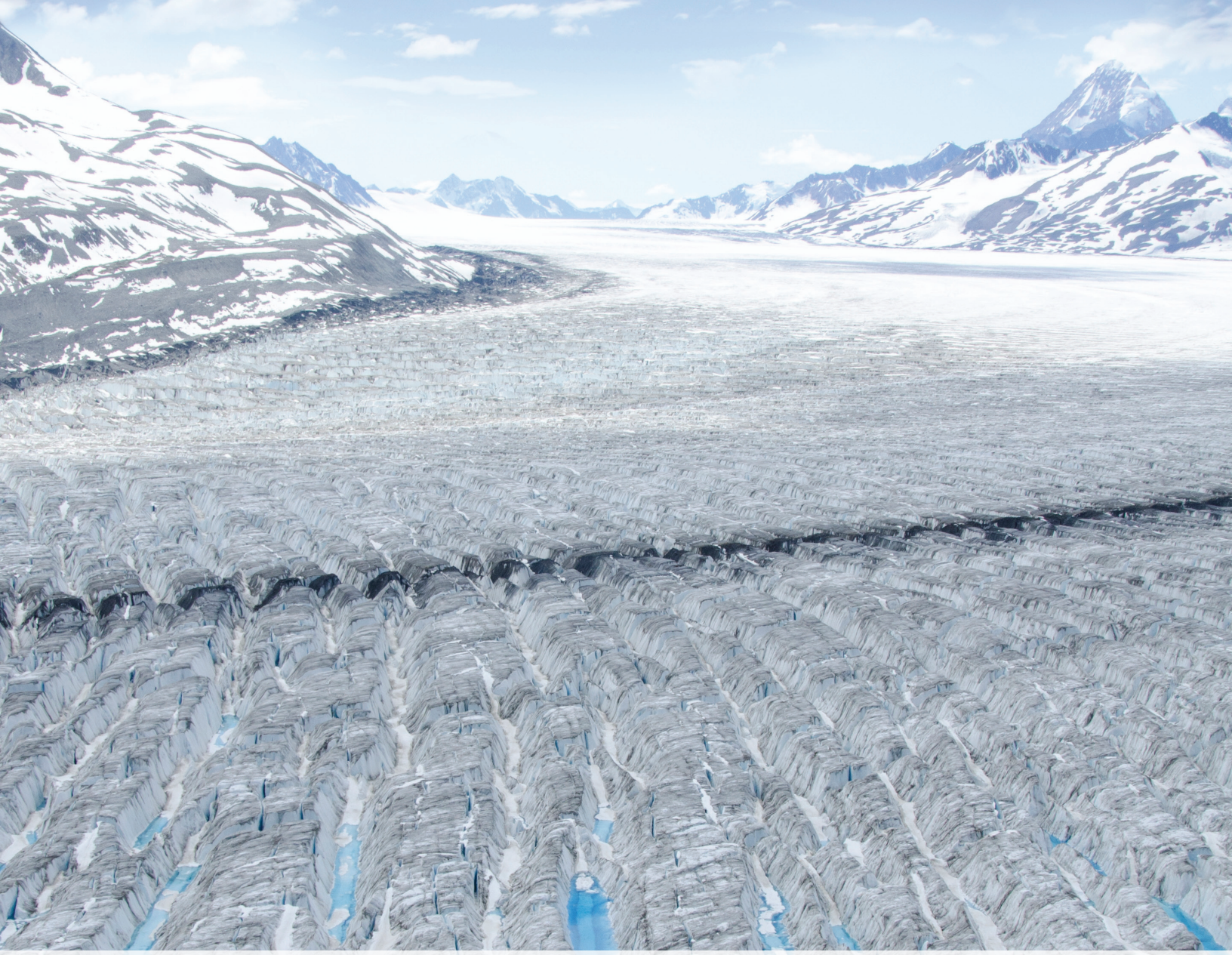

Compendium of Yukon Climate Change Science

2015 Supplement

Northern Climate ExChange
YUKON RESEARCH CENTRE · Yukon College

With funding support from Government of Yukon's Climate Change Secretariat.

This publication may be obtained from:

Northern Climate ExChange
Yukon Research Centre, Yukon College
500 College Drive
P.O. Box 2799,
Whitehorse, Yukon
Y1A 5K4
(867) 668-8895
1-800-661-0504
yukoncollege.yk.ca/research

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Front cover photograph: Kluane National Park. Photo credit: Government of Yukon.

Foreword

The Compendium is intended to provide an overview of recent climate change work involving Yukon. This document is intended to supplement the 2003-2013 version of the Compendium with climate change work that has taken place during 2014 and 2015. It is comprised of various types of documents, including scientific journal articles, government publications, workshop reports, and conference proceedings.

Information for the Compendium was gathered through:

- ASTIS Database
- Polar Data Catalogue
- Yukon Biodiversity Database
- Hydrocarbon Impacts (HI) database
- Wolf Creek Research Basin database
- Kluane Lake Research Station Bibliography
- NCE Library
- Northern Research Institute Fellowship Grants list
- Forest Management in a Changing Climate: Compendium of Information Sources
- Government of Canada and Government of Yukon websites
- AANDC Present and Past Climate Change Adaptation Projects list
- Internet searches
- Internal knowledge

The Compendium is not an exhaustive list of climate change-related work in Yukon over the 2014-2015 period. A greater emphasis was placed on information that is available online. That being said, the Northern Climate ExChange would appreciate being informed of any relevant information that should be included, or if there are any errors in the Compendium.

The Compendium is organized broadly by topic and subsequently separated into more detailed sections. The 'Local Relevance' section of each entry highlights information directly related to climate change in Yukon.

Entries can be searched by various keywords listed in the index, and all entries have been classified as south Yukon, south-central Yukon, central Yukon, north Yukon, or Yukon-wide. The keyword 'traditional knowledge' was used when the research integrated knowledge from First Nations communities, and the keyword 'local knowledge' was used when information was integrated from a multicultural community or broad area.

