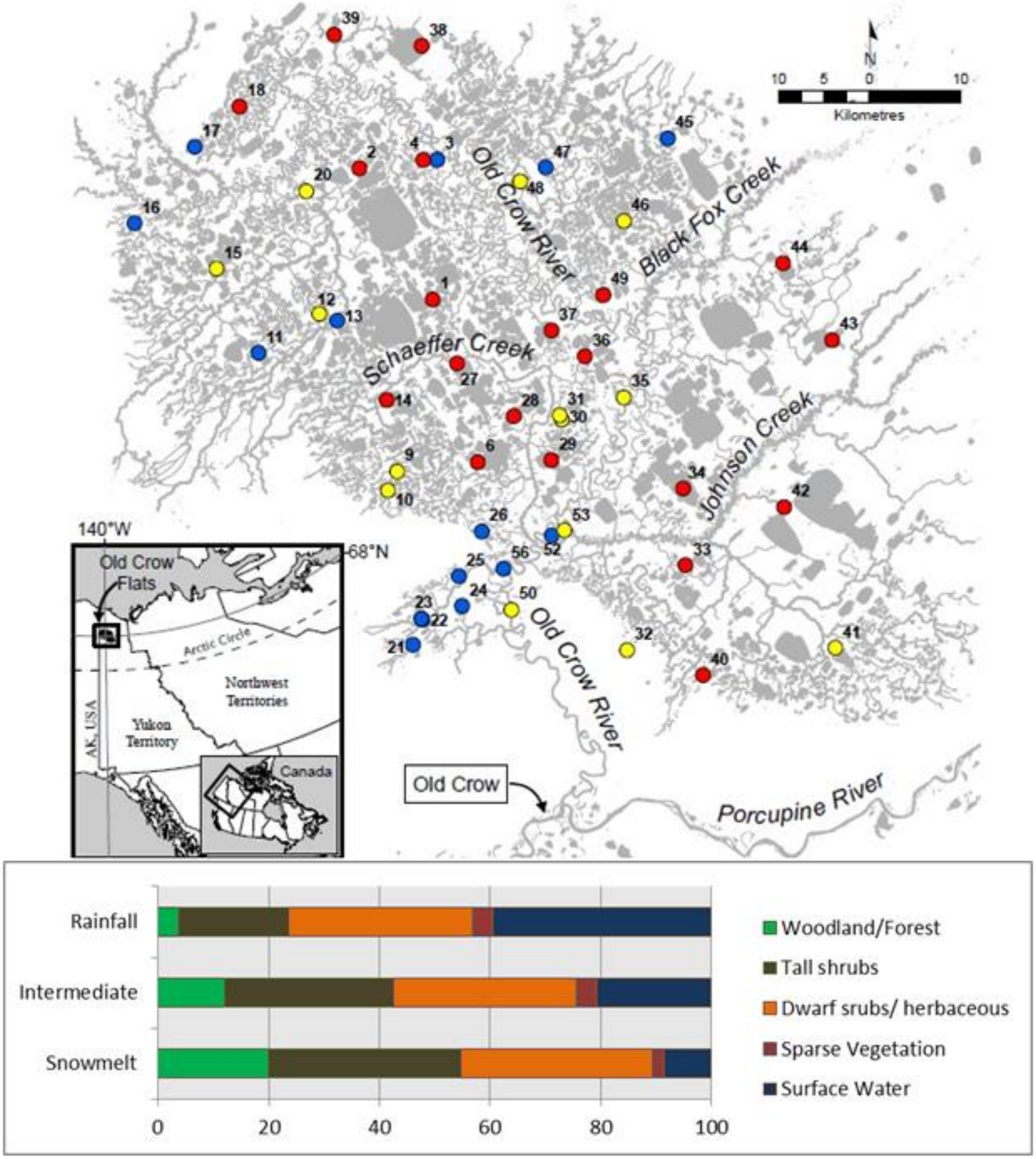

Figure 3.1: Map displaying locations of study lakes (n=49) in the Old Crow Flats, YT (top). Lakes are colour-coded by their input-water category: blue = snowmelt-dominated, yellow = intermediate, and red = rainfall-dominated. The percent composition of catchment features for study lakes are presented based on data modified from Turner et al. (2014) (bottom).

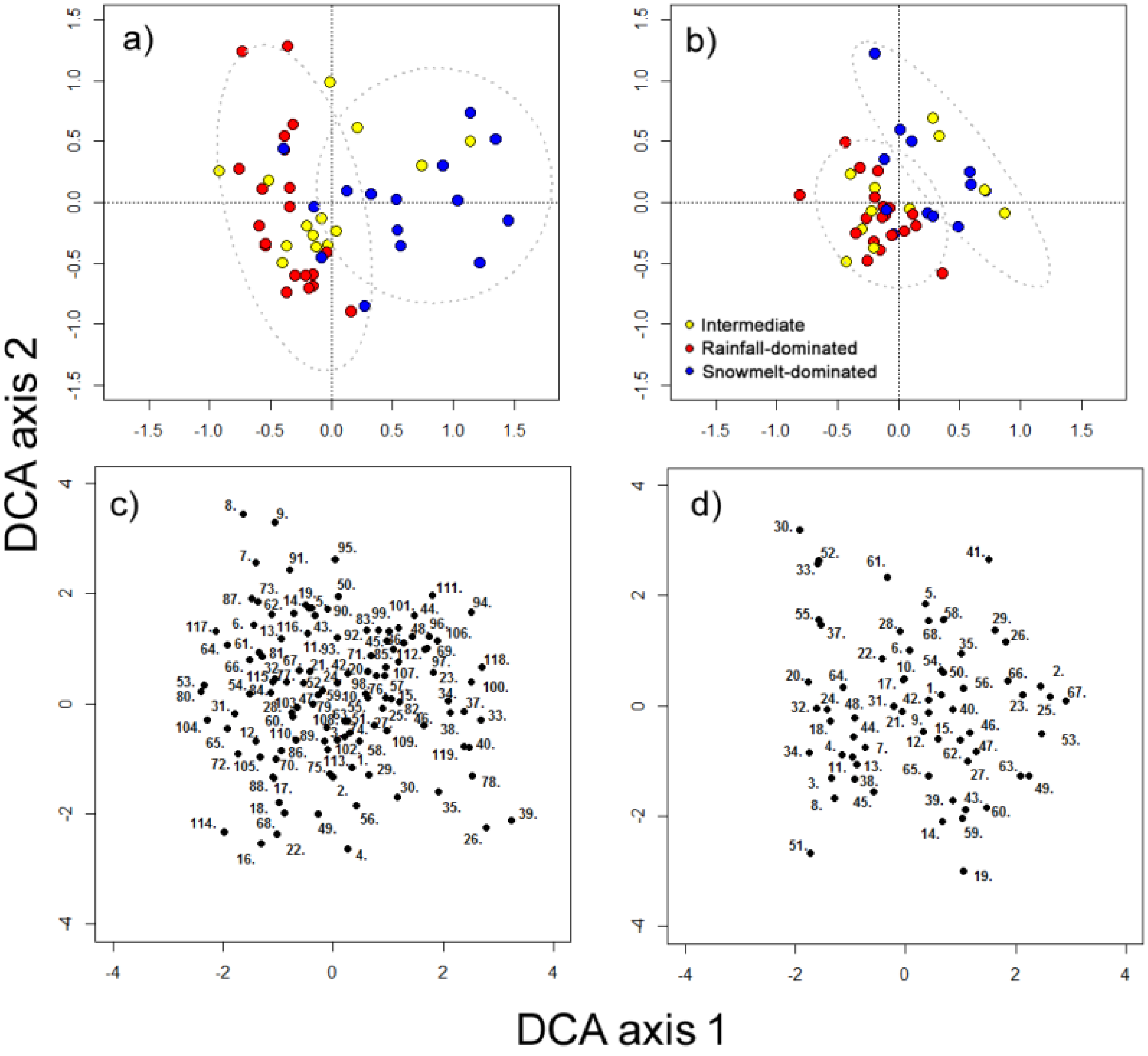

Figure 3.2: Detrended correspondence analysis (DCA) of a) study lakes (sample scores) as determined by surface sediment diatom assemblages, b) study lakes (sample scores) as determined by surface sediment chironomid assemblages, c) species scores based on diatoms, and d) species scores based on chironomids. The ellipses indicate a significant cluster of lakes determined through a K-means cluster analysis of biotic data. Species scores are labelled using numbers and the corresponding names of the diatom and chironomid taxa are provided in Tables S3 and S4, respectively.

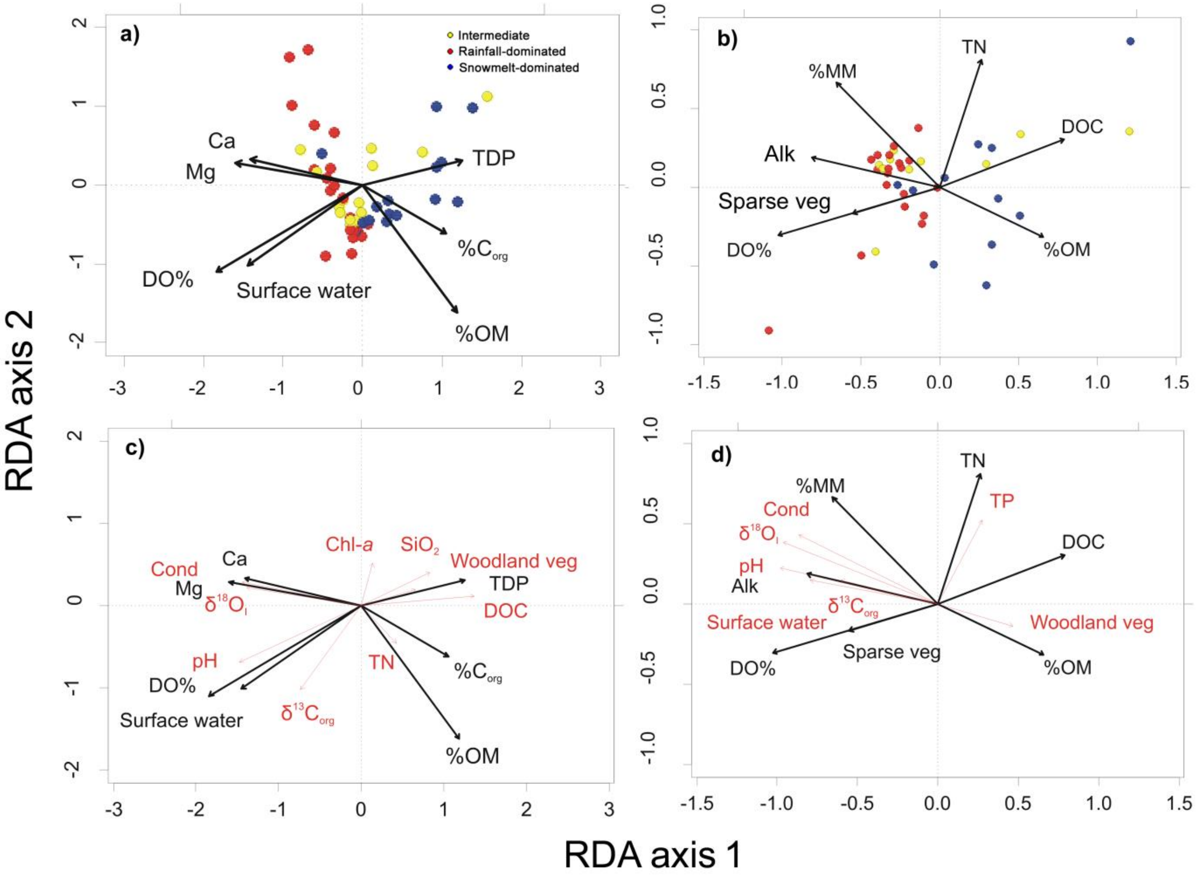

Figure 3.3: Redundancy Analysis (RDA) showing relations between the biotic assemblages (sample scores) and the independent and significant environmental indicators, as identified by parsimonious forward selection. Top ordination bi-plots display relations between environmental variables and a) diatom assemblages and b) chironomid assemblages in surficial sediments. Bottom ordination plots display relations between the forward-selected and non-selected environmental variables based on c) diatom assemblages and d) chironomid assemblages. Environmental variables not forward selected were added passively and appear in red to highlight relations among multiple collinear variables.

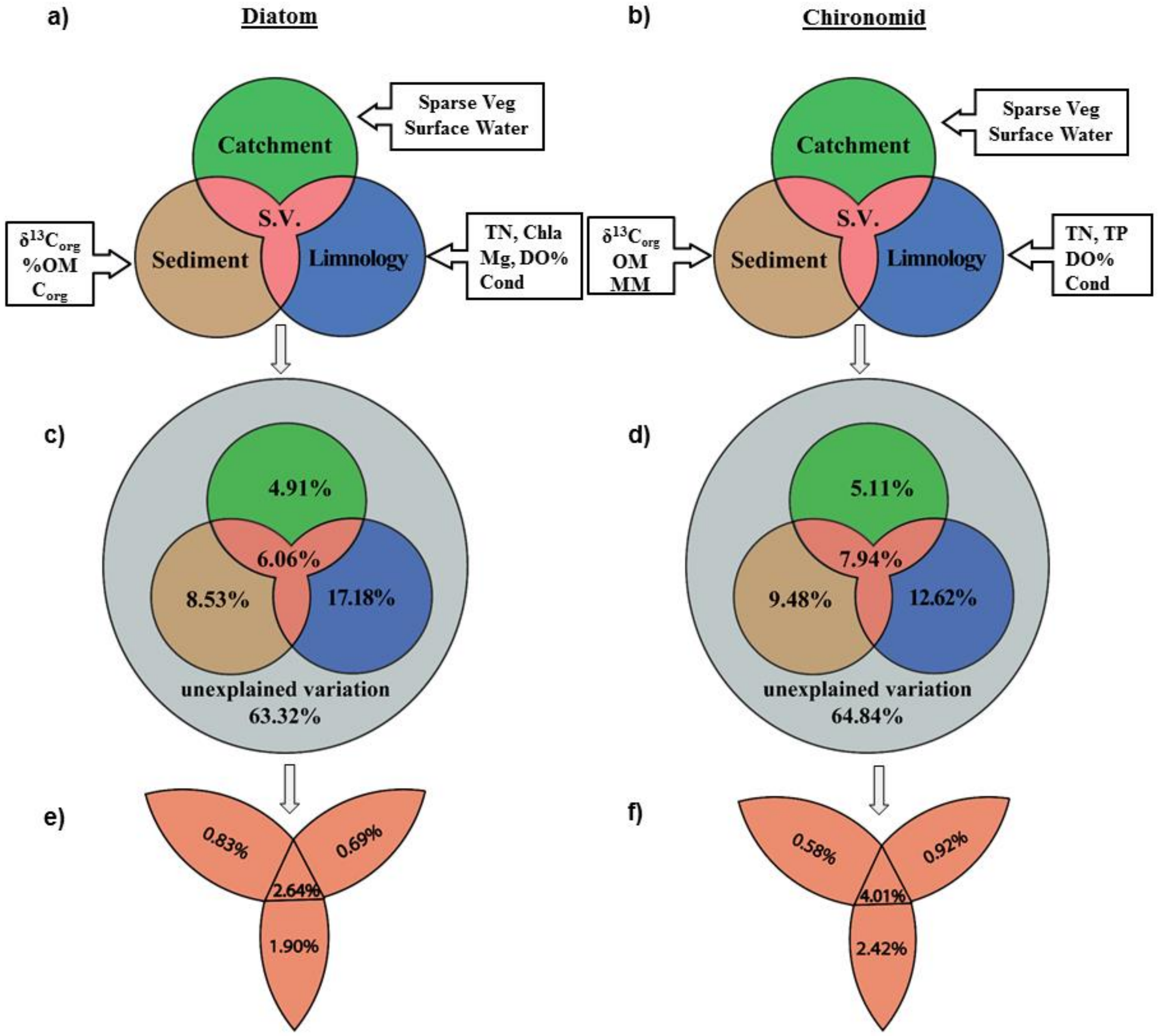

Figure 3.4: Venn diagrams showing results of variation partitioning analysis (VPA) for diatoms (left-hand column) and chironomids (right-hand column). The VPAs decompose variation in assemblage composition explained by classes of environmental variables (limnology (L), sediment properties (S), and catchment characteristics (C)), including shared variation terms for all three (LSC - labelled as 'S.V.'). The top panels (a and b) show the unique and shared variation components along with the list of the significant environmental variables selected for inclusion in each class. The middle panels (c and d) show variation explained uniquely by each class of environmental variables, the shared variation explained by the sum of all first- and second-order covariation terms, and the unexplained variation (outer grey region). The bottom panels (e and f) show the variation explained by each of the three first-order covariation terms, and by the second-order covariation term.

Table 3.1: Results of one-way ANOSIM tests on diatom and chironomid assemblages in surface sediments of the study lakes. ‘Overall’ tests the hypothesis that community composition does not differ among lakes in the three hydrological categories (snowmelt-dominated, rainfall-dominated, intermediate). The other tests present pairwise comparisons between the specified categories. P-values in bold are significant at α = 0.05.

| | Comparison | R statistic | P-value | #≥Observed |
|---|---|---|---|---|
| Diatom | Overall | 0.195 | **$4.0\times10^{-5}$** | 2184 |
| Diatom | Rainfall, Intermediate | 0.056 | 0.127 | 12692 |
| Diatom | Rainfall, Snowmelt | 0.352 | **$2.0\times10^{-5}$** | 1 |
| Diatom | Intermediate, Snowmelt | 0.159 | **0.007** | 687 |
| Chironomid | Overall | 0.086 | **0.022** | 3057 |
| Chironomid | Rainfall, Intermediate | 0.023 | 0.32 | 32203 |
| Chironomid | Rainfall, Snowmelt | 0.156 | **0.002** | 245 |
| Chironomid | Intermediate, Snowmelt | 0.049 | 0.17 | 17427 |

Table 3.2: Summary statistics for the first four axes of the DCA ordinations performed in this study, including eigenvalues (DCA, RDA), gradient lengths (DCA), taxa-environment correlations (RDA), and percent of variation for the taxa-environment relations. Total inertia for RDAs of the diatom and chironomid data is 4.393 and 2.561, respectively.

| Analysis | | Diatoms | | | | Chironomids | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Summary statistics | Axis 1 | Axis 2 | Axis 3 | Axis 4 | Axis 1 | Axis 2 | Axis 3 | Axis 4 |
| DCA | Eigenvalues | 0.264 | 0.210 | 0.117 | 0.128 | 0.128 | 0.110 | 0.081 | 0.079 |
| | Gradient lengths | 2.376 | 2.180 | 1.728 | 1.599 | 1.685 | 1.808 | 1.402 | 1.614 |
| RDA | Eigenvalues | 0.380 | 0.293 | 0.186 | 0.160 | 0.251 | 0.156 | 0.141 | 0.115 |
| | Taxa- env correlations | 0.953 | 0.889 | 0.902 | 0.879 | 0.884 | 0.848 | 0.884 | 0.722 |
| | % Variance of taxon-env relations | 0.290 | 0.224 | 0.142 | 0.122 | 0.291 | 0.181 | 0.163 | 0.133 |

Table 3.3: Average (± standard deviation) mid-season values (late-July 2007 and 2008) of limnological and sediment variables for the 49 study lakes within each input-water category. The variables that differ significantly ($p \leq 0.05$) among the input-water categories, as determined by non-parametric Kruskal-Wallis tests of significance, are indicated by an asterisk (*).

| | | Snowmelt-dominated (n=15) | Intermediate (n=14) | Rainfall-dominated (n=20) |
|---|---|---|---|---|
| Variable | SI unit | Average ± s.d. | Average ± s.d. | Average ± s.d. |
| Limnological variables | | | | |
| Depth | m | 1.64 ± 0.73 | 1.48 ± 1.02 | 1.10 ± 0.46 |
| Temp | °C | 16.81 ± 1.30 | 16.66 ± 1.44 | 16.11 ± 1.52 |
| Cond* | $\mu S \cdot cm^{-1}$ | 76.01 ± 48.83 | 124.56 ± 41.63 | 144.37 ± 36.77 |
| DO* | % | 108.08 ± 14.86 | 116.05 ±21.90 | 121.94 ± 1.52 |
| pH* | units | 7.46 ± 0.85 | 8.31 ± 0.93 | 8.87 ± 0.54 |
| Alkalinity* | $mEq \cdot L^{-1}$ | 0.67 ± 0.48 | 1.15 ± 0.41 | 1.32 ± 0.31 |
| $Cl^{-}$* | $mg \cdot L^{-1}$ | 0.18 ± 0.08 | 0.25 ± 0.12 | 0.33 ± 0.19 |
| $Ca^{2+}$* | $mg \cdot L^{-1}$ | 11.98 ± 9.21 | 15.64 ± 4.99 | 18.04 ± 6.31 |
| $Mg^{2+}$* | $mg \cdot L^{-1}$ | 2.49 ± 1.19 | 5.45 ± 1.78 | 6.75 ± 2.15 |
| $K^{+}$ | $mg \cdot L^{-1}$ | 0.88 ± 0.5 | 1.29 ± 0.75 | 1.17 ± 0.82 |
| $Na^{+}$* | $mg \cdot L^{-1}$ | 0.69 ± 0.46 | 2.53 ± 3.40 | 1.45 ± 0.54 |
| $SO_4^{2-}$* | $mg \cdot L^{-1}$ | 2.53 ± 6.00 | 4.06 ± 5.91 | 8.06 ± 8.56 |
| DOC* | $mg \cdot L^{-1}$ | 19.85 ± 5.83 | 19.09 ± 6.99 | 11.33 ± 2.97 |
| DIC* | $mg \cdot L^{-1}$ | 7.49 ± 4.87 | 11.46 ± 4.45 | 13.37 ± 4.09 |
| $SiO_2$ | $mg \cdot L^{-1}$ | 1.42 ± 1.34 | 1.06 ± 0.86 | 0.68 ± 0.57 |
| TN | $mg \cdot L^{-1}$ | 0.76 ± 0.13 | 0.97 ± 0.31 | 0.78 ± 0.23 |
| $NH_3$ | $\mu g \cdot L^{-1}$ | 68.57 ± 34.81 | 88.75 ± 27.31 | 80.43 ± 38.32 |
| TDP* | $\mu g \cdot L^{-1}$ | 28.22 ± 46.63 | 21.83 ± 18.93 | 8.40 ± 2.89 |
| TP | $\mu g \cdot L^{-1}$ | 43.23 ±63.01 | 35.58 ± 19.90 | 42.36 ± 50.07 |
| Chl-*a* | $\mu g \cdot L^{-1}$ | 3.50 ± 3.07 | 5.43 ± 3.71 | 6.11 ± 5.74 |
| Sediment Properties | | | | |
| $C_{org}$ | % | 16.03 ± 8.72 | 11.11 ± 6.78 | 10.33 ± 6.03 |
| N | % | 1.38 ± 0.69 | 1.09 ± 0.80 | 0.94 ± 0.57 |
| C:N | | 11.43 ± 1.36 | 10.78 ± 1.36 | 11.17 ± 1.36 |
| $\delta^{13}C_{org}$* | ‰ VPDB | -27.70 ± 3.39 | -26.39 ± 4.14 | -23.89 ± 3.28 |
| $\delta^{15}N$ | ‰ AIR | 2.46 ± 1.12 | 3.29 ± 1.33 | 2.86 ± 0.52 |
| OM | % | 29.64 ± 16.80 | 19.43 ±7.56 | 18.68 ± 8.72 |
| MM | % | 67.97 ± 17.45 | 77.04 ± 10.43 | 79.26 ± 8.80 |

## *3.10. Supplementary Figures and Tables*

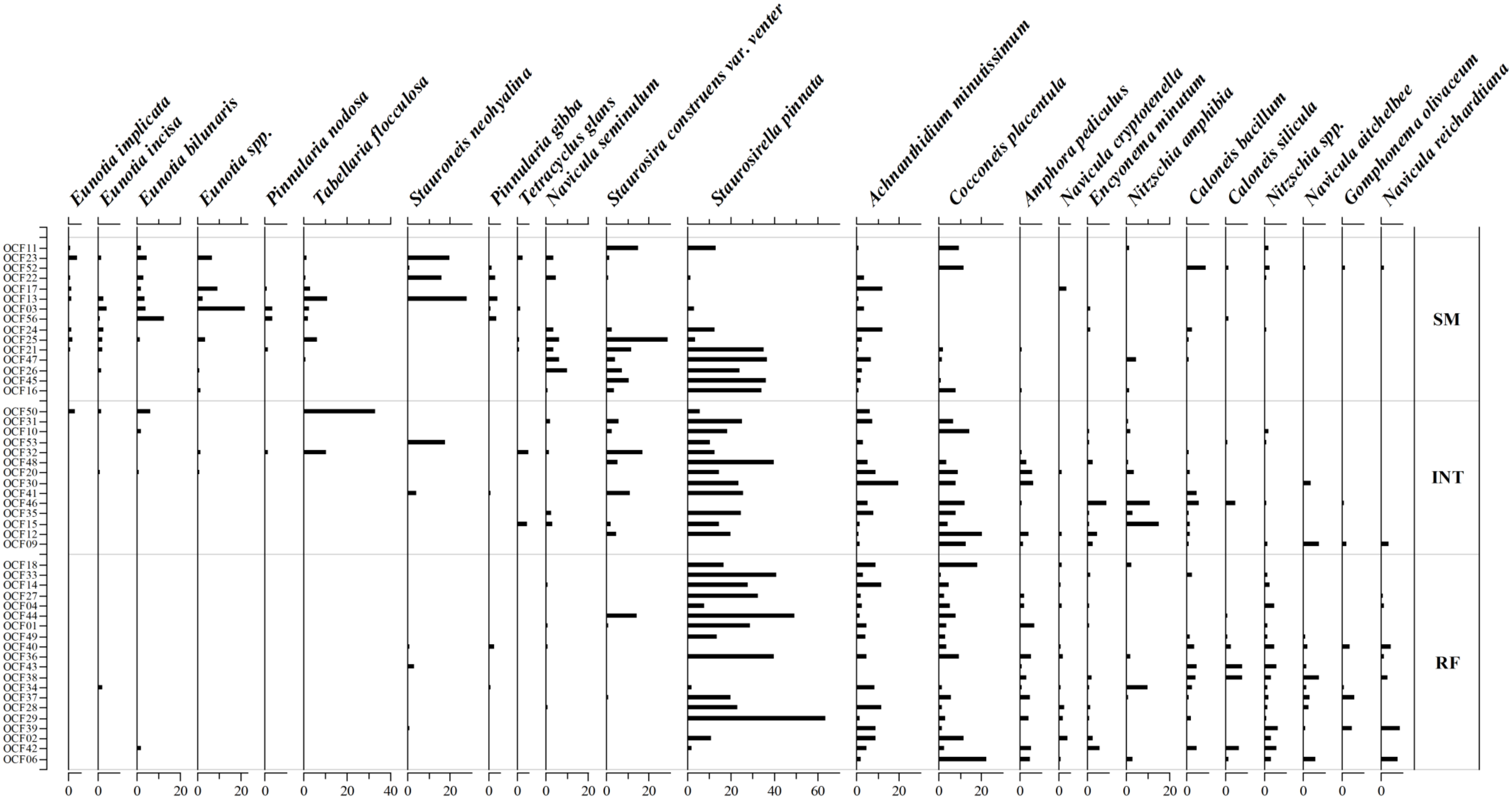

Figure S1: Horizontal bar graphs showing the percent abundances of common diatom taxa in surface sediments of the 49 study lakes within Old Crow Flats, Yukon. Lakes are positioned along the vertical axis from low to high values of $\delta^{18}O_I$ (bottom to top), and horizontal dotted lines separate lakes into the three input-water categories (RF = rainfall-dominated, INT = intermediate, SM = snowmelt-dominated).

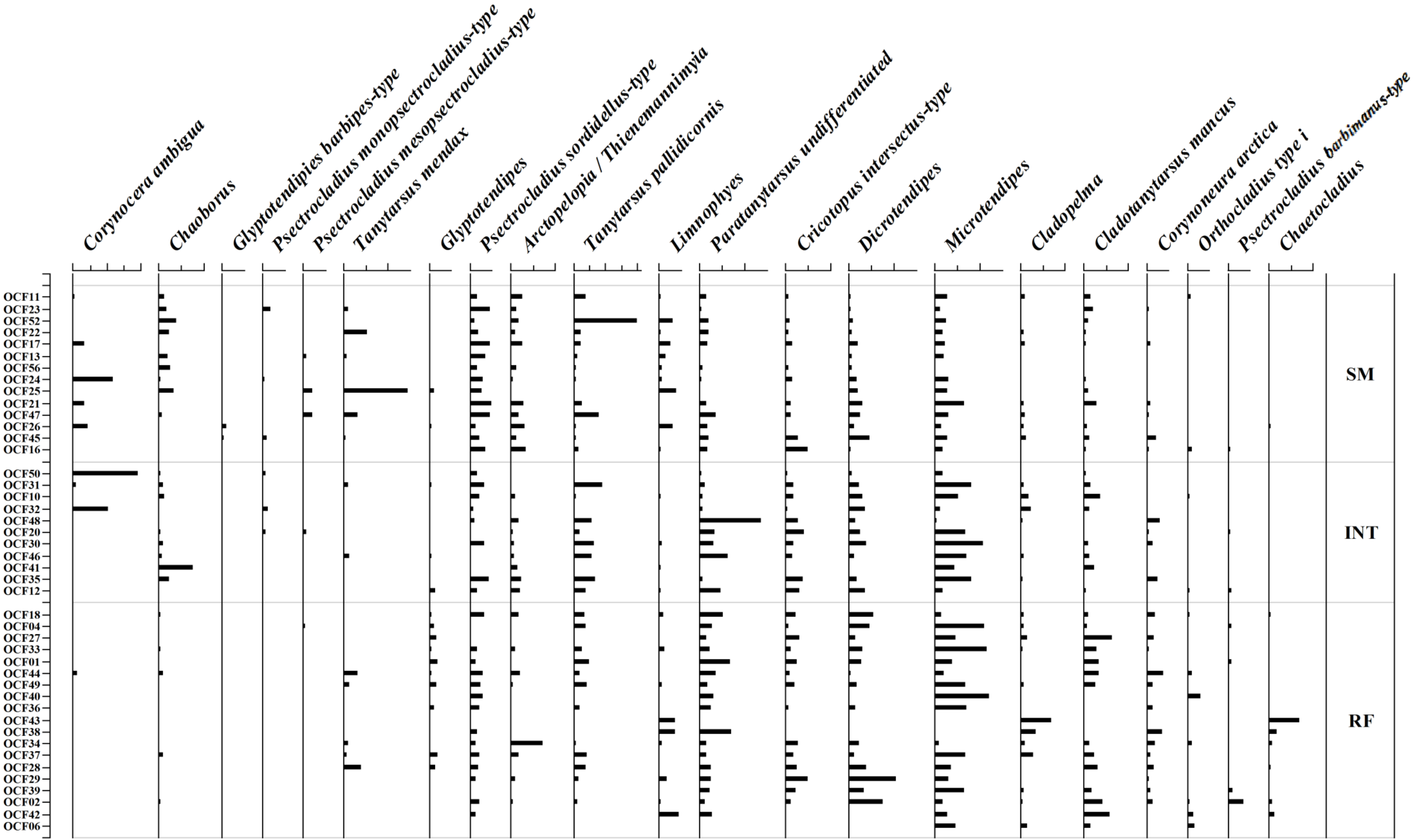

Figure S2: Horizontal bar graphs showing the percent abundances of common chironomid taxa in surface sediments of the 42 study lakes within Old Crow Flats, Yukon. Lakes are positioned along the vertical axis from low to high values of $\delta^{18}O_I$ (bottom to top), and horizontal dotted lines separate lakes into the three input-water categories (RF = rainfall-dominated, INT = intermediate, SM = snowmelt-dominated).

Table S1: Transformations applied to environmental variables before use in statistical analysis listed by class of explanatory variables.

| Environmental variable | Transformation in diatom analysis | Transformation in chironomid analysis | Class |
|---|---|---|---|
| Temp | - | - | Limnology |
| pH | - | - | Limnology |
| Alk | - | - | Limnology |
| Cond | - | Sqrt | Limnology |
| $Ca^{2+}$ | Sqrt | Sqrt | Limnology |
| $Mg^{2+}$ | - | - | Limnology |
| $K^+$ | Sqrt | - | Limnology |
| $Na^+$ | - | - | Limnology |
| $Cl^-$ | Sqrt | Sqrt | Limnology |
| $SO_4^{2-}$ | Sqrt | Sqrt | Limnology |
| DOC | Sqrt | Sqrt | Limnology |
| DIC | - | Sqrt | Limnology |
| $SiO_2$ | Sqrt | Sqrt | Limnology |
| TN | Log | Log | Limnology |
| $NH_3$ | Sqrt | Sqrt | Limnology |
| TDP | Log | Log | Limnology |
| TP | Log | Log | Limnology |
| DO% | - | - | Limnology |
| Chl-*a* | Log | Sqrt | Limnology |
| C:N | - | - | Sediment |
| $\delta^{13}C_{org}$ | - | - | Sediment |
| $\delta^{15}N$ | - | - | Sediment |
| %C | Log | Log | Sediment |
| %N | Sqrt | Sqrt | Sediment |
| %MM | - | - | Sediment |
| %OM | Log | Log | Sediment |
| Lake Area | Log | Log | Catchment |
| Catchment Area | Log | Log | Catchment |
| Surface water | Sqrt | Sqrt | Catchment |
| Woodland veg | Sqrt | Sqrt | Catchment |
| Tshrub | Sqrt | Sqrt | Catchment |
| DwShrub | Sqrt | Sqrt | Catchment |
| Sparse veg | Log | Log | Catchment |
| $\delta^{18}O_I$ | - | - | Hydrology |

Table S2: Diatom taxon names, numeric codes, and authority names presented in the DCA ordination.

| Code | Taxon Name | Authority |
|---|---|---|
| 1 | *Achnanthes implexiformis* | Lange-Bertalot |
| 2 | *Achnanthes lanceolata* | (Brébisson ex Kützing) Grunow |
| 3 | *Achnanthidium minutissimum* | (Kützing)Czarnecki |
| 4 | *Achnanthidium saprophilum* | (Kobayashi and Mayama) Round & Bukhtiyarova |
| 5 | *Achnanthidium* spp. | Kützing |
| 6 | *Amphora copulata* | (Kützing)Schoeman & R. E. M. Archibald |
| 7 | *Amphora fogediana* | Krammer |
| 8 | *Amphora inariensis* | Krammer |
| 9 | *Amphora lange-bertalotii* | Levkov and Metzeltin |
| 10 | *Amphora libyca* | Ehrenberg |
| 11 | *Amphora ovalis* | (Kützing)Kützing |
| 12 | *Amphora pediculus* | (Kützing) Grunow ex A. Schmidt |
| 13 | *Caloneis bacillum* | (Grunow) Cleve |
| 14 | *Caloneis silicula* | (Ehrenberg) Cleve |
| 15 | *Cavinula pseudoscutiformis* | (Hustedt) D. J. Mann& A. J. Stickle |
| 16 | *Chamaepinnularia cf. begeri* | (Krasske) Lange-Bertalot |
| 17 | *Cocconeis placentula* | Ehrenberg |
| 18 | *Cocconeis placentula  var. lineata* | (Ehrenberg) Van Heurck |
| 19 | *Craticula cf. molestiformis* | (Hustedt) Mayama |
| 20 | *Cymbella amphicephala* | Näegeli |
| 21 | *Cymbella cistula* | (Ehrenberg) O. Kirchner |
| 22 | *Cymbella microcephala* | Grunow |
| 23 | *Cymbella naviculiformis* | Auerswald ex Heiberg |
| 24 | *Cymbella silesiaca* | Bleisch |
| 25 | *Cymbella* spp. | |
| 26 | *Diploneis finnica* | (Ehrenberg) Cleve |
| 27 | *Eolimna* sp 2 | from Lavoie et al. (2008), Planche 24 |
| 28 | *Encyonema minutum* | (Hilse) D. G. Mann |
| 29 | *Sellaphora c.f. minima* | Grunow |
| 30 | *Eolimna* sp 4 | from Lavoie et al. (2008), Planche 24 |
| 31 | *Epithemia adnata* | (Kützing) Brébisson |
| 32 | *Epithemia turgida* | (Ehrenberg) Kützing |
| 33 | *Eunotia arcus* | Ehrenberg |
| 34 | *Eunotia bilunaris* | (Ehrenberg) Schaarschmidt |
| 35 | *Eunotia circumborealis* | Lange-Bertalot & Nörpel |
| 36 | *Eunotia exigua* | (Brébisson in Kützing) Rabenhorst |
| 37 | *Eunotia implicata* | Nörpel, Lange-Bertalot and Alles |
| 38 | *Eunotia incisa* | W. Smith ex W. Gregory |
| 39 | *Eunotia monodon* | Ehrenberg |
| 40 | *Eunotia* spp. | |
| 41 | *Fragilaria capucina forme 7* | Desmazières sensu Lavoie et al. (2008), Planche 8 |

| Code | Taxon Name | Authority |
|---|---|---|
| 42 | *Fragilaria capucina var gracilis* | (Oestrup) Hustedt |
| 43 | *Fragilaria exigua* | Grunow |
| 44 | *Fragilaria nana* | (F.Meister) Lange-Bertalot |
| 45 | *Fragilaria* spp. | |
| 46 | *Fragilariforma virescens* | (Ralfs) D. M. Williams & Roundas described in Morales and Spaulding |
| 47 | *Gomphonema brebissonii* | Kützing |
| 48 | *Gomphonema cf. augur* | Ehrenberg |
| 49 | *Gomphonema cf.pumilum* | (Grunow) E.Reichardt and Lange-Bertalot |
| 50 | *Gomphonema clavatum* | Ehrenberg |
| 51 | *Gomphonema gracile* | Ehrenberg |
| 52 | *Gomphonema minutum* | (C. Agardh) C. Agardh |
| 53 | *Gomphonema olivaceum* | (Hornemann) Brébisson |
| 54 | *Gomphonema acuminatum* | Ehrenberg |
| 55 | *Gomphonema affine* | Kützing |
| 56 | *Gomphonema angustum* | C. Agardh |
| 57 | *Gomphonema angustatum* | (Kützing) Rabenhorst |
| 58 | *Gomphonema parvulum* | (Kützing) Kützing |
| 59 | *Gomphonema* spp. | |
| 60 | *Gomphonema truncatum var capitatum* | (Ehrenberg) Woodhead and Tweed |
| 61 | *Gyrosigma acuminatum* | (Kützing) Rabenhorst |
| 62 | *Hippodonta hungarica* | (Grunow) Lange-Bertalot, Metzeltin and Witkowski |
| 63 | *Kobayasiella subtilissima* | (Cleve) Lange-Bertalot |
| 64 | *Navicula aitchelbee* | L. L. Bahls |
| 65 | *Navicula antonii* | Lange-Bertalot |
| 66 | *Navicula catalanogermanica* | Lange-Bertalot and G.Hofmann |
| 67 | *Navicula cryptocephala* | Kützing |
| 68 | *Navicula cryptotenella* | Lange-Bertalot |
| 69 | *Navicula cf. disjuncta* | Hustedt |
| 70 | *Navicula halophila* | (Grunow) Cleve |
| 71 | *Navicula laevissima var laevissima* | Kutzing |
| 72 | *Navicula lesmonensis* | Hustedt |
| 73 | *Navicula cf. medioconvexa* | Hustedt |
| 74 | *Navicula notha* | J. H. Wallace |
| 75 | *Navicula pupula var mutata* | (Krasske) Hustedt |
| 76 | *Sellaphora pupula* | (Kützing) Mereschkovsky |
| 77 | *Navicula pseudanglica* | Lange-Bertalot |
| 78 | *Navicula pseudoventralis* | Hustedt |
| 79 | *Navicula radiosa* | Kützing |
| 80 | *Navicula reichardtiana* | Lange-Bertalot |
| 81 | *Navicula salinarum* | Grunow |
| 82 | *Navicula seminulum* | Grunow |

| | Taxon Name | Authority |
|---|---|---|
| 83 | *Navicula* spp. | |
| 84 | *Navicula trivialis* | Lange-Bertalot |
| 85 | *Neidium bisulcatum* | (Lagerstedt) Cleve |
| 86 | *Nitzchia amphibia* | Grunow |
| 87 | *Nitzchia dissipata* | (Kützing) Rabenhorst |
| 88 | *Nitzchia fonticola* | (Grunow) Grunow |
| 89 | *Nitzchia palea* | (Kützing) W. Smith |
| 90 | *Nitzchia palea var debilis* | (Kützing) Grunow |
| 91 | *Nitzchia paleacea* | (Grunow) Grunow |
| 92 | *Nitzchia pusilla* | Grunow |
| 93 | *Nitzchia* spp. | |
| 94 | *Pinnularia brauniana* | (Grunow) Studnicka |
| 95 | *Pinnularia cf. microstauron* | (Ehrenberg) Cleve |
| 96 | *Pinnularia divergentissima* | (Grunow) Cleve |
| 97 | *Pinnularia gibba* | (Ehrenberg) Ehrenberg |
| 98 | *Pinnularia gigas* | Ehrenberg |
| 99 | *Pinnularia lundii* | Hustedt |
| 100 | *Pinnularia nodosa* | (Ehrenberg) W. Smith |
| 101 | *Pinnularia* spp. | |
| 102 | *Pseudostaurosira brevistriata* | (Grunow) D. M. Williams and Round |
| 103 | *Pseudostaurosira robusta* | (Fusey) D. M. Williams and Round |
| 104 | *Rhoicosphenia abbreviata* | (C. Agardh) Lange-Bertalot |
| 105 | *Rhopalodia gibba* | (Ehrenberg) OttoMüller |
| 106 | *Stauroneis amphicephala* | Kützing |
| 107 | *Stauroneis anceps* | Ehrenberg |
| 108 | *Staurosira construens* | Ehrenberg |
| 109 | *Staurosiraconstruens var. venter* | (Ehrenberg) P.B.Hamilton |
| 110 | *Staurosiralapponica* | (Grunow) Lange-Bertalot |
| 111 | *Stauroneis neohyalina* | LB nov.stat. |
| 112 | *Stauroneis phoenicenteron* | (Nitzsch) Ehrenberg |
| 113 | *Staurosirella pinnata* | (Ehrenberg) D.M.Williams and Round |
| 114 | *Staurosirella pinnata (long)* | (Ehrenberg) D.M.Williams and Round |
| 115 | *Staurosirella pinnata var intercedens* | (Grunow) P.B.Hamilton |
| 116 | *Stauroneis smithii* | Grunow |
| 117 | *Surirella angusta* | Kützing |
| 118 | *Tabellaria flocculosa* | (Roth) Kützing |
| 119 | *Tetracyclus glans* | (Ehrenberg) Mills |

Table S3: Chironomid taxon names, numeric codes, and authority names presented in the DCA ordination (Figure 3.2).

| Code | Taxon Name | Authority |
|---|---|---|
| 1 | *Arctopelopia / Thienemannimyia* | Fittkau |
| 2 | *Corynocera ambigua* | Zetterstedt |
| 3 | *Cardiocladius* | Kieffer |
| 4 | *Chaetocladius* | Kieffer |
| 5 | *Chaoborus* | Lichtenstein |
| 6 | *Chironomus* | Meigen |
| 7 | *Cricotopus intersectus*-type1 | Staeger |
| 8 | *Cricotopus intersectus*-type2 | Staeger |
| 9 | *Cladotanytarsus mancus* | Walker |
| 10 | *Chironomini larvula* | from Brooks and Birks (2001) |
| 11 | *Corynoneura arctica* | Kieffer |
| 12 | *Cladopelma* | Kieffer |
| 13 | *Cricotopus cylindraceus* (Type 275) | Kieffer |
| 14 | *Cricotopus bicintus* | Meigen |
| 15 | *Cricotopus sylvestris* | Fabricius |
| 16 | *Cricotopus laricomalis* | Edwards |
| 17 | *Cricotopus* type P | van der Wulp |
| 18 | *Cryptochironomus* | Kieffer |
| 19 | *Demicryptochironomus* | Lenz |
| 20 | *Derotanypus* | Roback |
| 21 | *Dicrotendipes* | Kieffer |
| 22 | *Endochironomus* undifferentiated | Kieffer |
| 23 | *Endochironomus albipennis* | Meigen |
| 24 | *Glyptotendipes* undifferentiated | Kieffer |
| 25 | *Glyptotendipes barbipes* | Staeger |
| 26 | *Lasiodiamesa* | Kieffer |
| 27 | *Lauterborniella* | Thienemann & Bause |
| 28 | *Limnophyes* | Eaton |
| 29 | *Mesocricotopus* | Brundin |
| 30 | *Metriocnemus* | van der Wulp |
| 31 | *Microtendipes* | Kieffer |
| 32 | *Micropsectra insignilobus* | Kieffer |
| 33 | *Monodiamesa* | Kieffer |
| 34 | *Nanocladius* | Kieffer |
| 35 | *Orthocladius* type 2 | van der Wulp |
| 36 | *Orthocladius* type C | van der Wulp |
| 37 | *Orthocladius consobrinus* | Holmgren |
| 38 | *Orthocladius* type i | van der Wulp |
| 39 | *Paratanytarsus austriacus* | Kieffer |
| 40 | *Parachironomus* | Lenz |
| 41 | *Paracladius* | Hirvenoja |

| | Taxon Name | Authority |
|---|---|---|
| 42 | *Parakiefferiella* type B | Thienemann |
| 43 | *Parakiefferiella nigra* | Brundin |
| 44 | *Paratanytarsus penicillatus* | Goetghebuer |
| 45 | *Paratanytarsus* undifferentiated | Thienemann & Bause |
| 46 | *Paratendipes* | Kieffer |
| 47 | *Phaenopsectra* | Kieffer |
| 48 | *Polypedilum* | Kieffer |
| 49 | *Potthastia* | Kieffer |
| 50 | *Procladius* | Skuse |
| 51 | *Psectrocladius barbimanus*-type | Edwards |
| 52 | *Psectrocladius mesopsectrocladius*-type | (Kieffer) Laville |
| 53 | *Psectrocladius monopsectrocladius*-type | (Kieffer) Wülker |
| 54 | *Psectrocladius sordidellus*-type | Zetterstedt |
| 55 | *Rheocricotopus* | Brundin |
| 56 | *Sergentia* | Kieffer |
| 57 | *Stempellina* | Thienemann & Bause |
| 58 | *Stictochironomus* | Kieffer |
| 59 | *Corynocera oliveri* | Lindeberg |
| 60 | *Tanytarsus lugens* | Kieffer |
| 61 | *Tanytarsus mendax* | Kieffer |
| 62 | *Tanytarsus* undifferentiated | van der Wulp |
| 63 | *Tanytarsus nemorosus* | Edwards |
| 64 | *Tanytarsus pallidicornis* | Walker |
| 65 | *Thienemanniella* | Kieffer |
| 66 | *Zalutschia lingulata pauca* | Saether |
| 67 | *Zalutschia zalutschicola* | Lipina |
| 68 | *Zavreliella* | Kiefer |

Table S4: P-values from a series of Kruskal-Wallis tests used to assess which of the limnological and sediment variables differ significantly among the three hydrological categories (snowmelt-dominated (n=15); rainfall-dominated (n=20); and intermediate (n=14)). Values are calculated based on average values from July 2007 and 2008. Degrees of freedom = 2. α = 0.05.

| Variable | SI Unit | *p*-value |
|---|---|---|
| Limnological variables | | |
| Depth | m | 0.176 |
| Temp | °C | 0.243 |
| Cond | $\mu S \cdot cm^{-1}$ | 0.001 |
| DO% | % | 0.003 |
| pH | units | 0.000 |
| Alkalinity | $mEq \cdot L^{-1}$ | 0.001 |
| $Cl^-$ | $mg \cdot L^{-1}$ | 0.021 |
| $Ca^{2+}$ | $mg \cdot L^{-1}$ | 0.024 |
| $Mg^{2+}$ | $mg \cdot L^{-1}$ | 0.000 |
| $K^+$ | $mg \cdot L^{-1}$ | 0.326 |
| $Na^+$ | $mg \cdot L^{-1}$ | 0.000 |
| $SO_4^{2-}$ | $mg \cdot L^{-1}$ | 0.001 |
| DOC | $mg \cdot L^{-1}$ | 0.000 |
| DIC | $mg \cdot L^{-1}$ | 0.002 |
| $SiO_2$ | $mg \cdot L^{-1}$ | 0.107 |
| N | $mg \cdot L^{-1}$ | 0.093 |
| $NH_3$ | $\mu g \cdot L^{-1}$ | 0.164 |
| TDP | $\mu g \cdot L^{-1}$ | 0.000 |
| TP | $\mu g \cdot L^{-1}$ | 0.582 |
| Chl-*a* | $\mu g \cdot L^{-1}$ | 0.090 |
| Sediment Properties | | |
| $C_{Org}$ | % | 0.125 |
| N | % | 0.154 |
| C:N | | 0.460 |
| $\delta^{13}C_{org}$ | ‰VPDB | 0.014 |
| $\delta^{15}N$ | ‰ AIR | 0.076 |
| OM | % | 0.107 |
| MM | % | 0.118 |

Table S5: Metrics for environmental variables along the first two axes of the RDA analysis of diatom and chironomid data.

| Biota | Env Variable | Regression coefficient | | Interset correlation | |
|---|---|---|---|---|---|
| | | AX1 | AX2 | AX1 | AX2 |
| Diatoms | DO% | -0.805 | -0.480 | -0.768 | -0.427 |
| | %OM | 0.519 | -0.707 | 0.494 | -0.629 |
| | $C_{org}$ | 0.460 | -0.271 | 0.439 | -0.241 |
| | TDP | 0.547 | 0.135 | 0.522 | 0.120 |
| | $Ca^{2+}$ | -0.616 | 0.146 | -0.587 | 0.129 |
| | $Mg^{2+}$ | -0.699 | 0.124 | -0.667 | 0.110 |
| Chiro-nomids | %OM | 0.527 | -0.254 | 0.466 | -0.215 |
| | Alk | -0.654 | 0.150 | -0.577 | 0.127 |
| | DO% | -0.824 | -0.244 | -0.728 | -0.207 |
| | %MM | -0.527 | 0.534 | -0.465 | 0.453 |
| | TN | 0.212 | 0.650 | 0.187 | 0.551 |
| | DOC | 0.633 | 0.244 | 0.559 | 0.207 |

# *Chapter 4. Community-based research, youth outdoor education and other highlights of a northern research internship experience in Old Crow, Yukon Territory*

This chapter has been published as: Balasubramaniam, A.M. 2009. Community-based research, youth outdoor education and other highlights of a northern research internship experience in Old Crow, Yukon Territory. Meridian Spring/Summer: 14 – 19.

## *4.1. Introduction*

As an early career northern researcher, I have come to realize that northern research is more than just the science and adventure associated with field research. It is also an opportunity to interact with people in Canada’s most remote communities and build relationships through sharing knowledge. Meaningful interaction with a community is best accomplished by spending long periods there, to show good will, build trust, and become familiar with how the community operates. This can be a tall order for most graduate students, who are limited by time and finances at northern field sites.

The Natural Sciences and Engineering Research Council (NSERC) Northern Internship (NRINT) program recognizes this, offering subsidies to offset the cost of an extended stay and encouraging partnerships between early career researchers and northern organizations. The internship aims to foster the development of qualified researchers in a way that is useful to northerners, and to bridge the communication gap between researchers and interested community members. It encourages students to get involved in communities and to perform educational outreach by sharing their findings with local people in accessible formats. The program can provide a perfect opportunity for young researchers to expand their portfolios and acquire a variety of skills while developing important connections within northern communities.

As an International Polar Year (IPY) researcher involved in a community-driven research project based in Old Crow, Yukon, I could see how a Northern Research Internship would allow me to expand my own research project while working within the community to *leave a legacy*, which is a central focus of the IPY. In the summer of 2008, during my second year of field research, I undertook a Northern Internship and stayed in Old Crow from June to September.

My host organization was the Vuntut Gwitchin First Nation Government's Natural Resource Department (NRD). We worked together to create three broad, mutually beneficial goals. The first, and the fundamental reason for the internship, pertained to community engagement, knowledge transfer and capacity building: to foster environmental stewardship and community-based scientific monitoring activities. The second involved furthering my research objectives by expanding my data set while exploring new areas of research. The third goal was to assist, on behalf of the NRD, in facilitating the fieldwork of other researchers studying in the Old Crow area. In this chapter, I will briefly describe the highlights of my summer internship and outline some lessons I learned.

## *4.2. Fostering the Development of Environmental Stewardship and Community-Based Scientific Monitoring*

The people of Old Crow are in a state of transition. Their harvesting opportunities are decreasing because of what they consider to be unprecedented environmental change occurring in their traditional territory. This community, historically one of hunters and gatherers, now faces complex natural resource management issues that go beyond basic sustainable harvesting. Over recent years community members report that their access to wildlife has been hindered by hydrological changes (low river water levels and lakes draining), diminished wildlife populations (low counts of caribou and fish stocks) and other environmental phenomena. The need for environmental stewardship and long-term data sets is becoming more apparent both to the community and the IPY researchers. The NRD faces the challenge of equipping local residents with the skills they need to undertake environmental stewardship programs based on scientific monitoring practices. Some programs are successfully focusing on wildlife population counts. However, there is a growing need for monitoring key ecosystem parameters that can indicate ecosystem-wide change, such as hydro-ecological change in lakes. During my internship in Old

Crow, given my interest and knowledge in freshwater ecosystems in the area, I worked with the NRD to overcome some of the obstacles associated with science-based research by actively engaging community members in science activities as often as possible using public education and cooperative research.

Public education within a community can take many forms and I found that the combination of formal presentations to groups and informal discussions with individuals worked best in Old Crow. Working at the NRD office gave me many opportunities to chat informally over tea with local people about some of the research on environmental changes in their traditional territory, the Old Crow Flats, which is the focus of IPY project in which I am participating. Each working day I would normally spend two or three hours chatting with visitors who came by the NRD office and asked questions. This was an excellent opportunity to discuss my research with interested community members and get their input. Conversations that started off with my work in the Flats often moved on to local stories of personal experiences. These increased my understanding of regional dynamics and highlighted new avenues to research.

During the Biennial Gwitchin Gathering, the Vuntut Gwitchin First Nation's international conference and celebration, I was asked to make a formal presentation as part of the climate change speakers' panel. This presentation encompassed an overall project description which I made in collaboration with my colleagues across Canada, and described recent findings in plain language. The presentation as delivered to an audience of over thirty people, and several key decision makers that were interested in understanding IPY research findings in order to initiate discussions and propose policies that would sustain their traditional hunting, fishing, and trapping activities in the context of rapid climate warming. The comments and questions from the audience and the discussions my talk generated really helped me gain a broader perspective on my project and understand the linkages between science and policy. The lakes I had sampled and discussed were no longer simply data points on a graph but rather living systems, part of the livelihood and cultural identity of the Vuntut Gwitchin First Nation.

As another, more formal way of engaging Old Crow residents in science, I launched a community-based lake biomonitoring project. A collaborative research effort supported financially by the NRD and the Yukon Government, it took place at nearby Mary Nitro Lake, which was selected due to its similar size, depth and macrophytes characteristics as study lakes located in the Flats. The lake also has a campsite and canoe launch that had been used by the late Mary Nitro, a respected elder, which made it an ideal site. The goals of the project were wide in scope, and included both improving local knowledge and research in freshwater research while, assessing seasonality and homogeneity of lake biotic communities and testing algal samplers (collecting periphyton) that my lab group was developing to deploy in the Old Crow Flats.

In order to engage locals, NRD hired a local youth, Ryan Kyikavichik, and assigned their game guardian, Robert Kyikavichik, to the project. Both worked as field assistants and participated in biweekly monitoring activites to test the ease of use of the samplers by assembling, deploying and retrieving them. The first trips went well. My field assistants were engaged and easy to work with when given proper explanations of methodology and research objectives and learned quickly how to use modern limnological tools – a YSI multi-meter (which measures water quality), a light meter, and plankton net tows. In fact, as a team we quickly found a rhythm and carried out our tasks efficiently. Robert raced through his tasks proficiently and excelled at using limnological meter-based testing. Ryan had a steeper learning curve, but with guidance from Robert and I, he quickly picked up tasks; he was very good at plankton tows and discovered everything from leeches to rare *Gordian* horse-hair worms. At times, however, even with the best of intentions and prior planning, trips had to be cancelled because of circumstances in the personal lives of the field assistants. I quickly learned that my field technicians had many priorities that took precedence over their roles on my research team. A flexible schedule proved more workable in the long run and best for maintaining interpersonal relationships.

Despite the occasional interruptions to sampling, the science goals of the project were achieved. Research findings demonstrated that neither water chemistry nor abundance and composition of periphytic diatoms differed substantially among sample sites within the lake. This suggested that the field methods utilized in my thesis research, that focused on collection of singular central samples of water and algal sediment samples, would adequately reflect whole - lake conditions. The success of this add-on research project was realized in the development of a peer-reviewed publication (*see* MacDonald et al. 2012) and the training of individuals in the community who understand the rationale behind the biomonitoring tools and freshwater research. The insights I gained regarding the usability and effectiveness of the periphyton samplers, the data collected in the Old Crow Flats, and lessons learned regarding deployment and collection of artificial-substrate samplers catalysed other graduate research in my lab group (see.Tondu J.E. 2012; Mohammed W. Thesis *In Progress.*).

Another memorable public education experience in Old Crow was organizing and leading a boys' and girls' science camp as a way to engage youth in science. Circumstances, including deaths in the close-knit community, meant that this was the only camp offered all summer and it provided the young people their only chance to get out on the land, a central element in their culture. The camp also offered an excellent opportunity to teach the children – the future community leaders – about environmental stewardship and the scientific method through firsthand experience. Planning all aspects of the camp was for me an enormous undertaking, but an enjoyable one. Earning the trust of the community and discovering the details of childcare in a First Nation community was a fascinating experience that I will not soon forget

The science camp ran for seven days, the time divided equally between girls and boys aged eight to fifteen years old – in separate time slots, as girls from previous camps had requested. The workshops were interactive and focused on basic scientific methodology. I encouraged the children to think of questions, make predictions, conduct experiments, and gather observations until they formulated their answer. These methods were new to them as most had not had the opportunity to take science at primary school. At the request of an elder, the camp also taught traditional skills and the sessions incorporated traditional medicine and plant diversity hikes conducted by Vuntut Gwitchin staff. Less formal sessions such as cooking the fish specimens after dissection and an anatomy lesson evolved unplanned because the staff did not want to let good food go to waste. The children learned the techniques for skinning, gutting and smoking fish from the camp steward, a respected elder.

Overall, the camp resembled camps of my own childhood, except for little details that highlighted the importance of culture and tradition to the children. For instance, in the girls' camp, following fish dissection lessons, some of the youngest female campers were more interested in gathering fish eggs and cooking them on the fire (Figure 4.1) than in eating the prepared cheese sandwiches they were being offered. On the other hand , the boys, who were often rambunctious, sat quietly during the 10 minutes of down-time between activities, constructing bows and arrows out of willow branches. These small differences really highlighted the need for an integrated camp that embraced their cultural heritage while teaching them modern scientific theory. Retrospectively, the fact that the youth enjoyed the camp and its combination of traditional knowledge and science is a positive sign for this community where schoolchildren typically feel overwhelmed by science subjects (Figure 4.2).

### *4.3. Expanding Research Objectives and Assessing Biomonitoring Tool Usability*

Research schedules in northern regions rarely permit add-on projects that allow for testing of established research methodology; but an extended stay at a field site can enable a researcher to study a system over a longer period of time and run quality-control tests. My primary field research schedule included three short trips into the field for helicopter surveys to retrieve one water sample per lake, and time and budget restraints left little room for more detailed studies. During my internship, however, I not only completed all three helicopter surveys but also collected multiple replicate data sets of water chemistry, periphyton, and light measurements from Mary Nitro Lake through the community-based biomonitoring project (Figure 4.3). As stated above, these strengthen my knowledge of the spatial and seasonal dynamics of regional shallow lakes and will aid in deciphering the length of time and release location of samplers within a lake. This additional quality-control analysis of thesis methodology enables me to refine and share methods with my lab group, as well as develop a comprehensive list of protocols for use by the community of Old Crow and our other northern agency partners.

### *4.4. Improving Researcher Collaboration and Field Coordination*

One of the most problematic aspects of remote northern research is the lack of field bases and local staff to help with logistical tasks, which makes it difficult for the many researchers studying the Old Crow Flats to collaborate and share logistics. I have often experienced logistical setbacks that an effective “go-to” person could easily have avoided. During my internship I assisted the NRD in this area, working with their staff IPY coordinator to facilitate researchers’ arrivals to town and departures to field sites and their access to logistics. I also coordinated and hosted meetings and dinners where researchers could discuss their field seasons, equipment needs, and future research directions. This kind of exchange among researchers – which usually occurs only during conferences and formal meetings – was always energizing, enjoyable, and generally informative. At one point, at the request of a researcher who needed assistance, I was even able to visit a field camp out on the Flats, and we sat down to have tea and discuss her progress as well as her needs. This type of collaboration really did enhance my summer experience and it allowed me to see another more administrative side of research. I now fully appreciate the cumulative weight of the tasks we ask of our northern research partners. Most importantly, it granted me the opportunity to get to know many of the scientists and learn more about their research. My internship was an extremely positive experience. I would recommend it to early career researchers interested in adding a different layer of context to their thesis projects. The experience has been of lasting benefit to my research by broadening my understanding of the ecosystem in which I work. It has also considerably strengthened my portfolio of skills for collaborating effectively in an integrative community-centered scientific research project and has given me a good perspective on the work needed to facilitate large research initiatives. Furthermore, the internship provided me with a unique opportunity to connect with the community of Old Crow in a meaningful way by assisting them with tasks they considered important. I have made many connections with people in the town and continue to work with them on other research and education projects. In the North, where interpersonal relationships are part of the cultural fabric, it is very rewarding to have been able to develop some strong friendships. These relationships would not have been possible had I not lived there for an extended period of time. This internship has been a success on many levels and significantly increased my connection to northerners. It likely has set the stage for me to develop a strong career as a northern researcher.

### *4.5.Acknowledgements*

I am grateful to NSERC for providing funding for my Northern Research Internship and would like to thank Shel Graupe (Director of NRD), Robert Kyikavichik, Ryan Kyikavichik, Megan Williams and all other NRD staff for their help in coordinating my internship and my field research at Mary Nitro Lake. I would also like to thank the Parks Canada staff Leila Sumi, Jeffery Peters and Lance Nukon as well as Brian Bell and Kristy Kennedy for their voluntary assistance with Science Camp. A special thanks to Erika Tizya-Tramm, Renee Charile, James Itse and Sharon Maureen Vittrekwa who staffed the camp and offered their expertise. A quick thank-you to the parents who have allowed me to use the photos of their children in this article. And a big thankyou to former Chief Joe Linklater, Stephen Frost and the community of Old Crow for their friendship and kindness which has given memories and experiences that I will always take with me. Lastly, I would like to thank my supervisors, Lauren MacDonald, and my lab group for their support and help throughout the internship period.

## 4.6. Figures

Figure 4.1: Frying up fish eggs at the girls' science camp, August 2008.

Figure 4.2: The final goodbye at the Science camp, August 2008

Figure 4.3: Fieldwork at Mary Nitro Lake as part of community biomonitoring research efforts.

# *Chapter 5. Working with Northern Communities to Build Collaborative Research Partnerships: Perspectives from Early Career Researchers*

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## *5.1. Introduction*

Partnerships between northern communities and academics have existed for decades, yet new attitudes regarding northern scholarship have shifted the research paradigm towards one that is more collaborative, interdisciplinary, and reflective of northern people’s priorities (Gearhead and Shirley, 2007; Wolfe et al. 2011; Adams et al. 2014). These shifting priorities have been largely driven by comprehensive land-claim agreements (e.g., the Yukon Umbrella Final Agreement, several land-claim agreements in the Northwest Territories, Nunavut, and northern Quebec, and the Labrador Inuit Land Claims Agreement) that have led to various types of natural resource management, from co-management through self-government. Community involvement is an important component of licensing requirements for research in the three Canadian territories, and communities are calling for increasing participation - at every level - in research programs that take place in their region (First Nations Centre 2007a, b; ITK and NRI 2007; Nickels and Knotsch 2011), including a role for indigenous researchers (McGregor et al. 2010).

This growing impetus for local community involvement in northern research is often driven by the rapid environmental, socioeconomic, and developmental changes affecting northern communities and ecosystems (Berkes and Jolly 2002; Armitage et al. 2011; Ford et al. 2013). The result has been efforts to form community-collaborative research programs across disciplines ranging from health (Jardine and Furgal 2010; Wesche et al. 2011) and environmental sciences (Marcoux et al. 2011) to social sciences (Nahanni 1977; Ryan and Robinson 1990; Caine et al. 2007; Lyons 2013), although many academic practices are still adapting to this paradigm shift.

Community-collaborative research, for the purposes of this paper, is an overarching term that encompasses different approaches to research (e.g., community-engaged research, community-based participatory research, community-based monitoring) that involves engaging local communities and individuals in the research process with the goal of sharing or co-generating knowledge to understand complex problems and bring about change through policy.

Several models of community-collaborative research have been adopted, which differ in the degree of community engagement (St. Denis 1992; Whitelaw et al. 2003; Armitage 2005; Danielsen et al. 2009). Regardless of the framework or approach used, the very core of community-collaborative research is developing a partnership between communities and visiting researchers and involving communities in the research process in a meaningful way.

Collaborations between visiting researchers and local communities are important, not only to advance northern scholarship, but to address the needs of local communities, build capacity, and inform local decision makers. Social and natural science research in the Arctic often directly and indirectly affect communities, whether through the research process itself, or through the implications of the research for policy and management (Pearce et al. 2009; Ogden and Thomas 2013; Audla and Smith 2014). Thus, it is an ethical responsibility to involve local communities in any research that is within their traditional territory. From a practical perspective, communities can also provide logistical support and local expertise through expert knowledge of the socio-ecological landscape and local protocols for respectful research, which is essential to most northern research programs. Furthermore, the inclusion of traditional and local knowledge in northern studies is becoming increasingly valuable for evolving Arctic research and advancing collaborative partnerships between researchers and northern communities (Reidlinger and Berkes 2001; McGregor et al. 2010; Knopp et al. 2012; Kokelj et al. 2012; Robus 2012; Simmons et al. 2012; Smith et al. 2012).

Including community-collaborative approaches in study design can inform and advance northern research programs (Mallory et al. 2003; Gilchrist et al. 2005) and decision making (Armitage 2005). For example, community-collaborative approaches have been successful in identifying health determinants (Jardine and Furgal 2010; Durkalec et al. 2014), characterizing food security (Lardeau et al. 2011),  informing monitoring and management of caribou (Parlee et al. 2005), waterfowl (Gilchrist et al. 2005) and marine mammals (Armitage 2005; Brook et al. 2009); and guiding archaeological research (Robinson 1996; Lyons 2011). Although research licensing authorities and organizations representing indigenous groups in Canada have set guidelines for community-collaborative research (First Nations Centre 2007a, b; ITK and NRI 2007; NAHI and IT 2009; Aurora Research Institute 2011; Government of Canada, 2013; Yukon Research Centre 2013), community stakeholders (residents, local governments, and regulatory authorities) have indicated that there is room for improvement (Aurora Research Institute 2013; Audla and Smith 2014). Accordingly, northern researchers are increasingly encouraged to familiarize themselves with best practices for integrating community collaboration into their research programs.

In Canada, early career researchers (ECRs) have a strong desire to meet the growing demand to work closely and collaboratively with northern communities, yet many ECRs are uncertain on how to proceed with this type of research design. Undertaking community-collaborative research can be a daunting task for ECRs who are often restricted by time and a lack of experience on how to effectively build and employ research collaborations with northern communities. Many ECRs report that they do not have enough mentorship within their institutions to support their community-collaborative research efforts, and they lack adequate skills and information required to undertake this task in a meaningful way. Despite the requirements and benefits of community-collaborative research, many researchers—even experienced ones—admit that they do not have the necessary contacts, experience, or resources to engage community members actively beyond the minimum permitting process.

To support ECRs in their efforts to conduct community-collaborative research and develop local community partnerships in northern Canada, the ArcticNet Student Association (ASA) and the Association of Polar Early Career Scientists (APECS) convened two “Community-driven Research” sessions during a two-day Career Development Workshop at the International Polar Year (IPY) 2012 Conference in Montreal, Canada. Here, we describe the sessions, report common themes that were addressed, and summarize the resulting discussions. We also provide our perspectives and lessons learned while working on community-collaborative research projects in northern Canada. We hope to provide insight from the experiences of ECRs that have been working towards the new northern research paradigm, and provide suggestions to guide new ECRs to conduct community-collaborative research successfully.

### *5.2. IPY Career Development Workshop Sessions for Community – Driven Research*

More than 150 undergraduate, graduate, post-graduate, and post-doctoral researchers attended the IPY career development workshop entitled “From Knowledge to Careers,” which aimed to help ECRs develop skills needed for work and collaboration in international and interdisciplinary circumpolar research. During the two-day workshop, a one-hour “community-driven research” session was held twice and led by APECS mentors (John Crump, Nikolaus Gantner, and Deborah Simmons) who have considerable experience working with northern indigenous communities. This mentor-based approach allowed for an iterative progression in framing the discussion and facilitated an informal dialogue during which ECRs could share their personal experiences, recommendations, and challenges and ask each other questions about how to work successfully within northern communities.

Over the two sessions, the discussion included voices of 46 ECRs from 28 different institutions in 10 countries: Argentina, Australia, Canada, Germany, France, Netherlands, New Zealand, Norway, Russia, and the USA. At the end of each session, participants were encouraged to write down recommendations or advice for future researchers and ask questions regarding community-collaborative research. The comments were collected, categorized, and analysed by Ann Balasubramaniam and Jana Tondu. Below we outline the key themes, resource gaps, and recommendations that emerged from the session discussions, 34 written responses, and subsequent conversations.

## *5.3. Key Themes for Developing Northern Community-Collaborative Relationships*

Session participants recognized that the context and conduct of Arctic research are evolving towards greater engagement with local communities. They highlighted several fundamental and interrelated themes that they deemed essential to establishing positive research relationships: dedicating time, being present, communicating, listening, respecting, understanding, building trust, making genuine collaborative efforts, and exchanging knowledge (Figure 5.1). While each northern community is unique, and relationship-building tools that work in one community may not always work in another, the concepts outlined in Figure 5.1 offer a guideline for enabling mutual collaborative efforts, facilitating knowledge exchange, and creating a forum for knowledge gain. ECRs recognize that achieving true community-collaborative research is a challenging task, especially in the very real context of ECR inexperience, lack of local knowledge, funding limits, and timeline constraints (e.g., short field seasons, program requirements) associated with most graduate programs. Yet, despite all the challenges and limitations, the collective experience of session participants indicated that with commitment and devoted effort—and with the assistance of knowledgeable and experienced local leaders and researchers—ECRs can successfully develop research collaborations with northern communities.

### *5.3.1. Dedicating Time*

Session participants most often identified investing the time needed to build trusting relationships as the first essential step in community-collaborative research. The conceptual model shown in Figure 5.1 shows that time is necessary for being present in a community, as well as for developing ways to communicate with a community, listening to community members, and understanding and respecting local culture and history. Spending time with people in these ways demonstrates a sincere interest in working with communities, and not just in them: it helps to build trust, earn respect, and establish relationships that are long-term commitments to northern communities. Many elements (e.g., ongoing communication, understanding local culture) are important for developing community relationships, and an investment of time before, during, and after visits to communities is essential. For example, because social media have become a very popular mode of communication in the North, investing time in these media can be an effective tool for staying connected and engaged even at a distance.

### *5.3.2. Being Present*

An extended presence in a community can help develop communication pathways, create opportunities to listen, and help ECRs learn, understand, and appreciate northern community cultures. Session participants identified physical presence in a community as central to nurturing meaningful relationships. Spending an additional few days in the community at the beginning and end of trips can provide opportunities to attend community meetings and cultural events, learn about issues important to the community, engage in open and honest dialogue about research, and develop rapport with the community. An extended presence in a community helps give a face to research and is a step towards building trust with individuals, community organizations, and researchers. Most importantly, ECRs should take the initiative to ensure their presence is noticed within the community by participating or volunteering in local activities and community events, arranging formal and informal meetings with local leaders and knowledge holders, and communicating about research activities as discussed below and in Table 5.1. Spending time in communities outside of the context of one's research project demonstrates dedication and commitment to the community (i.e., a vested interest beyond the scope of research) and provides an opportunity to share knowledge in a less formal context.

### *5.3.3. Communicating*

ECRs identified local communities as a critical audience for communicating northern research; however, scientific research is often reported in a language geared toward academic audiences. Northern licensing guidelines call for improved communication between researchers and communities, including (but not limited to) the proposal of research objectives, dissemination of results and conclusions, and discussion of implications for the community. To share information and keep community members up to date with research, it is important to host community workshops, schedule face-to-face meetings, deliver presentations, and develop short, easy-to-read documents such as posters, newsletters, pamphlets, short reports, and on-line posts. Session participants stressed the importance of preparing research reports in clear, accessible language to ensure mutual understanding of what is being communicated. A useful guide to plain language writing has been published by the NWT Literacy Council (2003). In addition, working with community researchers to find appropriate terms, concepts, and examples in the local language will help develop effective communication. Aboriginal communities will appreciate efforts to understand and document key concepts and terminology in their own language. This process is not always easy, and ECRs may require the assistance of a community language specialist for proper spellings, but it is well worth the effort (NWT Species at Risk Committee, 2014).

### *5.3.4. Listening*

A recurring theme highlighted by session participants was the need to listen. Listening to community members means not only receiving information, but paying thoughtful attention in order to hear what is really being said—a key skill that is often overlooked by ECRs, who are used to academic, one-way styles of communication (e.g., teaching, lecturing, presenting). Aboriginal learning methods and protocols in the north often strongly value listening skills, and researchers who listen respectfully and show that they are learning usually earn respect in return. Formal and informal meetings, gatherings, and community events can provide opportunities to listen. It is also important to consider that community members may relay information, questions, or concerns in the form of a story (Legat 2012). Listening is critical to identifying and understanding the context and valuable message(s) embedded in community-based information.

### *5.3.5. Respecting and Understanding*

Learning local history and culture and trying to operate respectfully within community cultural norms are also fundamental building blocks for developing relationships and engaging communities. Participants stressed the need for ECRs to learn and understand as much as possible about communities before visiting and to continue to learn during visits, in order to engage in a way appropriate to community-specific cultural norms. For example, providing food and refreshments during community meetings is a common tradition in most northern communities, but individual communities may have specific preferences about the types of food offered. In addition, practicing local customs and protocols during research visits creates a sense of familiarity and comfort between researchers and can lead to increased participation of community members in research-related events. Efforts to learn and practice the local language and cultural skills also help foster relationships and establish trust.

Northern communities are complex, and social structures may include recognized roles and protocols for community members of different genders and age groups and those with specialized knowledge. Respect for the livelihoods and historical traditions of those who live where research is being conducted should be combined with an understanding of local experiences and interest in adapting new technologies and practices to address issues. For example, elders are recognized for their high degree of knowledge and experience and have earned the right to pass knowledge on to others and are thus addressed with the utmost respect. At the same time, younger people are recognized for their knowledge and innovative practices. Understanding also includes learning about prior or current research that has been conducted with a community. This learning will not only develop a platform of knowledge gained from prior research, but will ensure that research is not duplicated and help identify community partners and potential collaborative research teams or initiatives.

### *5.3.6. Building Trust for Collaborative Efforts and Knowledge Exchange*

A strong relationship built on a foundation of mutual trust is essential for creating and maintaining genuine collaborative efforts and facilitating knowledge exchange. ECRs identified various ways to engage local residents in all phases of the research process: design, data collection, analysis in some cases, interpretation of results, conclusions, and recommendations (summarized in Table 5.1). ECRs emphasized that engaging with a community at the beginning of a research project to discuss objectives and project design is important for building trust and achieving successful community-collaborative research.

Working with local organizations and community members in a joint intellectual effort to realize shared goals generates research that will have a greater application and relevance to the community. ECRs shared their experiences of different approaches to community-collaborative research that involved education and outreach opportunities for local youth (Fig. 2a, b, and c) and collaboration with communities on research projects (Fig. 2d, e, and f). Overall, participants in these sessions agreed that including local residents in the research process generates mutual respect, results in further engagement and interest in the research project, and often sets the stage for knowledge exchange.

### *5.4. Important resources for ECRs conducting northern research in Canada*

Northern peoples in Canada have the need and ability to carry out research in their own communities, yet the influx of well-intentioned ECRs keen to carry out collaborative and locally relevant research can be overwhelming for the communities (Roburn and Tr’ondek Hwech’in Heritage Department, 2012). This is especially true at the start-up phase of a research project, when ECRs are learning about permitting processes and local politics, social norms, and resources,  meeting local experts, identifying local expert collaborators,  and becoming familiar with the ethics and protocols that surround working with human subjects and traditional knowledge. To help facilitate the added influx of northern researchers during the 2007 – 09 IPY period, the IPY, ArcticNet, Inuit Tapiriit Kanatami (ITK), the Nasivik Centre for Inuit Health and Changing Environments (Nasivvik), and the Northern Contaminants Program developed the Inuit Research Advisor and IPY coordinator positions for all northern regions in Canada (ITK and Nasivvik 2010).

Although both the Inuit Research Advisors and the IPY coordinators greatly increased the resources available to researchers working with communities in the North, session participants identified a need for improved access to resources on how to approach, initiate, and maintain meaningful community-collaborative research. In response, a list of key resources has been compiled by the authors to assist ECRs in this process. To make these resources readily available and easily accessible to all interested parties, we have created a special page on the APECS website (http://www.apecs.is/en/get-involved/national-committees/apecs-canada-sp-1927085779/canadian-resources/ccr-resources).

### *5.5. Recommendations from ECRs on How to Facilitate Relationship-Building Processes in Northern Communities*

As the second-largest polar nation, Canada has developed a Northern Strategy that emphasizes leadership in science and technology through a collaborative, interdisciplinary, and community-oriented research paradigm (Government of Canada 2009). Although community-collaborative research can be a challenging task, ECRs who participated in the 2012 IPY community-driven research sessions recognized and valued the importance of collaborating with northern communities and thereby empowering them to make evidence-based decisions regarding their culture, land, and resources. Here, we expand on the session discussions summarized above and recommend further practical actions that can be taken by ECRs to enable the integration of northern community collaboration into the ECR experience.

### *5.5.1. Actively Pursue Funding for Community-Collaborative Research*

As discussed above, fostering and building truly collaborative partnerships requires an investment of both time and money. Financial constraints can limit the number of visits and length of stays at northern research locations. ECRs should make it a priority to seek funding that will allow for longer stays within communities (Balasubramaniam 2009; Tondu 2011), including travel for community collaborators to forums where they can share research results. A list of major funding resources for ECRs within Canada can be found in the resource table on the APECS website (http:// www.apecs.is/en/research/funding-resources). In addition, funding and scholarship agencies must acknowledge and appreciate the time commitment that is needed to establish collaborative relationships between researchers and northern communities.

### *5.5.2. Incorporate Community-Collaborative Research Sections into Theses*

The methods used to initiate and maintain collaborative partnerships should be documented as part of the work undertaken to generate research results. To highlight these efforts, ECRs can dedicate a chapter or appendix to emphasizing the significance of community-collaborative research, and describe how this method added value to their thesis outcomes. These thesis sections can include a formal analysis of information contributed by communities (e.g., Robus 2012) or can report how the community was involved in data collection and other activities through-out the research. Formally incorporating these types of contributions into theses will encourage more supervisors and departments to acknowledge these activities officially. Through such efforts, ECRs can take an active role in ensuring that community-collaborative research efforts are formally recognized on a broader scale within their academic fields.

### *5.5.3. Publish Peer-Reviewed Papers that Describe Community-Collaborative Research Efforts*

Beyond incorporating community-collaborative research methods into theses, ECRs can also take an active role in sharing their experiences and community-collaborative research projects with the wider research community (e.g., Balasubramaniam 2009; Knopp 2010; Tondu 2011; Knopp et al. 2012; Provencher et al. 2013). Several research journals, including Arctic (InfoNorth), Northern Review, and Meridian, actively seek contributions reflecting on work that integrates community-collaborative programs. Publishing in these journals allows ECRs to both share their successes and lessons learned and gain citable references to add to their publication records, and it provides an opportunity to co-publish with northern partners and strengthen the collegial nature of the community-researcher relationship. Co-authorship is also a way to formally acknowledge community members who have played an active role in the research. Publication is also a great opportunity for ECRs to communicate how their community-collaborative research efforts are relevant and applicable to the wider academic audience.

### *5.5.4. Communicate and Share Community-Collaborative Research Efforts*

In addition to publications, another way of communicating and sharing community-collaborative research outcomes is to prepare a poster or give an oral presentation describing community-collaborative work in relevant sessions during conferences or meetings (e.g., Tondu et al. 2014). Consider presenting community-collaborative approaches as an integrated component of a research talk or as an additional presentation that might be in a different session. Presenting in a different session is also an excellent way to expose your work to new audiences. Inviting a community collaborator and presenting together can enrich both the collaborative process and the presentation itself. Ultimately, incorporating community-collaborative research projects in all presentations, whether in the community or region, at the departmental level, or at an international conference, will promote the importance of community-collaborative research. In preparing a presentation, it is important to keep in mind the nature of the audience.

Community and regional or non-academic audiences will require plain language presentations, ideally with a strong visual approach (Polfus et. al. 2014), or a conversational or storytelling approach that supports listening and avoids the slide presentation format.

### *5.5.5. Highlight Skills Developed from Community-Collaborative Experiences*

The multiple skills required to conduct community-collaborative research projects are highly relevant to industry, government, non-governmental organizations, and academia. Transferable skills acquired by both ECRs and community collaborators include communication, leadership, working as a team, adaptability, flexibility, and ability to work in cross-cultural environments and implement ethical protocols. ECRs should highlight these skills on their resumes, CVs, and scholarship applications and encourage community researchers to do the same. ECRs and community collaborators can also support each other's efforts to seek employment or further education by serving as references on applications.

### *5.5.6. Continue your Community-Collaborative Research Education*

The key themes and suggestions synthesized in this paper are not a comprehensive prescription for developing community-collaborative relationships in northern Canada, and each community will require unique approaches. To help promote community-collaborative research efforts and continue to learn successful approaches, it is important to form a network, or using existing networks, through which ECRs can share resources, knowledge, and experiences.

Organizing in-person workshops (e.g., during ArcticNet student days) or joining online forums (e.g., APECS Traditional Knowledge working group) are ways in which ECRs can expand networks, share knowledge, and learn from other ECRs. In addition, ECRs can organize and host special departmental seminars and group presentations that focus on or highlight aspects of community collaboration. By taking a leadership role in organizing community-collaborative research outreach events and activities, ECRs can expand their networks, shape the future of community-collaborative research, and solidify it as an integral part of northern research.