This supplementary 2014-2015 edition of the Compendium expands upon the previous edition (2003-2013). I would like to thank John Streicker, Bob Van Dijken, Rebecca World, Lacia Kinnear, Aynslie Ogden, and Alison Perrin for their assistance. I am also grateful to all of the Yukon First Nations that responded to our requests for information involving studies conducted in their respective traditional territories.

David Silas
Climate Change Assistant Analyst
Northern Climate ExChange
Yukon Research Centre, Yukon College
September 2015

Table of Contents

COMPENDIUM

1. CHANGING CLIMATE

1.1 CLIMATE CHANGE ADAPTATION

Impacts of climate change on biodiversity

Research Location: globe

Publication Type: Journal Article

Publication Date: 2014

Abstract: Considerable biotic changes have occurred globally during these cycles; for the last 11,000 years the Earth has been in a relatively stable warm phase of the cycle and is probably within a degree or two of being the warmest it has been for over 2 million years. At the global level, human activities have caused and will continue a loss in biodiversity. This paper considers the connection between climate and biodiversity. Climate change has synergistic effects with many of the biggest existing impacts to biodiversity. Many studies show potential climate change impacts on biodiversity through habitat loss and fragmentation, invasive species, species exploitation and nutrient enrichment. Distributions tend to shift down temperature gradients. The direction of shifts vary considerably among species depending on which bioclimatic variables are most important in the models for each species (e.g., changes in moisture availability may differ from changes in temperature, and the direction of temperature gradients may alter seasonally), and some species show little or no change.

Local Relevance: Climate change is both a cause and an effect of biodiversity change in Yukon. The capacity of ecosystems to adapt to climate change depends on the diversity of species they currently support. This study looks at the expansion and the impacts of agriculture on species diversity and dispersals. Furthermore, the researchers looked at variation among species in the size of their modeled future distributions: some expand, some do not change, some contract, and the distributions of some species are projected to disappear completely under some scenarios. Species that are not easily dispersed will respond more slowly to climate change, likely resulting in range contractions and reduced abundances

Keywords: biodiversity, climate change, distribution, global warming

Available Online: Full Document http://ijfas.com/wp-content/uploads/2014/08/811-818.pdf

Citation: Sharafi, S., Jou, P.H. and Tabaee, N.A., 2014. Impacts of climate change on biodiversity. International Journal of Farming and Allied Sciences, vol. 3, issue 7, p. 811-818.

Comparison of soil derived tetraether membrane lipid distributions and plant-wax δD compositions for reconstruction of Canadian Arctic temperatures

Research Location: Kluane Lake and the Klondike Goldfields, Yukon Territory, Canada

Publication Type: Journal Article

Publication Date: 2014

Abstract: Polar amplification of climate warming has received much attention as these rapidly rising temperatures have the potential to alter ecosystem function and biogeochemical cycles. In particular carbon preserved in Arctic tundra soil and permafrost may be especially vulnerable

resulting in carbon cycle perturbations providing an additional positive feedback to climate change. Reliable methods for reconstructing past temperature changes in polar regions have been established from ice cores and marine sediments; however techniques for the continental terrestrial environments are lacking, but are imperative to examine polar amplification of climate warming. Here we compare two molecular methods for reconstructing continental annual mean air temperature (MAT) for the Canadian Arctic based on the distribution of soil bacterial-derived glycerol dialkyl glycerol tetraether (GDGT) membrane lipids (MBT-CBT proxy) and the hydrogen isotopic composition (δD) of plant wax-derived *n*-alkanes. These two proxies were applied to both modern soil and paleosols collected from the Yukon Territory, Canada, to evaluate both the accuracy of the reconstructed absolute temperatures as well as the elative change in temperature between the Last Glacial and the Holocene. Branched GDGT-based estimates using the recently revised MBT'-CBT calibration are overall higher by ca. 6°C compared to the original calibration. MAT estimates for modern soils based on the original MBT-CBT calibration are comparable with those based on the δD of extracted C_{29} *n*-alkanes and instrumental data, however produced a 6°C higher temperature signal for the glacial paleosols. Therefore, branched GDGT based temperature reconstructions for glacial soils in the high Arctic may represent the higher temperatures at the time of soil formation when bacterial activity was optimal whereas δD of C_{29} *n*-alkane plant lipids appear to integrate an average annual signal. When used in tandem, these geochemical proxies may provide a more comprehensive method for reconstructing Arctic paleoclimate.

Local Relevance: An altered ecosystem from climate warming here in Yukon would have drastic consequences on the local ecosystems and the biodiversity they support. This increase in warming has the potential to alter permafrost composition in Yukon and release additional carbon adding to a positive feedback to climate change. In this study there is a focus on annual mean air temperature and isotopic composition of plant wax-derived *n*-alkanes; these are needed to accurately measure changes in temperature between the last glacial period and the Holocene. This baseline information can help to better understand the amplification of climate warming and what it means to Yukon's ecosystems and biogeochemical cycles. In southern Yukon, less than 25% of the land area is underlain by permafrost. In central Yukon, the distribution of permafrost is more extensive but still discontinuous (50-90% of the land surface is underlain by permafrost), whereas north of Dawson, it is nearly continuous (>90% of the land underlain by permafrost), which greatly increases Yukon's potential to contribute carbon to the positive feedback to climate change.

Keywords: paleoclimate reconstruction, biomarkers, branched glycerol dialkyl glycerol tetraethers, plant-wax *n*-alkanes, deuterium isotopes, terrestrial arctic

Available online: Full Document http://dx.doi.org/10.1016/j.palaeo.2014.03.038

Citation: Pautler, B., Reichart, G., Sanborn, P., Simpson, M., Weijers, J. 2014. Comparison of soil derived tetraether membrane lipid distributions and plant-wax δD compositions for reconstruction of Canadian Arctic temperatures. Palaeogeography, Palaeoclimatology, Palaeoecology, vol. 404, p. 78-88. doi: 10.1016/j.palaeo.2014.03.038.

Possible Impacts of Climate Change on Wind Gusts under Downscaled Future Climate Conditions: Updated for Canada

Research Location: Canada and Whitehorse YT

Publication Type: Journal Article

Publication Date: 2014

Abstract: The methods used in earlier research focusing on the province of Ontario, Canada, were adapted for the current paper to expand the study area over the entire nation of Canada where various industries (e.g., transportation, agriculture, energy, and commerce) and infrastructure are at risk of being impacted by extreme wind gust events. The possible impacts of climate change on future wind gust events across Canada were assessed using a three-step process: 1) development and validation of hourly and daily wind gust simulation models, 2) statistical downscaling to derive future station-scale hourly wind speed data, and 3) projection of changes in the frequency of future wind gust events. The wind gust simulation models could capture the historically observed daily and hourly wind gust events. For example, the percentage of excellent and good validations for hourly wind gust events ≥ 90 km h^{-1} ranges from 62% to 85% across Canada; the corresponding percentage for wind gust events ≥40 km h^{-1} is about 90%. For future projection, the modeled results indicated that the frequencies of the wind gust events could increase late this century over Canada using the ensemble of the downscaled eight-GCM simulations [Special Report on Emissions Scenarios (SRES) A2 and B1]. For example, the percentage increases in future daily wind gust events ≥70 km h^{-1} from the current condition could be 10%–20% in most of the regions across Canada; the corresponding increases in future hourly wind gust events ≥70 km h^{-1} are projected to be 20%–30%. In addition, the inter-GCM and inter-scenario uncertainties of future wind gust projections were quantitatively assessed.

Local Relevance: Historically the Whitehorse area has been prone to strong gusts of wind. The highest sustained wind speed was 40 mph (~64 km/h), occurring on November 22; the highest daily mean wind speed was 26 mph (~42 km/h; November 22); and the highest wind gust speed was 49 mph (~79 km/h; November 22). The windiest month was October, with an average wind speed of 11 mph (~18 km/h). The least windy month was July, with an average wind speed of 7 mph (~11 km/h). This study looks at the cost associated with destructive natural hazards like strong wind gusts. Climate information that examines wind gusts is required to determine wind loads for infrastructure design codes and standards, which play an important role in preventing damage and reducing risks to lives from extreme wind events. The cost of living in the north is high and the cost of building is even higher; it is therefore important to develop more effective ways of preventing loss due to climatic hazards such as extreme wind events. The projected results clearly show that Canada, including Yukon, could possibly receive more wind gust events late this century than has been historically experienced.

Keywords: industry, extreme wind gust events, climate change, future projections, decision-making

Available Online: Full Document http://journals.ametsoc.org/doi/abs/10.1175/JCLI-D-13-00020.1

Citation: Cheng, C.S., Lopes, E., Fu, C. and Huang, Z., 2014. Possible Impacts of Climate Change on Wind Gusts under Downscaled Future Climate Conditions: Updated for Canada. Journal of Climate, vol. 27, issue 3, p. 1255-1270. doi: http://dx.doi.org/10.1175/JCLI-D-13-00020.1

Analysis of Daily Air Temperatures across a Topographically Complex Alpine Region of Southwestern Yukon, Canada

Research Location: Kluane Lake Research Station

Publication Type: Journal Article

Publication Date: 2014

Abstract: This study provides an analysis of six years of daily air temperature data collected using 16 HOBO® UA-002-64 Pendant data loggers placed along a 280 km transect in southwestern Yukon and northern British Columbia. Correlation and time series analyses, including Seasonal Decomposition of Time Series by Loess (STL) methods, revealed very high correlations among all data series at daily to annual timescales. The two meteorological stations in the region are found to be generally representative of the greater area, and local temperature variability appears to be predominantly determined by synoptic-scale weather patterns. The annual temperature cycle in this region is complex and has annually repeating components at all study sites across the region. The analysis of daily data using the STL method can provide new insight into climate time series and enhance our ability to observe patterns and extremes in temperatures across varying spatial and temporal scales. Data loggers provide a cost-effective way of obtaining similar (and sometimes higher-quality) information compared to meteorological stations or gridded global datasets.

Local Relevance: The annual temperature cycle of southwestern Yukon is complex and this is owed to its close proximity to the Pacific Ocean and its physiographic location which places it in the rain shadow of the Coastal Mountains and in particular the St. Elias Mountains. This study was initiated following discussions by researchers attempting to explain the spatial patterning of plant communities in and around the Kluane region of northwestern Canada. The results of this study showed that mean daily temperatures can exceed 20˚C in summer and be as low as −46˚C in winter and scatterplots of daily temperatures from sites along the entire transect clearly show high correlation with data gathered from the two main meteorological stations (i.e., Haines Junction and Burwash Airport). Through this study it was concluded that the annual temperature cycle in the Kluane region is complex and can clearly be divided into two sub-annual components on the basis of temperature variability. This study has shown data loggers to be a cost-effective way of obtaining data similar to meteorological stations or gridded global datasets without the use of advanced technology or satellite communication.

Keywords: Yukon climate, HOBO data logger, meteorological station network, daily and hourly temperature dataset, time series analysis, seasonal-trend decomposition (STL)

Available Online: Full Document http://dx.doi.org/10.14430/arctic4427

Citation: Chaput, M.A. and Gajewski, K., 2014. Analysis of Daily Air Temperatures across a Topographically Complex Alpine Region of Southwestern Yukon, Canada. Arctic Institute of North America, vol. 67, no. 4, p. 537-553.