#### *5.5.7. Find a Mentor*

It is ideal to find a researcher with experience in the community or region who is willing to serve as a mentor. This continuum of knowledge is important for polar research, and many senior researchers and professionals are willing to serve as mentors for ECRs. In an effort to help guide the relationship between senior mentors and ECRs, APECS has created a mentorship program and a database of experts willing to serve as mentors in a variety of ways (http://www.apecs.is/en/careers/mentorship/find-a-mentor). In 2013, APECS Canada and the ASA developed a nomination-based mentor award program to acknowledge the time and energy that mentors dedicate to ECRs and their efforts to build a supportive community of northern researchers.

### *5.6. Conclusions*

As northern Canada continues to develop and evolve with changes in climate and political and socioeconomic pressures, conducting community-collaborative research approaches will ensure that world-class northern research continues and remains relevant to northern priorities. ECRs that shared their experiences and ideas in the 2012 Community-driven Research sessions demonstrated their commitment to such approaches. A synthesis of their input crystallized a number of concepts and recommendations that are essential to building trust and relationships needed to form effective working partnerships with northern communities. We hope the ideas presented here will catalyze future discussions and help build the momentum for community-collaborative research in northern Canada and throughout the circumpolar regions. The description and suggestions given here are based on our collective experiences and thus reflect community-collaborative research as seen by early career researchers. However, the authors would like to stress that continuing to include northern communities in this conversation while encouraging their perspectives and approaches is essential to effective collaboration. Though we are well on our way to achieving the new northern research paradigm, continued dialogue with and support from our northern communities, supervisors, departments, institutions, funding agencies, and other partners are critical to ensure that the effort it takes to reach out to communities through the research process continues and improves.

### *5.7.Acknowledgements*

We extend a huge thank you to the organizing committee of the IPY 2012 Career Development Workshop: From Knowledge to Careers; to Karley Campbell and Kimberley Keats for their role in organizing the Community-driven Research sessions; to session participants; and to ArcticNet and APECS for providing the opportunity for the sessions. We also thank Morgan Ip for providing final review, photos, and input into the paper. Thanks to Audrey Giles and Sarah Stratham for helping to carry forward valuable discussions regarding community-collaborative research. This paper would not be possible without the knowledge, guidance, and insights provided by the northern communities with whom we have collaborated. We extend deep appreciation to the communities of Arctic Bay, Arviat, Cape Dorset, Délıne, Gjoa Haven, Iqaluit, Kimmirut, Kuujjuaq, Old Crow, Paulatuk, Resolute Bay, Sachs Harbour, Sanikiluaq, Tuktoyaktuk, and Ulukhaktok, as well as to our incredible mentors in each of these communities. We owe much to our supervisors and departmental colleagues who have supported our pursuit of community-collaborative research. We are grateful for the many local, regional, cross-regional, and national organizations that have provided funding, in-kind, and practical support for ECR involvement in community-collaborative research.

## *5.8.Figures and Tables*

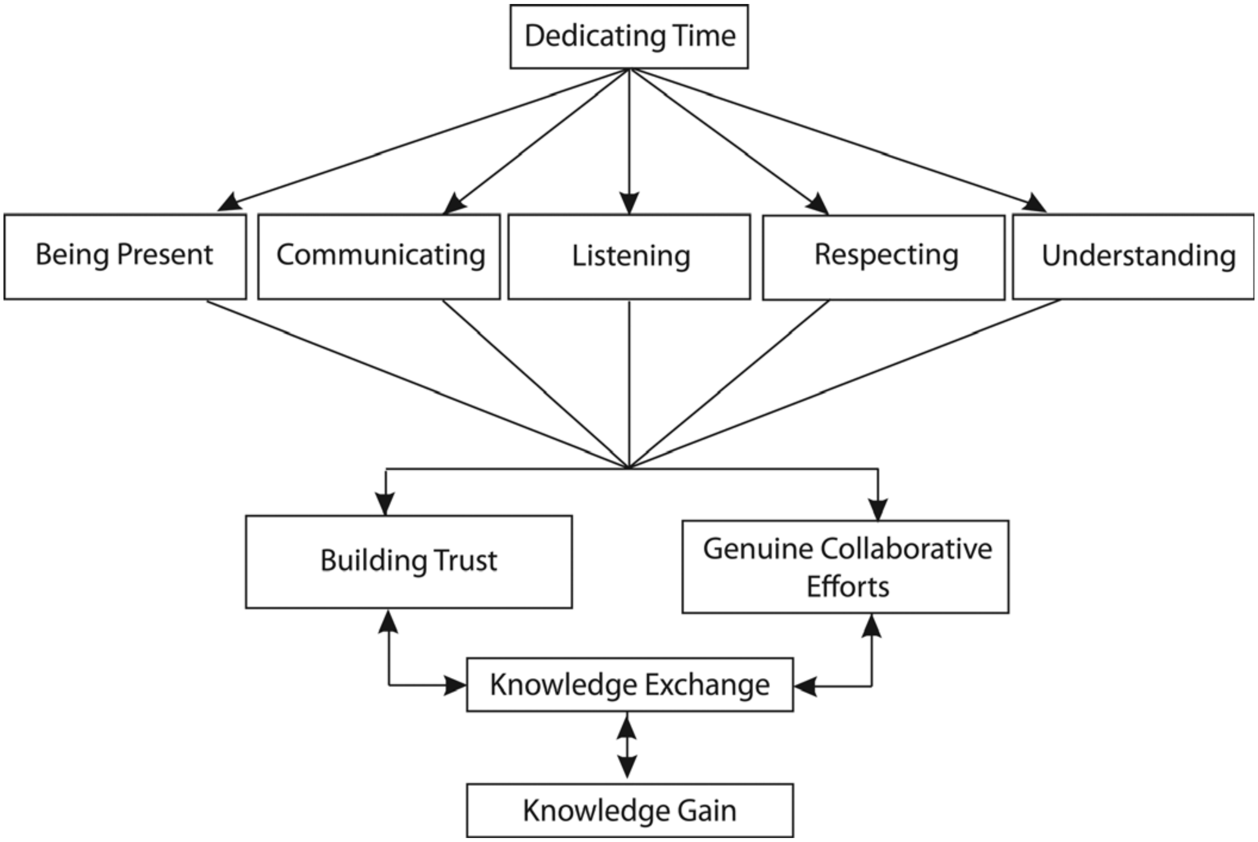

Figure 5.1: Conceptual model of the key themes important to developing community-collaborative research relationships.

Figure 5.2: Examples of early career researchers (ECR) working collaboratively with northern communities: a) youth science camp in Old Crow, Yukon: a program initiated by the Vuntut Gwitchin Government, that ECR helped coordinate and organize; b) marine bird dissection workshop held at Nunavut Arctic College in Iqaluit, Nunavut led by ECR in partnership with Carleton University and Environment Canada; c) an inaugural Youth Conference on Climate Change in Old Crow, Yukon where ECR worked with community leaders to provide workshops; d) community-based plant collections near Sanikiluaq, Nunavut organized by ECR and community members; e) Lake Trout samples drying in Sahtù traditional territory collected from Great Bear Lake in partnership with community members from Déline, NWT; and f) working with Inuit hunters from Gjoa Haven to conduct non-invasive surveys of polar bear tracks in the M'Clintock Channel, Nunavut. Respective photo credits: Leila Sumi, Jen Provencher, Kevin Turner, Lucy Mary Tookalook, Louise Chavarie, Pamela Wong.

Table 5.1: Suggested actions and activities ECR can do to work towards community-collaborative research

*Join in community life*

- Attend community events such as potlatches and feasts, recreational activities (e.g., baseball or hockey), and youth events.
- Go on a travel, hunting, or fishing trip when invited (offer to contribute funds or supplies to help with costs, bring appropriate gear, your own food, proper permits for your activity).
- Take part in traditional activities such as story-telling, music, dancing and food preparation.
- Take the time to listen to stories from Elders.
- Take the time to visit with community members.
- Invite people over tea and/or food and engage in conversation.
- Volunteer at community events.
- When at community events take the opportunity to discuss your research and answer questions in an informal setting.
- Work with a community leader to help you navigate community politics and cultural norms.

*Involve local community members in your research*

- Host a community workshop or hold open meetings to discuss your research.
- Work directly with local health, social, education, wildlife, and environment organizations. Choose appropriate collaborative organizations based on your area of study.
- Contact and consult communities, especially Elders identified as experts, local researchers, and knowledge holders when identifying research questions and planning your research project.
- Hire local assistants to help you collect samples.
- Hire local guides or community members to provide safety and transportation for fieldwork.
- Partner with local community members to conduct interviews and surveys.
- Plan ahead and ensure you have enough funding to reimburse people for services rendered. Payment can include money or gifts (i.e. gas). Find out what is normal before arriving in the community and budget for this when applying for funding to ensure you can cover the expected costs.
- Include community members in project design.
- Acknowledge community members that participated in the research project in peer-reviewed publications and reports, and co-author or co-present with community members where appropriate.
- Obtain funding to bring community members to work in your lab analyzing samples or invite them to a conference to assist in presentation of results.

*Communicate your research to the community*

- Offer to give a presentation about your research to community organizations (e.g.,

First Nations or Inuit Government, Renewable Resource Councils, or Community Corporations).
- Meal sharing in some communities is very important and having a meal at your presentation will help motivate people to attend, listen, and participate. Also consider offering door prizes as a way to thank your audience for their participation.
- Talk about your research on a local radio station.
- Present your research to the community when maximum audience participation is possible; plan things that do not conflict with community activities like hunting.
- Submit draft papers or reports to local organizations and governments that have a vested interest in the research project for an opportunity to review and provide comment.
- Disseminate results to the community in a straight-forward manner using plain language suitable for the general public through presentations, community meetings, posters, and non-technical documents.
- It is important to provide both project materials and presentations translated into the local language to be inclusive of all community members.

*Share your knowledge*

- Work with local collaborators to organize or facilitate community knowledge sharing events like a Science and Traditional Knowledge Camp. This actively engages youth and knowledge holders in the community and serves as a way to link traditional, local, and scientific knowledge.
- Make arrangements with teachers at the local school to go into classrooms and teach youth about your area of expertise and your research.
- Hold public training events and workshops that relate to your project.
- Bring educational materials to leave in the community (e.g., in schools, libraries, government and agency offices, colleges).

*Be visible and available*

- Be aware that northern communities work on different schedules than those to which you might be accustomed. Be flexible in your work hours and meet with community members at times that are convenient for them.
- Do some of your work outside (e.g. assembling field equipment, organizing samples) to allow curious members of the community an opportunity to informally ask questions and engage in discussions.
- Spend as much time in view of the community as possible. This will give people the opportunity to see you and approach you.
- Be aware of costs associated with staying in the community and that food and accommodation prices are high in remote areas.
- Use online tools like social media for both outreach and keeping in touch with people while you are not present in the community.
- Leave handouts and posters about your research and contact information where people can reach you when you are back at your research institution. Include your mailing address, phone number, email and if possible a personal cell phone number.
- Leave self-addressed envelopes in the community so people can send you mail.

Table 5.2: Key Resources for ECR conducting community collaborative research projects in northern Canada.

| **Resource** | **Website Link** |
|---|---|
| Summary of organizations and resources available to ECRs wanting to work with communities in northern Canada | http://test.apecs.is/en/get-involved/national-committees/apecs-canada-sp-1927085779/canadian-resources/ccr-resources |
| Materials covering ethics and guidelines for working with northern communities and including Traditional Knowledge in research | http://apecs.is/get-involved/working-groups/traditional-knowledge |
| Inuit Tuttarvingnat – Permits and Licences (Four Inuit Regions in Canada) | http://www.naho.ca/inuit/research-and-ethics/research-permits-and-licences/ |
| Inuit Research Advisors (Four Inuit Regions in Canada) | www.arcticnet.ulaval.ca/research/advisors.php |
| Nunavut Research Institute | http://www.nri.nu.ca/apps/authoring/dspPage.aspx?page=about |
| Nunavik Research Center | http://www.makivik.org/nunavik-research-centre/ |
| Aurora Research Institute – *Working together: A guide for researchers working in NWT* | https://nwtresearch.com/licensing-research/communicating-research/working-together-guide-researchers |
| Inuit Tapiriit Kanatmi – *Negotiating Research Relationships with Inuit Communities* | https://www.itk.ca/sites/default/files/Negotitiating-Research-Relationships-Researchers-Guide.pdf |
| Inuit Circumpolar Council – Declarations | http://inuitcircumpolar.com/section.php?Nav=Section&ID=25&Lang=En |
| Yukon Territory – *Protocols and Principles for Conducting Research with Yukon First Nations* | http://emrlibrary.gov.yk.ca/ebooks/Northern%20Research%20Institute/Protocols_principles_conducting_research_Yukon_First_Nations.pdf |
| First Nations Centre – *Considerations and Templates for Ethical Research Practices* | http://www.naho.ca/documents/fnc/english/FNC_ConsiderationsandTemplatesInformationResource.pdf |
| The First Nations Principles of OCAP$^{TM}$ (Ownership, Control, Access and Possession for data and knowledge management) | www.fnigc.ca/ocap.html |
| First Nations of Quebec and Labrador Research Protocol | http://www.cdrhpnq.qc.ca/afnql_research_protocol/summary/protocol_synth_en.pdf |
| Assembly of First Nations – *Ethics in First Nations Research* | http://www.afn.ca/uploads/files/rp-research_ethics_final.pdf |
| Resources connecting researchers and northern communities in Canada | http://www.arcticonnexion.ca/en |

# Chapter 6. Summary, Implications and Recommendations

Shallow lakes, ubiquitous in sub-arctic and Arctic regions across northern Canada, are widely recognized to be vulnerable to climate change. In recent years, numerous hydrological studies of shallow Arctic lakes have reported relations between warming climate conditions and changes in lake water-balances, yet few limnologists have attempted to test if hydrological processes influence limnological conditions and biota of lakes in this context. Understanding how changing hydrology and climate affect lake ecology is pertinent to developing a predictive capacity to anticipate potential future effects of environmental change. In partnership with the Vuntut Gwichin First Nation, this thesis aimed to assess the complex influence key hydrological processes exert on aquatic ecology of shallow lakes in Old Crow Flats. In accordance with the mandate of the International Polar Year, this thesis also attempts to leave a legacy of knowledge with the community by developing innovative methodology to engage the community in collaborative research. The following text summarizes the insights and new knowledge generated from quantitative testing of hydro-limnological relations and provides some recommendations to advance northern science methodology to embrace community-collaborative approaches.

## 6.1. Contributions to Knowledge

### *6.1.1. Influence of hydrology on limnology*

This thesis presents new data and insight into the influence of source-water inputs, as mediated by catchment characteristics, on water chemistry and biotic communities of shallow lakes underlain by relatively homogenous glacio-lacustrine sediments in a continuous permafrost landscape. Results demonstrate that lakes receiving snowmelt-dominated input waters, situated in catchments that support tall shrub and woodland vegetation, possess significantly higher nutrient and dissolved organic carbon concentrations relative to lakes with rainfall-dominated input waters. Conversely, rainfall-dominated lakes, located in catchments dominated by dwarf shrubs and sparse vegetation, have significantly higher concentrations of major ions and more alkaline pH. These limnological differences persisted throughout the ice-free season (Chapter 2), and between years (Chapter 3, Appendix A). Given relatively similar sestonic primary productivity in snowmelt- and rainfall - dominated lakes, lower $\delta^{13}C_{org}$ values in surface sediment of snowmelt-dominated lakes, compared to the rainfall-dominated lakes, suggests supply of soil-derived $^{13}C$-depleted DIC from forested catchments due to greater hydrological connectivity in these lakes. The enriched $\delta^{18}O$ values of rainfall-dominated lakes suggest that these lakes experience elevated evaporative concentration of ions compared to snowmelt dominated lakes likley due to their relatively greater surface area (Chapter 2). However, deposition of dissolved mineral matter from shoreline erosion, influx of ion-rich material delivered by storm water runoff, and dilution effects of snowmelt inputs are also possible mechanisms and require further research.

Seasonal analysis revealed that lakes within the snowmelt-dominated category experience the least change in limnological characteristics over time compared to lakes in the rainfall-dominated and intermediate categories (Chapter 2). Results also reveal that the water chemistry of a set of intermediate lakes, distinguished by a change in dominance of source-water type (i.e., snowment to rainfall) during the ice-free season, were unique in comparison to the lakes that remained in the snowmelt- and rainfall-dominated categories. In particular, analysis of seasonal water chemistry patterns identifies intermediate lakes to exhibit behaviour similar to snowmelt-dominated lakes in early-season, and subsequently mimic rainfall-dominated lakes as the influence of snowmelt wanes. This highlights the sensitivity of shallow lake water chemistry to shifting sources of input water, which provides insight into how climate related shifts in

precipitation may affect northern lakes.

### ***6.1.2.*** *Influence of hydrology on lake biota*

During the early part of the ice-free season, lakes dominated by snowmelt, which possess higher nutrient concentrations, have significantly higher phytoplankton biomass-inferred from sestonic Chl *a* compared to lakes receiving primarily rainfall (Chapter 2). By mid-season and into late-season, however, Chl *a* concentrations of lakes within all hydrological categories span similar ranges and did not differ significantly (Chapter 2). Thus it is likely that processes other than nutrient availability drive phytoplankton productivity in mid-season. This result challenges common perceptions that higher lake nutrient concentration equates to greater algal productivity in shallow northern lakes, and instead suggests other mechanisms (e.g. light limitation) may be important regulators of phytoplankton during mid- and late-season. More research would be needed to fully understand northern lake phytoplankton productivity as the influence of grazing was not quantified and remains unknown.

Composition of diatom and chironomid remains in recently-deposited surface sediments differs significantly among lakes within snowmelt- and rainfall-dominated categories (Chapter 3). However, unlike water chemistry variables that experienced strong regulation by hydrology, findings suggest that assemblage composition is regulated by a complex interplay of multiple factors. Results of variance partitioning analysis identify limnological variables to explain the largest proportion of variation in biotic communities. Important independent roles of sediment properties and catchment characteristics were also found. Notably, substantial shared variation among these classes of environmental variables identified cascading influence of input-water sources, as mediated by catchment characteristics, on water chemistry and sediment properties via direct and indirect pathways. Equally important is the large portion of unexplained variation, which draws attention to the limitations of point-in-time measurements in describing dynamic processes regulating biotic communities. Based on the results presented here, which were predicated on access to high quality data sets, it is strongly suggested that studies assessing biotic communities in shallow northern lakes move away from focusing on on singular associations (e.g. limnology) as they may miss the interplay of other factors are of equal importance. Overall, this research identifies that i) hydrology exerts a strong influence on biota via complex indirect pathways, and ii) biotic responses to environmental change are complex and non-linear and thus must be treated that way during analysis.

## *6.2. Contributions to northern research: from paradigms to practise*

### *6.2.1. Collaborative research methods as a basic model for northern scientists:*

Existing frameworks for conducting natural science research in the North are often criticized for not representing northern priorities. Indigenous communities, funders and government bodies have been prompting natural science researchers to engage in community-centered research. However, tangible methodology for community engagement which can be broadly implemented have yet to arise. In this thesis, methods developed while conducting research as part of the IPY project entitled Yendoo Nanh Nakhweenjit K’atr’ahanahtyaa (Chapter 4; Appendix C) and an analysis of the personal experiences of 46 Early Career Researchers (ECRs) from 28 different institutions across 10 countries provide some fundamental concepts for developing working relationships with northern communities. Spending extended periods of time in communities has been highlighted an important initial step in forging lasting relationships as it provides an opportunity for researchers to conduct activities outside of field research. These activities can include communicating with local individuals or organizations regarding your research and reciprocally listening to local observations or stories that may provide added insight to your work. Certainly, communication at the onset of the research project to include community in initial design process of research can be particularly successful for initiating strong research relationships (Appendix C). Equally important is the capacity of local governing bodies or community organizations to reciprocate researcher's efforts by providing a level of coordination to ensure effective community interaction (Chapter 4, Appendix C). Certainly, the work presented in this thesis greatly benefited from the support and commitment to collaborate displayed by various members of the community of Old Crow and the Vuntut Gwitchin Government .While this level of reciprocity may not be easily attained in every community, due to socio-economic instability, lack of capcity, or historical disenfranchisement related to legaicies of colonialism, it is advised that researchers take strides to understand and acknowledge existing issues and endeavor to build positive working relationships which respect indigenous rights and expertise. Once the project begins and data collection ensues, researchers should also make an attempt to be present in communities and attend community events as this shows a level of respect and understanding for local culture and traditions (Chapter 5). Ultimately, the goal of investing time to build relationships with individuals and community organizations is to develop a level of trust in order to facilitate genuine collaboration and knowledge exchange. It is only with effective knowledge exchange that the gap between science knowledge production and community uptake and implementation can be bridged.

### *6.2.2. Leaving a legacy of knowledge*

A central objective of the IPY was for research teams to ‘leave a legacy” for northern communities. This knowledge transfer could be achieved by communicating results in plain language, building local capacity for scientific research, or creating programming that allowed the community to continue to monitor relevant trends. Beyond plain language reporting, via regular yearly community meetings and science brochures, fulfilling the IPY requirements for building capacity and creating a monitoring program was challenging as there were few resources available for implementing these programs (Appendix C). However, by forming collaborations, seeking additional resources and forming partnerships, a community-based monitoring program was facilitated during an extended stay in the community during the ice-free season of 2008 (Chapter 4). Built into the community-based monitoring program was the training of community members in field work methods, hypothesis formation and results interpretation. The data analyzed also resulted in a peer –reviewed publication, and was foundational for two other thesis projects in my lab group, one of which launched a long-term monitoring program in collaboration with Parks-Canada (Chapter 4). Clearly, the scientific returns on the initial investment of time during my extended stay in the community were substantial.

Other unexpected benefits of my extended stay in the community included presenting research results at a meeting with political leaders within the community and being asked to assist in the coordination of science workshops for the inaugural youth conference on climate change in the region. These opportunities to translate science knowledge into plain language for current and future leaders are essential for bringing science into the policy arena.

### 6.3. Recommendations and considerations:

Given the clear relations between hydrology and limnology, it is recommended that limnologists studying shallow northern lakes add hydrological parameters to their sampling design. Water isotope tracers can be a quick and effective way to assess water balance of shallow lakes at a landscape scale, and can be easy to add on to existing limnological sampling protocols that involve large spatial surveys as they only require the addition of one 30 ml sample. Given that there is seasonal variation in lake water quality and hydrological inputs, it is also recommended that spatial surveys limited to only one sampling period aim for mid-season (late July to early August). This time frame represents a peak in lake sestonic productivity, and a period where an average hydrological signal can be determined with minimal influence of early-season snowmelt and late-season rainfall.

When conducting landscape-scale studies and evaluating lake biotic responses across hydro-limnological gradients, results suggest that researchers would benefit from measuring multiple environmental gradients. As a host of internal lake processes and external environmental factors likely simultaneously exert an influence on aquatic communities, a multifactor approach will give researchers a better understanding of the complex processes influencing biotic community structure. Our results highlight the efficacy of using catchment characteristics, hydrology, water chemistry, and sediment properties to assess benthic biota however other factors are also likely useful to measure. As these data can require considerable effort to collect/ quantify, it may be beneficial to access and utilize pre-existing environmental data for factor analysis, or alleviate some of the sampling burden by seeking collaborators.

When analyzing biotic datasets collected from a heterogeneous environment, researchers attempting to determine which environmental gradient best explains beta diversity often employ direct gradient analyses techniques. However, in the presence of multiple species and multiple environmental gradients where one or more environmental variable exerts influence on species composition via complex interactions with other environmental variables standard constrained correlational analysis may miss variables of importance. Instead, results from this thesis demonstrate the utility of decomposing variance and partialing out environmental variables that are not of direct interest in order to gain insight into some of the complex relations occurring. When possible, researchers should employ variance partitioning analysis to better characterize beta diversity.

Although Turner et al. (2010) described 5 hydrological lake types in the OCF, this thesis only concentrated on snowmelt-dominated, rainfall-dominated lakes and an intermediate category. The remaining categories, which characterized lakes dominated by groundwater seepages, evaporation and drainage, had insufficient sample size for statistical testing. While the influence of evaporation on lake water chemistry was acknowledged, it is likely that groundwater seepages and drainage also exert strong influence on limnological conditions of some lakes. Thus, it is recommended that these hydrological processess should be assessed in future, if hydrological conditions shift and allow for adequate sample sizes.

The interaction of northern shallow lakes with the permafrost landscape is broadly described in Chapter 2, but the specifics regarding the role of active layer depths, soil composition and water flow were not accounted for in this research. However, the active layer exerts strong control on surface and near-surface drainage of snowmelt and rainfall into shallow lakes. Knowledge of flow rates, soil characteristics, and water quality of seepages would further improve our knowledge of nutrient and ion delivery to lakes. More detailed studies are recommended to test the role of groundwater flow in catchments surrounding study lakes in the OCF. Certainly, installation of piezometers and wells within the active layer and sampling at different time periods during the ice-free season can be labour intensive so it would be recommended that a small subset of lakes be chosen in each hydrological category.

Conducting this research collaboratively with a northern community has enriched the quality of this thesis while providing new research opportunities to my lab group, and increasing the knowledge and capacity of individuals in the community of Old Crow. I recommend that more natural science researchers pursue collaborative research, using methods discussed here and elsewhere. Researchers should communicate how implementation of collaborative methods worked in their specific discipline in order to further the discussion and ensure progressive improvements to the basic model provided here. Regardless of the type of research being conducted within northern communities, early community engagement and involvement in aspects of decision making is fundamental to the new paradigm of northern research. As such, novel and creative thinking may be required to engage communities. Researchers must also advocate to departments and supervisors unfamiliar with the North about the value and urgent need for collaborative research approaches. Although this thesis focuses on methodology researchers should embrace in order to effectively collaborate with communities during the research process, for collaborative methods to work there is also a need for active participation of local governents and community organizations.  Undeniably, the success of the collaborative efforts described in this thesis were predicated on the fact that the Vuntut Gwitchin Government, members of the Vuntut Gwitchin First Nation, and Parks Canada all made efforts to participate, and sometimes facilitate collaboration. Going forward, as community-collaborative research gains momentum in the north, it will be important for northern communities to develop local capacity, policies, and infustructure to enable collaborate research approaches.

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# *Appendix A: Trends in water chemistry 2007 - 2009*

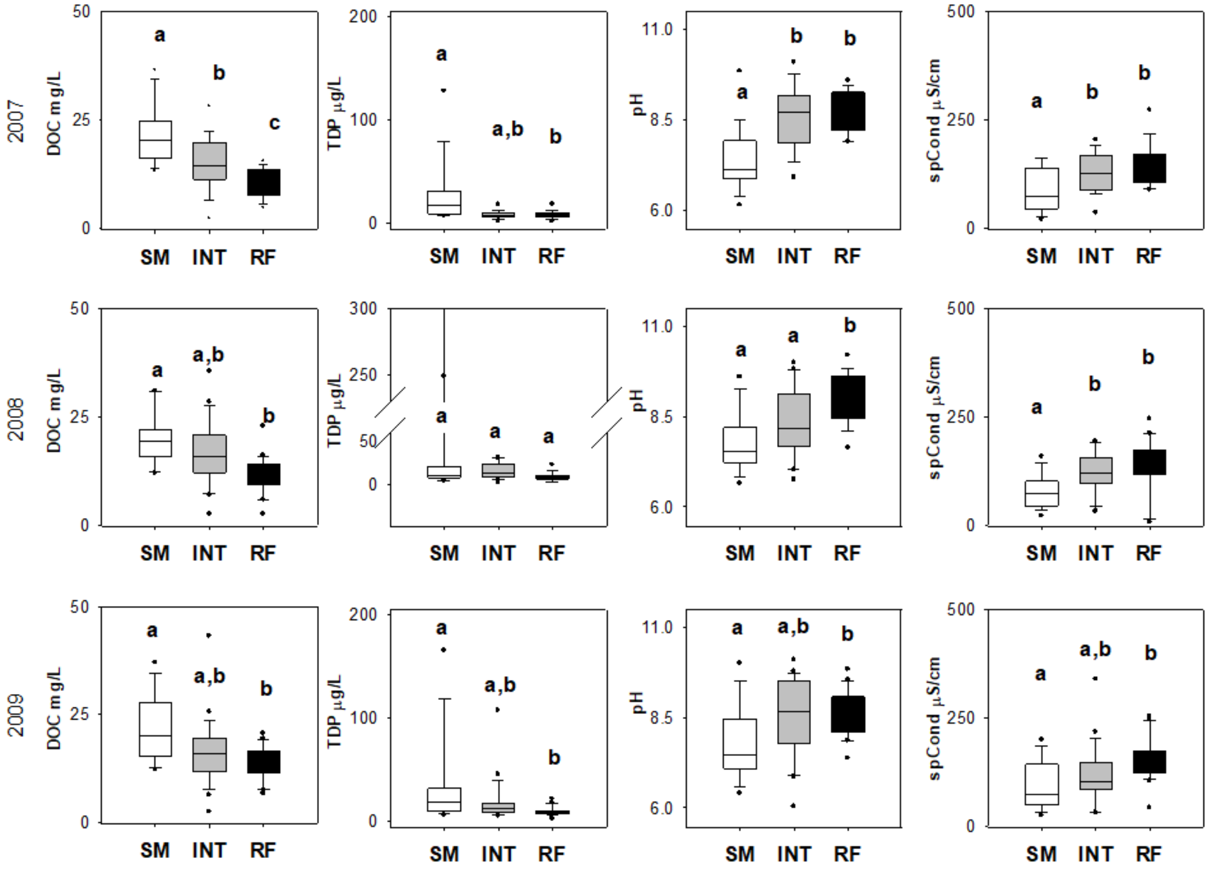

Figure A.1: Boxplots comparing the distributions of selected water chemistry variables among the lakes within the snowmelt-dominated(SM), intermediate (INT) and rainfall-dominated (RF) hydrological categories, based on data obtained in mid-season (late-July) of 2007 - 2009. Whiskers represent the 10th and 90th percentiles, and values beyond them are represented by black dots. Different lowercase letters (a, b, c) indicate that the distribution of the presented variable differs significantly (*p*≤0.05) among hydrological categories based on a Kruskal-Wallis test and subsequent Tukey post-hoc tests of that variable (see text for further details).

# *Appendix B: Raw Data*

Table B.1: Part 1 – Raw water chemistry data for 56 OCF lakes, measured at three time-points over the ice-out period in each of 2007 - 2009. Values reported in italicised red font indicate detection limits; n.d. indicates that no data is available; and, Cat. indicates the source-water category (SM: snowmelt; INT: intermediate; RF: rainfall).

| ID | Lake OCF | Y | M | Cat | Depth m | Temp ˚C | DO % | pH - | Alk meq/L | DIC mg/L | DOC mg/L | SpC µS/cm | SO$_4$ mg/L | Cl mg/L | Ca mg/L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 2007 | 6 | INT | 0.67 | 7.44 | 80 | 7.18 | 0.87 | 10.4 | 7.6 | 101 | 4.97 | 0.44 | 14.30 |
| 2 | 2 | 2007 | 6 | RF | 0.65 | 6.34 | 86 | 7.05 | 0.73 | 8.6 | 3.0 | 79 | 2.81 | 0.47 | 11.00 |
| 3 | 3 | 2007 | 6 | SM | 3.27 | 5.94 | 49 | 6.45 | 0.33 | 3.6 | 22.9 | 45 | 2.12 | 0.30 | 6.83 |
| 4 | 4 | 2007 | 6 | INT | 1.30 | 6.08 | 82 | 7.10 | 1.00 | 12.1 | 8.4 | 102 | 1.08 | 0.36 | 13.10 |
| 5 | 5 | 2007 | 6 | INT | 3.12 | 7.41 | 77 | 7.24 | 1.27 | 15.2 | 2.8 | 123 | ***0.02*** | 0.49 | 18.10 |
| 6 | 6 | 2007 | 6 | RF | 0.65 | 3.48 | 87 | 7.21 | 0.80 | 9.4 | 3.0 | 85 | 1.96 | 0.31 | 12.10 |
| 7 | 7 | 2007 | 6 | INT | 1.20 | 4.50 | 90 | 6.64 | 0.28 | 4.1 | 10.7 | 34 | 0.94 | 0.18 | 4.07 |
| 8 | 8 | 2007 | 6 | INT | 1.00 | 6.66 | 74 | 6.94 | 1.03 | 13.5 | 10.3 | 106 | 0.72 | 0.45 | 13.60 |
| 9 | 9 | 2007 | 6 | INT | 2.55 | 5.08 | 80 | 7.19 | 1.24 | 15.5 | 10.7 | 127 | 0.97 | 0.24 | 17.50 |
| 10 | 10 | 2007 | 6 | INT | 0.47 | 12.70 | 92 | 6.92 | 0.60 | 6.4 | 16.0 | 67 | 1.53 | 0.39 | 8.13 |
| 11 | 11 | 2007 | 6 | SM | 1.24 | 14.48 | 93 | 6.28 | 0.16 | 2.6 | 18.6 | 26 | 0.54 | 0.44 | 2.72 |
| 12 | 12 | 2007 | 6 | SM | 0.75 | 14.53 | 100 | 7.33 | 1.36 | 15.5 | 11.1 | 140 | 1.33 | 1.03 | 15.50 |
| 13 | 13 | 2007 | 6 | SM | 4.15 | 13.44 | 88 | 6.24 | 0.15 | 3.0 | 21.0 | 26 | 0.18 | 0.28 | 2.72 |
| 14 | 14 | 2007 | 6 | INT | 0.65 | 11.62 | 99 | 6.99 | 0.82 | 9.7 | 9.4 | 84 | 0.40 | 0.52 | 10.50 |
| 15 | 15 | 2007 | 6 | INT | 1.12 | 7.83 | 94 | 6.93 | 0.54 | 6.9 | 4.5 | 64 | 2.45 | 0.19 | 8.51 |
| 16 | 16 | 2007 | 6 | SM | 2.25 | 3.94 | 79 | 7.14 | 1.16 | 14.0 | 12.7 | 125 | 3.71 | 0.35 | 17.80 |
| 17 | 17 | 2007 | 6 | SM | 0.55 | 14.95 | 91 | 7.27 | 1.11 | 13.1 | 10.8 | 111 | ***0.02*** | 0.40 | 21.40 |
| 18 | 18 | 2007 | 6 | RF | 0.98 | 7.38 | 98 | 7.30 | 0.91 | 11.0 | 5.5 | 96 | 0.60 | 0.28 | 15.70 |
| 19 | 19 | 2007 | 6 | INT | 0.70 | 14.49 | 101 | 7.44 | 1.42 | 16.5 | 8.5 | 206 | 29.50 | 0.71 | 27.90 |
| 20 | 22 | 2007 | 6 | SM | 2.70 | 9.57 | 89 | 6.84 | 0.50 | 6.4 | 14.4 | 56 | 0.28 | 0.29 | 6.39 |
| 21 | 23 | 2007 | 6 | SM | 1.45 | 10.12 | 56 | 5.90 | 0.09 | 1.8 | 20.7 | 19 | 0.12 | 0.18 | 1.82 |
| 22 | 24 | 2007 | 6 | SM | 0.50 | 12.56 | 99 | 6.75 | 0.29 | 3.6 | 9.0 | 33 | 0.08 | 0.28 | 3.90 |
| 23 | 25 | 2007 | 6 | SM | 2.35 | 14.18 | 92 | 5.71 | 0.08 | 0.9 | 33.5 | 25 | 0.45 | 0.26 | 2.85 |
| 24 | 26 | 2007 | 6 | SM | 1.30 | 6.78 | 82 | 6.57 | 0.29 | 3.7 | 17.9 | 36 | 0.13 | 0.26 | 4.79 |
| 25 | 28 | 2007 | 6 | RF | 0.85 | 6.02 | 90 | 7.13 | 0.83 | 20.0 | 10.2 | 88 | 1.60 | 0.31 | 11.40 |
| 26 | 29 | 2007 | 6 | RF | 0.87 | 5.70 | 98 | 7.42 | 1.38 | 17.0 | 5.3 | 142 | 2.59 | 0.41 | 19.80 |
| 27 | 30 | 2007 | 6 | INT | 1.55 | 4.45 | 83 | 6.94 | n.d. | 16.0 | 17.3 | 151 | n.d. | n.d. | n.d. |
| 28 | 31 | 2007 | 6 | INT | 1.35 | 4.32 | 55 | 6.92 | 0.78 | 9.0 | 16.5 | 82 | 1.07 | 0.24 | 10.70 |
| 29 | 32 | 2007 | 6 | INT | 1.50 | 4.97 | 83 | 6.46 | 0.19 | 2.5 | 18.2 | 26 | 0.26 | 0.19 | 3.41 |
| 30 | 33 | 2007 | 6 | RF | 1.30 | 3.86 | 88 | 7.04 | 0.64 | 7.8 | 10.1 | 73 | 1.88 | 0.33 | 8.74 |
| 31 | 34 | 2007 | 6 | RF | 1.05 | 5.88 | 93 | 7.25 | 1.03 | 11.5 | 5.4 | 108 | 3.52 | 0.65 | 14.30 |
| 32 | 35 | 2007 | 6 | INT | 1.10 | 13.96 | 102 | 7.12 | 0.74 | 7.6 | 13.1 | 83 | 3.88 | 0.42 | 10.20 |
| 33 | 36 | 2007 | 6 | RF | 1.35 | 5.42 | 73 | 7.37 | 1.96 | 24.1 | 12.5 | 195 | 1.78 | 0.56 | 26.30 |
| 34 | 37 | 2007 | 6 | RF | 0.90 | 6.17 | 97 | 7.26 | 1.01 | 12.1 | 8.2 | 112 | 4.41 | 0.32 | 14.20 |
| 35 | 38 | 2007 | 6 | RF | 1.10 | 2.43 | 93 | 7.20 | 0.72 | 8.7 | 4.6 | 97 | 9.01 | 0.46 | 13.10 |
| 36 | 39 | 2007 | 6 | RF | 2.40 | 3.38 | 99 | 7.63 | 2.12 | 25.1 | 10.2 | 217 | 6.18 | 0.84 | 24.90 |
| 37 | 40 | 2007 | 6 | RF | 1.05 | 3.54 | 85 | 6.95 | 0.45 | 5.9 | 6.9 | 51 | 0.93 | 0.35 | 6.70 |
| 38 | 41 | 2007 | 6 | INT | 3.70 | 5.70 | 112 | 6.88 | 0.51 | 5.8 | 16.3 | 59 | 0.91 | 0.33 | 7.04 |
| 39 | 42 | 2007 | 6 | RF | 0.55 | 15.21 | 102 | 7.09 | 1.03 | 10.7 | 8.3 | 107 | 5.59 | 0.57 | 13.40 |
| 40 | 43 | 2007 | 6 | RF | 1.30 | 7.49 | 105 | 7.02 | 0.58 | 6.8 | 6.2 | 102 | 18.00 | 0.42 | 12.70 |
| 41 | 44 | 2007 | 6 | RF | 1.30 | 9.13 | 103 | 7.04 | 0.68 | 8.0 | 9.7 | 69 | 0.21 | 0.42 | 10.30 |
| 42 | 46 | 2007 | 6 | INT | 0.70 | 17.08 | 105 | 7.68 | 2.74 | 30.8 | 18.9 | 329 | 34.00 | 1.17 | 53.70 |