Distribution and landscape controls of organic layer thickness and carbon within the Alaskan Yukon River Basin

Research Location: Yukon River Basin

Publication Type: Journal Article

Publication Date: 2014

Abstract: Understanding of the organic layer thickness (OLT) and organic layer carbon (OLC) stocks in subarctic ecosystems is critical due to their importance in the global carbon cycle. Moreover, post-fire OLT provides an indicator of long-term successional trajectories and permafrost susceptibility to thaw. To these ends, we 1) mapped OLT and associated uncertainty at 30 m resolution in the Yukon River Basin (YRB), Alaska, employing decision tree models linking remotely sensed imagery with field and ancillary data, 2) converted OLT to OLC using a nonlinear regression, 3) evaluate landscape controls on OLT and OLC, and 4) quantified the post-fire recovery of OLT and OLC. Areas of shallow (<10 cm), moderate (≥10 cm and <20 cm), moderately thick (≥20 cm and <30 cm), and thick (≥30 cm) OLT, composed 34, 20, 14, and 18% of the YRB, respectively; the average OLT was 19.4 cm. Total OLC was estimated to be 3.38 Pg. A regional chronosequence analysis over 30 years revealed that OLT and OLC increased with stand age (OLT: R^2 = 0.68; OLC: R^2 = 0.66), where an average of 16 cm OLT and 5.3 kg/m^2 OLC were consumed by fires. Strong predictors of OLT included climate, topography, near-surface permafrost distributions, soil wetness, and spectral information. Our modeling approach enabled us to produce regional maps of OLT and OLC, which will be useful in understanding risks and feedbacks associated with fires and climate feedbacks.

Local Relevance: The northern circumpolar region (including Yukon Territory) has been estimated to contain 50% of the global belowground organic carbon pool. In this paper, the focus is on quantifying and mapping the near-surface organic layer in the Yukon River Basin (YRB) in interior Yukon. This will help researchers better understand and plan for seasonal freeze-thaw processes and moisture variations that may affect forest fire behaviour. Fires frequently burn deep into thick organic layers affecting ecosystem functions such as soil moisture and temperature. Furthermore, the study states that forest fires can thereby affect the active-layer thickness and lead to degradation of near-surface permafrost. This study will provide information essential to resource managers and modelers in understanding responses and feedbacks associated with forest fires and climate change in Yukon. It will also improve our understanding of carbon dynamics in organic layers and their contributions to ecosystem functionality.

Keywords: boreal forest, chronosequence, machine learning, soil carbon, organic layer thickness, remote sensing, succession, tundra, wetlands

Available Online: Full Document http://www.sciencedirect.com/science/article/pii/S0016706114001475

Citation: Pastick, N.J., Rigge, M., Wylie, B.K., Jorgenson, M.T., Rose, J.R., Johnson, K.D. and Ji, L., 2014. Distribution and landscape controls of organic layer thickness and carbon within the Alaskan Yukon River Basin. Geoderma, vol. 230-231, p. 79-94. doi: 10.1016/j.geoderma.2014.04.008

Estimating Temperature Fields from MODIS Land Surface Temperature and Air Temperature Observations in a Sub-Arctic Alpine Environment

Research Location: southwest Yukon and Alaska

Publication Type: Journal Article

Publication Date: 2014

Abstract: Spatially continuous satellite infrared temperature measurements are essential for understanding the consequences and drivers of change, at local and regional scales, especially in northern and alpine environments dominated by a complex cryosphere where *in situ* observations are scarce. We describe two methods for producing daily temperature fields using MODIS "clear-sky" day-time Land Surface Temperatures (LST). The Interpolated Curve Mean Daily Surface Temperature (ICM) method, interpolates single daytime Terra LST values to daily means using the coincident diurnal air temperature curves. The second method calculates daily mean LST from daily maximum and minimum LST (MMM) values from MODIS Aqua and Terra. These ICM and MMM models were compared to daily mean air temperatures recorded between April and October at seven locations in southwest Yukon, Canada, covering characteristic alpine land cover types (tundra, barren, glacier) at elevations between 1408 m and 2319 m. Both methods for producing mean daily surface temperatures have advantages and disadvantages. ICM signals are strongly correlated with air temperature (R^2 = 0.72 to 0.86), but have relatively large variability (RMSE = 4.09 to 4.90 K), while MMM values had a stronger correlation to air temperature (R^2 = 0.90) and smaller variability (RMSE = 2.67 K). Finally, when comparing 8-day LST averages, aggregated from the MMM method, to air temperature, we found a high correlation (R^2 = 0.84) with less variability (RMSE = 1.54 K). Where the trend was less steep and the y-intercept increased by 1.6 °C compared to the daily correlations. This effect is likely a consequence of LST temperature averages being differentially affected by cloud cover over warm and cold surfaces. We conclude that satellite infrared skin temperature (e.g., MODIS LST), which is often aggregated into multi-day composites to mitigate data reductions caused by cloud cover, changes in its relationship to air temperature depending on the period of aggregation.

Local Relevance: Yukon and parts of Alaska have experienced the greatest warming of sub-arctic environments over the last 50 years and this has major impacts on ecosystems, environmental health, and food security in the north. This study examines the effects on northern alpine ecosystems and the associated cryosphere, including snow extent, tundra land cover composition and distribution, permafrost, net ecosystem productivity, and population dynamics of animals and plants in southwest Yukon. Mean surface temperature provides a fundamental measure for understanding the changes occurring in Arctic, sub-Arctic and alpine land surface processes. Mean Daily Surface Temperature modelled from (1) MODIS LST tile data and interpolated daily air temperature curve shape (ICM) and (2) MODIS maximum and minimum data were compared to mean air temperatures from 7 alpine meteorological monitoring stations covering tundra, talus and glacier land cover at varying elevations (i.e., between 1408 m and 2319 m). This study found that the ICM is a viable gap-filling technique for situations where only single observations of day-time LST are available; however, the daily average of maximum and minimum LST values produce a better result compared to air temperature.

Keywords: mean daily surface temperature, land surface temperature, air temperature, MODIS, meteorological station, tundra, Yukon Canada

Available Online: Full Document http://www.mdpi.com/2072-4292/6/2/946/htm

Citation: Williamson, S.N., Hik, D.S., Gamon, J.A., Kavanaugh, J.L. and Flowers, G.E., 2014. Estimating temperature fields from MODIS land surface temperature and air temperature observations in a sub-arctic alpine environment. Remote Sensing, vol. 6, issue 2, p. 946-963. doi:10.3390/rs6020946

Sources and sinks of carbon in boreal ecosystems of interior Alaska: A review

Research Location: Interior Alaska

Publication Type: Journal Article

Publication Date: 2014

Abstract: Boreal ecosystems store large quantities of carbon but are increasingly vulnerable to carbon loss due to disturbance and climate warming. The boreal region in Alaska and Canada, largely underlain by discontinuous permafrost, presents a challenging landscape for itemizing carbon sources and sinks in soil and vegetation. The roles of fire, forest succession, and the presence (or absence) of permafrost on carbon cycle, vegetation, and hydrologic processes have been the focus of multidisciplinary research in boreal ecosystems for the past 20 years. However, projections of a warming future climate, an increase in fire severity and extent, and the potential degradation of permafrost could lead to major landscape and carbon cycle changes over the next 20 to 50 years. To assist land managers in interior Alaska in adapting and managing for potential changes in the carbon cycle we developed this review paper by incorporating an overview of the climate, ecosystem processes, vegetation, and soil regimes. Our objective is to provide a synthesis of the most current carbon storage estimates and measurements to guide policy and land management decisions on how to best manage carbon sources and sinks. We surveyed estimates of aboveground and belowground carbon stocks for interior Alaska boreal ecosystems and summarized methane and carbon dioxide fluxes. These data have been converted into similar units to facilitate comparison across ecosystem compartments. We identify potential changes in the carbon cycle with climate change and human disturbance. A novel research question is how compounding disturbances affect carbon sources and sinks associated with boreal ecosystem processes. Finally, we provide recommendations to address the challenges facing land managers in efforts to manage carbon cycle processes. The results of this study can be used for carbon cycle management in other locations within the boreal biome which encompasses a broad distribution from 45° to 83° north.

Local Relevance: A majority of Yukon consists of a boreal forest ecosystem. The boreal forest covers 12 million km^2 and accounts for about 1/3 of the planet's forests, making it one of the largest biomes in the world. In Canada, the boreal forest occupies about 35% of Canada's total land area and 77% of Canada's forested land, stretching across the country from the Yukon Territory to Newfoundland and Labrador. The Yukon's boreal forest is mostly underlain by discontinuous permafrost and is increasingly being affected by more intense wildfires. Wildfire activity is expected to increase with a projected warming climate in the future and could alter the Yukon's landscapes through degradation of permafrost as well as changes to the carbon cycle over the next 20 to 50 years. Anticipating these changes will assist decision makers in better preparing for potential changes in Yukon's environment and boreal ecosystems. The impacts of changes in the carbon cycle from climate change and human disturbance was assessed and recommendations were made. Any removal of the organic soil layer or moss ground cover will increase the ground heat flux, which promotes permafrost thaw. This includes road building, clearing fire lines, developing trails, and infrastructure development. Extensive insect outbreaks have been associated with climate warming in Yukon and the most notable are the spruce bark beetle (*Ips typographus*) outbreaks that have reached epidemic levels and caused widespread

spruce mortality in southwest Yukon. The unprecedented amount of standing dead spruce trees has caused regional managers to rethink fire management and emergency planning.

Keywords: boreal forest, wildfires, permafrost, carbon stock and carbon cycle, management, policy development

Available Online: Full Document https://www.elementascience.org/articles/32

Citation: Douglas, T.A., Jones, M.C., Hiemstra, C.A. and Arnold, J.R., 2014. Sources and sinks of carbon in boreal ecosystems of interior Alaska: A review. Elementa Science of the Anthropocene, 2: 000032. doi: 10.12952/journal.elementa.000032

1.2 HISTORICAL INFLUENCE

American mastodon extirpation in the Arctic and Subarctic predates human colonization and terminal Pleistocene climate change

Research Location: Alaska and Yukon

Publication Type: Journal Article

Publication Date: 2014

Abstract: Existing radiocarbon (^{14}C) dates on American mastodon (*Mammut americanum*) fossils from eastern Beringia (Alaska and Yukon) have been interpreted as evidence they inhabited the Arctic and Subarctic during Pleistocene full-glacial times (~18,000 ^{14}C years B.P.). However, this chronology is inconsistent with inferred habitat preferences of mastodons and correlative paleoecological evidence. To establish a last appearance date (LAD) for *M. americanum* regionally, we obtained 53 new ^{14}C dates on 36 fossils, including specimens with previously published dates. Using collagen ultrafiltration and single amino acid (hydroxyproline) methods, these specimens consistently date to beyond or near the ~50,000 y B.P. limit of ^{14}C dating. Some erroneously "young" ^{14}C dates are due to contamination by exogenous carbon from natural sources and conservation treatments used in museums. We suggest mastodons inhabited the high latitudes only during warm intervals, particularly the Last Interglacial [Marine Isotope Stage (MIS) 5] when boreal forests existed regionally. Our ^{14}C dataset suggests that mastodons were extirpated from eastern Beringia during the MIS 4 glacial interval (~75,000 y ago), following the ecological shift from boreal forest to steppe tundra. Mastodons thereafter became restricted to areas south of the continental ice sheets, where they suffered complete extinction ~10,000 ^{14}C years B.P. Mastodons were already absent from eastern Beringia several tens of millennia before the first humans crossed the Bering Isthmus or the onset of climate changes during the terminal Pleistocene. Local extirpations of mastodons and other mega faunal populations in eastern Beringia were asynchronous and independent of their final extinction south of the continental ice sheets.

Local Relevance: Understanding how the Yukon's landscape was shaped during the last glacial retreat can give scientists better insight into what the climate was like and how it contributed to the demise of the megafauna in the territory. New radiocarbon (^{14}C) dates on American mastodon (*Mammut americanum*) fossils in Alaska and Yukon suggest this species suffered local extirpation before terminal Pleistocene climate changes or human colonization. Ecological changes during the Wisconsinan glaciation (~75,000 y ago) led to habitat loss and population collapse. This study presents 53 new ^{14}C dates from 36 fossils that clearly indicate that extirpation of mastodons and other megafaunal species in high latitudes was independent of their later extinction which occurred south of the main ice sheet.