| ID | Lake OCF | Y | M | Cat | Depth m | Temp ˚C | DO % | pH - | Alk meq/L | DIC mg/L | DOC mg/L | SpC µS/cm | $SO_4$ mg/L | Cl mg/L | Ca mg/L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 43 | 47 | 2007 | 6 | INT | 2.25 | 9.22 | 95 | 6.95 | 0.83 | 10.4 | 12.4 | 87 | 0.49 | 0.45 | 13.30 |
| 44 | 48 | 2007 | 6 | INT | 1.50 | 10.19 | 120 | 7.57 | 2.08 | 23.9 | 3.0 | 196 | 0.14 | 0.85 | 28.00 |
| 45 | 49 | 2007 | 6 | RF | 1.00 | 5.41 | 94 | 7.24 | 1.32 | 15.8 | 6.8 | 141 | 5.65 | 0.42 | 19.20 |
| 46 | 50 | 2007 | 6 | SM | 0.60 | 8.50 | 83 | 6.59 | 0.43 | 4.8 | 35.4 | 81 | 13.10 | 0.32 | 11.20 |
| 47 | 52 | 2007 | 6 | SM | 1.55 | 17.24 | 98 | 7.21 | 1.08 | 12.7 | 17.8 | 113 | 0.82 | 0.36 | 18.30 |
| 48 | 53 | 2007 | 6 | INT | 2.11 | 11.66 | 93 | 7.25 | 1.19 | 13.8 | 13.4 | 124 | 0.17 | 1.84 | 16.00 |
| 49 | 54 | 2007 | 6 | SM | 6.20 | 10.34 | 88 | 7.07 | 0.76 | 8.6 | 18.9 | 82 | 0.51 | 0.30 | 14.00 |
| 50 | 56 | 2007 | 6 | SM | 0.68 | 11.37 | 85 | 6.83 | 0.76 | 4.6 | 30.1 | 83 | 0.48 | 0.39 | 12.40 |
| 51 | 1 | 2007 | 7 | INT | 0.70 | 13.89 | 106 | 8.74 | 1.16 | 11.7 | 12.7 | 132 | 7.91 | 0.59 | 16.50 |
| 52 | 2 | 2007 | 7 | RF | 1.80 | 16.63 | 106 | 8.96 | 1.26 | 12.5 | 9.4 | 135 | 7.78 | 0.25 | 14.40 |
| 53 | 3 | 2007 | 7 | SM | 2.10 | 16.64 | 96 | 7.15 | 0.50 | 5.5 | 30.9 | 74 | 2.89 | 0.24 | 12.10 |
| 54 | 4 | 2007 | 7 | INT | 0.90 | 16.38 | 111 | 9.03 | 1.41 | 13.5 | 15.1 | 140 | 3.28 | 0.25 | 16.80 |
| 55 | 5 | 2007 | 7 | INT | 1.00 | 16.78 | 101 | 8.14 | 2.16 | 25.7 | 2.2 | 204 | 0.05 | 0.60 | 30.30 |
| 56 | 6 | 2007 | 7 | RF | 1.50 | 13.90 | 108 | 9.29 | 0.90 | 7.4 | 7.3 | 92 | 2.53 | 0.08 | 11.90 |
| 57 | 7 | 2007 | 7 | INT | 0.80 | 15.72 | 95 | 7.34 | 0.75 | 8.3 | 11.2 | 80 | 2.01 | 0.26 | 10.30 |
| 58 | 8 | 2007 | 7 | INT | 0.95 | 16.90 | 113 | 9.61 | 0.81 | 5.5 | 12.9 | 86 | 1.13 | 0.11 | 9.80 |
| 59 | 9 | 2007 | 7 | INT | 3.70 | 18.15 | 110 | 8.11 | 1.25 | 12.0 | 11.3 | 123 | 1.39 | 0.15 | 15.70 |
| 60 | 10 | 2007 | 7 | INT | 0.45 | 17.22 | 113 | 8.73 | 0.85 | 7.0 | 18.8 | 86 | 1.08 | 0.06 | 11.10 |
| 61 | 11 | 2007 | 7 | SM | 0.50 | 19.85 | 88 | 7.11 | 0.37 | 3.8 | 22.6 | 49 | 0.45 | 0.16 | 5.86 |
| 62 | 12 | 2007 | 7 | INT | 0.55 | 19.52 | 104 | 9.85 | 1.44 | 9.6 | 18.3 | 147 | 1.23 | 0.37 | 13.80 |
| 63 | 13 | 2007 | 7 | SM | 1.90 | 18.28 | 60 | 6.79 | 0.35 | 3.8 | 29.5 | 43 | 0.04 | 0.19 | 6.40 |
| 64 | 14 | 2007 | 7 | INT | 0.75 | 19.17 | 111 | 8.89 | 1.03 | 9.4 | 14.6 | 100 | 0.11 | 0.20 | 12.50 |
| 65 | 15 | 2007 | 7 | INT | 0.70 | 15.16 | 108 | 9.76 | 0.77 | 5.4 | 10.6 | 88 | 1.78 | 0.06 | 10.70 |
| 66 | 16 | 2007 | 7 | SM | 0.70 | 19.57 | 108 | 8.37 | 1.47 | 15.1 | 13.8 | 161 | 9.74 | 0.20 | 24.60 |
| 67 | 17 | 2007 | 7 | SM | 0.50 | 18.80 | 93 | 7.92 | 1.67 | 19.1 | 14.0 | 160 | 0.22 | 0.27 | 32.50 |
| 68 | 18 | 2007 | 7 | RF | 1.45 | 16.96 | 107 | 9.24 | 0.91 | 7.4 | 11.0 | 88 | 0.58 | 0.11 | 13.60 |
| 69 | 19 | 2007 | 7 | INT | 1.10 | 16.52 | 109 | 9.73 | 1.03 | 7.1 | 14.5 | 169 | 28.20 | 0.11 | 17.10 |
| 70 | 20 | 2007 | 7 | INT | 0.75 | 15.48 | 110 | 9.15 | 1.27 | 10.9 | 17.6 | 127 | 1.63 | 0.60 | 13.70 |
| 71 | 21 | 2007 | 7 | SM | 1.05 | 17.94 | 77 | 7.01 | 0.34 | 3.6 | 22.9 | 45 | 0.04 | 0.13 | 6.64 |
| 72 | 22 | 2007 | 7 | SM | 2.15 | 18.09 | 75 | 7.13 | 0.45 | 5.3 | 16.3 | 54 | 0.16 | 0.11 | 6.35 |
| 73 | 23 | 2007 | 7 | SM | 1.75 | 17.55 | 77 | 6.38 | 0.13 | 1.2 | 22.8 | 21 | 0.08 | 0.10 | 2.40 |
| 74 | 24 | 2007 | 7 | SM | 0.50 | 17.02 | 95 | 7.14 | 0.49 | 5.2 | 13.2 | 54 | 0.05 | 0.27 | 7.36 |
| 75 | 25 | 2007 | 7 | SM | 2.05 | 17.40 | 88 | 6.14 | 0.15 | 0.9 | 36.5 | 28 | 0.57 | 0.09 | 3.47 |
| 76 | 26 | 2007 | 7 | SM | 1.50 | 17.64 | 95 | 6.88 | 0.31 | 3.2 | 18.5 | 36 | 0.09 | 0.13 | 4.81 |
| 77 | 27 | 2007 | 7 | INT | 1.05 | 15.42 | 104 | 8.13 | 2.76 | 32.0 | 4.7 | 273 | 9.30 | 0.25 | 49.80 |
| 78 | 28 | 2007 | 7 | RF | 0.70 | 17.00 | 117 | 9.60 | 1.04 | 8.8 | 14.3 | 111 | 2.64 | 0.11 | 11.50 |
| 79 | 29 | 2007 | 7 | RF | 1.30 | 16.90 | 109 | 9.44 | 1.02 | 8.1 | 7.8 | 111 | 4.14 | 0.13 | 10.80 |
| 80 | 30 | 2007 | 7 | INT | 1.65 | 17.33 | 110 | 7.88 | 1.20 | 12.4 | 19.8 | 130 | 3.49 | 0.12 | 18.50 |
| 81 | 31 | 2007 | 7 | INT | 0.70 | 17.24 | 114 | 8.54 | 0.87 | 7.4 | 19.9 | 99 | 5.01 | 0.07 | 13.30 |
| 82 | 32 | 2007 | 7 | INT | 2.65 | 17.43 | 95 | 6.91 | 0.29 | 2.6 | 22.0 | 36 | 0.39 | 0.17 | 5.30 |
| 83 | 33 | 2007 | 7 | RF | 1.30 | 16.98 | 109 | 8.32 | 1.34 | 13.1 | 15.5 | 142 | 5.19 | 0.26 | 18.60 |
| 84 | 34 | 2007 | 7 | RF | 1.60 | 16.25 | 114 | 8.55 | 1.40 | 14.0 | 11.1 | 149 | 6.54 | 0.49 | 18.90 |
| 85 | 35 | 2007 | 7 | INT | 1.20 | 16.30 | 100 | 7.87 | 1.54 | 17.2 | 19.8 | 174 | 7.47 | 0.37 | 23.40 |
| 86 | 36 | 2007 | 7 | RF | 1.25 | 16.16 | 108 | 8.61 | 1.53 | 16.5 | 14.6 | 161 | 5.74 | 0.24 | 18.30 |
| 87 | 37 | 2007 | 7 | RF | 0.40 | 16.05 | 110 | 9.03 | 1.02 | 8.1 | 12.5 | 119 | 8.96 | 0.12 | 12.80 |
| 88 | 38 | 2007 | 7 | RF | 0.50 | 14.68 | 102 | 7.94 | 1.50 | 16.9 | 5.8 | 183 | 15.90 | 0.57 | 27.60 |
| 89 | 39 | 2007 | 7 | RF | 1.10 | 15.75 | 111 | 8.78 | 1.83 | 18.4 | 13.5 | 193 | 9.56 | 0.48 | 17.40 |
| 90 | 40 | 2007 | 7 | RF | 1.30 | 17.08 | 118 | 8.52 | 0.98 | 8.7 | 10.5 | 97 | 1.08 | 0.19 | 13.40 |
| 91 | 41 | 2007 | 7 | INT | 4.55 | 17.35 | 98 | 7.37 | 0.77 | 8.5 | 22.4 | 90 | 0.90 | 0.39 | 11.40 |
| 92 | 42 | 2007 | 7 | RF | 0.65 | 15.11 | 110 | 8.43 | 2.06 | 22.6 | 7.8 | 204 | 5.29 | 0.39 | 27.20 |
| 93 | 43 | 2007 | 7 | RF | 0.75 | 14.22 | 106 | 7.90 | 1.35 | 16.2 | 6.6 | 198 | 31.40 | 0.62 | 27.90 |

| ID | Lake<br>OCF | Y | M | Cat | Depth<br>m | Temp<br>˚C | DO<br>% | pH<br>- | Alk<br>meq/L | DIC<br>mg/L | DOC<br>mg/L | SpC<br>µS/cm | $SO_4$<br>mg/L | Cl<br>mg/L | Ca<br>mg/L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 94 | 44 | 2007 | 7 | RF | 0.50 | 16.64 | 107 | 7.92 | 1.238 | 13.5 | 11.4 | 123 | 0.60 | 0.19 | 19.20 |
| 95 | 45 | 2007 | 7 | INT | 0.75 | 15.97 | 107 | 9.17 | 1.202 | 11.2 | 12.3 | 157 | 20.90 | 0.16 | 28.30 |
| 96 | 46 | 2007 | 7 | INT | 0.60 | 15.55 | 128 | 10.10 | 1.25 | 7.6 | 28.1 | 191 | 28.50 | 0.25 | 26.30 |
| 97 | 47 | 2007 | 7 | INT | 3.50 | 17.51 | 102 | 7.36 | 0.74 | 8.6 | 14.2 | 79 | 0.38 | 0.25 | 11.80 |
| 98 | 48 | 2007 | 7 | SM | 0.45 | 16.81 | 115 | 8.79 | 1.91 | 21.8 | 6.5 | 175 | 0.59 | 0.49 | 15.40 |
| 99 | 49 | 2007 | 7 | RF | 1.75 | 16.07 | 110 | 9.33 | 1.39 | 13.4 | 11.3 | 153 | 11.10 | 0.31 | 16.20 |
| 100 | 50 | 2007 | 7 | SM | 0.65 | 15.16 | 33 | 7.18 | 1.26 | 16.0 | 34.5 | 138 | 3.75 | 0.07 | 21.40 |
| 101 | 52 | 2007 | 7 | SM | 2.15 | 18.78 | 117 | 8.50 | 1.12 | 11.5 | 18.7 | 110 | 0.51 | 0.09 | 18.10 |
| 102 | 53 | 2007 | 7 | INT | 4.00 | 18.38 | 102 | 7.62 | 1.24 | 14.4 | 13.9 | 123 | ***0.02*** | 0.35 | 16.30 |
| 103 | 54 | 2007 | 7 | SM | 6.20 | 18.42 | 104 | 7.31 | 0.79 | 9.0 | 20.4 | 86 | 0.52 | 0.29 | 14.60 |
| 104 | 55 | 2007 | 7 | SM | 3.85 | 18.12 | 87 | 6.91 | 0.38 | 4.0 | 20.9 | 45 | 0.67 | 0.24 | 5.97 |
| 105 | 56 | 2007 | 7 | SM | 0.65 | 13.91 | 56 | 6.67 | 0.80 | 10.5 | 24.6 | 82 | 0.23 | 0.07 | 12.80 |
| 106 | 2 | 2007 | 9 | RF | n.d. | 2.06 | 98 | 8.13 | 1.26 | 13.2 | 7.6 | 140 | 9.83 | 0.23 | 13.00 |
| 107 | 5 | 2007 | 9 | INT | n.d. | 1.50 | 100 | 8.14 | 2.40 | 27.6 | 1.9 | 219 | 0.04 | 0.77 | 31.50 |
| 108 | 6 | 2007 | 9 | RF | n.d. | 3.89 | 99 | 7.74 | 1.84 | 21.2 | 7.7 | 176 | 1.59 | 0.42 | 24.40 |
| 109 | 7 | 2007 | 9 | INT | n.d. | 3.60 | 107 | 7.39 | 0.90 | 10.2 | 10.3 | 98 | 3.14 | 0.32 | 12.00 |
| 110 | 8 | 2007 | 9 | INT | n.d. | 3.66 | 102 | 9.13 | 0.95 | n.d. | n.d. | 96 | 1.92 | 0.10 | 11.70 |
| 111 | 9 | 2007 | 9 | INT | n.d. | 2.53 | 98 | 7.93 | 1.13 | 11.5 | 11.7 | 111 | 1.60 | 0.13 | 12.70 |
| 112 | 10 | 2007 | 9 | INT | n.d. | 3.66 | 75 | 7.29 | 0.92 | 9.5 | 16.4 | 97 | 4.41 | 0.10 | 11.60 |
| 113 | 11 | 2007 | 9 | SM | n.d. | 6.30 | 91 | 6.80 | 0.30 | 3.2 | 14.9 | 42 | 3.05 | 0.10 | 4.06 |
| 114 | 13 | 2007 | 9 | SM | n.d. | 5.42 | 73 | 6.69 | 0.43 | 4.6 | 27.3 | 51 | 0.09 | 0.26 | 6.87 |
| 115 | 14 | 2007 | 9 | INT | n.d. | 3.32 | 98 | 7.29 | 0.81 | 13.7 | 12.3 | 84 | 2.97 | 0.11 | 10.50 |
| 116 | 15 | 2007 | 9 | INT | n.d. | 2.74 | 107 | 7.51 | 1.18 | 8.5 | 10.3 | 117 | 0.39 | 0.19 | 14.90 |
| 117 | 18 | 2007 | 9 | RF | n.d. | 3.50 | 106 | 8.89 | 0.99 | 9.1 | 10.8 | 95 | 0.78 | 0.08 | 14.80 |
| 118 | 20 | 2007 | 9 | INT | n.d. | 3.04 | 113 | 7.89 | 1.33 | 13.7 | 18.4 | 131 | 0.40 | 0.26 | 17.50 |
| 119 | 21 | 2007 | 9 | SM | n.d. | 4.61 | 95 | 6.88 | 0.37 | 3.9 | 19.1 | 43 | 0.04 | 0.16 | 5.80 |
| 120 | 22 | 2007 | 9 | SM | n.d. | 3.56 | 89 | 7.07 | 0.48 | 5.6 | 15.7 | 56 | 0.19 | 0.12 | 6.36 |
| 121 | 23 | 2007 | 9 | SM | n.d. | 4.11 | 82 | 6.27 | 0.13 | 1.6 | 20.8 | 21 | 0.16 | 0.12 | 2.29 |
| 122 | 24 | 2007 | 9 | SM | n.d. | 3.50 | 104 | 7.02 | 0.46 | 5.5 | 11.5 | 51 | 0.08 | 0.28 | 6.32 |
| 123 | 27 | 2007 | 9 | INT | n.d. | 2.22 | 101 | 7.62 | 1.34 | 14.0 | 11.2 | 135 | 5.28 | 0.14 | 17.70 |
| 124 | 28 | 2007 | 9 | RF | n.d. | 2.16 | 101 | 8.26 | 1.27 | 12.6 | 11.9 | 127 | 3.39 | 0.16 | 14.20 |
| 125 | 29 | 2007 | 9 | RF | n.d. | 1.97 | 110 | 7.93 | 1.37 | 14.9 | 8.4 | 142 | 5.54 | 0.19 | 15.90 |
| 126 | 30 | 2007 | 9 | INT | n.d. | 2.54 | 99 | 7.53 | 1.23 | 13.3 | 19.6 | 139 | 6.89 | 0.19 | 19.50 |
| 127 | 31 | 2007 | 9 | INT | n.d. | 2.60 | 113 | 8.83 | 0.86 | 7.0 | 20.2 | 102 | 7.44 | 0.05 | 13.80 |
| 128 | 38 | 2007 | 9 | RF | n.d. | 1.74 | 101 | 8.03 | 1.95 | 21.9 | 6.0 | 228 | 19.70 | 0.74 | 35.60 |
| 129 | 52 | 2007 | 9 | SM | n.d. | 4.06 | 95 | 7.57 | 1.19 | 12.7 | 17.8 | 119 | 0.76 | 0.15 | 18.80 |
| 130 | 53 | 2007 | 9 | INT | n.d. | 3.56 | 98 | 7.64 | 1.34 | 14.8 | 14.0 | 133 | 0.05 | 0.38 | 17.40 |
| 131 | 55 | 2007 | 9 | SM | n.d. | 3.58 | 86 | 6.80 | 0.47 | 5.1 | 21.2 | 54 | 0.67 | 0.36 | 7.09 |
| 132 | 1 | 2008 | 6 | RF | 0.50 | 13.66 | 100 | 8.11 | 2.00 | 22.9 | 9.0 | 220 | 12.20 | 0.77 | 33.70 |
| 133 | 2 | 2008 | 6 | RF | 1.25 | 14.15 | 123 | 8.09 | 1.93 | 22.1 | 5.1 | 196 | 5.98 | 0.63 | 27.20 |
| 134 | 3 | 2008 | 6 | SM | 3.25 | 16.90 | 148 | 7.37 | 0.54 | 6.3 | 29.5 | 73 | 2.16 | 0.36 | 11.30 |
| 135 | 4 | 2008 | 6 | RF | 1.55 | 16.28 | 130 | 8.05 | 1.99 | 22.6 | 12.2 | 196 | 2.54 | 0.56 | 26.40 |
| 136 | 5 | 2008 | 6 | INT | 135.00 | 16.72 | 147 | 8.31 | 2.24 | 26.4 | 2.3 | 210 | ***0.02*** | 0.58 | 32.40 |
| 137 | 6 | 2008 | 6 | RF | 0.20 | 17.33 | 122 | 7.71 | 1.76 | 18.9 | 9.0 | 280 | 62.40 | 1.45 | 37.70 |
| 138 | 7 | 2008 | 6 | INT | n.d. | 18.33 | 129 | 7.33 | 0.39 | 4.8 | 14.4 | 48 | 1.18 | 0.28 | 5.90 |
| 139 | 8 | 2008 | 6 | INT | n.d. | 17.64 | 124 | 7.77 | 0.99 | 11.3 | 11.0 | 103 | 0.77 | 0.54 | 13.00 |
| 140 | 9 | 2008 | 6 | INT | 1.65 | 16.20 | 124 | 7.87 | 1.53 | 16.4 | 11.1 | 146 | 0.80 | 0.32 | 19.70 |
| 141 | 10 | 2008 | 6 | INT | 0.85 | 16.87 | 137 | 7.64 | 0.92 | 10.2 | 15.9 | 97 | 1.19 | 0.42 | 11.90 |
| 142 | 11 | 2008 | 6 | SM | 0.70 | 15.99 | 141 | 7.06 | 0.34 | 4.1 | 23.6 | 49 | 0.85 | 0.87 | 5.44 |
| 143 | 12 | 2008 | 6 | RF | 0.63 | 16.58 | 136 | 8.02 | 1.83 | 19.6 | 14.5 | 184 | 1.32 | 1.32 | 20.90 |
| 144 | 13 | 2008 | 6 | SM | 2.30 | 16.62 | 80 | 6.61 | 0.23 | 2.8 | 29.1 | 33 | 0.08 | 0.29 | 4.29 |

| ID | Lake OCF | Y | M | Cat | Depth m | Temp ˚C | DO % | pH - | Alk meq/L | DIC mg/L | DOC mg/L | SpC µS/cm | SO$_4$ mg/L | Cl mg/L | Ca mg/L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 145 | 14 | 2008 | 6 | RF | 0.90 | 18.90 | 124 | 7.82 | 1.13 | 12.4 | 12.9 | 115 | 0.14 | 0.48 | 15.00 |
| 146 | 15 | 2008 | 6 | INT | 1.00 | 5.77 | 150 | 7.89 | 1.19 | 12.8 | 8.0 | 125 | 2.84 | 0.38 | 17.70 |
| 147 | 16 | 2008 | 6 | INT | 1.90 | 14.00 | 123 | 7.72 | 1.03 | 19.6 | 13.0 | 182 | 7.27 | 0.47 | 23.90 |
| 148 | 17 | 2008 | 6 | SM | 0.55 | 15.40 | 110 | 7.87 | 1.32 | 15.0 | 16.1 | 134 | ***0.02*** | 0.92 | 26.10 |
| 149 | 18 | 2008 | 6 | INT | 0.85 | 15.65 | 143 | 8.14 | 1.75 | 19.5 | 9.0 | 170 | 0.75 | 0.50 | 29.20 |
| 150 | 19 | 2008 | 6 | INT | 0.40 | 16.99 | 138 | 8.07 | 1.86 | 25.9 | 11.6 | 280 | 30.60 | 1.19 | 33.80 |
| 151 | 20 | 2008 | 6 | SM | 1.50 | 15.44 | 137 | 7.95 | 1.65 | 18.8 | 16.3 | 159 | 0.17 | 0.32 | 23.70 |
| 152 | 21 | 2008 | 6 | SM | 1.15 | 15.02 | 110 | 7.08 | 0.21 | 3.2 | 19.6 | 34 | ***0.02*** | 0.37 | 4.36 |
| 153 | 22 | 2008 | 6 | SM | 3.80 | 13.83 | 108 | 7.36 | 0.49 | 6.3 | 16.3 | 56 | 0.10 | 0.31 | 6.49 |
| 154 | 23 | 2008 | 6 | SM | 1.35 | 15.84 | 111 | 6.46 | 0.13 | 1.9 | 24.8 | 122 | 0.07 | 0.19 | 2.38 |
| 155 | 24 | 2008 | 6 | SM | 1.75 | 14.21 | 110 | 7.50 | 0.42 | 5.4 | 11.6 | 46 | 0.04 | 0.38 | 5.64 |
| 156 | 25 | 2008 | 6 | SM | 2.50 | 13.84 | 113 | 5.68 | 0.10 | 1.6 | 36.2 | 25 | 0.30 | 0.11 | 2.89 |
| 157 | 26 | 2008 | 6 | INT | 1.45 | 14.42 | 115 | 7.12 | 0.27 | 3.8 | 19.6 | 38 | ***0.02*** | 0.26 | 5.03 |
| 158 | 27 | 2008 | 6 | RF | n.d. | n.d. | n.d. | 7.9 | 1.84 | 19.3 | 9.7 | 185 | 3.15 | 0.53 | 27.3 |
| 159 | 28 | 2008 | 6 | RF | 0.75 | 17.69 | 126 | 8.02 | 1.59 | 18.1 | 8.7 | 184 | 2.55 | 0.53 | 22.10 |
| 160 | 29 | 2008 | 6 | RF | 1.10 | 18.28 | 123 | 8.17 | 1.72 | 19.8 | 6.1 | 168 | 3.37 | 0.51 | 24.40 |
| 161 | 30 | 2008 | 6 | INT | 1.20 | 14.84 | 149 | 7.85 | 1.42 | 16.1 | 18.4 | 170 | 1.64 | 0.33 | 21.30 |
| 162 | 31 | 2008 | 6 | INT | 1.40 | 16.34 | 151 | 7.76 | 1.08 | 12.3 | 19.8 | 125 | 2.10 | 0.40 | 15.60 |
| 163 | 32 | 2008 | 6 | INT | 1.40 | 16.85 | 149 | 6.70 | 0.22 | 2.7 | 22.1 | 117 | 0.20 | 0.17 | 4.23 |
| 164 | 33 | 2008 | 6 | INT | 3.10 | 14.54 | 97 | 7.71 | 1.28 | 14.7 | 13.9 | 29 | 3.81 | 0.53 | 17.90 |
| 165 | 34 | 2008 | 6 | RF | 1.50 | 13.95 | 112 | 7.91 | 1.78 | 20.0 | 8.3 | 136 | 7.81 | 1.21 | 27.00 |
| 166 | 35 | 2008 | 6 | INT | 1.70 | 13.00 | 114 | 7.70 | 1.10 | 12.3 | 17.5 | 192 | 9.01 | 0.55 | 17.30 |
| 167 | 36 | 2008 | 6 | RF | 1.40 | 14.48 | 108 | 7.90 | 2.06 | 22.7 | 14.1 | 133 | 3.28 | 0.70 | 26.90 |
| 168 | 37 | 2008 | 6 | RF | 1.40 | 16.02 | 143 | 7.83 | 1.80 | 20.1 | 11.6 | 104 | 4.96 | 0.63 | 25.00 |
| 169 | 38 | 2008 | 6 | RF | 1.40 | 16.69 | 149 | 7.80 | 0.92 | 10.9 | 4.2 | 187 | 11.90 | 0.57 | 16.60 |
| 170 | 39 | 2008 | 6 | RF | 1.50 | 11.78 | 148 | 7.84 | 1.86 | 20.8 | 10.7 | 120 | 4.01 | 1.18 | 19.90 |
| 171 | 40 | 2008 | 6 | RF | 2.30 | 10.72 | 137 | 7.56 | 1.02 | 11.6 | 10.0 | 184 | 1.05 | 0.59 | 14.30 |
| 172 | 41 | 2008 | 6 | INT | 2.35 | 13.97 | 103 | 7.39 | 0.72 | 8.8 | 21.1 | 104 | 1.05 | 0.45 | 10.20 |
| 173 | 42 | 2008 | 6 | RF | 3.35 | 12.63 | 104 | 7.85 | 1.19 | 13.6 | 5.8 | 79 | 5.99 | 0.46 | 16.60 |
| 174 | 43 | 2008 | 6 | RF | 0.55 | 10.99 | 117 | 7.85 | 1.04 | 12.6 | 5.4 | 128 | 27.70 | 0.59 | 21.60 |
| 175 | 44 | 2008 | 6 | RF | 0.90 | 10.98 | 122 | 7.73 | 1.17 | 14.3 | 9.2 | 165 | 0.45 | 0.62 | 17.50 |
| 176 | 45 | 2008 | 6 | SM | 1.50 | 7.60 | 129 | 7.91 | 1.74 | 20.1 | 12.1 | 116 | 15.70 | 0.71 | 37.10 |
| 177 | 46 | 2008 | 6 | INT | 1.20 | 14.50 | 100 | 8.15 | 2.92 | 31.6 | 22.1 | 205 | 30.00 | 1.55 | 49.10 |
| 178 | 47 | 2008 | 6 | SM | 0.25 | 12.33 | 110 | 7.76 | 0.94 | 11.4 | 14.1 | 330 | ***0.02*** | 0.44 | 14.70 |
| 179 | 48 | 2008 | 6 | INT | 3.10 | 14.65 | 142 | 8.15 | 2.08 | 23.6 | 4.8 | 97 | 1.10 | 0.64 | 27.70 |
| 180 | 49 | 2008 | 6 | RF | 0.55 | 17.60 | 152 | 8.06 | 2.34 | 27.2 | 10.8 | 199 | 7.17 | 0.86 | 31.60 |
| 181 | 50 | 2008 | 6 | INT | 1.25 | 13.72 | 102 | 6.55 | 0.32 | 3.6 | 40.0 | 236 | 9.46 | 0.08 | 9.08 |
| 182 | 52 | 2008 | 6 | SM | 0.70 | 13.89 | 112 | 8.03 | 4.06 | 46.4 | 17.8 | 64 | 28.40 | 2.57 | 44.30 |
| 183 | 53 | 2008 | 6 | INT | 2.15 | 17.04 | 102 | 7.74 | 1.24 | 14.6 | 13.8 | 107 | ***0.02*** | 0.44 | 17.00 |
| 184 | 54 | 2008 | 6 | SM | n.d. | 14.11 | 100 | 7.43 | 0.80 | 9.6 | 20.6 | 124 | 0.46 | 0.33 | 15.00 |
| 185 | 55 | 2008 | 6 | SM | 6.20 | 12.76 | 97 | 6.93 | 0.38 | 4.5 | 23.4 | 86 | 0.33 | 0.40 | 6.88 |
| 186 | 56 | 2008 | 6 | SM | 4.80 | 15.59 | 88 | 6.98 | 0.77 | 9.7 | 34.1 | 46 | 1.19 | 0.64 | 12.60 |
| 187 | 1 | 2008 | 7 | RF | 0.58 | 18.51 | 149 | 9.36 | 1.13 | 10.1 | 13.8 | 131 | 8.56 | 0.27 | 15.60 |
| 188 | 2 | 2008 | 7 | RF | 0.71 | 18.11 | 133 | 9.47 | 1.05 | 10.4 | 9.2 | 130 | 8.77 | 0.26 | 10.50 |
| 189 | 3 | 2008 | 7 | SM | 1.46 | 18.50 | 124 | 7.91 | 0.66 | 6.19 | 30.9 | 78 | 2.09 | 0.45 | 12.40 |
| 190 | 4 | 2008 | 7 | RF | 1.23 | 18.01 | 129 | 8.76 | 1.35 | 13.5 | 14.0 | 131 | 3.63 | 0.19 | 15.40 |
| 191 | 5 | 2008 | 7 | INT | 2.11 | 18.56 | 132 | 8.40 | 2.06 | 23.1 | 2.5 | 191 | 0.02 | 0.64 | 26.20 |
| 192 | 6 | 2008 | 7 | RF | 0.36 | 18.55 | 151 | 8.47 | 1.13 | 12.2 | 11.8 | 212 | 45.60 | 1.22 | 21.50 |
| 193 | 7 | 2008 | 7 | INT | 0.47 | 17.80 | 123 | 7.70 | 0.73 | 8.6 | 12.3 | 77 | 2.14 | 0.29 | 9.90 |
| 194 | 8 | 2008 | 7 | INT | 0.96 | 17.97 | 158 | 9.82 | 0.83 | 6.6 | 13.4 | 102 | 0.94 | 0.09 | 10.10 |
| 195 | 9 | 2008 | 7 | INT | 2.11 | 17.00 | 145 | 8.23 | 1.34 | 14.6 | 12.1 | 127 | 1.21 | 0.20 | 17.30 |

| ID | Lake<br>OCF | Y | M | Cat | Depth<br>m | Temp<br>˚C | DO<br>% | pH<br>- | Alk<br>meq/L | DIC<br>mg/L | DOC<br>mg/L | SpC<br>µS/cm | $SO_4$<br>mg/L | Cl<br>mg/L | Ca<br>mg/L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 196 | 10 | 2008 | 7 | INT | 0.88 | 18.21 | 130 | 7.80 | 0.95 | 10.5 | 16.6 | 100 | 1.69 | 0.29 | 13.20 |
| 197 | 11 | 2008 | 7 | SM | 0.55 | 16.25 | 120 | 7.55 | 0.37 | 4.6 | 22.1 | 50 | 0.73 | 0.28 | 6.05 |
| 198 | 12 | 2008 | 7 | RF | 0.31 | 16.41 | 135 | 9.50 | 1.62 | 13.5 | 22.8 | 161 | 1.08 | 0.21 | 15.40 |
| 199 | 13 | 2008 | 7 | SM | 2.15 | 16.75 | 92 | 6.96 | 0.36 | 3.9 | 30.8 | 43 | 0.04 | 0.10 | 6.47 |
| 200 | 14 | 2008 | 7 | RF | 0.58 | 18.52 | 142 | 8.41 | 1.05 | 10.4 | 14.0 | 101 | 0.14 | 0.19 | 13.00 |
| 201 | 15 | 2008 | 7 | INT | 0.75 | 16.07 | 139 | 8.49 | 0.94 | 9.3 | 11.6 | 94 | 2.70 | 0.15 | 12.30 |
| 202 | 16 | 2008 | 7 | INT | 1.81 | 16.77 | 140 | 8.41 | 1.80 | 19.0 | 15.2 | 193 | 12.40 | 0.15 | 27.60 |
| 203 | 17 | 2008 | 7 | SM | 0.53 | 16.67 | 124 | 8.20 | 1.63 | 17.4 | 15.7 | 158 | 0.05 | 0.34 | 32.40 |
| 204 | 18 | 2008 | 7 | INT | 0.78 | 18.34 | 143 | 9.40 | 0.91 | 8.3 | 12.1 | 96 | 0.47 | 0.14 | 13.30 |
| 205 | 19 | 2008 | 7 | INT | 1.44 | 15.40 | 137 | 9.59 | 1.27 | 10.2 | 17.3 | 135 | 1.76 | 0.21 | 13.00 |
| 206 | 20 | 2008 | 7 | SM | 2.54 | 17.85 | 139 | 8.39 | 1.43 | 14.2 | 17.2 | 133 | 0.16 | 0.14 | 19.90 |
| 207 | 21 | 2008 | 7 | SM | 0.96 | 15.34 | 134 | 7.40 | 0.33 | 4.4 | 20.1 | 42 | 0.02 | 0.22 | 5.90 |
| 208 | 22 | 2008 | 7 | SM | 1.66 | 15.59 | 130 | 6.65 | 0.15 | 2.1 | 21.4 | 21 | 0.06 | 0.15 | 2.61 |
| 209 | 23 | 2008 | 7 | SM | 2.56 | 15.38 | 122 | 7.38 | 0.49 | 6.3 | 15.7 | 54 | 0.14 | 0.19 | 6.58 |
| 210 | 24 | 2008 | 7 | SM | 0.68 | 14.66 | 137 | 7.22 | 0.40 | 5.2 | 12.5 | 44 | 0.06 | 0.22 | 6.16 |
| 211 | 26 | 2008 | 7 | INT | 1.86 | 15.07 | 135 | 7.03 | 0.43 | 3.9 | 18.3 | 33 | 0.13 | 0.25 | 4.77 |
| 212 | 27 | 2008 | 7 | RF | 1.13 | 18.03 | 149 | 10.20 | 0.97 | 7.5 | 12.7 | 131 | 3.04 | 0.18 | 12.40 |
| 213 | 28 | 2008 | 7 | RF | 0.74 | 18.05 | 138 | 9.32 | 1.30 | 12.7 | 13.0 | 126 | 2.86 | 0.24 | 15.30 |
| 214 | 29 | 2008 | 7 | RF | 1.01 | 17.28 | 135 | 9.83 | 1.12 | 10.2 | 9.2 | 117 | 3.34 | 0.33 | 11.60 |
| 215 | 30 | 2008 | 7 | INT | 1.14 | 17.56 | 127 | 8.18 | 1.10 | 11.6 | 19.6 | 118 | 4.72 | 0.19 | 16.80 |
| 216 | 31 | 2008 | 7 | INT | 0.85 | 17.85 | 125 | 7.68 | 0.97 | 10.7 | 21.1 | 111 | 5.63 | 0.31 | 14.70 |
| 217 | 32 | 2008 | 7 | INT | 3.70 | 14.16 | 120 | 6.75 | 0.25 | 3.3 | 21.5 | 31 | 0.25 | 0.14 | 4.74 |
| 218 | 33 | 2008 | 7 | INT | 1.02 | 13.32 | 104 | 7.80 | 1.48 | 16.1 | 16.1 | 147 | 4.89 | 0.32 | 20.50 |
| 219 | 34 | 2008 | 7 | RF | 1.43 | 16.32 | 147 | 9.28 | 1.32 | 13.5 | 10.8 | 140 | 6.52 | 0.81 | 16.50 |
| 220 | 36 | 2008 | 7 | RF | 0.97 | 17.60 | 146 | 9.75 | 1.33 | 12.0 | 16.0 | 140 | 6.18 | 0.18 | 15.50 |
| 221 | 37 | 2008 | 7 | RF | 0.87 | 18.17 | 137 | 9.64 | 1.11 | 10.1 | 14.1 | 125 | 7.68 | 0.12 | 13.50 |
| 222 | 38 | 2008 | 7 | RF | 0.98 | 16.89 | 128 | 8.20 | 1.68 | 19.6 | 5.8 | 198 | 17.60 | 0.70 | 30.40 |
| 223 | 39 | 2008 | 7 | RF | 2.28 | 16.85 | 134 | 9.32 | 1.73 | 17.8 | 13.0 | 175 | 8.31 | 0.56 | 16.80 |
| 224 | 40 | 2008 | 7 | RF | 0.97 | 12.65 | 128 | 7.63 | 0.93 | 10.2 | 11.8 | 90 | 1.06 | 0.23 | 13.00 |
| 225 | 41 | 2008 | 7 | INT | 2.20 | 15.82 | 120 | 7.49 | 0.82 | 9.3 | 21.3 | 85 | 1.06 | 0.50 | 11.10 |
| 226 | 42 | 2008 | 7 | RF | 0.14 | 12.08 | 111 | 8.76 | 1.98 | 21.9 | 6.4 | 181 | 5.11 | 0.41 | 25.00 |
| 227 | 43 | 2008 | 7 | RF | 1.03 | 11.37 | 130 | 8.11 | 1.74 | 20.7 | 6.2 | 245 | 38.90 | 0.77 | 34.80 |
| 228 | 44 | 2008 | 7 | RF | 1.47 | 12.15 | 134 | 8.44 | 1.28 | 13.4 | 13.3 | 117 | 0.50 | 0.24 | 18.80 |
| 229 | 45 | 2008 | 7 | SM | 1.13 | 12.60 | 135 | 9.60 | 0.85 | 7.8 | 11.9 | 132 | 22.50 | 0.12 | 22.40 |
| 230 | 46 | 2008 | 7 | INT | 0.13 | 11.37 | 140 | 10.00 | 1.24 | 9.0 | 28.4 | 172 | 16.10 | 0.17 | 22.30 |
| 231 | 47 | 2008 | 7 | SM | 2.37 | 17.50 | 133 | 7.75 | 0.79 | 9.2 | 14.6 | 80 | 0.28 | 0.27 | 12.10 |
| 232 | 48 | 2008 | 7 | INT | 1.13 | 19.03 | 153 | 9.36 | 2.00 | 20.0 | 9.2 | 186 | 0.86 | 0.28 | 16.50 |
| 233 | 49 | 2008 | 7 | RF | 1.11 | 12.50 | 130 | 9.81 | 1.18 | 12.0 | 12.3 | 137 | 9.64 | 0.19 | 12.70 |
| 234 | 50 | 2008 | 7 | INT | 0.64 | 12.98 | 56 | 7.15 | 0.86 | 10.6 | 35.5 | 142 | 13.60 | 0.08 | 18.00 |
| 235 | 52 | 2008 | 7 | SM | 1.37 | 18.66 | 149 | 9.02 | 1.02 | 10.3 | 19.4 | 101 | 0.24 | 0.12 | 16.40 |
| 236 | 53 | 2008 | 7 | INT | 3.20 | 17.44 | 140 | 8.02 | 1.24 | 14.2 | 13.7 | 121 | 0.06 | 0.41 | 16.10 |
| 237 | 54 | 2008 | 7 | SM | 3.97 | 16.59 | 133 | 7.73 | 0.91 | 10.1 | 20.7 | 90 | 0.52 | 0.42 | 15.60 |
| 238 | 55 | 2008 | 7 | SM | 3.57 | 17.35 | 133 | 7.36 | 0.54 | 7.9 | 18.9 | 64 | 1.97 | 0.52 | 8.41 |
| 239 | 56 | 2008 | 7 | SM | 0.58 | 14.70 | 107 | 6.93 | 0.67 | 8.9 | 25.9 | 73 | 0.25 | 0.13 | 10.70 |
| 240 | 1 | 2008 | 9 | RF | 0.36 | 8.70 | 136 | 8.07 | 1.43 | 15.7 | 17.5 | 173 | 15.80 | 0.25 | 24.10 |
| 241 | 2 | 2008 | 9 | RF | 0.80 | 9.78 | 129 | 9.45 | 1.77 | 10.7 | 8.8 | 132 | 9.70 | 0.23 | 10.90 |
| 242 | 3 | 2008 | 9 | SM | 3.85 | 10.25 | 92 | 7.50 | 0.59 | 6.9 | 29.7 | 77 | 2.26 | 0.32 | 12.10 |
| 243 | 4 | 2008 | 9 | RF | 1.47 | 9.78 | 92 | 7.92 | 1.57 | 17.5 | 14.0 | 156 | 4.14 | 0.20 | 19.70 |
| 244 | 5 | 2008 | 9 | INT | 0.85 | 8.77 | 86 | 8.29 | 2.12 | 24.4 | 1.9 | 198 | 0.10 | 0.71 | 27.10 |
| 245 | 6 | 2008 | 9 | RF | 12.00 | 6.72 | 131 | 7.94 | 1.89 | 21.1 | 11.1 | 272 | 43.70 | 1.52 | 33.10 |
| 246 | 7 | 2008 | 9 | INT | 0.85 | 7.57 | 134 | 7.72 | 0.74 | 7.9 | 12.1 | 79 | 2.77 | 0.27 | 9.92 |