Keywords: extinctions, Pleistocene, radiocarbon, megafauna, Beringia

Available Online: Full Document http://www.pnas.org/content/111/52/18460.full

Citation: Zazula, G.D., MacPhee, R.D.E., Metcalfe, J.Z., Reyes, A.V., Brock, F., Druckenmiller, P.S., Groves, P., Harington, C.R., Hodgins G.W.L., Kunz, M.L., Longstaffe, F.J., Mann, D.H., McDonald, H.G., Nalawade-Chavan, S. and Southon, J.R., 2014. American mastodon extirpation in the Arctic and Subarctic predates human colonization and terminal Pleistocene climate change. PNAS, vol. 111, no. 52, p. 18460-18465. doi: 10.1073/pnas.1416072111

Paleoenvironmental Studies in Southwestern Yukon

Research Location: southwest Yukon

Publication Type: Journal Article

Publication Date: 2014

Abstract: The St. Elias Mountain region has occupied an important place in the study of the Quaternary because it presents a relatively accessible non-polar ice field and an array of environments from tundra to boreal forest. Paleoenvironmental studies in southwestern Yukon have documented the broad-scale climatic changes of the past 20 000 years, although few studies exist with well-dated sequences at high temporal resolution. *Picea glauca* arrived across the entire region around 10 000 years ago; however, the details regarding its migration pathways are not well known. Available records indicate few major changes in the composition of the boreal forest vegetation since that time. A slightly more intense fire regime in the early to mid-Holocene has been suggested, but this conclusion is based on only a few studies. Variations in the tree line during the Holocene have been examined, but these studies also lack details. There is no evidence for more extensive grasslands in the area during the Holocene. Paleolimnological studies indicate that changes in populations of aquatic organisms have occurred in response to either Holocene climates or watershed variability.

Local Relevance: In recent years palaeolimnologists have recognized that climate is a dominant force in aquatic ecosystem processes. Southwest Yukon occurs at the easternmost part of the ancient landmass known as Beringia. This research used paleolimnological studies to develop paleoenvironmental reconstructions of the Kluane region. The basic data was obtained from sediment cores collected in lakes or from wetlands in southwest Yukon. Radiocarbon dating of microfossils from the sediment core samples revealed that the boreal forest in southwest Yukon was established by ~10 000 years ago as the climate began warming. This warming also coincided with the introduction of spruce into the region. Although no generalization of the history of the freshwater ecosystems could be made for the region during the Holocene, paleo studies such as these help to improve our understanding of ecosystem functioning in northern boreal regions. Understanding paleoenvironments and their associated climate may help to predict future changes in ecosystems related to climate change.

Keywords: Quaternary, Holocene, boreal forest, Yukon, Kluane Lake, paleoecology, pollen analysis, paleolimnology, climatic change, dendroclimatology, fire history

Available Online: Full Document http://arctic.journalhosting.ucalgary.ca/arctic/index.php/arctic/article/view/4349

Citation: Gajewski, K., Bunbury, J., Vetter, M., Kroeker, N. and Kahn, A.H., 2014. Paleoenvironmental Studies in Southwestern Yukon. Arctic, vol. 67, no. 5, p. 58-70. doi: http://dx.doi.org/10.14430/arctic4349

1.3 TRADITIONAL/INDIGENOUS KNOWLEDGE

Measuring perceptions of climate change in northern Alaska: pairing ethnography with cultural consensus analysis

Research Location: northwestern North America

Publication Type: Journal Article

Publication Date: 2014

Abstract: Given current and projected warming trends in the Arctic and the important role played by subsistence hunting and fishing in the life of northern rural communities, it is increasingly important to document local observations of climate change and its impacts on livelihood practices. We describe ethnographic research exploring local observations of climate changes and related impacts on subsistence fisheries in three Iñupiat communities in northwest Alaska and six Athabascan communities in the Yukon River drainage. We found consistent agreement among perceptions concerning a broad range of environmental changes affecting subsistence practices in these communities. These observations of environmental changes are not experienced in isolation but within the context of accompanying social changes that are continually reshaping rural Alaskan communities and subsistence economies. In this paper we reflect on our research approach combining multiple methods of inquiry. Participant observation and semi-directed interviews provided the conceptual framework for broadening our focus from climate and environmental change to community residents' understanding of climate change in the context of their holistic human-environment worldview. Cultural consensus analysis allowed us to assess the extent to which perceptions of change are shared among hunters and fishers within and between villages and regions and to identify those phenomena occurring or experienced at smaller scales. Reflecting on this multi-methods approach, we highlight important questions that have emerged about how we understand, synthesize, and represent local knowledge, especially as it is used in regulatory or management arenas.

Local Relevance: Northern ecosystems are undergoing rapid shifts as a result of global climate change, with significant implications for the livelihoods of indigenous peoples who rely heavily on wild resources. In Yukon, climate change is affecting the traditional ways of life; for example, climate change has altered hunting routes resulting in changes such as an unsafe route due to ice conditions, erosion and landslides, as well as shifts in animal migration patterns. Previous studies in the Arctic have established that indigenous observations can strengthen climate change research by providing a rich source of environmental history and baseline data. These data may be used as a framework for formulating research questions, and give insight into impacts and adaptations for Yukoners as a whole. This study took into consideration local observations and impacts of climate change on subsistence hunting and fishing in nine rural communities in northern Alaska and the people interviewed pursued a wide range of game and fish. Furthermore, each community is situated in ecologically distinct areas in order to represent the variety of habitats across northern Alaska. The results showed consistent and significant indications of the effects of climate change on northern and rural communities. The main findings included 1) physical environmental change; 2) fish distribution, abundance, and quality; 3) travel and access to resources; 4) fish processing; and 5) socioeconomic and cultural change. In addition to changing climatic conditions, the study found that changing living conditions,

decreasing interest by younger generations in pursuing subsistence lifestyles, and economic challenges in rural northern communities have the potential to forever change the fabric of a lifestyle practiced for millennia.

Keywords: arctic, climate change, cultural consensus analysis, fishing, indigenous peoples, local and traditional ecological knowledge, subsistence

Available online: Full Document http://www.ecologyandsociety.org/vol19/iss4/art27/

Citation: Carothers, C., Brown, C., Moerlein, K.J., López, J.A., Andersen, D.B. and Retherford, B., 2014. Measuring perceptions of climate change in northern Alaska: pairing ethnography with cultural consensus analysis. Ecology and Society vol. 19, no. 4, Article 27. http://dx.doi.org/10.5751/ES-06913-190427

Guarding Against Exploitation: Protecting Indigenous Knowledge in the Age of Climate Change

Research Location: Alaska

Publication Type: Journal Article

Publication Date: 2015

Abstract: Indigenous knowledge has the potential to ameliorate the extreme, destructive impacts of climate change. Given their enduring connection to place, indigenous communities are the subjects of knowledge acquisition relevant to the changing climate. Yet, because this traditional knowledge has been exploited by outsiders, indigenous communities may be wary to share such valuable information with individuals outside of their communities. And, even if traditional knowledge is shared, indigenous peoples may wish to maintain control over its use to guard against exploitation. This article addresses concerns associated with the stewarding of such traditional knowledge, in hopes of providing legal structure to the conversation. As the application of traditional knowledge becomes more apparent in the climate change context, a conversation to invoke action in the academy and legal systems is needed to create structures that value as well as protect the complexities of indigenous community-based research. Ultimately, this article strives to explore methods of holding those who seek and steward traditional knowledge accountable to indigenous communities. To accomplish this goal, this article examines traditional knowledge held by tribes within the United States that may prove helpful in the fight against the deleterious impacts of climate change. Then, having identified valuable knowledge possessed by tribes, the article goes on to examine the potential for existing domestic and international law to protect against the exploitation of such knowledge. After concluding that the existing law provides inadequate protection at best, the article asserts that tribes may be better served by enacting their own tribal laws to protect against such exploitation, and then explores the existing tribal law enacted to protect tribal traditional knowledge. This is the first article to provide concrete examples of traditional knowledge useful in combating the impacts of climate change and how the law may apply in such instances. This is also the first article to examine the use of tribal law to address the protection of traditional knowledge in-depth and provide a discussion of how some tribes are already utilizing tribal law to accomplish such goals. Accordingly, this article constitutes an important addition to the scholarship surrounding protection of traditional knowledge.

Local Relevance: This research explores the use of traditional knowledge (TK) and its relevance to combating climate change through the enduring connections to the land shown by indigenous peoples. In Yukon there are 14 Fist Nations groups that all have a connection to their local

surrounding areas. The use and protection of TK is a concern of the local peoples because they are weary of its use and ownership. This paper outlines the process and the associated legalities of the protection and use of TK. As the climate changes, indigenous peoples are relying on place-based knowledge systems as a mechanism of resilience and adaptation. Yukon Final Agreements give more leverage for the use of TK in Yukon and is increasingly being looked to as a tool to combat the impacts of climate change in the territory; e.g., traditional knowledge is one of the key elements used by the Yukon Environmental and Socio-economic Assessment Board (YESSAB) when reviewing project proposals for development. As the climate changes, indigenous peoples are relying on place-based knowledge systems as a mechanism of resilience and adaptation to maintain Yukon's ecosystems and lifestyles for all Yukoners. As a result, traditional knowledge born from indigenous communities and specific to place, are contributing to the global issues associated with environmental change.

Keywords: traditional knowledge, indigenous knowledge, climate change, intellectual property, tribes, Native Americans, American Indians, Indigenous People, Indians

Available Online: Abstract http://ssrn.com/abstract=2567995

Citation: Brewer, J.P. and Kronk-Warner, E.A., 2015. Guarding Against Exploitation: Protecting Indigenous Knowledge in the Age of Climate Change. Social Science Research Network, USA, 42 p.

Traditional food consumption is associated with better diet quality and adequacy among Inuit adults in Nunavut, Canada

Research Location: Arctic and Sub-Arctic

Publication Type: Journal Article

Publication Date: 2015

Abstract: The Inuit population is undergoing a rapid nutrition transition as a result of reduced consumption of traditional foods. This study aims to describe the differences in dietary adequacy between non-traditional and traditional eaters among Inuit populations in Nunavut, Canada. A cross-sectional survey was conducted using a culturally appropriate quantitative food frequency questionnaire. Participants included 208 Inuit adults from three isolated communities in Nunavut. Traditional eaters consumed a more nutrient-dense diet and achieved better dietary adequacy than non-traditional eaters. Traditional foods accounted for 7 and 27% of energy intake among non-traditional and traditional eaters, respectively. Non-nutrient-dense foods accounted for a greater proportion of energy intake in non-traditional eaters; however, these were consumed in significant amounts by both the groups (36 and 27% of total energy). Consumption of traditional foods is associated with greater diet quality and dietary adequacy. Efforts should be made to promote traditional and non-traditional foods of high-nutritional quality.

Local Relevance: Dietary transition is a consequence of lifestyle changes in the Arctic. In Yukon, as climate change makes hunting and gathering county foods more difficult, it is important to document any changes that non-traditional food might have on the indigenous populations. Traditional foods are being replaced in the diet by imported, processed foods high in fat and sugar and of relatively low-nutritional quality. These non-traditional foods are also expensive to obtain and there are many families in northern Yukon that cannot afford an adequate amount of store-bought foods. Furthermore, this study has shown that some non-traditional foods are unhealthy and lack the energy-storage capacity necessary for the people to survive

in a harsh and cold environment. The results showed that from 208 Inuit adult participants, the mean vitamin E and dietary fibre consumptions for all men and women were below the dietary reference intakes (DRIs). The diet of traditional eaters contained a higher density of protein, omega-3 fatty acids, riboflavin, niacin, pantothenic acid, vitamin B-12, iron, magnesium, potassium, selenium, zinc (p0.0001), thiamin (p0.001) and vitamin A (p0.05), as well as a more favourable omega 6:3 ratio than that of non-traditional eaters (5:1 versus 10:1, respectively). This study confirms that for Yukon First Nation peoples, consumption of traditional foods is associated with greater nutrient density, specifically with regard to protein and a number of vitamins and minerals. Promoting the consumption of traditional foods will lead to fewer costs to the medical and health sectors when caring for northern peoples in the Yukon Territory.