| ID | Lake<br>OCF | Y | M | Cat | Depth<br>m | Temp<br>˚C | DO<br>% | pH<br>- | Alk<br>meq/L | DIC<br>mg/L | DOC<br>mg/L | SpC<br>µS/cm | $SO_4$<br>mg/L | Cl<br>mg/L | Ca<br>mg/L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 247 | 8 | 2008 | 9 | INT | 0.95 | 8.32 | 142 | 9.33 | 0.95 | 9.5 | 13.5 | 93 | 1.78 | 0.11 | 11.00 |
| 248 | 9 | 2008 | 9 | INT | 1.29 | 8.62 | 136 | 8.12 | 1.32 | 15.0 | 11.4 | 129 | 1.65 | 0.16 | 16.20 |
| 249 | 10 | 2008 | 9 | INT | 0.75 | 7.97 | 137 | 7.69 | 0.90 | 10.9 | 15.8 | 100 | 2.81 | 0.17 | 12.10 |
| 250 | 11 | 2008 | 9 | SM | 0.40 | 7.73 | 48 | 7.34 | 0.36 | 4.5 | 18.6 | 47 | 1.47 | 0.29 | 5.17 |
| 251 | 12 | 2008 | 9 | RF | 0.35 | 8.70 | 59 | 9.60 | 1.45 | 12.9 | 19.4 | 145 | 1.28 | 0.31 | 13.80 |
| 252 | 13 | 2008 | 9 | SM | 1.72 | 8.15 | 37 | 7.05 | 0.28 | 3.9 | 25.9 | 36 | 0.32 | 0.21 | 5.66 |
| 253 | 14 | 2008 | 9 | RF | 0.56 | 8.21 | 128 | 7.71 | 1.00 | 11.5 | 14.1 | 96 | 0.17 | 0.49 | 15.00 |
| 254 | 15 | 2008 | 9 | INT | 0.75 | 7.74 | 37 | 8.85 | 0.83 | 8.4 | 10.5 | 89 | 3.73 | 0.06 | 10.50 |
| 255 | 16 | 2008 | 9 | INT | 1.25 | 7.51 | 57 | 8.45 | 1.56 | 3.3 | 3.2 | 178 | 12.40 | 0.12 | 25.50 |
| 256 | 17 | 2008 | 9 | SM | 0.51 | 7.85 | 44 | 8.12 | 1.71 | 3.8 | 2.9 | 165 | 0.19 | 0.20 | 32.20 |
| 257 | 18 | 2008 | 9 | INT | 0.65 | 9.48 | 118 | 8.82 | 0.98 | 9.8 | 11.4 | 94 | 0.83 | 0.25 | 14.00 |
| 258 | 19 | 2008 | 9 | INT | 0.35 | 10.05 | 146 | 9.76 | 1.24 | 10.4 | 16.3 | 181 | 25.50 | 0.20 | 18.40 |
| 259 | 20 | 2008 | 9 | SM | 1.30 | 10.26 | 109 | 8.32 | 1.26 | 13.1 | 17.5 | 118 | 0.32 | 0.15 | 16.30 |
| 260 | 21 | 2008 | 9 | SM | 0.85 | 10.71 | 23 | 7.35 | 0.32 | 4.2 | 19.1 | 39 | 0.03 | 0.16 | 5.28 |
| 261 | 22 | 2008 | 9 | SM | 3.53 | 9.95 | 21 | 7.48 | 0.44 | 5.9 | 15.9 | 51 | 0.14 | 0.14 | 5.78 |
| 262 | 23 | 2008 | 9 | SM | 1.65 | 8.46 | 19 | 6.54 | 0.13 | 2.1 | 21.1 | 20 | 0.11 | 0.11 | 2.19 |
| 263 | 24 | 2008 | 9 | SM | 0.60 | 9.82 | 25 | 7.34 | 0.34 | 4.9 | 11.7 | 38 | 0.12 | 0.18 | 5.12 |
| 264 | 25 | 2008 | 9 | SM | 3.05 | 8.64 | 21 | 5.91 | 0.12 | 2.0 | 37.5 | 26 | 0.60 | 0.10 | 3.42 |
| 265 | 27 | 2008 | 9 | RF | 0.48 | 7.86 | 136 | 8.13 | 1.12 | 11.3 | 11.7 | 116 | 3.31 | 0.18 | 14.50 |
| 266 | 28 | 2008 | 9 | RF | 0.77 | 7.85 | 132 | 8.43 | 1.24 | 12.9 | 11.8 | 125 | 4.04 | 0.12 | 15.30 |
| 267 | 29 | 2008 | 9 | RF | 0.93 | 8.48 | 78 | 8.96 | 1.24 | 12.6 | 7.5 | 123 | 4.70 | 0.21 | 14.00 |
| 268 | 30 | 2008 | 9 | INT | 1.37 | 8.91 | 71 | 7.53 | 0.99 | 11.5 | 17.3 | 121 | 8.10 | 0.09 | 16.90 |
| 269 | 31 | 2008 | 9 | INT | 1.20 | 8.88 | 71 | 7.34 | 0.78 | 9.2 | 17.7 | 108 | 11.20 | 0.14 | 13.70 |
| 270 | 32 | 2008 | 9 | INT | 3.50 | 9.83 | 23 | 6.82 | 0.23 | 2.9 | 19.3 | 27 | 0.53 | 0.15 | 4.31 |
| 271 | 33 | 2008 | 9 | INT | 1.20 | 9.24 | 38 | 7.87 | 1.49 | 16.6 | 15.8 | 158 | 6.43 | 0.37 | 20.30 |
| 272 | 34 | 2008 | 9 | RF | 1.45 | 8.32 | 40 | 8.53 | 1.43 | 15.1 | 10.7 | 156 | 9.83 | 0.69 | 18.40 |
| 273 | 35 | 2008 | 9 | INT | 0.70 | 8.40 | 43 | 7.85 | 1.59 | 17.8 | 19.6 | 198 | 19.60 | 0.41 | 26.00 |
| 274 | 36 | 2008 | 9 | RF | 1.00 | 8.55 | 73 | 9.48 | 1.26 | 11.3 | 14.5 | 136 | 8.06 | 0.10 | 14.90 |
| 275 | 37 | 2008 | 9 | RF | 1.11 | 9.00 | 83 | 9.19 | 1.07 | 10.1 | 12.7 | 127 | 10.70 | 0.09 | 14.90 |
| 276 | 38 | 2008 | 9 | RF | 0.95 | 8.60 | 114 | 8.12 | 1.85 | 20.9 | 5.5 | 217 | 19.60 | 0.71 | 33.20 |
| 277 | 39 | 2008 | 9 | RF | 1.81 | 9.14 | 139 | 9.29 | 1.53 | 14.5 | 12.5 | 174 | 15.70 | 0.34 | 16.10 |
| 278 | 40 | 2008 | 9 | RF | 3.55 | 9.48 | 31 | 7.80 | 0.93 | 10.5 | 11.6 | 93 | 1.03 | 0.21 | 12.80 |
| 279 | 41 | 2008 | 9 | INT | 3.35 | 10.81 | 32 | 7.50 | 0.69 | 8.6 | 18.9 | 81 | 1.49 | 0.44 | 9.84 |
| 280 | 42 | 2008 | 9 | RF | 0.28 | 10.59 | 40 | 8.04 | 1.97 | 22.1 | 5.3 | 206 | 11.30 | 0.82 | 26.00 |
| 281 | 43 | 2008 | 9 | RF | 0.90 | 6.36 | 38 | 8.14 | 1.93 | n.d. | n.d. | 269 | 42.90 | 0.82 | 38.10 |
| 282 | 44 | 2008 | 9 | RF | 1.20 | 9.69 | 44 | 7.83 | 1.18 | 12.7 | 12.2 | 115 | 0.72 | 0.33 | 16.80 |
| 283 | 45 | 2008 | 9 | SM | 0.85 | 9.59 | 49 | 9.33 | 0.84 | 7.9 | 11.6 | 147 | 29.70 | 0.14 | 24.40 |
| 284 | 46 | 2008 | 9 | INT | 0.15 | 12.31 | 46 | 8.05 | 1.56 | 15.0 | 30.2 | 208 | 25.80 | 0.72 | 28.90 |
| 285 | 47 | 2008 | 9 | SM | 1.80 | 9.83 | 98 | 7.59 | 0.74 | 8.5 | 13.5 | 78 | 0.40 | 0.25 | 11.40 |
| 286 | 48 | 2008 | 9 | INT | 0.53 | 9.56 | 93 | 8.25 | 2.22 | 23.6 | 7.1 | 193 | 0.20 | 0.68 | 15.80 |
| 287 | 49 | 2008 | 9 | RF | 1.18 | 9.50 | 51 | 9.09 | 1.21 | 12.0 | 12.1 | 145 | 15.40 | 0.19 | 15.50 |
| 288 | 50 | 2008 | 9 | INT | 0.50 | 5.80 | 33 | 7.35 | 1.29 | 14.8 | 27.9 | 145 | 6.90 | 0.12 | 20.90 |
| 289 | 52 | 2008 | 9 | SM | 2.05 | 9.06 | 52 | 7.87 | 0.94 | 10.0 | 18.2 | 96 | 0.49 | 0.11 | 15.60 |
| 290 | 53 | 2008 | 9 | INT | 2.95 | 9.17 | 44 | 7.90 | 1.22 | 13.3 | 13.2 | 120 | 0.07 | 0.39 | 16.00 |
| 291 | 54 | 2008 | 9 | SM | 2.45 | 9.41 | 47 | 7.63 | 0.85 | 9.5 | 19.6 | 93 | 0.51 | 0.36 | 16.10 |
| 292 | 55 | 2008 | 9 | SM | 2.80 | 8.27 | 45 | 7.06 | 0.37 | 4.7 | 21.4 | 49 | 0.44 | 0.38 | 6.50 |
| 293 | 56 | 2008 | 9 | SM | 0.30 | 8.88 | 19 | 6.84 | 0.42 | 6.5 | 19.4 | 47 | 0.91 | 0.13 | 6.57 |
| 294 | 1 | 2009 | 6 | RF | 0.52 | 17.29 | 129 | 8.20 | 2.10 | 25.9 | 10.2 | 233 | 12.70 | 0.66 | 37.50 |
| 295 | 2 | 2009 | 6 | RF | 1.15 | 10.70 | 118 | 7.88 | 1.73 | 21.1 | 5.7 | 179 | 5.92 | 0.53 | 24.90 |
| 296 | 3 | 2009 | 6 | SM | 4.15 | 15.23 | 116 | 7.14 | 0.51 | 5.9 | 30.1 | 70 | 1.84 | 0.33 | 10.70 |
| 297 | 4 | 2009 | 6 | RF | 1.40 | 14.83 | 122 | 7.80 | 2.00 | 23.3 | 12.1 | 195 | 2.66 | 0.57 | 27.70 |

| ID | Lake OCF | Y | M | Cat | Depth m | Temp ˚C | DO % | pH - | Alk meq/L | DIC mg/L | DOC mg/L | SpC µS/cm | $SO_4$ mg/L | Cl mg/L | Ca mg/L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 298 | 5 | 2009 | 6 | INT | 0.65 | 15.65 | 128 | 8.20 | 2.20 | 26.4 | 2.4 | 209 | 0.05 | 0.62 | 31.60 |
| 299 | 6 | 2009 | 6 | RF | 0.28 | 17.02 | 156 | 8.07 | 2.34 | 26.6 | 9.4 | 314 | 46.70 | 1.32 | 41.70 |
| 300 | 7 | 2009 | 6 | SM | 1.46 | 15.74 | 129 | 7.21 | 0.41 | 4.8 | 14.3 | 48 | 1.12 | 0.15 | 5.74 |
| 301 | 8 | 2009 | 6 | INT | 1.45 | 16.52 | 123 | 7.51 | 1.08 | 12.6 | 11.7 | 108 | 0.65 | 0.47 | 13.50 |
| 302 | 9 | 2009 | 6 | INT | 1.60 | 16.33 | 126 | 7.80 | 1.61 | 19.1 | 11.0 | 160 | 0.96 | 0.32 | 22.60 |
| 303 | 10 | 2009 | 6 | INT | 1.45 | 16.57 | 139 | 7.42 | 0.86 | 10.0 | 15.6 | 94 | 1.50 | 0.38 | 11.50 |
| 304 | 11 | 2009 | 6 | SM | 0.85 | 17.40 | 108 | 6.92 | 0.52 | 3.8 | 27.3 | 43 | 0.63 | 0.21 | 5.08 |
| 305 | 12 | 2009 | 6 | SM | 1.40 | 15.76 | 72 | 7.80 | 1.79 | 21.2 | 13.3 | 180 | 0.83 | 0.98 | 21.80 |
| 306 | 13 | 2009 | 6 | SM | 0.70 | 16.82 | 133 | 6.18 | 0.25 | 4.5 | 26.1 | 33 | 0.14 | 0.11 | 4.38 |
| 307 | 14 | 2009 | 6 | INT | 1.04 | 17.04 | 141 | 7.69 | 1.02 | 12.1 | 11.0 | 105 | 0.20 | 0.42 | 13.80 |
| 308 | 15 | 2009 | 6 | INT | 2.50 | 16.33 | 115 | 7.68 | 1.40 | 16.4 | 8.7 | 139 | 1.92 | 0.34 | 20.20 |
| 309 | 16 | 2009 | 6 | SM | 0.60 | 18.75 | 123 | 7.64 | 1.39 | 15.5 | 14.0 | 142 | 5.11 | 0.26 | 22.10 |
| 310 | 17 | 2009 | 6 | SM | 0.90 | 15.34 | 126 | 7.90 | 1.70 | 20.1 | 15.1 | 171 | 0.06 | 0.37 | 33.80 |
| 311 | 18 | 2009 | 6 | INT | 0.28 | 14.11 | 115 | 7.93 | 1.88 | 21.8 | 10.0 | 181 | 0.59 | 0.49 | 30.90 |
| 312 | 19 | 2009 | 6 | INT | 1.50 | 14.89 | 115 | 8.05 | 2.40 | 28.2 | 11.2 | 273 | 20.90 | 0.76 | 38.60 |
| 313 | 20 | 2009 | 6 | INT | 1.15 | 14.79 | 127 | 7.79 | 1.63 | 18.8 | 21.8 | 159 | 0.23 | 0.30 | 23.80 |
| 314 | 21 | 2009 | 6 | SM | 2.70 | 14.68 | 114 | 7.14 | 0.24 | 3.2 | 18.8 | 37 | 0.06 | 0.28 | 4.71 |
| 315 | 22 | 2009 | 6 | SM | 2.00 | 14.83 | 110 | 7.18 | 0.46 | 5.5 | 16.8 | 55 | 0.08 | 0.27 | 6.13 |
| 316 | 23 | 2009 | 6 | SM | 0.75 | 13.36 | 128 | 6.18 | 0.16 | 1.4 | 22.6 | 21 | 0.07 | 0.15 | 2.05 |
| 317 | 24 | 2009 | 6 | RF | 2.30 | 14.11 | 118 | 7.30 | 0.33 | 4.1 | 10.4 | 40 | 0.09 | 0.27 | 4.76 |
| 318 | 25 | 2009 | 6 | INT | 1.70 | 15.46 | 108 | 5.71 | 0.10 | 2.2 | 36.5 | 23 | 0.22 | 0.08 | 2.54 |
| 319 | 26 | 2009 | 6 | INT | 1.83 | 15.27 | 138 | 6.82 | 0.38 | 3.2 | 18.8 | 33 | 0.11 | 0.15 | 4.38 |
| 320 | 27 | 2009 | 6 | RF | 1.10 | 15.79 | 128 | 7.88 | 1.65 | 19.0 | 10.8 | 164 | 2.07 | 0.47 | 23.20 |
| 321 | 28 | 2009 | 6 | RF | 1.30 | 12.64 | 137 | 7.91 | 1.80 | 20.4 | 10.2 | 178 | 2.82 | 0.48 | 25.20 |
| 322 | 29 | 2009 | 6 | RF | 1.70 | 14.70 | 128 | 8.03 | 1.92 | 22.7 | 6.5 | 193 | 3.63 | 0.51 | 27.50 |
| 323 | 30 | 2009 | 6 | RF | 1.40 | 14.58 | 119 | 7.65 | 1.29 | 14.9 | 18.6 | 138 | 3.20 | 0.27 | 20.10 |
| 324 | 31 | 2009 | 6 | INT | 2.05 | 14.83 | 119 | 7.45 | 0.93 | 10.9 | 19.9 | 110 | 4.25 | 0.30 | 14.30 |
| 325 | 32 | 2009 | 6 | INT | 1.65 | 14.28 | 134 | 6.65 | 0.27 | 2.1 | 19.1 | 26 | 0.22 | 0.08 | 3.52 |
| 326 | 33 | 2009 | 6 | RF | 1.80 | 12.67 | 131 | 7.68 | 1.32 | 15.1 | 14.0 | 136 | 3.30 | 0.48 | 18.30 |
| 327 | 34 | 2009 | 6 | RF | 1.30 | 14.33 | 133 | 7.84 | 1.70 | 20.3 | 7.9 | 184 | 6.54 | 0.97 | 26.00 |
| 328 | 35 | 2009 | 6 | RF | 1.40 | 13.48 | 123 | 7.69 | 1.21 | 13.7 | 17.2 | 133 | 5.80 | 0.39 | 17.70 |
| 329 | 36 | 2009 | 6 | RF | 1.45 | 14.15 | 124 | 7.93 | 2.04 | 25.2 | 14.1 | 213 | 3.91 | 0.61 | 28.90 |
| 330 | 37 | 2009 | 6 | RF | 1.30 | 7.95 | 131 | 7.88 | 1.80 | 21.9 | 10.9 | 193 | 6.31 | 0.55 | 27.40 |
| 331 | 38 | 2009 | 6 | RF | 2.10 | 10.26 | 122 | 7.75 | 0.90 | 10.6 | 5.7 | 117 | 10.40 | 0.56 | 16.30 |
| 332 | 39 | 2009 | 6 | RF | 1.70 | 13.09 | 132 | 7.86 | 2.00 | 24.2 | 10.9 | 210 | 5.03 | 1.21 | 23.40 |
| 333 | 40 | 2009 | 6 | INT | 4.55 | 13.03 | 128 | 7.45 | 0.78 | 9.4 | 11.4 | 85 | 0.65 | 0.41 | 11.50 |
| 334 | 41 | 2009 | 6 | INT | 0.90 | 9.62 | 131 | 7.41 | 0.67 | 7.5 | 19.6 | 80 | 1.49 | 0.44 | 9.33 |
| 335 | 42 | 2009 | 6 | RF | 1.70 | 10.24 | 133 | 7.82 | 1.01 | 11.6 | 5.3 | 107 | 3.84 | 0.33 | 13.30 |
| 336 | 43 | 2009 | 6 | INT | 1.95 | 3.22 | 114 | 7.77 | 0.92 | 10.7 | 6.7 | 150 | 24.60 | 0.55 | 19.50 |
| 337 | 44 | 2009 | 6 | INT | 1.70 | 13.26 | 110 | 7.57 | 1.08 | 12.7 | 9.4 | 108 | 0.36 | 0.62 | 16.00 |
| 338 | 45 | 2009 | 6 | SM | 0.65 | 12.21 | 132 | 7.79 | 1.69 | 19.6 | 12.1 | 202 | 18.40 | 0.47 | 37.90 |
| 339 | 46 | 2009 | 6 | INT | 2.45 | 14.62 | 123 | 8.12 | 2.50 | 30.0 | 19.1 | 284 | 19.10 | 1.02 | 43.90 |
| 340 | 47 | 2009 | 6 | INT | 0.50 | 15.25 | 135 | 7.60 | 0.88 | 10.2 | 13.4 | 92 | 0.32 | 0.42 | 14.10 |
| 341 | 48 | 2009 | 6 | INT | 1.40 | 14.28 | 120 | 8.11 | 2.22 | 25.8 | 5.4 | 215 | 0.94 | 0.54 | 29.90 |
| 342 | 49 | 2009 | 6 | RF | 0.75 | 15.55 | 109 | 8.11 | 2.44 | 29.4 | 10.9 | 254 | 8.47 | 0.80 | 36.20 |
| 343 | 50 | 2009 | 6 | SM | 2.40 | 14.57 | 148 | 6.78 | 0.56 | 4.4 | 25.7 | 64 | 7.02 | 0.05 | 8.76 |
| 344 | 52 | 2009 | 6 | INT | 3.80 | 15.43 | 135 | 7.67 | 1.11 | 12.5 | 18.0 | 115 | 0.76 | 0.23 | 19.10 |
| 345 | 53 | 2009 | 6 | RF | 6.25 | 13.34 | 124 | 7.81 | 1.17 | 13.9 | 14.4 | 123 | 0.05 | 0.40 | 16.20 |
| 346 | 54 | 2009 | 6 | INT | 4.15 | 16.19 | 116 | 7.39 | 0.78 | 8.6 | 21.3 | 84 | 0.43 | 0.29 | 14.20 |
| 347 | 55 | 2009 | 6 | SM | 0.80 | 13.27 | 58 | 6.91 | 0.51 | 3.5 | 22.8 | 43 | 0.51 | 0.29 | 5.45 |
| 348 | 56 | 2009 | 6 | INT | 4.45 | 14.34 | 122 | 6.85 | 0.80 | 5.9 | 23.2 | 65 | 0.12 | 0.18 | 8.69 |

| ID | Lake OCF | Y | M | Cat | Depth m | Temp ˚C | DO % | pH - | Alk meq/L | DIC mg/L | DOC mg/L | SpC µS/cm | $SO_4$ mg/L | Cl mg/L | Ca mg/L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 349 | 1 | 2009 | 7 | RF | n.d. | n.d. | n.d. | 8.56 | 1.23 | 13.1 | 11.9 | 148 | 11.60 | 0.25 | 19.00 |
| 350 | 2 | 2009 | 7 | RF | 0.87 | 21.85 | 185 | 9.84 | 1.13 | 9.0 | 9.1 | 124 | 6.88 | 0.24 | 10.80 |
| 351 | 3 | 2009 | 7 | SM | 3.45 | 21.45 | 132 | 7.34 | 0.53 | 5.8 | 31.0 | 74 | 2.08 | 0.28 | 11.30 |
| 352 | 4 | 2009 | 7 | RF | 2.10 | 21.58 | 162 | 8.33 | 1.58 | 17.6 | 13.3 | 165 | 4.66 | 0.30 | 19.50 |
| 353 | 5 | 2009 | 7 | INT | 0.20 | 22.76 | 147 | 8.15 | 1.92 | 22.9 | 2.5 | 186 | 0.07 | 0.64 | 24.30 |
| 354 | 6 | 2009 | 7 | RF | 0.10 | 29.00 | 196 | 9.03 | 1.51 | 15.2 | 16.3 | 252 | 51.40 | 0.42 | 27.70 |
| 355 | 7 | 2009 | 7 | SM | 1.00 | 22.42 | 152 | 7.64 | 0.62 | 7.1 | 13.1 | 71 | 1.84 | 0.21 | 8.69 |
| 356 | 8 | 2009 | 7 | INT | n.d. | n.d. | n.d. | 9.56 | 0.89 | 7.1 | 13.8 | 92 | 1.33 | 0.15 | 10.40 |
| 357 | 9 | 2009 | 7 | INT | n.d. | n.d. | n.d. | 8.76 | 1.34 | 14.0 | 11.6 | 131 | 1.17 | 0.18 | 16.50 |
| 358 | 10 | 2009 | 7 | INT | n.d. | n.d. | n.d. | 8.38 | 0.91 | 8.7 | 18.2 | 95 | 1.34 | 0.21 | 11.70 |
| 359 | 11 | 2009 | 7 | SM | 1.00 | 25.67 | 168 | 7.48 | 0.42 | 4.5 | 20.2 | 54 | 0.75 | 0.10 | 6.35 |
| 360 | 12 | 2009 | 7 | SM | 0.70 | 23.94 | 224 | 10.00 | 1.43 | 9.9 | 18.0 | 140 | 0.50 | 0.20 | 12.70 |
| 361 | 13 | 2009 | 7 | SM | 0.85 | 23.50 | 108 | 6.84 | 0.45 | 4.6 | 37.0 | 50 | 0.09 | 0.07 | 7.82 |
| 362 | 14 | 2009 | 7 | INT | n.d. | n.d. | n.d. | 9.13 | 1.04 | 9.7 | 14.4 | 102 | 0.25 | 0.19 | 12.50 |
| 363 | 15 | 2009 | 7 | INT | 0.90 | 20.97 | 167 | 9.63 | 0.86 | 6.6 | 11.0 | 91 | 1.88 | 0.12 | 10.10 |
| 364 | 16 | 2009 | 7 | SM | 1.55 | 19.67 | 169 | 8.80 | 1.29 | 13.3 | 15.0 | 145 | 8.68 | 0.21 | 21.60 |
| 365 | 17 | 2009 | 7 | SM | 0.60 | 20.59 | 115 | 8.14 | 2.06 | 23.8 | 15.6 | 199 | 0.04 | 0.11 | 40.30 |
| 366 | 18 | 2009 | 7 | INT | 1.06 | 21.10 | 178 | 9.09 | 1.06 | 10.1 | 12.4 | 104 | 0.43 | 0.18 | 14.80 |
| 367 | 19 | 2009 | 7 | INT | 0.70 | 20.98 | 182 | 9.78 | 1.19 | 9.6 | 14.7 | 166 | 20.90 | 0.12 | 15.90 |
| 368 | 20 | 2009 | 7 | INT | 1.30 | 21.29 | 178 | 8.90 | 1.38 | 14.3 | 17.5 | 135 | 0.25 | 0.15 | 18.90 |
| 369 | 21 | 2009 | 7 | SM | 0.90 | 21.39 | 147 | 7.35 | 0.37 | 4.1 | 21.6 | 47 | 0.04 | 0.17 | 6.10 |
| 370 | 22 | 2009 | 7 | SM | 2.65 | 20.48 | 140 | 7.48 | 0.47 | 5.4 | 16.8 | 55 | 0.10 | 0.14 | 6.10 |
| 371 | 23 | 2009 | 7 | SM | 1.75 | 21.01 | 125 | 6.40 | 0.13 | 1.6 | 23.6 | 24 | 0.10 | 0.10 | 2.50 |
| 372 | 24 | 2009 | 7 | RF | 0.65 | 21.89 | 140 | 7.38 | 0.38 | 4.4 | 13.6 | 42 | 0.05 | 0.12 | 5.68 |
| 373 | 25 | 2009 | 7 | INT | 1.25 | 20.63 | 124 | 6.03 | 0.18 | 1.4 | 43.1 | 30 | 0.31 | 0.05 | 4.14 |
| 374 | 26 | 2009 | 7 | INT | n.d. | n.d. | n.d. | 7.10 | 0.22 | 2.9 | 17.5 | 32 | 0.19 | 0.12 | 4.25 |
| 375 | 27 | 2009 | 7 | RF | 1.70 | 23.05 | 196 | 9.03 | 1.34 | 13.3 | 12.2 | 135 | 3.18 | 0.25 | 17.20 |
| 376 | 28 | 2009 | 7 | RF | 0.85 | 22.62 | 137 | 8.03 | 1.17 | 12.6 | 17.6 | 120 | 2.40 | 0.33 | 14.90 |
| 377 | 29 | 2009 | 7 | RF | 1.10 | 22.12 | 215 | 9.54 | 1.15 | 10.2 | 8.1 | 117 | 3.57 | 0.17 | 12.00 |
| 378 | 30 | 2009 | 7 | RF | n.d. | n.d. | n.d. | 7.86 | 1.18 | 13.2 | 19.4 | 131 | 5.90 | 0.10 | 19.20 |
| 379 | 31 | 2009 | 7 | INT | n.d. | n.d. | n.d. | 8.00 | 1.20 | 12.9 | 18.9 | 135 | 5.89 | 0.12 | 19.50 |
| 380 | 32 | 2009 | 7 | INT | 1.65 | 19.30 | 136 | 6.86 | 0.20 | 2.1 | 19.1 | 29 | 0.40 | 0.19 | 4.04 |
| 381 | 33 | 2009 | 7 | RF | 1.45 | 20.52 | 155 | 8.49 | 1.55 | 16.7 | 16.9 | 160 | 4.60 | 0.33 | 21.00 |
| 382 | 34 | 2009 | 7 | RF | 1.65 | 19.91 | 204 | 9.12 | 1.51 | 16.1 | 11.0 | 158 | 6.79 | 0.48 | 19.50 |
| 383 | 35 | 2009 | 7 | RF | n.d. | n.d. | n.d. | 8.17 | 1.60 | 18.4 | 20.6 | 181 | 9.36 | 0.32 | 24.20 |
| 384 | 36 | 2009 | 7 | RF | 1.15 | 22.42 | 196 | 9.41 | 1.40 | 12.9 | 15.9 | 147 | 5.62 | 0.19 | 16.30 |
| 385 | 37 | 2009 | 7 | RF | n.d. | n.d. | n.d. | 8.94 | 1.23 | 12.2 | 12.8 | 139 | 9.18 | 0.22 | 15.80 |
| 386 | 38 | 2009 | 7 | RF | 1.30 | 19.20 | 145 | 8.17 | 1.60 | 18.7 | 6.7 | 189 | 15.10 | 0.64 | 28.90 |
| 387 | 39 | 2009 | 7 | RF | 2.06 | 19.29 | 159 | 8.36 | 2.22 | 25.9 | 12.2 | 248 | 18.30 | 0.98 | 28.40 |
| 388 | 40 | 2009 | 7 | INT | 1.10 | 19.15 | 172 | 9.36 | 1.02 | 8.6 | 12.3 | 94 | 0.93 | 0.24 | 13.00 |
| 389 | 41 | 2009 | 7 | INT | 3.20 | 19.20 | 145 | 7.55 | 0.70 | 8.2 | 21.1 | 85 | 1.29 | 0.40 | 10.20 |
| 390 | 42 | 2009 | 7 | RF | 1.50 | 16.17 | 144 | 8.23 | 2.32 | 27.0 | 7.5 | 225 | 3.61 | 0.45 | 29.20 |
| 391 | 43 | 2009 | 7 | INT | 1.55 | 17.97 | 138 | 8.15 | 1.47 | 17.3 | 6.4 | 217 | 33.20 | 0.64 | 29.70 |
| 392 | 44 | 2009 | 7 | INT | 1.80 | 19.29 | 165 | 8.80 | 1.20 | 11.7 | 11.2 | 117 | 0.45 | 0.17 | 17.20 |
| 393 | 45 | 2009 | 7 | SM | 1.00 | 20.33 | 162 | 8.83 | 1.20 | 12.3 | 12.3 | 162 | 20.60 | 0.13 | 27.80 |
| 394 | 46 | 2009 | 7 | INT | 0.55 | 19.87 | 181 | 10.10 | 1.12 | 7.9 | 19.8 | 149 | 13.10 | 0.14 | 19.40 |
| 395 | 47 | 2009 | 7 | INT | 1.95 | 21.21 | 158 | 7.85 | 0.71 | 7.9 | 14.5 | 77 | 0.27 | 0.18 | 11.00 |
| 396 | 48 | 2009 | 7 | INT | 0.45 | 22.69 | 200 | 9.65 | 1.56 | 14.0 | 8.9 | 151 | 0.28 | 0.16 | 10.60 |
| 397 | 49 | 2009 | 7 | RF | 1.20 | 21.40 | 191 | 9.36 | 1.30 | 11.8 | 12.4 | 156 | 14.50 | 0.28 | 15.00 |
| 398 | 50 | 2009 | 7 | SM | 0.60 | 19.18 | 20 | 7.10 | 0.98 | 11.9 | 30.7 | 115 | 3.69 | 0.10 | 16.00 |
| 399 | 52 | 2009 | 7 | INT | n.d. | n.d. | n.d. | 9.63 | 1.04 | 7.4 | 20.7 | 103 | 0.52 | 0.04 | 18.00 |

| ID | Lake OCF | Y | M | Cat | Depth m | Temp ˚C | DO % | pH - | Alk meq/L | DIC mg/L | DOC mg/L | SpC µS/cm | $SO_4$ mg/L | Cl mg/L | Ca mg/L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 400 | 53 | 2009 | 7 | RF | 4.50 | 21.82 | 155 | 8.04 | 1.21 | 13.4 | 14.6 | 122 | 0.04 | 0.34 | 15.70 |
| 401 | 54 | 2009 | 7 | INT | n.d. | n.d. | n.d. | 7.75 | 0.78 | 8.4 | 21.4 | 87 | 0.41 | 0.27 | 14.40 |
| 402 | 55 | 2009 | 7 | SM | 3.60 | 19.51 | 132 | 7.07 | 0.30 | 3.4 | 24.9 | 44 | 0.45 | 0.12 | 5.75 |
| 403 | 56 | 2009 | 7 | INT | n.d. | 20.34 | 70 | 6.91 | 0.64 | 7.5 | 25.6 | 71 | 0.17 | 0.13 | 10.20 |
| 404 | 1 | 2009 | 9 | RF | 0.85 | 11.88 | 123 | 8.57 | 1.21 | 12.3 | 11.1 | 140 | 10.90 | 0.18 | 18.70 |
| 405 | 2 | 2009 | 9 | RF | 0.95 | 11.70 | 140 | 6.62 | 1.00 | 10.8 | 7.7 | 30 | 1.30 | 0.22 | 3.61 |
| 406 | 3 | 2009 | 9 | SM | 3.50 | 11.88 | 104 | 7.11 | 0.50 | 5.4 | 29.3 | 71 | 2.36 | 0.27 | 11.10 |
| 407 | 4 | 2009 | 9 | RF | 1.55 | 11.51 | 108 | 7.86 | 1.62 | 18.8 | 12.6 | 172 | 5.88 | 0.26 | 21.90 |
| 408 | 5 | 2009 | 9 | INT | 0.75 | 10.69 | 105 | 8.21 | 2.06 | 25.0 | 2.0 | 199 | ***0.02*** | 0.74 | 27.10 |
| 409 | 6 | 2009 | 9 | RF | 0.15 | 15.79 | 147 | 9.39 | 1.18 | 10.9 | 10.7 | 216 | 46.50 | 0.60 | 21.90 |
| 410 | 7 | 2009 | 9 | SM | 0.90 | 10.93 | 100 | 7.45 | 0.55 | 6.7 | 14.0 | 67 | 2.08 | 0.27 | 8.25 |
| 411 | 8 | 2009 | 9 | INT | 1.05 | 12.82 | 122 | 8.46 | 0.85 | 8.7 | 14.4 | 90 | 1.74 | 0.10 | 10.60 |
| 412 | 9 | 2009 | 9 | INT | 1.30 | 11.55 | 113 | 8.23 | 1.17 | 13.2 | 11.5 | 118 | 1.31 | 0.16 | 14.30 |
| 413 | 10 | 2009 | 9 | INT | 0.97 | 12.34 | 110 | 7.43 | 0.67 | 7.7 | 17.5 | 81 | 2.51 | 0.11 | 9.90 |
| 414 | 11 | 2009 | 9 | SM | 0.70 | 8.75 | 84 | 6.91 | 0.43 | 5.0 | 18.9 | 50 | 0.90 | 0.13 | 6.04 |
| 415 | 12 | 2009 | 9 | SM | 0.55 | 12.46 | 136 | 9.06 | 1.54 | 14.2 | 16.6 | 149 | 0.78 | 0.22 | 14.10 |
| 416 | 13 | 2009 | 9 | SM | 1.85 | 10.50 | 80 | 6.48 | 0.18 | 1.7 | 23.3 | 29 | 0.13 | 0.06 | 3.89 |
| 417 | 14 | 2009 | 9 | INT | 0.60 | 11.95 | 111 | 7.76 | 0.97 | 10.7 | 12.9 | 98 | 0.35 | 0.12 | 12.60 |
| 418 | 15 | 2009 | 9 | INT | 0.95 | 9.18 | 113 | 8.75 | 0.81 | 8.0 | 10.1 | 87 | 2.49 | 0.14 | 9.85 |
| 419 | 16 | 2009 | 9 | SM | 1.30 | 8.83 | 96 | 7.72 | 1.01 | 11.7 | 16.2 | 124 | 8.10 | 0.08 | 17.60 |
| 420 | 17 | 2009 | 9 | SM | 0.70 | 9.23 | 84 | 7.85 | 2.04 | 24.4 | 13.2 | 198 | 0.02 | 0.20 | 40.20 |
| 421 | 18 | 2009 | 9 | INT | 0.75 | 9.87 | 106 | 8.30 | 1.04 | 10.6 | 11.4 | 103 | 0.63 | 0.14 | 15.40 |
| 422 | 19 | 2009 | 9 | INT | 0.44 | 9.62 | 135 | 9.66 | 1.23 | 9.4 | 13.5 | 168 | 20.70 | 0.17 | 18.10 |
| 423 | 20 | 2009 | 9 | INT | 1.50 | 11.26 | 108 | 7.89 | 1.48 | 16.6 | 16.6 | 148 | 0.35 | 0.20 | 21.50 |
| 424 | 21 | 2009 | 9 | SM | 0.90 | 8.68 | 81 | 6.75 | 0.28 | 2.2 | 25.9 | 36 | 0.05 | 0.16 | 5.27 |
| 425 | 22 | 2009 | 9 | SM | 2.15 | 9.64 | 87 | 7.22 | 0.43 | 5.2 | 15.8 | 53 | 0.23 | 0.15 | 5.84 |
| 426 | 23 | 2009 | 9 | SM | 1.95 | 9.00 | 74 | 6.08 | 0.12 | 0.8 | 26.5 | 23 | 0.18 | 0.10 | 2.70 |
| 427 | 24 | 2009 | 9 | RF | 0.65 | 8.83 | 90 | 7.16 | 0.32 | 3.6 | 11.0 | 37 | 0.11 | 0.13 | 4.46 |
| 428 | 25 | 2009 | 9 | INT | 1.75 | 8.50 | 73 | 5.26 | 0.12 | 2.6 | 51.5 | 32 | 0.55 | 0.11 | 4.23 |
| 429 | 26 | 2009 | 9 | INT | 1.90 | 9.48 | 92 | 6.94 | 0.25 | 2.2 | 19.1 | 33 | 0.37 | 0.08 | 4.42 |
| 430 | 27 | 2009 | 9 | RF | 1.75 | 11.22 | 122 | 8.92 | 1.10 | 12.4 | 10.9 | 114 | 2.85 | 0.22 | 13.00 |
| 431 | 28 | 2009 | 9 | RF | 1.07 | 11.28 | 109 | 7.96 | 1.48 | 16.6 | 13.1 | 146 | 2.90 | 0.21 | 20.10 |
| 432 | 29 | 2009 | 9 | RF | 1.35 | 9.83 | 117 | 9.05 | 1.24 | 12.7 | 7.2 | 127 | 3.85 | 0.16 | 14.20 |
| 433 | 30 | 2009 | 9 | RF | 1.25 | 10.70 | 12 | 7.44 | 1.03 | 11.5 | 17.1 | 127 | 9.06 | 0.08 | 18.40 |
| 434 | 31 | 2009 | 9 | INT | 1.30 | 10.45 | 111 | 7.21 | 0.65 | 7.4 | 19.5 | 92 | 8.12 | 0.11 | 12.30 |
| 435 | 32 | 2009 | 9 | INT | 2.10 | 9.93 | 95 | 6.43 | 0.17 | 1.8 | 21.9 | 26 | 0.38 | 0.08 | 3.75 |
| 436 | 33 | 2009 | 9 | RF | 1.60 | 10.62 | 111 | 7.87 | 1.44 | 16.0 | 16.2 | 150 | 5.77 | 0.34 | 19.40 |
| 437 | 34 | 2009 | 9 | RF | 1.70 | 8.70 | 98 | 8.79 | 1.29 | 14.7 | 10.3 | 138 | 6.72 | 0.40 | 16.00 |
| 438 | 35 | 2009 | 9 | RF | 1.00 | 10.62 | 101 | 7.72 | 1.56 | 17.8 | 20.7 | 181 | 12.40 | 0.35 | 24.20 |
| 439 | 36 | 2009 | 9 | RF | 1.25 | 10.72 | 121 | 8.90 | 1.30 | 13.2 | 13.8 | 139 | 6.98 | 0.14 | 15.50 |
| 440 | 37 | 2009 | 9 | RF | 1.15 | 11.26 | 121 | 9.24 | 1.11 | 10.5 | 11.4 | 125 | 8.81 | 0.10 | 14.10 |
| 441 | 38 | 2009 | 9 | RF | 1.35 | 9.25 | 105 | 8.11 | 1.67 | 19.4 | 5.9 | 199 | 15.90 | 0.73 | 29.20 |
| 442 | 39 | 2009 | 9 | RF | 2.05 | 9.19 | 106 | 8.14 | 2.00 | 22.9 | 10.6 | 236 | 22.20 | 0.80 | 25.20 |
| 443 | 40 | 2009 | 9 | INT | 0.95 | 10.69 | 120 | 8.59 | 0.84 | 8.8 | 12.3 | 85 | 1.08 | 0.13 | 11.90 |
| 444 | 41 | 2009 | 9 | INT | 2.75 | 11.18 | 107 | 7.25 | 0.67 | 7.4 | 22.2 | 78 | 1.25 | 0.39 | 9.66 |
| 445 | 42 | 2009 | 9 | RF | 0.70 | 9.25 | 109 | 8.02 | 1.69 | 19.4 | 9.1 | 176 | 7.12 | 0.55 | 22.40 |
| 446 | 43 | 2009 | 9 | INT | 2.00 | 8.21 | 105 | 7.98 | 1.54 | 18.2 | 6.8 | 223 | 34.30 | 0.67 | 30.10 |
| 447 | 44 | 2009 | 9 | INT | 1.90 | 9.00 | 113 | 8.39 | 1.09 | 12.5 | 11.4 | 108 | 0.33 | 0.17 | 16.20 |
| 448 | 45 | 2009 | 9 | SM | 1.15 | 11.01 | 108 | 7.93 | 1.00 | 10.8 | 17.8 | 131 | 13.70 | 0.12 | 22.80 |
| 449 | 46 | 2009 | 9 | INT | 0.60 | 12.18 | 154 | 9.93 | 1.25 | 8.6 | 17.9 | 167 | 19.50 | 0.11 | 21.30 |
| 450 | 47 | 2009 | 9 | INT | 2.10 | 10.59 | 103 | 7.52 | 0.67 | 7.7 | 13.8 | 73 | 0.45 | 0.18 | 10.70 |

| ID | Lake OCF | Y | M | Cat | Depth m | Temp ˚C | DO % | pH - | Alk meq/L | DIC mg/L | DOC mg/L | SpC µS/cm | $SO_4$ mg/L | Cl mg/L | Ca mg/L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 451 | 48 | 2009 | 9 | INT | 0.50 | 10.93 | 107 | 8.23 | 2.64 | 30.6 | 7.1 | 268 | 7.89 | 0.64 | 30.80 |
| 452 | 49 | 2009 | 9 | RF | 1.35 | 10.30 | 110 | 8.63 | 1.41 | 16.0 | 11.5 | 170 | 16.60 | 0.21 | 18.80 |
| 453 | 50 | 2009 | 9 | SM | 0.75 | 6.35 | 60 | 6.21 | 0.29 | 4.0 | 29.0 | 91 | 23.00 | 0.04 | 12.20 |
| 454 | 52 | 2009 | 9 | INT | 1.35 | 10.25 | 106 | 7.79 | 0.96 | 10.4 | 20.2 | 101 | 0.75 | 0.05 | 16.30 |
| 455 | 53 | 2009 | 9 | RF | 3.90 | 10.67 | 100 | 7.78 | 1.15 | 13.2 | 13.6 | 119 | 0.02 | 0.32 | 15.20 |
| 456 | 54 | 2009 | 9 | INT | 7.30 | 10.50 | 87 | 7.44 | 0.78 | 9.0 | 21.1 | 89 | 0.38 | 0.28 | 14.90 |
| 457 | 55 | 2009 | 9 | SM | 6.10 | 8.93 | 67 | 6.70 | 0.37 | 4.0 | 26.4 | 46 | 0.36 | 0.19 | 6.31 |
| 458 | 56 | 2009 | 9 | INT | 0.85 | 7.34 | 69 | 7.00 | 0.62 | 6.1 | 25.4 | 68 | 0.39 | 0.11 | 10.70 |

Table A.1: Part 2 – Raw water chemistry data for 56 OCF lakes, measured at three time-points over the ice-out period in each of 2007, 2008, and 2009. Red italicized font indicates values were below given detection limit. “n.d.” indicates that no data was collected. “Cat” Indicates the hydrological input category (SM: snowmelt; INT: intermediate; RF: rainfall).

| ID | Lake OCF | Y | M | Cat | Mg mg/L | K mg/L | Na mg/L | $SiO_2$ mg/L | $NO_3NO_2$ µg/L | $NH_3$ µg/L | TN µg/L | TDP µg/L | TP µg/L | Chl-*a* mg/L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 2007 | 6 | INT | 2.72 | 1.49 | 0.71 | 0.28 | 7.0 | 139 | 510 | 11.1 | 23.7 | 1.45 |
| 2 | 2 | 2007 | 6 | RF | 2.07 | 1.09 | 0.52 | 0.34 | *5.0* | 262 | 484 | 5.6 | 19.8 | 0.16 |
| 3 | 3 | 2007 | 6 | SM | 1.47 | 1.05 | 0.50 | 1.80 | 42.0 | 38 | 656 | 9.8 | 20.0 | 0.53 |
| 4 | 4 | 2007 | 6 | INT | 4.02 | 1.06 | 0.76 | 0.61 | 5.0 | 178 | 612 | 7.8 | 23.1 | 0.62 |
| 5 | 5 | 2007 | 6 | INT | 2.31 | 1.42 | 3.17 | 4.02 | *5.0* | 11 | 140 | 5.2 | 12.3 | 1.27 |
| 6 | 6 | 2007 | 6 | RF | 2.54 | 0.71 | 0.59 | 0.35 | *5.0* | 14 | 204 | 3.3 | 9.6 | 0.47 |
| 7 | 7 | 2007 | 6 | INT | 1.32 | 0.80 | 0.57 | 0.83 | 6.0 | 40 | 429 | 28.8 | 30.2 | 0.91 |
| 8 | 8 | 2007 | 6 | INT | 3.75 | 1.11 | 1.68 | 1.16 | *5.0* | 57 | 573 | 7.0 | 37.9 | 5.63 |
| 9 | 9 | 2007 | 6 | INT | 4.54 | 0.87 | 1.29 | 0.92 | *5.0* | 13 | 490 | 7.0 | 19.2 | 2.73 |
| 10 | 10 | 2007 | 6 | INT | 2.22 | 1.28 | 1.73 | 1.13 | 5.0 | 75 | 649 | 24.2 | 62.4 | 5.54 |
| 11 | 11 | 2007 | 6 | SM | 0.75 | 2.01 | 0.53 | 0.94 | 7.0 | 96 | 740 | 33.8 | 48.9 | 3.54 |
| 12 | 12 | 2007 | 6 | SM | 4.86 | 2.69 | 4.18 | 0.03 | 9.0 | 116 | 728 | 14.2 | 33.6 | 0.95 |
| 13 | 13 | 2007 | 6 | SM | 0.91 | 1.64 | 0.51 | 1.47 | 6.0 | 69 | 595 | 39.7 | 45.0 | 1.80 |
| 14 | 14 | 2007 | 6 | INT | 3.11 | 1.32 | 1.40 | 0.41 | 7.0 | 84 | 552 | 11.2 | 40.0 | 2.25 |
| 15 | 15 | 2007 | 6 | INT | 1.72 | 1.47 | 0.40 | 0.38 | 7.0 | 79 | 449 | 8.4 | 38.9 | 2.96 |
| 16 | 16 | 2007 | 6 | SM | 3.96 | 1.22 | 1.24 | 2.84 | 7.0 | 159 | 702 | 17.2 | 59.2 | 2.01 |
| 17 | 17 | 2007 | 6 | SM | 0.82 | 1.00 | 0.43 | 1.45 | 6.0 | 35 | 517 | 17.1 | 9.6 | 0.46 |
| 18 | 18 | 2007 | 6 | RF | 1.58 | 1.13 | 0.58 | 0.66 | 13.0 | 128 | 471 | 6.7 | 30.6 | 1.42 |
| 19 | 19 | 2007 | 6 | INT | 6.29 | 4.13 | 1.43 | 0.49 | 8.0 | 58 | 487 | 16.0 | 51.1 | 1.60 |
| 20 | 22 | 2007 | 6 | SM | 2.60 | 1.45 | 0.53 | 1.49 | 11.0 | 121 | 659 | 17.8 | 46.7 | 7.60 |
| 21 | 23 | 2007 | 6 | SM | 0.86 | 0.85 | 0.32 | 0.75 | 10.0 | 22 | 515 | 9.8 | 21.2 | 4.71 |
| 22 | 24 | 2007 | 6 | SM | 1.23 | 1.08 | 0.41 | 0.04 | 9.0 | 67 | 455 | 7.7 | 26.1 | 2.68 |
| 23 | 25 | 2007 | 6 | SM | 1.20 | 1.21 | 0.44 | 2.70 | 13.0 | 6 | 633 | 38.3 | 66.7 | 2.18 |
| 24 | 26 | 2007 | 6 | SM | 1.43 | 0.87 | 0.39 | 1.57 | 11.0 | 131 | 633 | 25.9 | 61.2 | 4.57 |
| 25 | 28 | 2007 | 6 | RF | 3.30 | 0.82 | 0.92 | 0.31 | 11.0 | 96 | 471 | 6.1 | 17.1 | 1.06 |
| 26 | 29 | 2007 | 6 | RF | 5.43 | 0.69 | 1.03 | 0.54 | 9.0 | 11 | 344 | 4.3 | 13.6 | 2.18 |
| 27 | 30 | 2007 | 6 | INT | n.d. | n.d. | n.d. | n.d. | 10.0 | 92 | 869 | 9.3 | 42.0 | 0.29 |
| 28 | 31 | 2007 | 6 | INT | 3.40 | 1.27 | 0.55 | 1.33 | 10.0 | 135 | 867 | 20.9 | 91.1 | 2.11 |
| 29 | 32 | 2007 | 6 | INT | 1.02 | 0.65 | 0.55 | 3.20 | 25.0 | 47 | 602 | 20.7 | 40.9 | 0.96 |
| 30 | 33 | 2007 | 6 | RF | 2.96 | 1.27 | 0.51 | 0.53 | 10.0 | 270 | 772 | 7.6 | 24.1 | 1.35 |
| 31 | 34 | 2007 | 6 | RF | 3.32 | 2.46 | 0.57 | 0.52 | 12.0 | 127 | 500 | 10.1 | 31.0 | 1.27 |
| 32 | 35 | 2007 | 6 | INT | 3.22 | 2.06 | 0.59 | 0.31 | 5.0 | 103 | 765 | 15.7 | 32.1 | 3.34 |

| ID | Lake OCF | Y | M | Cat | Mg mg/L | K mg/L | Na mg/L | $SiO_2$ mg/L | $NO_3NO_2$ µg/L | $NH_3$ µg/L | TN µg/L | TDP µg/L | TP µg/L | Chl-*a* mg/L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 33 | 36 | 2007 | 6 | RF | 7.94 | 1.65 | 1.61 | 1.24 | 6.0 | 74 | 849 | 7.6 | 38.8 | 5.82 |
| 34 | 37 | 2007 | 6 | RF | 4.46 | 1.19 | 0.96 | 0.72 | 6.0 | 109 | 668 | 6.7 | 31.4 | 0.45 |
| 35 | 38 | 2007 | 6 | RF | 2.92 | 1.09 | 0.62 | 0.23 | 6.0 | 24 | 234 | 5.1 | 9.7 | 0.29 |
| 36 | 39 | 2007 | 6 | RF | 10.70 | 2.40 | 2.62 | 0.84 | ***5.0*** | 35 | 571 | 8.7 | 20.8 | 0.73 |
| 37 | 40 | 2007 | 6 | RF | 1.73 | 1.15 | 0.59 | 0.92 | 10.0 | 172 | 746 | 9.1 | 42.8 | 1.28 |
| 38 | 41 | 2007 | 6 | INT | 2.48 | 1.90 | 0.83 | 1.75 | ***5.0*** | 60 | 769 | 15.5 | 38.3 | 2.04 |
| 39 | 42 | 2007 | 6 | RF | 4.29 | 1.54 | 1.29 | 0.30 | 5.0 | 34 | 408 | 8.8 | 20.7 | 0.90 |
| 40 | 43 | 2007 | 6 | RF | 3.56 | 1.24 | 0.69 | 0.22 | 7.0 | 18 | 306 | 12.6 | 24.7 | 0.72 |
| 41 | 44 | 2007 | 6 | RF | 2.00 | 1.52 | 0.49 | 1.87 | 8.0 | 79 | 554 | 9.7 | 20.8 | 1.43 |
| 42 | 46 | 2007 | 6 | INT | 8.39 | 3.59 | 1.71 | 1.40 | ***5.0*** | 109 | 1300 | 16.3 | 43.3 | 0.61 |
| 43 | 47 | 2007 | 6 | INT | 2.50 | 1.30 | 0.55 | 0.96 | 8.0 | 62 | 786 | 13.7 | 20.4 | 3.10 |
| 44 | 48 | 2007 | 6 | INT | 4.53 | 2.23 | 5.92 | 4.05 | 8.0 | 121 | 381 | 7.5 | 24.5 | 1.98 |
| 45 | 49 | 2007 | 6 | RF | 5.55 | 1.14 | 0.98 | 0.57 | 8.0 | 34 | 449 | 5.0 | 14.2 | 0.03 |
| 46 | 50 | 2007 | 6 | SM | 3.40 | 1.42 | 0.56 | 0.62 | 10.0 | 59 | 1500 | 36.4 | 78.1 | 3.66 |
| 47 | 52 | 2007 | 6 | SM | 3.28 | 1.72 | 0.54 | 2.19 | 7.0 | 23 | 605 | 27.7 | 48.2 | 1.11 |
| 48 | 53 | 2007 | 6 | INT | 5.43 | 1.78 | 1.02 | 1.10 | 7.0 | 33 | 693 | 7.6 | 19.4 | 0.94 |
| 49 | 54 | 2007 | 6 | SM | 2.48 | 1.18 | 0.41 | 2.33 | 10.0 | 47 | 719 | 12.0 | 24.9 | 1.57 |
| 50 | 56 | 2007 | 6 | SM | 2.68 | 4.40 | 0.33 | 2.16 | 10.0 | 31 | 857 | 59.7 | 94.6 | 1.14 |
| 51 | 1 | 2007 | 7 | INT | 5.71 | 2.00 | 1.48 | 0.56 | ***5.0*** | 163 | 1160 | 8.1 | 40.7 | 3.52 |
| 52 | 2 | 2007 | 7 | RF | 7.56 | 1.37 | 1.69 | 0.35 | ***5.0*** | 55 | 644 | 8.5 | 15.3 | 1.80 |
| 53 | 3 | 2007 | 7 | SM | 2.70 | 1.22 | 0.49 | 1.17 | 5.0 | 30 | 745 | 10.2 | 16.5 | 1.16 |
| 54 | 4 | 2007 | 7 | INT | 7.98 | 0.85 | 1.36 | 0.80 | ***5.0*** | 58 | 754 | 9.4 | 21.1 | 1.02 |
| 55 | 5 | 2007 | 7 | INT | 4.47 | 2.24 | 6.57 | 8.12 | 17.0 | 8 | 173 | 2.1 | 4.9 | 0.14 |
| 56 | 6 | 2007 | 7 | RF | 4.21 | 0.13 | 0.89 | 0.49 | 6.0 | 61 | 619 | 18.0 | 52.5 | 2.56 |
| 57 | 7 | 2007 | 7 | INT | 3.45 | 1.66 | 1.33 | 0.86 | 8.0 | 42 | 483 | 12.7 | 45.0 | 1.24 |
| 58 | 8 | 2007 | 7 | INT | 3.75 | 0.66 | 1.96 | 0.53 | 5.0 | 59 | 655 | 10.9 | 19.9 | 0.81 |
| 59 | 9 | 2007 | 7 | INT | 5.91 | 0.77 | 1.66 | 0.28 | 5.0 | 66 | 586 | 7.6 | 21.0 | 2.18 |
| 60 | 10 | 2007 | 7 | INT | 3.68 | 0.44 | 2.43 | 1.56 | 7.0 | 171 | 1010 | 42.5 | 74.6 | 8.46 |
| 61 | 11 | 2007 | 7 | SM | 2.02 | 2.02 | 1.51 | 0.85 | 9.0 | 104 | 858 | 79.1 | 102.0 | 2.96 |
| 62 | 12 | 2007 | 7 | INT | 7.27 | 2.12 | 7.49 | 0.47 | 15.0 | 70 | 1150 | 17.3 | 33.1 | 1.90 |
| 63 | 13 | 2007 | 7 | SM | 2.04 | 1.11 | 0.63 | 2.38 | 12.0 | 34 | 557 | 21.9 | 32.1 | 2.02 |
| 64 | 14 | 2007 | 7 | INT | 5.26 | 0.57 | 1.86 | 0.44 | 11.0 | 50 | 812 | 9.9 | 19.4 | 1.91 |
| 65 | 15 | 2007 | 7 | INT | 3.64 | 1.26 | 0.82 | 1.01 | 12.0 | 50 | 737 | 9.0 | 14.0 | 0.19 |
| 66 | 16 | 2007 | 7 | SM | 5.68 | 0.89 | 1.85 | 1.02 | 11.0 | 48 | 619 | 14.1 | 24.6 | 1.04 |
| 67 | 17 | 2007 | 7 | SM | 1.71 | 0.48 | 0.83 | 4.37 | 11.0 | 22 | 669 | 6.8 | 10.6 | 0.46 |
| 68 | 18 | 2007 | 7 | RF | 3.04 | 0.52 | 0.90 | 0.21 | 12.0 | 50 | 651 | 10.3 | 18.4 | 0.66 |
| 69 | 19 | 2007 | 7 | INT | 8.59 | 4.50 | 2.13 | 0.60 | 11.0 | 73 | 947 | 19.9 | 34.2 | 0.79 |
| 70 | 20 | 2007 | 7 | INT | 7.29 | 0.80 | 3.29 | 0.29 | 12.0 | 84 | 1020 | 15.0 | 27.1 | 4.31 |
| 71 | 21 | 2007 | 7 | SM | 1.98 | 0.53 | 0.95 | 1.19 | 13.0 | 104 | 918 | 22.5 | 41.8 | 3.93 |
| 72 | 22 | 2007 | 7 | SM | 2.74 | 0.89 | 0.54 | 0.64 | 12.0 | 33 | 570 | 12.5 | 19.6 | 1.50 |
| 73 | 23 | 2007 | 7 | SM | 1.15 | 0.64 | 0.40 | 0.31 | 13.0 | 21 | 571 | 8.8 | 13.5 | 1.76 |
| 74 | 24 | 2007 | 7 | SM | 2.20 | 0.99 | 0.47 | 0.47 | 12.0 | 94 | 884 | 8.9 | 25.0 | 2.95 |
| 75 | 25 | 2007 | 7 | SM | 1.47 | 1.03 | 0.46 | 2.29 | 14.0 | 149 | 658 | 31.7 | 61.0 | 12.58 |
| 76 | 26 | 2007 | 7 | SM | 1.55 | 0.68 | 0.41 | 0.45 | 13.0 | 62 | 612 | 19.8 | 35.3 | 3.17 |
| 77 | 27 | 2007 | 7 | INT | 5.12 | 0.58 | 0.58 | 3.24 | 29.0 | 5 | 171 | 1.8 | 4.2 | 3.12 |
| 78 | 28 | 2007 | 7 | RF | 6.27 | 0.16 | 1.57 | 0.33 | 13.0 | 45 | 695 | 7.8 | 16.3 | 1.55 |
| 79 | 29 | 2007 | 7 | RF | 6.52 | 0.17 | 1.33 | 0.48 | 12.0 | 74 | 654 | 5.8 | 28.7 | 4.51 |
| 80 | 30 | 2007 | 7 | INT | 5.17 | 0.71 | 0.89 | ***0.02*** | 13.0 | 90 | 861 | 8.2 | 23.7 | 8.50 |
| 81 | 31 | 2007 | 7 | INT | 4.65 | 0.33 | 0.56 | 0.33 | 13.0 | 61 | 824 | 12.4 | 23.8 | 2.43 |
| 82 | 32 | 2007 | 7 | INT | 1.50 | 0.59 | 0.66 | 2.61 | 14.0 | 53 | 562 | 36.0 | 55.5 | 9.29 |
| 83 | 33 | 2007 | 7 | RF | 6.10 | 1.67 | 0.83 | 0.35 | 12.0 | 75 | 732 | 6.6 | 19.9 | 5.34 |

| ID | Lake OCF | Y | M | Cat | Mg mg/L | K mg/L | Na mg/L | SiO$_2$ mg/L | NO$_3$NO$_2$ µg/L | NH$_3$ µg/L | TN µg/L | TDP µg/L | TP µg/L | Chl-*a* mg/L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 84 | 34 | 2007 | 7 | RF | 6.09 | 2.90 | 0.94 | 0.57 | 12.0 | 35 | 600 | 10.4 | 17.6 | 1.61 |
| 85 | 35 | 2007 | 7 | INT | 7.19 | 2.57 | 1.01 | 0.74 | 13.0 | 53 | 924 | 13.0 | 23.7 | 3.43 |
| 86 | 36 | 2007 | 7 | RF | 8.69 | 1.28 | 1.78 | 0.25 | 13.0 | 59 | 758 | 8.8 | 17.7 | 1.83 |
| 87 | 37 | 2007 | 7 | RF | 6.47 | 0.75 | 1.34 | 0.52 | 12.0 | 84 | 952 | 8.8 | 43.9 | 11.83 |
| 88 | 38 | 2007 | 7 | RF | 4.98 | 2.04 | 0.88 | 0.61 | 18.0 | 37 | 346 | 5.5 | 97.7 | 6.45 |
| 89 | 39 | 2007 | 7 | RF | 12.70 | 2.31 | 3.10 | 0.20 | 13.0 | 52 | 678 | 10.3 | 21.5 | 2.64 |
| 90 | 40 | 2007 | 7 | RF | 3.60 | 0.88 | 1.08 | 0.62 | 12.0 | 88 | 880 | 9.9 | 65.2 | 20.32 |
| 91 | 41 | 2007 | 7 | INT | 3.79 | 2.68 | 1.17 | 2.06 | 14.0 | 78 | 892 | 13.3 | 29.6 | 6.44 |
| 92 | 42 | 2007 | 7 | RF | 9.12 | 1.06 | 1.73 | 0.51 | 12.0 | 28 | 393 | 3.9 | 8.6 | 0.72 |
| 93 | 43 | 2007 | 7 | RF | 6.67 | 2.10 | 1.14 | 0.93 | 22.0 | 51 | 327 | 6.0 | 106.0 | 5.24 |
| 94 | 44 | 2007 | 7 | RF | 3.79 | 1.58 | 0.76 | 2.06 | 13.0 | 127 | 774 | 7.0 | 37.8 | 15.87 |
| 95 | 45 | 2007 | 7 | INT | 2.98 | 0.23 | 0.47 | 1.13 | 14.0 | 54 | 704 | 9.7 | 28.0 | 5.07 |
| 96 | 46 | 2007 | 7 | INT | 7.78 | 1.65 | 2.40 | 0.87 | 15.0 | 60 | 1510 | 25.1 | 41.0 | 1.05 |
| 97 | 47 | 2007 | 7 | INT | 2.57 | 1.00 | 0.56 | 0.33 | 14.0 | 42 | 711 | 7.5 | 13.9 | 3.31 |
| 98 | 48 | 2007 | 7 | SM | 7.37 | 1.77 | 12.10 | 0.61 | 17.0 | 100 | 623 | 16.9 | 33.9 | 1.27 |
| 99 | 49 | 2007 | 7 | RF | 9.51 | 1.25 | 1.68 | 0.50 | 15.0 | 63 | 737 | 6.7 | 21.9 | 5.07 |
| 100 | 50 | 2007 | 7 | SM | 5.84 | 0.55 | 0.44 | 0.34 | 15.0 | 68 | 1510 | 68.7 | 45.9 | 11.27 |
| 101 | 52 | 2007 | 7 | SM | 3.78 | 0.71 | 0.46 | 0.63 | 12.0 | 32 | 682 | 11.7 | 17.8 | 1.90 |
| 102 | 53 | 2007 | 7 | INT | 5.51 | 1.62 | 0.92 | 0.75 | 12.0 | 31 | 564 | 6.3 | 12.6 | 2.06 |
| 103 | 54 | 2007 | 7 | SM | 2.54 | 1.19 | 0.40 | 1.82 | 12.0 | 32 | 640 | 7.9 | 15.3 | 8.12 |
| 104 | 55 | 2007 | 7 | SM | 2.16 | 1.25 | 0.38 | 0.82 | 14.0 | 32 | 606 | 20.2 | 28.8 | 3.50 |
| 105 | 56 | 2007 | 7 | SM | 3.01 | 1.37 | 0.32 | 2.19 | 14.0 | 103 | 784 | 128.0 | 196.0 | 7.84 |
| 106 | 2 | 2007 | 9 | RF | 7.94 | 0.91 | 1.86 | 0.02 | 12.0 | 64 | 618 | 7.0 | 14.3 | 5.82 |
| 107 | 5 | 2007 | 9 | INT | 4.96 | 2.41 | 7.68 | 9.45 | 46.0 | 31 | 201 | 2.8 | 5.8 | 0.22 |
| 108 | 6 | 2007 | 9 | RF | 7.20 | 0.49 | 1.42 | 0.23 | 108.0 | ***5*** | 627 | 7.5 | 26.5 | 2.84 |
| 109 | 7 | 2007 | 9 | INT | 4.19 | 1.57 | 1.51 | 0.16 | 22.0 | 43 | 488 | 11.7 | 28.7 | 2.30 |
| 110 | 8 | 2007 | 9 | INT | 4.36 | 0.36 | 2.10 | 0.08 | 14.0 | 41 | 706 | 12.3 | 35.5 | 0.51 |
| 111 | 9 | 2007 | 9 | INT | 5.85 | 0.36 | 1.69 | 0.13 | 42.0 | 24 | 588 | 7.5 | 14.7 | 1.17 |
| 112 | 10 | 2007 | 9 | INT | 3.89 | 0.33 | 2.73 | 0.25 | 74.0 | 6 | 840 | 23.0 | 42.2 | 1.23 |
| 113 | 11 | 2007 | 9 | SM | 1.42 | 1.20 | 1.73 | 0.40 | 41.0 | 78 | 826 | 30.7 | 52.2 | 4.35 |
| 114 | 13 | 2007 | 9 | SM | 2.18 | 0.92 | 0.62 | 2.87 | 148.0 | 153 | 1190 | 34.8 | 53.6 | 6.77 |
| 115 | 14 | 2007 | 9 | INT | 3.95 | 0.39 | 0.61 | 0.13 | 24.0 | 58 | 771 | 7.8 | 13.9 | 1.62 |
| 116 | 15 | 2007 | 9 | INT | 5.15 | 0.40 | 2.06 | 0.04 | 59.0 | 7 | 645 | 11.3 | 18.2 | 2.30 |
| 117 | 18 | 2007 | 9 | RF | 3.23 | 0.13 | 0.79 | 0.02 | 20.0 | 41 | 720 | 9.6 | 16.5 | 1.66 |
| 118 | 20 | 2007 | 9 | INT | 6.58 | 0.44 | 1.43 | 0.23 | 64.0 | ***5*** | 852 | 8.6 | 19.1 | 3.52 |
| 119 | 21 | 2007 | 9 | SM | 1.83 | 0.22 | 1.05 | 0.27 | 97.0 | 10 | 920 | 15.5 | 29.4 | 5.64 |
| 120 | 22 | 2007 | 9 | SM | 2.83 | 1.09 | 0.59 | 0.83 | 34.0 | 67 | 669 | 17.0 | 27.2 | 5.69 |
| 121 | 23 | 2007 | 9 | SM | 1.13 | 0.54 | 0.39 | 0.26 | 9.0 | 32 | 621 | 6.6 | 9.9 | 1.60 |
| 122 | 24 | 2007 | 9 | SM | 2.24 | 0.56 | 0.51 | 0.11 | 25.0 | 44 | 760 | 6.4 | 11.7 | 2.24 |
| 123 | 27 | 2007 | 9 | INT | 6.00 | 0.35 | 1.32 | 0.84 | 230.0 | ***5*** | 1070 | 10.6 | 33.3 | 4.23 |
| 124 | 28 | 2007 | 9 | RF | 7.45 | 0.04 | 1.63 | 0.06 | 55.0 | ***5*** | 734 | 8.1 | 12.6 | 1.10 |
| 125 | 29 | 2007 | 9 | RF | 8.04 | 0.09 | 1.52 | 0.22 | 74.0 | 5 | 614 | 7.7 | 19.7 | 1.57 |
| 126 | 30 | 2007 | 9 | INT | 5.78 | 0.50 | 1.02 | 0.09 | 103.0 | ***5*** | 897 | 10.2 | 22.8 | 4.40 |
| 127 | 31 | 2007 | 9 | INT | 5.04 | ***0.01*** | 0.41 | 0.24 | 38.0 | 21 | 835 | 12.1 | 15.5 | 0.45 |
| 128 | 38 | 2007 | 9 | RF | 6.71 | 2.23 | 1.11 | 0.14 | 13.0 | 18 | 331 | 4.8 | 17.8 | 1.58 |
| 129 | 52 | 2007 | 9 | SM | 4.46 | 0.72 | 0.52 | 0.06 | 17.0 | 54 | 703 | 9.8 | 18.6 | 1.55 |
| 130 | 53 | 2007 | 9 | INT | 6.29 | 1.67 | 1.05 | 1.17 | 55.0 | ***5*** | 621 | 6.5 | 12.7 | 2.65 |
| 131 | 55 | 2007 | 9 | SM | 2.55 | 1.53 | 0.45 | 1.15 | 58.0 | 126 | 904 | 31.8 | 58.8 | 6.51 |
| 132 | 1 | 2008 | 6 | RF | 5.54 | 2.71 | 1.23 | 0.22 | 7.0 | 54 | 645 | 7.2 | 21.2 | 2.13 |
| 133 | 2 | 2008 | 6 | RF | 6.79 | 1.57 | 1.51 | 0.38 | ***5.0*** | 48 | 430 | 5.0 | 19.9 | 2.02 |
| 134 | 3 | 2008 | 6 | SM | 2.53 | 1.34 | 0.50 | 2.79 | 5.0 | 31 | 671 | 12.1 | 21.5 | 2.36 |

| ID | Lake OCF | Y | M | Cat | Mg mg/L | K mg/L | Na mg/L | $SiO_2$ mg/L | $NO_3NO_2$ µg/L | $NH_3$ µg/L | TN µg/L | TDP µg/L | TP µg/L | Chl-*a* mg/L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 135 | 4 | 2008 | 6 | RF | 8.11 | 1.04 | 1.42 | 0.88 | 5.0 | 42 | 627 | 5.9 | 15.4 | 1.28 |
| 136 | 5 | 2008 | 6 | INT | 3.86 | 2.00 | 5.21 | 4.02 | 10.0 | 25 | 187 | 3.2 | 8.2 | 0.59 |
| 137 | 6 | 2008 | 6 | RF | 10.80 | 4.31 | 2.31 | 0.63 | 103.0 | 1050 | 2120 | 22.7 | 116.0 | 14.37 |
| 138 | 7 | 2008 | 6 | INT | 1.97 | 1.10 | 0.87 | 0.44 | 22.0 | 104 | 755 | 13.7 | 29.5 | 1.29 |
| 139 | 8 | 2008 | 6 | INT | 3.73 | 1.37 | 1.77 | 0.69 | 6.0 | 58 | 494 | 9.2 | 21.6 | 1.56 |
| 140 | 9 | 2008 | 6 | INT | 5.63 | 1.13 | 1.62 | 0.89 | 8.0 | 62 | 513 | 8.8 | 19.7 | 3.92 |
| 141 | 10 | 2008 | 6 | INT | 3.54 | 1.49 | 2.20 | 1.05 | 8.0 | 125 | 733 | 19.3 | 48.0 | 7.63 |
| 142 | 11 | 2008 | 6 | SM | 1.68 | 2.65 | 1.24 | 0.67 | 8.0 | 113 | 856 | 33.7 | 57.2 | 3.50 |
| 143 | 12 | 2008 | 6 | RF | 6.97 | 3.39 | 5.50 | 0.11 | 9.0 | 57 | 768 | 11.5 | 26.2 | 3.70 |
| 144 | 13 | 2008 | 6 | SM | 1.38 | 1.16 | 0.61 | 1.24 | 9.0 | 69 | 595 | 20.8 | 50.6 | 7.40 |
| 145 | 14 | 2008 | 6 | RF | 4.37 | 1.40 | 1.57 | 0.14 | 10.0 | 76 | 644 | 13.0 | 27.4 | 3.10 |
| 146 | 15 | 2008 | 6 | INT | 3.80 | 2.39 | 0.79 | 0.58 | 8.0 | 88 | 603 | 8.8 | 18.0 | 1.26 |
| 147 | 16 | 2008 | 6 | INT | 5.59 | 1.35 | 1.88 | 3.01 | 10.0 | 44 | 504 | 11.6 | 26.2 | 3.97 |
| 148 | 17 | 2008 | 6 | SM | 1.11 | 1.22 | 0.72 | 3.59 | 8.0 | 21 | 703 | 6.4 | 13.1 | 0.76 |
| 149 | 18 | 2008 | 6 | INT | 3.05 | 1.65 | 1.03 | 0.33 | 7.0 | 64 | 569 | 8.1 | 17.8 | 1.88 |
| 150 | 19 | 2008 | 6 | INT | 8.33 | 5.87 | 2.41 | 0.80 | 7.0 | 99 | 763 | 15.3 | 47.4 | 6.57 |
| 151 | 20 | 2008 | 6 | SM | 5.79 | 1.25 | 1.24 | 0.85 | 9.0 | 77 | 746 | 9.0 | 22.5 | 1.23 |
| 152 | 21 | 2008 | 6 | SM | 1.33 | 0.82 | 0.84 | 0.33 | 10.0 | 58 | 694 | 14.3 | 28.1 | 3.42 |
| 153 | 22 | 2008 | 6 | SM | 2.66 | 1.54 | 0.57 | 1.08 | 11.0 | 46 | 504 | 13.6 | 27.5 | 4.75 |
| 154 | 23 | 2008 | 6 | SM | 1.08 | 0.94 | 0.37 | 0.41 | 13.0 | 39 | 589 | 8.7 | 14.3 | 0.69 |
| 155 | 24 | 2008 | 6 | SM | 1.83 | 1.23 | 0.58 | 0.03 | 7.0 | 64 | 633 | 7.6 | 25.9 | 5.36 |
| 156 | 25 | 2008 | 6 | SM | 1.25 | 0.85 | 0.42 | 1.51 | 11.0 | 4 | 861 | 22.2 | 37.0 | 2.33 |
| 157 | 26 | 2008 | 6 | INT | 1.51 | 0.90 | 0.43 | 0.95 | 11.0 | 49 | 680 | 14.7 | 34.4 | 3.47 |
| 158 | 27 | 2008 | 6 | RF | 6.26 | 1.28 | 1.37 | 0.47 | 7.0 | 104 | 911 | 8.7 | 4.9 | 2.33 |
| 159 | 28 | 2008 | 6 | RF | 5.87 | 1.04 | 1.40 | 0.21 | 11.0 | 58 | 530 | 6.3 | 15.6 | 2.16 |
| 160 | 29 | 2008 | 6 | RF | 6.27 | 0.97 | 1.18 | 0.47 | 8.0 | 36 | 395 | 5.8 | 13.8 | 3.16 |
| 161 | 30 | 2008 | 6 | INT | 5.20 | 1.31 | 0.97 | 1.27 | 9.0 | 102 | 810 | 13.2 | 31.2 | 4.67 |
| 162 | 31 | 2008 | 6 | INT | 4.92 | 1.84 | 0.79 | 0.09 | 10.0 | 97 | 820 | 14.4 | 44.3 | 3.03 |
| 163 | 32 | 2008 | 6 | INT | 1.20 | 0.56 | 0.62 | 2.28 | 10.0 | 56 | 842 | 26.3 | 48.1 | 3.38 |
| 164 | 33 | 2008 | 6 | INT | 5.82 | 1.82 | 0.78 | 0.41 | 9.0 | 69 | 628 | 9.3 | 21.1 | 2.14 |
| 165 | 34 | 2008 | 6 | RF | 5.97 | 4.11 | 0.98 | 0.36 | 18.0 | 101 | 649 | 10.6 | 32.5 | 4.72 |
| 166 | 35 | 2008 | 6 | INT | 5.44 | 2.63 | 0.83 | 0.25 | 7.0 | 53 | 749 | 12.0 | 21.3 | 1.13 |
| 167 | 36 | 2008 | 6 | RF | 8.92 | 1.88 | 1.91 | 1.25 | 9.0 | 68 | 788 | 9.4 | 22.8 | 2.55 |
| 168 | 37 | 2008 | 6 | RF | 7.34 | 2.18 | 1.50 | 1.30 | 11.0 | 73 | 857 | 9.1 | 33.8 | 4.75 |
| 169 | 38 | 2008 | 6 | RF | 3.63 | 1.33 | 0.71 | 0.09 | 10.0 | 20 | 242 | 3.8 | 13.5 | 0.80 |
| 170 | 39 | 2008 | 6 | RF | 10.30 | 2.35 | 2.70 | 1.06 | 10.0 | 137 | 749 | 13.0 | 32.7 | 4.11 |
| 171 | 40 | 2008 | 6 | RF | 3.56 | 1.55 | 1.08 | 0.92 | 9.0 | 71 | 744 | 12.7 | 44.8 | 7.10 |
| 172 | 41 | 2008 | 6 | INT | 3.45 | 2.57 | 1.12 | 3.73 | 9.0 | 77 | 864 | 22.9 | 41.8 | 3.41 |
| 173 | 42 | 2008 | 6 | RF | 5.23 | 1.40 | 1.00 | 0.20 | 11.0 | 32 | 363 | 6.4 | 33.7 | 1.53 |
| 174 | 43 | 2008 | 6 | RF | 5.75 | 1.79 | 1.02 | 0.21 | 11.0 | 15 | 256 | 5.5 | 63.2 | 1.21 |
| 175 | 44 | 2008 | 6 | RF | 3.63 | 1.76 | 0.76 | 1.86 | 10.0 | 50 | 574 | 8.8 | 19.8 | 1.63 |
| 176 | 45 | 2008 | 6 | SM | 2.97 | 1.15 | 0.58 | 2.26 | 11.0 | 36 | 577 | 9.1 | 17.1 | 2.19 |
| 177 | 46 | 2008 | 6 | INT | 11.70 | 4.68 | 2.71 | 0.14 | 8.0 | 67 | 1390 | 18.4 | 60.1 | 4.28 |
| 178 | 47 | 2008 | 6 | SM | 2.91 | 1.37 | 0.89 | 3.74 | 8.0 | 54 | 637 | 9.1 | 17.9 | 2.37 |
| 179 | 48 | 2008 | 6 | INT | 4.98 | 2.32 | 6.18 | 0.26 | 9.0 | 123 | 522 | 12.9 | 40.7 | 4.00 |
| 180 | 49 | 2008 | 6 | RF | 9.90 | 1.89 | 1.77 | 0.96 | 8.0 | 52 | 658 | 7.6 | 20.5 | 1.98 |
| 181 | 50 | 2008 | 6 | INT | 2.93 | 0.62 | 0.49 | 2.75 | 11.0 | 22 | 1610 | 30.6 | 56.1 | 0.86 |
| 182 | 52 | 2008 | 6 | SM | 17.20 | 4.00 | 25.60 | 4.47 | 15.0 | 115 | 802 | 30.8 | 102.0 | 2.25 |
| 183 | 53 | 2008 | 6 | INT | 5.53 | 1.81 | 1.01 | 1.25 | 8.0 | 45 | 597 | 8.3 | 18.3 | 2.75 |
| 184 | 54 | 2008 | 6 | SM | 2.50 | 1.26 | 0.49 | 2.68 | 9.0 | 75 | 693 | 16.6 | 25.0 | 6.33 |
| 185 | 55 | 2008 | 6 | SM | 2.13 | 1.55 | 0.49 | 1.25 | 12.0 | 55 | 661 | 27.7 | 45.4 | 2.55 |

| ID | Lake OCF | Y | M | Cat | Mg mg/L | K mg/L | Na mg/L | $SiO_2$ mg/L | $NO_3NO_2$ µg/L | $NH_3$ µg/L | TN µg/L | TDP µg/L | TP µg/L | Chl-*a* mg/L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 186 | 56 | 2008 | 6 | SM | 2.64 | 6.74 | 0.52 | 2.72 | 11.0 | 27 | 1370 | 73.0 | 101.0 | 1.36 |
| 187 | 1 | 2008 | 7 | RF | 5.60 | 1.65 | 1.49 | 1.28 | 12.0 | 102 | 1180 | 10.3 | 20.3 | 4.60 |
| 188 | 2 | 2008 | 7 | RF | 7.74 | 0.88 | 1.82 | 0.24 | ***5.0*** | 52 | 722 | 9.8 | 14.7 | 2.30 |
| 189 | 3 | 2008 | 7 | SM | 2.79 | 1.23 | 0.59 | 2.71 | ***5.0*** | 48 | 1140 | 8.8 | 14.6 | 3.68 |
| 190 | 4 | 2008 | 7 | RF | 7.75 | 0.32 | 1.41 | 0.59 | ***5.0*** | 68 | 903 | 7.0 | 23.3 | 4.06 |
| 191 | 5 | 2008 | 7 | INT | 4.40 | 2.29 | 6.87 | 9.25 | 11.0 | 28 | 167 | 2.7 | 4.9 | 0.42 |
| 192 | 6 | 2008 | 7 | RF | 9.93 | 2.41 | 3.02 | 0.48 | ***5.0*** | 178 | 1170 | 15.8 | 57.8 | 17.37 |
| 193 | 7 | 2008 | 7 | INT | 3.47 | 2.06 | 1.39 | 1.39 | 12.0 | 92 | 1060 | 10.6 | 77.4 | 5.52 |
| 194 | 8 | 2008 | 7 | INT | 3.91 | 0.35 | 1.90 | 0.25 | ***5.0*** | 52 | 691 | 12.8 | 19.9 | 0.70 |
| 195 | 9 | 2008 | 7 | INT | 5.94 | 0.79 | 1.61 | 0.42 | ***5.0*** | 94 | 692 | 10.4 | 22.9 | 6.09 |
| 196 | 10 | 2008 | 7 | INT | 3.97 | 1.20 | 2.41 | 0.92 | 25.0 | 81 | 874 | 28.0 | 49.7 | 2.27 |
| 197 | 11 | 2008 | 7 | SM | 1.99 | 1.58 | 1.63 | 0.41 | 9.0 | 91 | 956 | 50.5 | 66.6 | 3.74 |
| 198 | 12 | 2008 | 7 | RF | 8.13 | 2.14 | 7.49 | 0.21 | 8.0 | 169 | 1610 | 23.0 | 48.1 | 17.86 |
| 199 | 13 | 2008 | 7 | SM | 1.95 | 0.52 | 0.50 | 3.17 | 12.0 | 164 | 1140 | 31.0 | 41.7 | 4.34 |
| 200 | 14 | 2008 | 7 | RF | 4.98 | 0.19 | 1.75 | 0.28 | 7.0 | 84 | 863 | 8.8 | 19.5 | 2.79 |
| 201 | 15 | 2008 | 7 | INT | 4.30 | 0.93 | 0.75 | 0.13 | 9.0 | 68 | 709 | 13.5 | 21.9 | 1.55 |
| 202 | 16 | 2008 | 7 | INT | 6.70 | 0.37 | 1.97 | 1.30 | ***5.0*** | 54 | 623 | 11.4 | 20.3 | 1.97 |
| 203 | 17 | 2008 | 7 | SM | 1.45 | 0.16 | 0.74 | 6.00 | ***5.0*** | 27 | 719 | 5.4 | 8.9 | 0.45 |
| 204 | 18 | 2008 | 7 | INT | 3.20 | 0.48 | 0.94 | 0.24 | 14.0 | 75 | 837 | 12.6 | 22.9 | 2.84 |
| 205 | 19 | 2008 | 7 | INT | 8.28 | 0.11 | 2.66 | 0.34 | 5.0 | 60 | 881 | 13.3 | 24.5 | 1.96 |
| 206 | 20 | 2008 | 7 | SM | 6.04 | 0.48 | 1.24 | 0.52 | ***5.0*** | 75 | 852 | 8.3 | 20.3 | 3.94 |
| 207 | 21 | 2008 | 7 | SM | 1.82 | 0.49 | 1.02 | 0.44 | 8.0 | 61 | 841 | 17.6 | 27.2 | 1.77 |
| 208 | 22 | 2008 | 7 | SM | 1.10 | 0.58 | 0.38 | 0.34 | ***5.0*** | 41 | 555 | 4.5 | 12.0 | 1.79 |
| 209 | 23 | 2008 | 7 | SM | 2.75 | 1.04 | 0.55 | 0.81 | 13.0 | 56 | 613 | 14.3 | 21.9 | 1.83 |
| 210 | 24 | 2008 | 7 | SM | 1.91 | 0.36 | 0.36 | 0.28 | ***5.0*** | 58 | 772 | 7.7 | 18.0 | 1.76 |
| 211 | 26 | 2008 | 7 | INT | 1.53 | 0.61 | 0.45 | 0.51 | 5.0 | 66 | 688 | 15.9 | 31.7 | 4.72 |
| 212 | 27 | 2008 | 7 | RF | 5.54 | 0.09 | 1.27 | 0.86 | ***5.0*** | 112 | 962 | 9.5 | 36.6 | 8.65 |
| 213 | 28 | 2008 | 7 | RF | 7.35 | 0.17 | 1.79 | 0.32 | ***5.0*** | 62 | 805 | 6.7 | 14.3 | 2.51 |
| 214 | 29 | 2008 | 7 | RF | 6.69 | 0.08 | 1.34 | 1.09 | ***5.0*** | 110 | 806 | 6.5 | 36.0 | 7.12 |
| 215 | 30 | 2008 | 7 | INT | 5.30 | 0.65 | 0.96 | 0.31 | ***5.0*** | 91 | 849 | 9.7 | 23.5 | 2.48 |
| 216 | 31 | 2008 | 7 | INT | 5.19 | 1.57 | 0.74 | 0.33 | ***5.0*** | 120 | 972 | 16.4 | 24.7 | 4.11 |
| 217 | 32 | 2008 | 7 | INT | 1.33 | 0.47 | 0.62 | 1.54 | 25.0 | 223 | 1110 | 30.7 | 55.8 | 18.82 |
| 218 | 33 | 2008 | 7 | INT | 7.31 | 1.75 | 0.90 | 0.39 | 6.0 | 140 | 951 | 8.2 | 45.4 | 8.56 |
| 219 | 34 | 2008 | 7 | RF | 6.95 | 3.64 | 1.15 | 0.76 | 6.0 | 77 | 764 | 10.7 | 19.9 | 1.22 |
| 220 | 36 | 2008 | 7 | RF | 8.58 | 0.61 | 1.81 | 0.23 | ***5.0*** | 70 | 964 | 11.1 | 25.3 | 6.22 |
| 221 | 37 | 2008 | 7 | RF | 6.79 | 0.54 | 1.51 | 0.37 | ***5.0*** | 127 | 1080 | 8.9 | 34.0 | 8.97 |
| 222 | 38 | 2008 | 7 | RF | 5.71 | 2.04 | 0.99 | 0.16 | ***5.0*** | 42 | 352 | 4.5 | 18.8 | 2.74 |
| 223 | 39 | 2008 | 7 | RF | 12.10 | 1.88 | 3.08 | 0.41 | ***5.0*** | 107 | 853 | 11.0 | 25.7 | 6.46 |
| 224 | 40 | 2008 | 7 | RF | 3.70 | 0.67 | 1.18 | 0.80 | 46.0 | 171 | 1460 | 7.6 | 139.0 | 25.22 |
| 225 | 41 | 2008 | 7 | INT | 3.68 | 2.68 | 1.18 | 3.14 | ***5.0*** | 118 | 966 | 14.6 | 35.5 | 5.63 |
| 226 | 42 | 2008 | 7 | RF | 9.05 | 1.07 | 1.83 | 0.48 | 4.0 | 28 | 337 | 3.6 | 10.5 | 0.43 |
| 227 | 43 | 2008 | 7 | RF | 8.51 | 2.33 | 1.39 | 0.53 | 22.0 | 22 | 582 | 3.6 | 364.0 | 2.55 |
| 228 | 44 | 2008 | 7 | RF | 4.26 | 1.32 | 0.78 | 2.81 | ***5.0*** | 232 | 1240 | 8.1 | 64.8 | 21.69 |
| 229 | 45 | 2008 | 7 | SM | 2.93 | 0.12 | 0.23 | 1.26 | 4.0 | 65 | 733 | 11.2 | 19.4 | 1.05 |
| 230 | 46 | 2008 | 7 | INT | 6.26 | 0.62 | 2.40 | 0.69 | 5.0 | 92 | 1640 | 25.3 | 50.0 | 2.38 |
| 231 | 47 | 2008 | 7 | SM | 2.77 | 0.93 | 0.60 | 0.24 | ***5.0*** | 68 | 817 | 8.9 | 15.1 | 2.42 |
| 232 | 48 | 2008 | 7 | INT | 7.88 | 2.05 | 13.10 | 2.87 | 8.0 | 116 | 909 | 30.5 | 38.2 | 6.43 |
| 233 | 49 | 2008 | 7 | RF | 8.92 | 0.45 | 1.73 | 0.81 | ***5.0*** | 98 | 985 | 8.2 | 27.2 | 6.10 |
| 234 | 50 | 2008 | 7 | INT | 5.16 | 0.57 | 0.50 | 4.91 | 5.0 | 71 | 1480 | 90.6 | 119.0 | 9.82 |
| 235 | 52 | 2008 | 7 | SM | 3.64 | 0.57 | 0.41 | 0.46 | ***5.0*** | 48 | 766 | 11.1 | 19.3 | 1.50 |
| 236 | 53 | 2008 | 7 | INT | 5.66 | 1.53 | 0.95 | 1.03 | 8.0 | 46 | 595 | 6.2 | 12.2 | 1.60 |

| ID | Lake<br>OCF | Y | M | Cat | Mg<br>mg/L | K<br>mg/L | Na<br>mg/L | SiO$_2$<br>mg/L | NO$_3$NO$_2$<br>µg/L | NH$_3$<br>µg/L | TN<br>µg/L | TDP<br>µg/L | TP<br>µg/L | Chl-*a*<br>mg/L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 237 | 54 | 2008 | 7 | SM | 2.65 | 1.23 | 0.44 | 1.84 | ***5.0*** | 28 | 625 | 10.3 | 18.2 | 2.05 |
| 238 | 55 | 2008 | 7 | SM | 2.85 | 1.79 | 0.51 | 0.58 | ***5.0*** | 53 | 709 | 21.3 | 32.3 | 2.92 |
| 239 | 56 | 2008 | 7 | SM | 2.23 | 2.93 | 0.33 | 2.98 | ***5.0*** | 198 | 1140 | 249.0 | 327.0 | 15.78 |
| 240 | 1 | 2008 | 9 | RF | 6.19 | 1.59 | 1.57 | ***0.02*** | 120.0 | 9 | 1200 | 8.1 | 41.5 | 2.83 |
| 241 | 2 | 2008 | 9 | RF | 7.96 | 0.73 | 1.92 | 0.12 | ***5.0*** | 78 | 774 | 9.3 | 16.7 | 2.41 |
| 242 | 3 | 2008 | 9 | SM | 2.76 | 1.11 | 0.49 | 2.37 | 5.0 | 48 | 801 | 14.2 | 24.8 | 3.59 |
| 243 | 4 | 2008 | 9 | RF | 8.18 | 0.44 | 1.39 | 0.74 | 87.0 | 71 | 922 | 8.9 | 31.6 | 2.85 |
| 244 | 5 | 2008 | 9 | INT | 4.64 | 2.61 | 7.57 | 9.40 | 10.0 | 43 | 224 | 3.3 | 9.5 | 5.75 |
| 245 | 6 | 2008 | 9 | RF | 11.50 | 2.73 | 3.38 | 0.14 | 208.0 | 14 | 997 | 15.6 | 66.3 | 2.12 |
| 246 | 7 | 2008 | 9 | INT | 3.66 | 1.91 | 1.33 | 1.53 | 20.0 | 79 | 926 | 13.1 | 101.0 | 1.13 |
| 247 | 8 | 2008 | 9 | INT | 4.08 | 0.34 | 2.04 | 0.10 | 12.0 | 69 | 743 | 16.4 | 26.6 | 0.85 |
| 248 | 9 | 2008 | 9 | INT | 5.83 | 0.69 | 1.63 | ***0.02*** | 75.0 | 16 | 647 | 8.1 | 18.2 | 5.52 |
| 249 | 10 | 2008 | 9 | INT | 3.91 | 0.94 | 2.53 | ***0.02*** | 109.0 | 70 | 972 | 20.1 | 44.0 | 0.80 |
| 250 | 11 | 2008 | 9 | SM | 1.85 | 1.35 | 1.86 | 0.23 | 13.0 | 53 | 951 | 23.1 | 39.4 | 0.33 |
| 251 | 12 | 2008 | 9 | RF | 7.11 | 1.15 | 7.11 | 0.13 | n.d. | n.d. | n.d. | 15.8 | 24.4 | 1.41 |
| 252 | 13 | 2008 | 9 | SM | 1.74 | 0.47 | 0.62 | 3.25 | 22.0 | 151 | 1160 | 35.9 | 66.0 | 0.81 |
| 253 | 14 | 2008 | 9 | RF | 3.07 | 1.17 | 1.03 | 3.18 | 18.0 | 53 | 690 | 6.5 | 18.8 | 0.17 |
| 254 | 15 | 2008 | 9 | INT | 4.22 | 0.73 | 0.70 | 0.06 | 16.0 | 71 | 860 | 8.6 | 14.7 | 0.97 |
| 255 | 16 | 2008 | 9 | INT | 6.40 | 0.13 | 1.94 | 0.28 | 57.0 | 28 | 693 | 10.5 | 20.8 | 0.46 |
| 256 | 17 | 2008 | 9 | SM | 1.58 | 0.08 | 0.71 | 5.00 | 7.0 | 25 | 744 | 4.9 | 8.6 | 2.11 |
| 257 | 18 | 2008 | 9 | INT | 3.28 | 0.30 | 1.11 | 0.07 | 7.0 | 104 | 873 | 11.2 | 19.5 | 0.84 |
| 258 | 19 | 2008 | 9 | INT | 8.58 | 3.76 | 2.16 | 0.83 | 47.0 | 61 | 1100 | 17.6 | 32.5 | 11.64 |
| 259 | 20 | 2008 | 9 | SM | 5.84 | 0.38 | 1.25 | 0.14 | 94.0 | 69 | 981 | 10.1 | 28.1 | 2.88 |
| 260 | 21 | 2008 | 9 | SM | 1.70 | 0.22 | 0.99 | 0.20 | 19.0 | 71 | 859 | 11.8 | 24.9 | 0.29 |
| 261 | 22 | 2008 | 9 | SM | 2.60 | 1.00 | 0.53 | 0.41 | 18.0 | 55 | 657 | 18.1 | 26.5 | 0.34 |
| 262 | 23 | 2008 | 9 | SM | 1.05 | 0.46 | 0.33 | 0.25 | 8.0 | 41 | 638 | 6.7 | 12.3 | 1.75 |
| 263 | 24 | 2008 | 9 | SM | 1.72 | 0.36 | 0.39 | 0.03 | ***5.0*** | 75 | 830 | 6.9 | 18.3 | 2.14 |
| 264 | 25 | 2008 | 9 | SM | 1.54 | 0.54 | 0.37 | 1.91 | 7.0 | 39 | 625 | 17.3 | 29.1 | 1.50 |
| 265 | 27 | 2008 | 9 | RF | 6.00 | 0.26 | 1.41 | 0.64 | 8.0 | 37 | 1270 | 8.8 | 55.7 | 5.58 |
| 266 | 28 | 2008 | 9 | RF | 7.05 | 0.05 | 1.59 | 0.04 | 54.0 | 18 | 780 | 6.9 | 12.7 | 0.96 |
| 267 | 29 | 2008 | 9 | RF | 7.35 | 0.12 | 1.43 | 0.19 | ***5.0*** | 76 | 662 | 8.4 | 22.5 | 2.77 |
| 268 | 30 | 2008 | 9 | INT | 5.09 | 0.47 | 0.95 | 0.13 | 38.0 | 123 | 916 | 11.4 | 27.6 | 3.97 |
| 269 | 31 | 2008 | 9 | INT | 4.80 | 1.37 | 0.71 | 0.08 | 106.0 | 134 | 1060 | 15.6 | 45.3 | 10.69 |
| 270 | 32 | 2008 | 9 | INT | 1.22 | 0.46 | 0.69 | 0.52 | 63.0 | 161 | 887 | 33.1 | 58.4 | 15.83 |
| 271 | 33 | 2008 | 9 | INT | 7.74 | 1.83 | 1.02 | 0.05 | 14.0 | 95 | 857 | 8.8 | 8.8 | 1.70 |
| 272 | 34 | 2008 | 9 | RF | 7.73 | 3.56 | 1.19 | 0.08 | 11.0 | 57 | 799 | 9.8 | 16.9 | 0.80 |
| 273 | 35 | 2008 | 9 | INT | 8.70 | 2.69 | 1.22 | 0.08 | 6.0 | 71 | 1000 | 10.4 | 18.6 | 1.48 |
| 274 | 36 | 2008 | 9 | RF | 8.25 | 0.15 | 1.80 | 0.11 | ***5.0*** | 60 | 886 | 9.1 | 13.0 | 1.33 |
| 275 | 37 | 2008 | 9 | RF | 6.77 | 0.17 | 1.39 | 0.20 | 118.0 | 26 | 1020 | 12.7 | 32.6 | 2.64 |
| 276 | 38 | 2008 | 9 | RF | 6.28 | 2.14 | 1.09 | 0.14 | 6.0 | 39 | 338 | 4.8 | 16.3 | 0.38 |
| 277 | 39 | 2008 | 9 | RF | 11.50 | 1.50 | 3.19 | 0.17 | 108.0 | 60 | 412 | 15.7 | 29.4 | 10.07 |
| 278 | 40 | 2008 | 9 | RF | 3.71 | 0.58 | 1.22 | 1.25 | ***5.0*** | 14 | 1140 | 10.0 | 81.1 | 9.36 |
| 279 | 41 | 2008 | 9 | INT | 3.36 | 2.66 | 1.18 | 3.72 | 90.0 | 72 | 877 | 16.3 | 36.9 | 2.44 |
| 280 | 42 | 2008 | 9 | RF | 9.34 | 1.72 | 2.11 | 0.37 | 46.0 | 16 | 554 | 3.7 | 181.0 | 4.77 |
| 281 | 43 | 2008 | 9 | RF | 9.39 | 2.45 | 1.57 | 0.42 | ***5.0*** | 43 | 328 | 4.7 | 22.1 | 0.41 |
| 282 | 44 | 2008 | 9 | RF | 4.34 | 1.43 | 0.86 | 2.02 | ***5.0*** | 86 | 942 | 11.5 | 54.8 | 5.91 |
| 283 | 45 | 2008 | 9 | SM | 2.98 | 0.11 | 0.33 | 0.70 | 8.0 | 58 | 738 | 11.9 | 19.4 | 0.27 |
| 284 | 46 | 2008 | 9 | INT | 8.12 | 1.77 | 3.54 | 0.41 | 122.0 | 18 | 2000 | 29.9 | 65.7 | 2.26 |
| 285 | 47 | 2008 | 9 | SM | 2.64 | 0.96 | 0.60 | 0.16 | ***5.0*** | 68 | 848 | 7.3 | 14.8 | 1.32 |
| 286 | 48 | 2008 | 9 | INT | 9.57 | 2.24 | 15.00 | 3.28 | 41.0 | 89 | 707 | 19.9 | 48.2 | 2.78 |
| 287 | 49 | 2008 | 9 | RF | 9.41 | 0.48 | 1.87 | 0.45 | 54.0 | 158 | 1340 | 8.6 | 20.1 | 1.21 |

| ID | Lake<br>OCF | Y | M | Cat | Mg<br>mg/L | K<br>mg/L | Na<br>mg/L | $SiO_2$<br>mg/L | $NO_3NO_2$<br>µg/L | $NH_3$<br>µg/L | TN<br>µg/L | TDP<br>µg/L | TP<br>µg/L | Chl-*a*<br>mg/L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 288 | 50 | 2008 | 9 | INT | 6.47 | 1.22 | 0.80 | 0.39 | 11.0 | 188 | 1540 | 72.2 | 103.0 | 8.38 |
| 289 | 52 | 2008 | 9 | SM | 3.88 | 0.62 | 0.45 | 0.07 | ***5.0*** | 47 | 737 | 10.3 | 17.2 | 2.34 |
| 290 | 53 | 2008 | 9 | INT | 6.03 | 1.55 | 1.03 | 1.15 | 11.0 | 43 | 602 | 5.2 | 12.5 | 0.80 |
| 291 | 54 | 2008 | 9 | SM | 2.85 | 1.26 | 0.44 | 2.42 | ***5.0*** | 34 | 654 | 18.7 | 30.1 | 1.74 |
| 292 | 55 | 2008 | 9 | SM | 2.48 | 1.47 | 0.44 | 1.04 | ***5.0*** | 117 | 757 | 20.0 | 33.3 | 6.79 |
| 293 | 56 | 2008 | 9 | SM | 1.54 | 2.13 | 0.36 | 0.58 | ***5.0*** | 596 | 1670 | 193.0 | 314.0 | 19.85 |
| 294 | 1 | 2009 | 6 | RF | 5.48 | 2.64 | 1.05 | 0.33 | ***5.0*** | 53 | 629 | 7.0 | 15.6 | 0.90 |
| 295 | 2 | 2009 | 6 | RF | 6.34 | 1.38 | 1.34 | 0.31 | ***5.0*** | 61 | 487 | 6.9 | 17.6 | 1.45 |
| 296 | 3 | 2009 | 6 | SM | 2.41 | 1.29 | 0.43 | 2.27 | ***5.0*** | 42 | 756 | 13.2 | 22.4 | 4.52 |
| 297 | 4 | 2009 | 6 | RF | 7.59 | 1.35 | 1.23 | 0.86 | ***5.0*** | 64 | 684 | 7.9 | 22.9 | 4.38 |
| 298 | 5 | 2009 | 6 | INT | 4.04 | 2.08 | 5.29 | 7.19 | ***5.0*** | 25 | 198 | 3.9 | 9.7 | 0.50 |
| 299 | 6 | 2009 | 6 | RF | 12.00 | 3.37 | 1.88 | 0.06 | ***5.0*** | 89 | 774 | 11.8 | 32.2 | 2.90 |
| 300 | 7 | 2009 | 6 | SM | 1.89 | 0.90 | 0.78 | 0.79 | ***5.0*** | 19 | 559 | 13.5 | 30.5 | 1.59 |
| 301 | 8 | 2009 | 6 | INT | 3.90 | 1.43 | 1.77 | 1.21 | ***5.0*** | 54 | 519 | 11.6 | 33.2 | 5.56 |
| 302 | 9 | 2009 | 6 | INT | 5.65 | 1.25 | 1.49 | 0.63 | ***5.0*** | 50 | 581 | 9.1 | 22.2 | 2.15 |
| 303 | 10 | 2009 | 6 | INT | 3.41 | 1.41 | 1.89 | 0.91 | ***5.0*** | 83 | 769 | 20.0 | 44.1 | 5.26 |
| 304 | 11 | 2009 | 6 | SM | 1.54 | 1.43 | 0.74 | 1.38 | ***5.0*** | 92 | 673 | 34.2 | 68.8 | 2.50 |
| 305 | 12 | 2009 | 6 | SM | 7.06 | 2.77 | 4.76 | 0.19 | ***5.0*** | 58 | 850 | 12.5 | 40.3 | 5.00 |
| 306 | 13 | 2009 | 6 | SM | 1.30 | 0.81 | 0.44 | 2.43 | 11.0 | 83 | 679 | 23.8 | 65.4 | 5.52 |
| 307 | 14 | 2009 | 6 | INT | 4.05 | 1.11 | 1.38 | 0.27 | ***5.0*** | 39 | 492 | 9.1 | 18.0 | 1.31 |
| 308 | 15 | 2009 | 6 | INT | 4.33 | 1.99 | 0.75 | 0.78 | 6.0 | 77 | 590 | 9.3 | 22.9 | 2.27 |
| 309 | 16 | 2009 | 6 | SM | 4.22 | 1.02 | 1.28 | 2.72 | 5.0 | 27 | 492 | 13.4 | 23.9 | 2.60 |
| 310 | 17 | 2009 | 6 | SM | 1.36 | 0.86 | 0.55 | 5.35 | ***5.0*** | 24 | 673 | 6.8 | 13.5 | 0.74 |
| 311 | 18 | 2009 | 6 | INT | 3.43 | 1.43 | 1.10 | 0.40 | ***5.0*** | 76 | 683 | 8.5 | 20.5 | 0.51 |
| 312 | 19 | 2009 | 6 | INT | 9.40 | 4.83 | 1.80 | 0.74 | 7.0 | 66 | 710 | 17.1 | 28.4 | 0.89 |
| 313 | 20 | 2009 | 6 | INT | 5.52 | 1.17 | 1.15 | 0.81 | 5.0 | 65 | 769 | 11.0 | 24.8 | 4.41 |
| 314 | 21 | 2009 | 6 | SM | 1.49 | 0.63 | 0.81 | 0.54 | ***5.0*** | 48 | 699 | 16.2 | 32.3 | 1.19 |
| 315 | 22 | 2009 | 6 | SM | 2.57 | 1.37 | 0.50 | 0.70 | ***5.0*** | 28 | 542 | 14.9 | 25.3 | 2.83 |
| 316 | 23 | 2009 | 6 | SM | 0.97 | 0.62 | 0.29 | 0.63 | 5.0 | 19 | 526 | 9.5 | 15.8 | 0.32 |
| 317 | 24 | 2009 | 6 | RF | 1.54 | 0.91 | 0.45 | 0.04 | ***5.0*** | 29 | 537 | 8.5 | 15.8 | 0.46 |
| 318 | 25 | 2009 | 6 | INT | 1.12 | 0.67 | 0.29 | 1.94 | 8.0 | 6 | 478 | 28.0 | 42.5 | 1.33 |
| 319 | 26 | 2009 | 6 | INT | 1.32 | 0.51 | 0.31 | 1.03 | 10.0 | 37 | 512 | 19.2 | 34.4 | 3.20 |
| 320 | 27 | 2009 | 6 | RF | 6.23 | 0.89 | 1.33 | 0.87 | ***5.0*** | 37 | 744 | 7.6 | 25.0 | 3.76 |
| 321 | 28 | 2009 | 6 | RF | 6.66 | 0.93 | 1.48 | 0.34 | 9.0 | 34 | 545 | 6.6 | 14.0 | 1.07 |
| 322 | 29 | 2009 | 6 | RF | 7.00 | 0.76 | 1.22 | 0.59 | 5.0 | 37 | 407 | 5.6 | 16.1 | 1.40 |
| 323 | 30 | 2009 | 6 | RF | 4.79 | 1.16 | 0.90 | 0.93 | ***5.0*** | 81 | 788 | 10.7 | 30.3 | 5.00 |
| 324 | 31 | 2009 | 6 | INT | 4.47 | 1.51 | 0.67 | 0.96 | ***5.0*** | 125 | 893 | 19.9 | 72.1 | 12.64 |
| 325 | 32 | 2009 | 6 | INT | 0.99 | 0.25 | 0.48 | 2.77 | 5.0 | 47 | 569 | 19.0 | 44.2 | 4.37 |
| 326 | 33 | 2009 | 6 | RF | 5.89 | 1.87 | 0.75 | 0.40 | ***5.0*** | 57 | 619 | 9.5 | 21.4 | 2.59 |
| 327 | 34 | 2009 | 6 | RF | 5.79 | 3.43 | 0.87 | 0.50 | ***5.0*** | 99 | 600 | 12.6 | 30.7 | 4.72 |
| 328 | 35 | 2009 | 6 | RF | 5.47 | 1.93 | 0.74 | 0.68 | 5.0 | 67 | 717 | 12.5 | 26.1 | 0.49 |
| 329 | 36 | 2009 | 6 | RF | 8.78 | 1.53 | 1.80 | 1.28 | 30.0 | 83 | 798 | 9.8 | 25.7 | 1.78 |
| 330 | 37 | 2009 | 6 | RF | 7.03 | 1.68 | 1.39 | 0.79 | 22.0 | 82 | 725 | 8.4 | 28.4 | 4.10 |
| 331 | 38 | 2009 | 6 | RF | 3.45 | 1.17 | 0.69 | 0.37 | 25.0 | 26 | 274 | 6.0 | 13.6 | 0.80 |
| 332 | 39 | 2009 | 6 | RF | 10.80 | 2.31 | 2.76 | 1.01 | 25.0 | 84 | 679 | 13.4 | 37.2 | 3.16 |
| 333 | 40 | 2009 | 6 | INT | 2.82 | 1.08 | 0.81 | 0.85 | 26.0 | 115 | 631 | 16.0 | 37.7 | 8.11 |
| 334 | 41 | 2009 | 6 | INT | 3.21 | 2.30 | 1.07 | 3.32 | 32.0 | 68 | 806 | 13.5 | 32.4 | 2.04 |
| 335 | 42 | 2009 | 6 | RF | 4.58 | 0.72 | 0.93 | 0.23 | 28.0 | 23 | 258 | 4.9 | 10.7 | 0.31 |
| 336 | 43 | 2009 | 6 | INT | 5.15 | 1.68 | 0.93 | 0.22 | 30.0 | 15 | 261 | 8.0 | 50.3 | 0.37 |
| 337 | 44 | 2009 | 6 | INT | 3.29 | 1.59 | 0.69 | 2.10 | 29.0 | 87 | 562 | 10.2 | 29.3 | 2.65 |
| 338 | 45 | 2009 | 6 | SM | 2.72 | 1.12 | 0.43 | 3.45 | 28.0 | 39 | 527 | 8.9 | 19.3 | 2.46 |

| ID | Lake OCF | Y | M | Cat | Mg mg/L | K mg/L | Na mg/L | $SiO_2$ mg/L | $NO_3NO_2$ µg/L | $NH_3$ µg/L | TN µg/L | TDP µg/L | TP µg/L | Chl-*a* mg/L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 339 | 46 | 2009 | 6 | INT | 9.23 | 3.20 | 2.00 | 0.66 | 29.0 | 42 | 882 | 16.9 | 34.3 | 1.46 |
| 340 | 47 | 2009 | 6 | INT | 2.56 | 1.29 | 0.57 | 0.39 | 30.0 | 40 | 656 | 7.0 | 15.0 | 0.72 |
| 341 | 48 | 2009 | 6 | INT | 5.64 | 2.18 | 6.87 | 0.32 | 29.0 | 117 | 552 | 15.3 | 35.7 | 7.86 |
| 342 | 49 | 2009 | 6 | RF | 9.91 | 1.80 | 1.73 | 0.95 | 30.0 | 95 | 746 | 8.9 | 24.2 | 4.69 |
| 343 | 50 | 2009 | 6 | SM | 2.59 | 0.70 | 0.40 | 1.04 | 31.0 | 85 | 1540 | 43.7 | 91.0 | 8.03 |
| 344 | 52 | 2009 | 6 | INT | 3.07 | 1.46 | 0.43 | 1.60 | 28.0 | 37 | 657 | 13.9 | 30.2 | 3.05 |
| 345 | 53 | 2009 | 6 | RF | 5.44 | 1.72 | 0.89 | 1.14 | 24.0 | 42 | 573 | 6.1 | 16.4 | 0.39 |
| 346 | 54 | 2009 | 6 | INT | 2.46 | 1.15 | 0.37 | 1.44 | 25.0 | 33 | 653 | 19.5 | 34.0 | 2.41 |
| 347 | 55 | 2009 | 6 | SM | 1.95 | 1.39 | 0.36 | 1.58 | 26.0 | 55 | 608 | 23.0 | 38.3 | 4.06 |
| 348 | 56 | 2009 | 6 | INT | 1.93 | 3.76 | 0.29 | 1.27 | 26.0 | 161 | 747 | 138.0 | 215.0 | 4.38 |
| 349 | 1 | 2009 | 7 | RF | 5.75 | 1.85 | 1.30 | 0.72 | ***5.0*** | 93 | 896 | 8.4 | 17.3 | 1.62 |
| 350 | 2 | 2009 | 7 | RF | 7.91 | 1.11 | 1.79 | 0.37 | ***5.0*** | 42 | 685 | 7.9 | 12.9 | 1.07 |
| 351 | 3 | 2009 | 7 | SM | 2.66 | 1.25 | 0.51 | 2.00 | ***5.0*** | 45 | 1070 | 9.5 | 14.5 | 1.50 |
| 352 | 4 | 2009 | 7 | RF | 8.31 | 1.03 | 1.43 | 0.42 | ***5.0*** | 64 | 776 | 8.9 | 17.9 | 1.25 |
| 353 | 5 | 2009 | 7 | INT | 4.39 | 2.50 | 6.81 | 9.21 | 31.0 | 80 | 465 | 5.0 | 28.1 | 1.53 |
| 354 | 6 | 2009 | 7 | RF | 13.30 | 2.52 | 2.75 | 0.79 | ***5.0*** | 121 | 1280 | 21.1 | 53.3 | 2.43 |
| 355 | 7 | 2009 | 7 | SM | 2.98 | 1.48 | 1.13 | 1.13 | ***5.0*** | 46 | 563 | 18.1 | 40.7 | 2.04 |
| 356 | 8 | 2009 | 7 | INT | 4.10 | 0.73 | 2.07 | 0.29 | ***5.0*** | 41 | 690 | 12.0 | 14.4 | 0.70 |
| 357 | 9 | 2009 | 7 | INT | 5.98 | 0.80 | 1.62 | 0.19 | ***5.0*** | 41 | 605 | 8.9 | 14.3 | 0.86 |
| 358 | 10 | 2009 | 7 | INT | 3.79 | 0.94 | 2.21 | 1.35 | ***5.0*** | 158 | 1220 | 24.9 | 49.9 | 0.67 |
| 359 | 11 | 2009 | 7 | SM | 2.12 | 1.32 | 1.39 | 0.35 | 17.0 | 101 | 866 | 41.8 | 67.2 | 2.41 |
| 360 | 12 | 2009 | 7 | SM | 7.33 | 1.61 | 6.19 | 0.32 | 11.0 | 74 | 1200 | 16.7 | 27.3 | 5.46 |
| 361 | 13 | 2009 | 7 | SM | 2.53 | 0.39 | 0.52 | 2.93 | 9.0 | 141 | 973 | 49.5 | 67.6 | 9.03 |
| 362 | 14 | 2009 | 7 | INT | 5.05 | 0.26 | 1.62 | 0.27 | ***5.0*** | 70 | 843 | 9.1 | 21.2 | 3.36 |
| 363 | 15 | 2009 | 7 | INT | 4.33 | 1.38 | 0.86 | 0.35 | ***5.0*** | 61 | 770 | 8.4 | 16.2 | 2.08 |
| 364 | 16 | 2009 | 7 | SM | 5.03 | 0.24 | 1.54 | 0.98 | ***5.0*** | 52 | 647 | 19.8 | 12.0 | 0.44 |
| 365 | 17 | 2009 | 7 | SM | 1.76 | 0.24 | 0.61 | 7.49 | ***5.0*** | 35 | 729 | 5.5 | 11.2 | 0.69 |
| 366 | 18 | 2009 | 7 | INT | 3.63 | 0.51 | 1.17 | 0.16 | ***5.0*** | 72 | 846 | 12.0 | 24.0 | 0.39 |
| 367 | 19 | 2009 | 7 | INT | 9.27 | 3.47 | 1.88 | 1.40 | ***5.0*** | 54 | 872 | 12.4 | 20.7 | 2.40 |
| 368 | 20 | 2009 | 7 | INT | 5.83 | 0.68 | 1.19 | 0.33 | ***5.0*** | 64 | 797 | 9.0 | 19.4 | 1.40 |
| 369 | 21 | 2009 | 7 | SM | 1.96 | 0.56 | 0.92 | 0.50 | ***5.0*** | 86 | 857 | 21.0 | 34.6 | 2.59 |
| 370 | 22 | 2009 | 7 | SM | 2.71 | 1.06 | 0.52 | 0.55 | ***5.0*** | 51 | 594 | 13.0 | 21.3 | 4.08 |
| 371 | 23 | 2009 | 7 | SM | 1.12 | 0.51 | 0.33 | 0.52 | ***5.0*** | 39 | 557 | 7.8 | 12.9 | 0.77 |
| 372 | 24 | 2009 | 7 | RF | 1.70 | 0.21 | 0.28 | 0.22 | ***5.0*** | 70 | 821 | 8.4 | 17.9 | 1.22 |
| 373 | 25 | 2009 | 7 | INT | 1.73 | 0.60 | 0.33 | 3.18 | 7.0 | 117 | 970 | 33.1 | 74.7 | 5.11 |
| 374 | 26 | 2009 | 7 | INT | 1.42 | 0.43 | 0.37 | 0.28 | ***5.0*** | 62 | 620 | 16.9 | 29.0 | 1.83 |
| 375 | 27 | 2009 | 7 | RF | 6.38 | 0.49 | 1.34 | 0.45 | ***5.0*** | 117 | 1200 | 6.2 | 33.2 | 8.33 |
| 376 | 28 | 2009 | 7 | RF | 5.68 | 0.69 | 1.51 | 1.04 | ***5.0*** | 169 | 1030 | 17.5 | 119.0 | 5.69 |
| 377 | 29 | 2009 | 7 | RF | 7.17 | 0.04 | 1.33 | 0.36 | ***5.0*** | 50 | 594 | n/a | 17.8 | 0.71 |
| 378 | 30 | 2009 | 7 | RF | 5.11 | 0.76 | 0.89 | 0.33 | ***5.0*** | 103 | 879 | 8.5 | 73.5 | n.d. |
| 379 | 31 | 2009 | 7 | INT | 5.07 | 0.79 | 0.93 | 0.31 | ***5.0*** | 101 | 844 | 9.2 | 24.5 | n.d. |
| 380 | 32 | 2009 | 7 | INT | 1.18 | 0.32 | 0.60 | 0.90 | 50.0 | 120 | 626 | 29.9 | 50.6 | 8.03 |
| 381 | 33 | 2009 | 7 | RF | 7.60 | 1.80 | 0.92 | 0.29 | ***5.0*** | 92 | 845 | 8.1 | 28.9 | 3.03 |
| 382 | 34 | 2009 | 7 | RF | 7.37 | 2.89 | 1.11 | 0.45 | ***5.0*** | 70 | 759 | 9.9 | 19.4 | 2.39 |
| 383 | 35 | 2009 | 7 | RF | 7.76 | 2.28 | 0.98 | 0.23 | ***5.0*** | 66 | 906 | 13.5 | 20.2 | 1.09 |
| 384 | 36 | 2009 | 7 | RF | 8.78 | 0.81 | 1.78 | 0.22 | ***5.0*** | 68 | 903 | 9.5 | 21.5 | 1.40 |
| 385 | 37 | 2009 | 7 | RF | 7.30 | 0.91 | 1.51 | 0.28 | ***5.0*** | 87 | 850 | 10.6 | 24.8 | 1.24 |
| 386 | 38 | 2009 | 7 | RF | 5.33 | 1.96 | 0.95 | 0.37 | ***5.0*** | 39 | 361 | 6.1 | 15.2 | 0.96 |
| 387 | 39 | 2009 | 7 | RF | 13.60 | 2.85 | 3.36 | 0.56 | ***5.0*** | 60 | 688 | 8.9 | 18.4 | 1.34 |
| 388 | 40 | 2009 | 7 | INT | 3.68 | 0.60 | 1.07 | 0.53 | ***5.0*** | 80 | 881 | 6.9 | 48.6 | 7.26 |
| 389 | 41 | 2009 | 7 | INT | 3.57 | 2.55 | 1.13 | 1.14 | ***5.0*** | 111 | 879 | 13.5 | 29.7 | 1.33 |

| ID | Lake OCF | Y | M | Cat | Mg mg/L | K mg/L | Na mg/L | $SiO_2$ mg/L | $NO_3NO_2$ µg/L | $NH_3$ µg/L | TN µg/L | TDP µg/L | TP µg/L | Chl-*a* mg/L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 390 | 42 | 2009 | 7 | RF | 10.30 | 1.29 | 1.96 | 0.65 | ***5.0*** | 31 | 360 | 4.9 | 9.5 | 0.25 |
| 391 | 43 | 2009 | 7 | INT | 7.42 | 2.22 | 1.25 | 0.64 | ***5.0*** | 43 | 341 | 4.3 | 20.1 | 0.76 |
| 392 | 44 | 2009 | 7 | INT | 3.87 | 1.25 | 0.71 | 2.11 | ***5.0*** | 93 | 825 | 8.0 | 38.5 | 6.50 |
| 393 | 45 | 2009 | 7 | SM | 3.02 | 0.23 | 0.39 | 1.24 | ***5.0*** | 49 | 658 | 9.2 | 21.0 | 7.09 |
| 394 | 46 | 2009 | 7 | INT | 6.60 | 0.10 | 1.52 | 0.39 | 11.0 | 44 | 1050 | 17.3 | 33.3 | 4.45 |
| 395 | 47 | 2009 | 7 | INT | 2.61 | 0.82 | 0.58 | 0.21 | 11.0 | 72 | 785 | 6.5 | 12.5 | 1.61 |
| 396 | 48 | 2009 | 7 | INT | 6.45 | 1.33 | 12.20 | 5.42 | 6.0 | 124 | 826 | 45.0 | 67.5 | 1.91 |
| 397 | 49 | 2009 | 7 | RF | 9.64 | 0.87 | 1.84 | 0.56 | 6.0 | 75 | 822 | 7.4 | 24.4 | 4.73 |
| 398 | 50 | 2009 | 7 | SM | 4.74 | 0.70 | 0.57 | 1.77 | 9.0 | 404 | 2170 | 165.0 | 201.0 | 3.03 |
| 399 | 52 | 2009 | 7 | INT | 3.63 | 0.08 | 0.28 | 0.85 | 5.0 | 43 | 798 | 12.3 | 23.7 | 1.56 |
| 400 | 53 | 2009 | 7 | RF | 5.55 | 1.51 | 0.94 | 0.76 | 7.0 | 40 | 582 | 6.0 | 12.0 | 1.50 |
| 401 | 54 | 2009 | 7 | INT | 2.58 | 1.11 | 0.40 | 0.68 | 10.0 | 24 | 629 | 11.1 | 17.5 | 2.91 |
| 402 | 55 | 2009 | 7 | SM | 2.11 | 0.96 | 0.37 | 0.66 | 12.0 | 101 | 922 | 18.0 | 36.5 | 3.04 |
| 403 | 56 | 2009 | 7 | INT | 2.44 | 1.39 | 0.38 | 1.68 | 11.0 | 174 | 1140 | 107.0 | 291.0 | 1.82 |
| 404 | 1 | 2009 | 9 | RF | 5.59 | 1.27 | 1.19 | 0.16 | 6.0 | 74 | 901 | 5.8 | 19.7 | 2.09 |
| 405 | 2 | 2009 | 9 | RF | 1.10 | 0.25 | 1.02 | 6.96 | ***5.0*** | 39 | 686 | 10.9 | 14.2 | 1.83 |
| 406 | 3 | 2009 | 9 | SM | 2.53 | 1.14 | 0.42 | 2.79 | ***5.0*** | 63 | 1100 | 3.1 | 19.2 | 4.57 |
| 407 | 4 | 2009 | 9 | RF | 7.87 | 0.92 | 1.29 | 0.34 | ***5.0*** | 101 | 797 | 3.6 | 30.8 | 7.58 |
| 408 | 5 | 2009 | 9 | INT | 4.27 | 2.39 | 6.52 | 8.55 | ***5.0*** | 32 | 276 | 8.4 | 11.5 | 1.24 |
| 409 | 6 | 2009 | 9 | RF | 11.40 | 1.89 | 2.31 | 0.15 | ***5.0*** | 75 | 1230 | 6.1 | 68.0 | 7.71 |
| 410 | 7 | 2009 | 9 | SM | 2.94 | 1.23 | 1.05 | 1.57 | ***5.0*** | 37 | 589 | 3.0 | 43.3 | 1.70 |
| 411 | 8 | 2009 | 9 | INT | 3.98 | 0.69 | 1.90 | 0.21 | ***5.0*** | 46 | 712 | 17.8 | 18.7 | 2.12 |
| 412 | 9 | 2009 | 9 | INT | 5.61 | 0.64 | 1.52 | 0.23 | ***5.0*** | 35 | 590 | 11.5 | 35.4 | 1.04 |
| 413 | 10 | 2009 | 9 | INT | 3.08 | 0.69 | 1.70 | 0.97 | ***5.0*** | 92 | 880 | 23.3 | 48.7 | 6.54 |
| 414 | 11 | 2009 | 9 | SM | 1.97 | 0.91 | 1.19 | 2.36 | ***5.0*** | 93 | 727 | 27.4 | 56.4 | 5.65 |
| 415 | 12 | 2009 | 9 | SM | 7.89 | 1.28 | 6.17 | 0.17 | ***5.0*** | 135 | 1350 | 9.5 | 37.5 | 17.37 |
| 416 | 13 | 2009 | 9 | SM | 1.36 | 0.20 | 0.45 | 5.36 | 10.0 | 81 | 888 | 2.8 | 36.6 | 2.71 |
| 417 | 14 | 2009 | 9 | INT | 4.47 | 0.19 | 1.49 | 0.12 | ***5.0*** | 75 | 823 | 7.3 | 13.8 | 2.31 |
| 418 | 15 | 2009 | 9 | INT | 4.12 | 1.12 | 0.76 | 0.24 | ***5.0*** | 55 | 721 | 9.2 | 19.8 | 0.93 |
| 419 | 16 | 2009 | 9 | SM | 4.64 | 0.19 | 1.50 | 0.79 | ***5.0*** | 46 | 713 | 11.7 | 23.1 | 3.93 |
| 420 | 17 | 2009 | 9 | SM | 1.68 | 0.23 | 0.55 | 5.29 | ***5.0*** | 56 | 769 | 5.7 | 15.3 | 0.87 |
| 421 | 18 | 2009 | 9 | INT | 3.40 | 0.45 | 1.13 | 0.05 | ***5.0*** | 54 | 804 | 7.6 | 14.7 | 1.40 |
| 422 | 19 | 2009 | 9 | INT | 8.80 | 2.90 | 1.99 | 1.40 | ***5.0*** | 49 | 880 | 11.6 | 21.0 | 1.54 |
| 423 | 20 | 2009 | 9 | INT | 5.64 | 0.91 | 1.18 | 0.30 | ***5.0*** | 90 | 891 | 10.3 | 25.8 | 8.40 |
| 424 | 21 | 2009 | 9 | SM | 1.61 | 0.26 | 0.80 | 2.64 | ***5.0*** | 56 | 861 | 19.1 | 35.3 | 4.12 |
| 425 | 22 | 2009 | 9 | SM | 2.57 | 1.13 | 0.51 | 0.91 | 10.0 | 87 | 695 | 22.6 | 35.3 | 5.21 |
| 426 | 23 | 2009 | 9 | SM | 1.22 | 0.44 | 0.34 | 2.35 | 6.0 | 36 | 1040 | 9.3 | 12.0 | 1.33 |
| 427 | 24 | 2009 | 9 | RF | 1.60 | 0.40 | 0.35 | 0.03 | ***5.0*** | 52 | 756 | 8.5 | 13.7 | 2.50 |
| 428 | 25 | 2009 | 9 | INT | 1.82 | 0.21 | 0.41 | 5.49 | 7.0 | 31 | 1410 | 24.7 | 33.6 | 1.40 |
| 429 | 26 | 2009 | 9 | INT | 1.43 | 0.42 | 0.41 | 1.07 | 7.0 | 45 | 644 | 15.8 | 23.7 | 3.01 |
| 430 | 27 | 2009 | 9 | RF | 6.18 | 0.44 | 1.31 | 1.09 | ***5.0*** | 49 | 1000 | 6.2 | 50.8 | 13.27 |
| 431 | 28 | 2009 | 9 | RF | 6.82 | 0.34 | 1.54 | 0.18 | ***5.0*** | 60 | 773 | 8.5 | 22.6 | 2.11 |
| 432 | 29 | 2009 | 9 | RF | 7.07 | 0.09 | 1.26 | 0.21 | ***5.0*** | 40 | 49 | 9.1 | 20.8 | 1.53 |
| 433 | 30 | 2009 | 9 | RF | 4.67 | 0.63 | 0.86 | 0.35 | ***5.0*** | 110 | 908 | 10.2 | 30.0 | 9.93 |
| 434 | 31 | 2009 | 9 | INT | 3.93 | 1.04 | 0.60 | 0.60 | ***5.0*** | 111 | 880 | 11.9 | 39.2 | 6.32 |
| 435 | 32 | 2009 | 9 | INT | 1.11 | 0.19 | 0.58 | 4.13 | 8.0 | 66 | 618 | 17.3 | 33.7 | 2.60 |
| 436 | 33 | 2009 | 9 | RF | 7.18 | 1.59 | 0.88 | 0.19 | ***5.0*** | 68 | 809 | 8.6 | 20.9 | 3.42 |
| 437 | 34 | 2009 | 9 | RF | 6.78 | 2.67 | 1.00 | 0.15 | 6.0 | 56 | 817 | 11.2 | 41.7 | 3.29 |
| 438 | 35 | 2009 | 9 | RF | 7.97 | 2.04 | 1.00 | 0.36 | ***5.0*** | 55 | 939 | 10.9 | 18.8 | 3.18 |
| 439 | 36 | 2009 | 9 | RF | 8.05 | 0.47 | 1.61 | 0.10 | ***5.0*** | 44 | 863 | 8.4 | 16.9 | 0.79 |
| 440 | 37 | 2009 | 9 | RF | 6.83 | 0.30 | 1.36 | 0.75 | ***5.0*** | 69 | 939 | 8.0 | 28.1 | 3.77 |

| ID | Lake OCF | Y | M | Cat | Mg mg/L | K mg/L | Na mg/L | $SiO_2$ mg/L | $NO_3NO_2$ µg/L | $NH_3$ µg/L | TN µg/L | TDP µg/L | TP µg/L | Chl-*a* mg/L |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 441 | 38 | 2009 | 9 | RF | 5.51 | 1.89 | 0.95 | 0.16 | ***5.0*** | 48 | 434 | 5.3 | 17.0 | 1.07 |
| 442 | 39 | 2009 | 9 | RF | 13.00 | 2.45 | 3.27 | 0.36 | ***5.0*** | 62 | 712 | 8.0 | 18.1 | 1.48 |
| 443 | 40 | 2009 | 9 | INT | 3.38 | 0.33 | 0.94 | 0.89 | ***5.0*** | 47 | 959 | 7.5 | 60.9 | 12.61 |
| 444 | 41 | 2009 | 9 | INT | 3.34 | 2.32 | 1.06 | 1.52 | ***5.0*** | 100 | 975 | 17.4 | 42.1 | 7.67 |
| 445 | 42 | 2009 | 9 | RF | 7.87 | 1.36 | 1.58 | 0.57 | ***5.0*** | 45 | 471 | 6.2 | 30.1 | 2.47 |
| 446 | 43 | 2009 | 9 | INT | 7.56 | 2.14 | 1.25 | 0.70 | ***5.0*** | 34 | 343 | 4.4 | 83.8 | 4.98 |
| 447 | 44 | 2009 | 9 | INT | 3.74 | 1.09 | 0.62 | 3.56 | ***5.0*** | 94 | 832 | 9.4 | 47.6 | 9.45 |
| 448 | 45 | 2009 | 9 | SM | 2.69 | 0.07 | 0.42 | 1.76 | ***5.0*** | 42 | 759 | 10.1 | 17.6 | 0.84 |
| 449 | 46 | 2009 | 9 | INT | 7.85 | 0.24 | 1.41 | 0.33 | ***5.0*** | 17 | 917 | 15.4 | 24.5 | 1.10 |
| 450 | 47 | 2009 | 9 | INT | 2.51 | 0.85 | 0.51 | 0.41 | ***5.0*** | 40 | 759 | 7.7 | 13.7 | 2.15 |
| 451 | 48 | 2009 | 9 | INT | 9.29 | 2.10 | 11.60 | 3.12 | 10.0 | 103 | 624 | 16.5 | 35.0 | 2.33 |
| 452 | 49 | 2009 | 9 | RF | 9.32 | 0.65 | 1.68 | 0.91 | ***5.0*** | 58 | 848 | 9.1 | 20.8 | 2.61 |
| 453 | 50 | 2009 | 9 | SM | 3.57 | 0.16 | 0.53 | 6.83 | 7.0 | 33 | 1710 | 29.0 | 39.4 | 0.82 |
| 454 | 52 | 2009 | 9 | INT | 3.56 | 0.24 | 0.43 | 1.63 | ***5.0*** | 33 | 706 | 11.8 | 18.6 | 0.74 |
| 455 | 53 | 2009 | 9 | RF | 5.29 | 1.41 | 0.88 | 0.98 | ***5.0*** | 31 | 621 | 6.8 | 13.1 | 1.99 |
| 456 | 54 | 2009 | 9 | INT | 2.64 | 1.00 | 0.37 | 1.79 | 10.0 | 49 | 667 | 24.8 | 34.5 | 1.03 |
| 457 | 55 | 2009 | 9 | SM | 2.25 | 1.01 | 0.33 | 2.23 | ***5.0*** | 85 | 1200 | 19.1 | 33.9 | 5.48 |
| 458 | 56 | 2009 | 9 | INT | 2.55 | 1.01 | 0.34 | 3.57 | ***5.0*** | 80 | 832 | 37.7 | 55.5 | 4.95 |

# *Appendix C: Environmental change and traditional use of the Old Crow Flats in Northern Canada: An IPY opportunity to meet the challenges of the new northern research paradigm*

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## *Introduction*

The Old Crow Flats (OCF), northern Yukon Territory, is homeland to the Vuntut Gwitchin First Nation (VGFN) and is a Ramsar Wetland of International Importance. This vast northern area encompasses 5600 km2 and approximately 2700 shallow thermokarst lakes, creating a freshwater landscape that has long been an important refuge for Arctic wildlife, while also supporting the traditional lifestyle of the VGFN. Observations and traditional knowledge of the VGFN indicate that OCF is undergoing pronounced changes in temperature, precipitation, vegetation cover, lake and river water levels, and ice integrity, along with changes in diversity and distribution of wildlife. Of even greater concern to the VGFN is the apparent rate at which these changes are occurring. Placing these changes within the context of recent environmental change (decades to centuries) and within the perspective of previous change under conditions similar to those projected for the future is necessary to formulate an effective strategy of stewardship for OCF, and to ensure future food security for the residents of Old Crow.

Here we describe the evolution of a community– researcher partnership that defines the Government of Canada International Polar Year (IPY) investigation on "Environmental change and traditional use of the Old Crow Flats in northern Canada (Yeendoo Nanh Nakhweenjit K'atr'ahanahtyaa; hereafter referred to as YNNK)"—one of very few fully endorsed programs led by northern-based individuals or aboriginal organizations in Canada (Church, 2009). The YNNK project, led by the Vuntut Gwitchin Government in collaboration with Yukon Environment, Parks Canada, and a multidisciplinary team of southern based researchers, focuses on addressing the complexities of climate change impacts on OCF and the nearby First Nation community of Old Crow. Research expertise spans the disciplines of Quaternary paleontology, dendroclimatology, permafrost science, hydroecology, terrestrial ecology, wildlife biology, community health, and traditional knowledge of the land and its processes. Overarching goals are to (1) document the history of environmental change in OCF from a unique assemblage of archives that record natural history from the last interglacial to the present; (2) assess the distribution and abundance of vegetation and wildlife and identify the processes linking these to the changing physical environment; (3) evaluate the impact of changes in the physical and biological environment on traditional food sources of the VGFN and community adaptation options; and (4) develop a long-term environmental monitoring program for OCF conducted by the VGFN through the IPY and into the future.

This undertaking also aims to fulfill the mandate of the new research paradigm in northern Canada—one that is collaborative, interdisciplinary, reflective of northern priorities, and policy-oriented (Graham and Fortier, 2005; Wolfe et al., 2007). Much of our progress towards achieving these objectives can be attributed to the strong community–researcher partnership that developed at the onset of this project. This partnership was made possible by the willingness of a fully engaged, motivated, and research experienced northern community, as well as the exceptional opportunity afforded by the NSERC Northern Research Chair Program and Government of Canada IPY programs. Although YNNK, like every research project, is unique, we believe many of the project outcomes and lessons learned are applicable to community-based, multidisciplinary research across the circum-Arctic. Generalities that emerge from the YNNK experience, which are described in the narrative below, include the importance of (1) community research experience and capacity, (2) community consultation prior to proposal writing, (3) legitimate convergence of community priorities and researcher interests, (4) funding agency guidelines that reward innovative but costly approaches to community-based research, (5) ongoing communication between researchers and the community at all project stages, (6) planning for contingencies, including the timing of funding deadlines, (7) the informal social networks that populate the northern research landscape, and (8) the personal relationships and trust that emerge from working closely together on shared interests.

### *The Community of Old Crow*

Old Crow has a population of ~300, mainly Vuntut Gwitchin ("People of the Lakes"), and is the northernmost community in the Yukon Territory. It is thought that the people of Old Crow may be the descendants of the first peoples of North America who migrated across the Bering Strait land bridge from Asia (western Beringia) into eastern Beringia (Morlan et al., 1990). They found refuge in this non-glaciated north-western corner of Canada, where Ice Age wildlife, including bison, caribou, and mammoth, existed. The timing of this migration remains controversial, but the earliest widespread, indisputable evidence of human occupation is dated to ~12 000 years ago in eastern Beringia (Goebel et al., 2008). However, evidence from the Bluefish Caves southwest of Old Crow suggests people may have lived in the region as early as

~24 000 years ago (Cinq-Mars, 1979), and still older evidence from the Old Crow basin hints at human presence as early as 35 000 – 40 000 years ago (Morlan et al., 1990; Morlan, 2003). Connections between the land and the earliest peoples of OCF have persisted to the recent past and remain central to the cultural identity of the Vuntut Gwitchin (Vuntut Gwitchin First Nation and Smith, 2009). While the lifestyle of the people of Old Crow is closely linked to the migrations of the Porcupine caribou herd, all families contain at least one member who participates in the modern wage economy.

Old Crow is a self-governing community, and the VGFN has a rich history of managing its natural resources, as well as taking an active role in scientific research within its traditional territory. For example, a long legacy of paleontological research in the region, conducted by Dick Harrington and others, has involved several generations of Old Crow residents as guides and field assistants, leaving a lasting impression that scientific research creates local employment and, at the same time, international recognition. In 1994, the community participated in the development of the Arctic Borderlands Ecological Knowledge Co-op, an ecological monitoring program for the northern Yukon focused on the impacts of climate change, contaminants, and regional development. This unique partnership highlighted the importance of integrating science with local and traditional knowledge. From these and other past initiatives, the community of Old Crow had obtained considerable experience in collaborative undertakings in scientific research and resource management, which provided a critical foundation for our YNNK project.

### *Climate change: an emerging issue for Old Crow*

> “It’s really warm. I don’t trust the weather. You can’t read the weather anymore.”

> “We’re getting much milder weather—warm winds from the west wind. The winter is warmer.”
>
> “Weather changes a lot and is unpredictable—cold to warm, warm to cold.”
>
> (Old Crow Citizens, ABEK Co-op, 2007).

Environmental change observations of the citizens of Old Crow are well aligned with both the instrumental record and tree-ring reconstructions of past climate (T. Porter and M. Pisaric, unpubl. data). A regional temperature composite record spanning 1930 – 2000 indicates that mean temperatures have warmed during all seasons except autumn. The winter season has warmed the most (+1.9˚C), followed by spring (+1.6˚C) and then summer (+1.2˚C). Autumn temperatures have decreased slightly during the same time period (-0.4˚C). YNNK has extended our knowledge of past climate by examining tree-ring records from eight white spruce sites sampled across the Old Crow region. The regional ring-width chronology extends from 1700 to 2007 and is highly correlated with annual Northern Hemisphere temperature anomalies from 1850 to 2007. From these climate-growth relations and the growth record, it is evident that warming during the past two to three decades exceeds that of any other period during the past 300 years.

Observational evidence and concerns associated with the environmental consequences of recent warming (e.g., low water levels in rivers and lakes, thawing permafrost, changing wildlife abundance) motivated the local community’s interest in climate-focused research. Indeed, convergence of community needs and researcher expertise was an important factor that contributed to the formulation of the YNNK project, as described below.

### *Genesis of a community-researcher partnership*

The initial connection between many of the researchers that became involved in YNNK was the Natural Sciences and Engineering Research Council of Canada (NSERC) Northern Research Chair Program (NRCP). The creation of this program was one of several recommendations of a joint NSERC and Social Sciences and Humanities Research Council Task Force on Northern Research established in 1998, which found that Canadian northern research was in crisis and that immediate action was required to train a new generation of northern researchers and to increase the amount of high-quality research being done in the North. The NSERC NRCP has the following four objectives: (1) Research: to contribute to the body of knowledge in fields of northern natural sciences and engineering, (2) Training: to train new northern researchers, (3) Partnerships: to build meaningful northern research partnerships, and (4) Communications and promotion: to communicate northern research issues and promote northern research and training within Canadian universities. The first and only NRCP competition was completed in 2002, and six university chairs were funded, with research programs focused on Quaternary geology (Alberta), permafrost (Carleton), plant ecology (Laval), fisheries science (Manitoba), traditional food security (McGill), and hydrology (Wilfrid Laurier).

As the six chairs became familiar with one another's research programs and shared perspectives on northern research during annual meetings, they became interested in conducting a collective, multidisciplinary research project consistent with the objectives of the NRCP. One chair frequently mentioned the community of Old Crow as an excellent candidate partner for such research. Although he had limited direct experience working with this community, he and several of the other chairs were aware that Old Crow was a community that strongly valued traditional lifestyles and had a strong track record of support for, and involvement in, community-based research. In fact, one of the other chairs and a newly hired collaborator of yet another chair had already initiated research projects in Old Crow.

The emergence of Canadian funding in support of IPY activities created an opportunity for the NSERC NRCs to put their plans for a collaborative research project into action. The first Canadian IPY funding opportunity to be announced was a $6 million, three-year NSERC IPY Program intended to support the participation of Canadian researchers in IPY projects. One of six criteria on which projects were to be judged was the involvement of Northerners, including (1) plans to engage Northerners in the planning, conduct, and dissemination of the research, (2) relevance of the proposed research and training to the needs and objectives of Northerners, and (3) plans for inclusion of traditional knowledge in the research. The NSERC IPY program was announced in early September 2005 with an application deadline of 5 November 2005, which was later extended to 28 November 2005.

The extremely short timeline between NSERC's IPY program announcement and the submission deadline initiated a flurry of proposal and project-development activity throughout the Canadian northern research community, including the NSERC NRCs' discussion regarding a potential Old Crow-based project. After several email exchanges and conference calls, it became evident that although most of the chairs and collaborators were genuinely interested in the possibility of submitting a proposal for an Old Crow IPY project, they disagreed about the feasibility and advisability of attempting to submit a proposal in time for the NSERC deadline. One group, including two researchers who had direct research experience with Old Crow, felt there was too little time for adequate community consultation and involvement prior to the deadline and tried actively to dissuade the other researchers from moving forward with a proposal. The other group was hesitant to let this funding opportunity pass and was more optimistic about the potential for rapidly engaging the community in a project proposal. The researchers did not speak as a group with representatives from the community of Old Crow during this period, but several researchers had informal conversations with community representatives to assess the community's potential interest and support.

Around this time, it became apparent that there would be an additional, larger pool of funds available in the form of a $150 million Government of Canada IPY Program, which included a call for research proposals with an application deadline of 10 March 2006, later extended to 31 March 2006. Although this deadline was only four months after the NSERC deadline, it provided the chairs and the community of Old Crow a critical window of opportunity for communication and co-development of a community-based research proposal. Following the false start generated by the short NSERC timeline, both the researchers and the community now had at least a little more time to restart the process with a blank slate, as well as more available funding if a competitive proposal could be pulled together. In hindsight, a strong foundation to the evolving partnership between the community and the researchers was established during that four-month interval. That period has had lasting, positive impacts on the research and partnership outcomes, and it represents an extremely important juncture for the subsequent successes of the project.

### *Setting the community agenda for collaborative research*

Upon invitation from the community, three of the NSERC Northern Research Chairs and two of their collaborators, along with a representative from Parks Canada and the Northern Regional Biologist for the Government of Yukon, gathered in Old Crow in January 2006 for a two day meeting. Their goal was to explore the possibility of developing a collaborative research program aligned with the scientific priorities set out by the Government of Canada IPY Program: Climate Change Impacts and Adaptation and Health and Well-being of Northern Communities. Staff of the Vuntut Gwitchin Government (VGG) Natural Resources Department (NRD) and the North Yukon Renewable Resources Council (NYRRC) hosted the meeting, and they greeted the researchers at the Old Crow airport with agenda in hand – a welcome, tangible sign that local capacity was in place to take a leadership role in developing the research program.

Discussions during Day 1 focused on sharing information regarding the nature of previous research conducted in the Old Crow Flats, knowledge gaps that inhibited comprehensive development of an ecosystem management plan, and directions of scientific enquiry that researchers thought could help to fill the knowledge gaps. A community dinner was held at the end of Day 1, which was followed by introductions and presentations by the researchers to the community. The evening concluded with compelling testimonies by community members, who recounted their observations on the effects of the accelerating rate of climate change (e.g., thawing permafrost and slumped banks along the rivers, vegetation changes, falling water levels in lakes and rivers, and declining wildlife populations). The instrumental weather record from Old Crow airport for 18 January 2006 indicates that outside air temperature while this meeting took place was -42˚C. Hearing the community speak with such consensus about the reality of a warming climate and the widespread impacts it was having on their land and lives, on such a cold night, made a strong and lasting impression on all of the researchers present at the meeting. The observations shared with researchers that evening are echoed in Old Crow contributions to the Arctic Borderlands Ecological Knowledge Co-op around the same time period.

> "The water in the rivers is low. Everything is drying up."
>
> "I see a lot of land slides and a lot of lakes drying up."
>
> "I notice that the willows are growing bigger and the trees are growing faster"

(Old Crow Citizens, ABEK Co-op, 2007)

> "I see a lot of bank erosions along the river and permafrost melt."
>
> "The land is drying up and the permafrost is melting fast."
>
> "The weather is getting warmer and warmer. Plants are growing faster, especially the willows."
>
> "There are lots of willows—lots of growth."
>
> (Old Crow Citizens, ABEK Co-op, 2008)

While several community members welcomed the opportunity to share their stories, many also welcomed the researchers to offer their expertise to complement local understanding of their traditional territory.

This first community meeting was particularly effective and important for two main reasons. First, it provided the community with the opportunity to set the agenda for the research program at the outset of the research planning process, thereby establishing community engagement, which has been a strong feature of the project throughout its existence. Secondly, the community clearly conveyed its main concerns, which armed the researchers with the knowledge necessary to start formulating research objectives for the IPY pre-proposal on Day 2. The pre-proposal was written on various laptops spread around a large table in the NYRRC office, with the active participation of community members and local leadership, including the NYRRC chair, the VGG NRD director, and the VGG Chief, who were present throughout the day. By the end of Day 2, the pre-proposal was largely complete, including a section on community consultation written by the Chief. Further defining of specific roles among the researchers and NRD staff laid the groundwork for preparing the full proposal over the following three months, a task which was adeptly and efficiently coordinated by staff of the NRD.

A year later, after learning that the full proposal had received a positive review but before any funding was granted, several of the researchers as well as prospective graduate students once again met in Old Crow on 23–26 February 2007 to make tentative plans for the summer field season. Because of the time required to address various logistical needs for fieldwork, such as arranging accommodation and hiring local field research assistants, it was not possible to delay this meeting until confirmation of the grant, which was not expected for several weeks. Two evenings were set aside to meet with the community, mainly to remind people of the IPY project that they had helped to design and provide another opportunity to contribute to the research now that general objectives were about to be translated into specific research activities. This was a challenging transition because some community members had not participated in the previous year's meeting or needed to be reminded of the extent to which this research project was motivated by their previous input. After the first evening of community meetings, the researchers realized that an effective graphic was needed to explain various components of the project and how they related to each other. Thus, Figure 0.1 was crafted later that evening by several of the researchers with their laptop computers around a kitchen table. It was introduced during the second evening and has been used as a visual aid and reminder of the project in subsequent meetings and written reports produced for the community. While these efforts were aimed at improving our ability to communicate to the community, collective design of Figure 0.1 also challenged the researchers to identify clearly the links between the several individual projects and where integration could potentially occur. Thus designing Figure 0.1 was also an important team-building exercise.

Furthermore, now that funds were soon to start flowing and research activities would soon begin, the logistical complexities and funding allocations involved in remote, collaborative research had to be addressed. Where would researchers and their equipment stay in town, and at what cost? How would local hiring of guides, equipment, and research assistants be arranged? When can you travel from Old Crow to Old Crow Flats by skidoo or boat, and where can you go once you get there? It quickly become apparent that project logistics and research activities would require at least as much innovative community-researcher partnership and communication as was involved in the project proposal development. Thus, a particular focus and highlight of the second evening of community meetings was a successful mapping workshop that provided opportunity for community members to identify locations of interest and travel routes in OCF, which served to help establish lake study sites for the hydroecological research group (Fig. 2). Discussions with community members focused mainly on whether they had recently observed changes in water level and the timing and location of these observations. This reporting was another key element in the process of directly engaging community members and incorporating traditional knowledge in the study design. For example, during the mapping workshop, one member expressed concern over the impending drainage of a large lake in his family's traditional territory, which, as predicted, came to pass in June 2007 (see Wolfe and Turner, 2008).

Notably, the initial two research planning meetings in Old Crow occurred before any fieldwork took place—the first, more than one year in advance of receiving IPY funding. The collective estimated cost of travel and accommodation for these two meetings was roughly $50 000, which was absorbed by a small group of northern scientists, most of whom were fortunate to have access to NSERC NRC funding that prioritized northern partnerships. Certainly, these are unique circumstances upon which a northern research program has been constructed. A key outcome, however, is that these efforts to build relationships before the research was designed and implemented have created a positive framework that has ensured ongoing applicability of the research to community needs. Indeed, these key early steps may serve as a model for effective collaboration among northern communities, researchers, and funding agencies to address environmental consequences of climate change.

### *Ongoing knowledge exchange activities and training*

Subsequent field seasons and annual winter meetings in 2008, 2009, and 2010 have formed the cornerstone of knowledge transfer and exchange. Numerous research presentations and posters have been provided to the community, and plain language pamphlets summarizing research activities, progress, and findings have been distributed. These activities have not only kept community members informed of the research progress, but also provided excellent opportunities for them to contribute directly to the research endeavour by sharing their knowledge, observations, and concerns, as described above. Many local residents have been hired to work with YNNK research teams, and several of these assistants have gained experience with multiple research teams focused on diverse aspects of environmental research. For example, the muskrat research component of YNNK has relied heavily on a carcass collection program involving local trappers and administered by the NYRRC. Local trappers record the location of trapped muskrats and the date. Carcasses are then shipped to a university facility to be analyzed for nutritional and health status, which is reported back to the community. In addition, interviews on muskrat ecology, harvesting, and processing have been conducted with local knowledge experts to formally document and broaden the scope of the traditional knowledge that has already been contributed informally and incorporated into the project.

Highlighted among our knowledge-exchange activities was an NSERC Northern Research Internship awarded to PhD student Ann Balasubramaniam during the summer of 2008 (Balasubramaniam, 2009). Ann’s internship activities, supported by the partnership with the VGG, were numerous, far-reaching, and lasting. She provided expertise to the NRD, trained NRD staff in field activities that will lead to the development of a community-based hydroecological monitoring program, delivered a research seminar at the Biennial Gwitchin Gathering, led a science camp for the children of Old Crow, and overall raised the profile of the research program while serving as an excellent role model for the community’s younger generation. Ann’s efforts strengthened what were already strong ties with this community, which has had long-lasting positive effects as YNNK has evolved. She continues to work with NRD staff on YNNK-related projects, which included serving as a liaison between NRD staff and researchers to coordinate and lead subsequent community–researcher winter meetings in 2009 and 2010.

Indeed, the northern training experiences for graduate students participating in YNNK have been particularly enriching. Four graduate students began their programs at the MSc level but decided to fast-track to the PhD program to take greater advantage of research opportunities within YNNK. Many of the participating graduate students have been to Old Crow on numerous occasions to conduct fieldwork and to meet with the community to report research progress. Some PhD students have been to the community for as many as four consecutive winter meetings to plan their research, share their findings, and obtain feedback from the community. They, in particular, have developed vitally important skills in communicating their science in language that is understandable and relevant to community members, as shown by the comments one community member sent to the NRD director following the 2010 winter meeting:

> I was very much impressed with the outcome of the International Polar Year, Annual General Meetings held in Old Crow last weekend from February 19 to 21, 2010. Each time I was there, there were many local people in attendance. I think that was because many of the local people were involved with the researchers, helping them out in some way either by skidoo or boats or by sharing of their traditional knowledge. And seeing the number of people there at the meeting that told me they were interested in the findings of the researchers, the findings of the research that took place in Vuntut territory and also the relationships that had built up as a result of this amount of research for a small remote community.
>
> This IPY research as was stated many times was a collaborative effort from the beginning. It was made clear to the researchers from the beginning to always be in touch with the community and keep it simple. That is what they did last weekend, they brought it home to the folks here, their information, their presentations with many pictures in an easy to understand simple language format.
>
> I think all future joint meetings whether it be with Parks, Fisheries etc, should be done in this manner. Maybe it is done but this weekend sure showed how well things can go if everyone is on the same page going in the same direction at a good pace, not rushed, not slow, just right.
>
> Mahsi' Choo [Thank you] for all your coordinated efforts in seeing the IPY file going in a good way from the beginning. This is a huge amount of work that has accumulated over 3 years but work that has good results also and that is what we need to see as a community and we need to continue to see it so we are always kept in the loop and kept informed about the scientific changes and mesh this with the traditional knowledge, the changes that we ourselves see on our lands.

This project has thus provided necessary and excellent opportunities for graduate students to learn what communities, as well as government agencies and funding bodies, expect from northern researchers. Training of the next generation of northern researchers has been of exceptionally high quality.

During the community–researcher meeting of winter 2009 in Old Crow, the researchers and their graduate students had a special opportunity to participate in a very successful outreach program. Organized by leaders of the Arctic Health Research Network (including an Old Crow community member), with funding from Health Canada, the “Our Changing Homelands, Our Changing Lives” youth conference brought ~25 students from Whitehorse (many originally from Old Crow) to Old Crow to participate in the annual community–researcher meeting. A major focus of the conference was climate change workshops (including Historical Air Photos, Permafrost, Wildlife, Fossils, Tree Rings and Hydrology; Fig. 3) conducted by YNNK team members. Each research team was challenged to construct an interactive, fun workshop that would run for two to three hours and present research in a way that young people could easily understand. The northern students who participated in these workshops became much more aware of both the changes that are occurring in their traditional territory and the natural science approaches researchers are using to understand how the Old Crow Flats landscape is responding to a warming climate. For instance, one of the workshops used sprouts (representing moss) and broccoli (representing trees), among other ingredients, to examine the effects of different surface features on thawing “ice-cream” permafrost. This workshop was particularly effective in delivering its scientific message (and made for an interesting post-experiment snack for workshop participants!). Senior members of the community of Old Crow also participated in these workshops and made important contributions. For example, during the Tree Ring workshop, a YNNK coinvestigator was showing samples of tree cores collected from OCF, all of which displayed remarkably thicker growth rings over the last few decades (as described above). After the presenter explained that these rings are thicker than any other decade since ~AD 1700 because of the positive growth response to recent climate warming, a community elder remarked that his personal experience also told him that changes in the Flats began in the 1950s. Thus, findings from a natural science IPY-supported study and traditional knowledge converged, and the youth who attended the workshop had the special opportunity to experience this firsthand. Committed local leadership combined with the creativity of researchers and their graduate students in workshop design generated considerable energy that translated into a memorable experience for all.

### *Challenges*

The successes we have highlighted above were accompanied by challenges that are common to many collaborative research undertakings in the North. Some of these have been overcome, while others remain to be addressed. Below we describe some of these challenges in the context of our project, offer insights into how they have been met, and lay out plans for achieving future goals.

The consistency and continuity of research engagement with northern communities over a multiple-year collaborative study can be strongly influenced by the high staff turnover in local government positions (e.g., Wolfe et al., 2007). During the very early phases of project development, an individual who served as the Lands Manager for the NRD played a pivotal role in coordinating elements of the IPY proposal, which included writing key sections on behalf of the VGG and organizing and leading the community– researcher meeting in 2007. This individual’s tremendous leadership and communication skills contributed substantially to the successful outcome of the grant application to the Government of Canada’s IPY Program. She played a similarly critical role in helping to launch many of the project components once funding was in place (e.g., coordinating fieldwork logistics such as arranging accommodation and hiring local field assistants). Upon learning in early 2007 that she was leaving her position to go back to university, many researchers were concerned that her departure could derail the project since she had all of the local corporate memory of the collaborative project from its initial conception, was well respected by members of the community, and communicated extremely well with the researchers. Around this time, however, a new NRD director was hired, and YNNK-related roles and responsibilities of the Lands Manager were effectively and successfully transferred. Thus, the project has not suffered but rather thrived in this respect because, while different community-based individuals have held important leadership positions over the five years that span project conceptualization, development, and execution, an integral constant has been the presence of strong local capacity. In the absence of key staff members committed to project goals, researchers may commonly find themselves revisiting issues they thought had previously been addressed to the satisfaction of community representatives (e.g., research objectives, methodology), which can significantly impede research progress. While steps such as these may very well be a frequent reality of the collaborative process, the consistent presence of effective local leaders has meant that we did not need to spend much effort on revisiting old issues.

The cost of conducting northern research is a perennial challenge, and our YNNK project is no exception. While our ~$1.7M grant application was fully funded, it represented only a small proportion of the real cost of conducting this research program. For the hydroecology group, for example, funding from IPY has been used almost exclusively to charter a helicopter for repeated water sampling of lakes and rivers in OCF. Overall, this research component has had an operating budget of ~200K/yr. Approximately 30%–40% has been supported directly by IPY, and the remainder (e.g., research assistantships, local field assistants, analytical costs, travel for fieldwork, community meetings and conferences) was covered by other sources (including NSERC NRCP, the Polar Continental Shelf Program, the Northern Scientific Training Program, and Parks Canada). Leveraging to obtain a new NSERC Strategic Project grant has also been successful. This new grant has further strengthened partnerships between researchers, the NRD, and Parks Canada, and it has provided additional resources to support development of a hydroecological monitoring program for OCF—a key objective of the IPY project. Assembling various funding sources to support Canadian research in the North is certainly not a new reality, but the magnitude and corresponding impact of the research has very clearly benefited from implementation of the Task Force on Northern Research recommendations and the IPY. Although unprecedented resources have recently been available, concerns over our ability to sustain such research activity post-IPY are frequently mentioned by Old Crow residents during our annual meetings and indeed expressed by many in the Canadian northern research community (e.g., England, 2010). Certainly, many of the researchers would like to continue their Old Crow research beyond the IPY grant period, although new funding opportunities are required to develop formal plans.

A key criterion of the Government of Canada IPY Program was for projects to leave a legacy, and proposals were asked to address long-term benefits, such as knowledge translation to communities, capacity building, and future collaborations. While considerable progress has been made, especially with regard to knowledge translation, other legacy aspects remain to be achieved. For example, one of our collective goals outlined in our proposal is to establish community-based environmental monitoring activities (e.g., measurements of snow and active-layer depth to monitor permafrost, water sampling to monitor lake water balance, and animal tracking to monitor wildlife abundance) to maintain the integrity of observations from the YNNK into the future. The benefits for the community of continuing these activities are clear. Establishing a long-term monitoring program for OCF will generate the necessary knowledge to provide ongoing assessments on the status of OCF landscape and responses to changes in climate, so that appropriate adaptation plans can be developed and implemented to sustain traditional ways of life. Preliminary discussions with NRD staff have been positive, but concerns about sufficient local capacity to fully commit to such a program are an unfortunate reality, as for many northern communities. On the other hand, productive and ongoing discussions with Parks Canada staff regarding a collaborative undertaking to implement an aquatic ecosystem monitoring program for both Vuntut National Park and the VGFN Special Management Area of OCF suggest that this may indeed be possible. Much work is still required to design a monitoring program that balances scientific rationale with logistical constraints in a post-IPY funding environment, however, and accomplishing this work is a major goal of field activity planned for the final two years of IPY funded research.

### *Concluding comments*

"Vision, capacity and partnership": these words by Bob Van Dijken of the Yukon IPY Coordination Office in his opening address at the 2010 YNNK community–researcher winter meeting in Old Crow eloquently expressed why this project had succeeded. Leaders of the community of Old Crow had the vision to engage with researchers collaboratively to identify the effects and consequences of climate warming on their traditional territory, although convergence of community interest, researcher expertise, and funding opportunity cannot be overemphasized. Local capacity was in place to ensure the research agenda spoke to the needs of the community from the outset of the planning process, through conceptualization, development, and execution, while the community also welcomed the skills and knowledge that government scientists and a group of southern university researchers could bring. The partnership not only has been sustained, but also has evolved over a five-year period—from designing research questions, to conducting field-based research, to delivering collaborative outreach activities, to communicating findings in an effective format—which speaks to both the vitality and uniqueness of this northern community and the commitment and energy of the researchers and graduate students.

We acknowledge that much of what we have described is seen through the lens of the researchers involved in this project. Certainly, no one would disagree that the community perspective is likewise essential to capture and relay, and thus it is the subject of an ongoing PhD thesis within our program (Brunet, 2010). It is our hope that documenting our collective experiences of a collaborative community– researcher undertaking that strove to meet the challenges of the new northern research paradigm will also leave an important IPY legacy.

## *Acknowledgements*

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## *Figures*

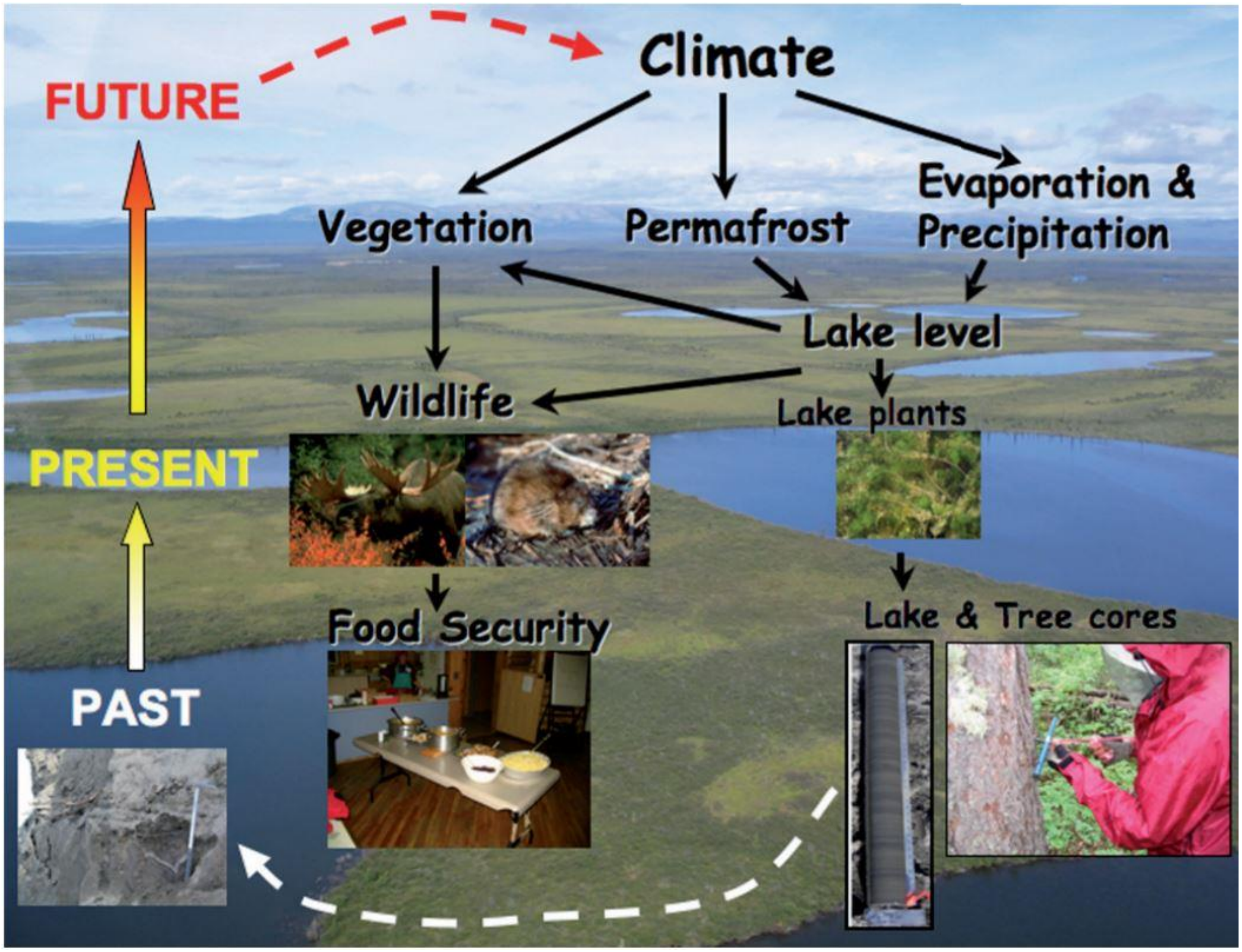

Figure 0.1: Graphic used to explain research elements and interactions within the YNNK IPY project “Environmental Change and Traditional Use of the Old Crow Flats in Northern Canada” to the community of Old Crow.

Figure 0.2: Photographs of a mapping workshop held with the community of Old Crow (February 2007).

Figure 0.3: Photographs of climate change workshops offered to youth during the “Our Changing Homelands, Our Changing Lives” youth conference (January 2009). Clockwise from upper left: Tree Rings, Wildlife, Historical Air Photos, and Permafrost.