Keywords: Aboriginal populations, nutrient density, nutrition transition, traditional eaters

Available Online: Full Document http://www.informahealthcare.com

Citation: Sheehy, T., Kolahdooz, F., Roache, C. and Sharma, S., 2015. Traditional food consumption is associated with better diet quality and adequacy among Inuit adults in Nunavut, Canada. International Journal of Food Sciences and Nutrition, vol. 66, issue 4, p. 445-451. doi: 10.3109/09637486.2015.1035232

Voices of the Caribou People: a participatory videography method to document and share local knowledge from the North American human- Rangifer systems

Research Location: North American Arctic

Publication Type: Journal Article

Publication Date: 2014

Abstract: "Voices of the Caribou People" is a participatory videography project for documenting and sharing the local knowledge of caribou-user communities about social-ecological changes. The project was conducted in partnership with indigenous people who share a long and close relationship with caribou and self-identify as the "Caribou People." The Caribou People desired to share their knowledge, experiences, challenges, and coping strategies with other indigenous communities and with scientists and wildlife managers. Six communities in the North American Arctic participated in the project, with 99 people interviewed about the ecological, cultural, spiritual, and nutritional aspects of their relationship with caribou. The Caribou People wished to tell their stories with their own voices, without the filter of a researcher's interpretations of their messages. The communities defined three project goals, i.e., documentation, communication, and sharing of knowledge, and we identified methodological challenges associated with these goals. Through videography, we sought to overcome these challenges and accomplish community goals, which formed the basis for our project's evaluation. Participants reported changes and concerns ranging from impacts of oil and gas exploration, mining activities, nonlocal hunting, and high energy costs to impacts of climate-related conditions. All interviews were made available in the public domain via the Internet for sharing. In the view of the communities, videography preserved their legacy and served as a repository of traditional knowledge in changing times; visual images were seen as a powerful medium to communicate with policy makers and the public at large and were seen as a preferred informal, unstructured approach. We have (1) described the approach of the Voices of the Caribou People project as a collaborative video methodology and (2) discussed the effectiveness of this method in meeting the goals of participatory research. General insights into the process of using videography as a participatory research tool to study social ecological systems in partnership with indigenous communities have been provided.

Local Relevance: Caribou are essential to Yukon First Nation's culture, not only as a food source but many native communities also maintain strong spiritual ties with the caribou and identify themselves as "Caribou People". This research uses video-based documentation of the indigenous knowledge, observations and perspectives of the Caribou People with a focus on social-ecological changes. . The goal of the project is to document local people's experiences of change, perceptions of impacts, and responses to those changes from six communities across the North American Arctic. These changes and concerns include impacts of oil and gas exploration, mining activities, nonlocal hunting, and high energy costs to impacts of climate-related conditions. Furthermore, the researchers set out to document the context and breadth of the social ecological system encompassing Arctic people and caribou. The community of Old Crow (one of the six selected communities) believes the main threat to the Porcupine caribou herd is from potential oil and gas development in the Arctic National Wildlife Refuge, and for past two decades, Vuntut Gwitchin representatives have been participating in the lobbying efforts in Washington, D.C., to avoid development within the refuge. This study demonstrates the importance of incorporating local knowledge and perspectives in scientific research in order to achieve a holistic understanding of change thus promoting the adaptive capacity of northern communities.

Keywords: Caribou People, human-rangifer systems, indigenous communities, local knowledge, participatory research, traditional knowledge, videography

Available Online: Full Document http://www.ecologyandsociety.org/vol19/iss2/art16/

Citation: Bali, A. and Kofinas, G.P., 2014. Voices of the Caribou People: a participatory videography method to document and share local knowledge from the North American human-*Rangifer* systems. Ecology and Society vol. 19, no. 2, art. 16. http://dx.doi.org/10.5751/ES-06327-190216

Indigenous Knowledge of Hydrologic Change in the Yukon River Basin: A Case Study of Ruby, Alaska

Research Location: Yukon River Basin

Publication Type: Journal Article

Publication Date: 2014

Abstract: In the Arctic and Subarctic, the contribution of Indigenous knowledge to understanding environmental change has been established over the last several decades. This paper explores the role of Indigenous knowledge of water in understanding hydrologic change within complex social-ecological systems. Observations of hydrology in the Yukon River Basin, contributed by 20 community experts from Ruby Village, Alaska, in semi-structured interviews, are compared with findings from scientific literature to illustrate the commonalities and differences. Research findings reveal the contribution of Indigenous knowledge to understandings of hydrologic change in the Yukon River and its tributaries, which includes insights regarding alterations in sediment and river ice regimes. Recommendations for future research that incorporates Indigenous knowledge of water to gain insight into hydrologic changes in the watershed include combining multiple case studies that are distributed geographically. Our findings suggest 1) that using participatory research approaches to research will help ensure that it benefits the communities whose livelihoods are affected by hydrologic changes, and 2) that a multidisciplinary approach that combines qualitative and quantitative methods from the social and biophysical sciences would be most effective to help us understand and respond to hydrologic changes.

Local Relevance: Freshwater ecosystems located in the Yukon Territory are sensitive to climatic changes because they depend on complex interactions between temperature, precipitation, and permafrost. In Yukon, an increased warming trend has been observed over the past decade. This warming is expected to bring changes to the local ecosystems and result in alterations to water and sediment chemistry in Yukon waters. Due to the lack of knowledge on the most vulnerable watersheds in Yukon, researchers are increasingly looking at Indigenous or Traditional Knowledge to fill the information gap. Yukon has 14 First Nation communities with extensive local knowledge. The value of Indigenous knowledge for perceiving and responding to changes in water resources has been acknowledged in a number of contexts. The authors of this paper define Indigenous knowledge as "a cumulative body of knowledge, practice, and belief, evolving by adaptive processes and handed down through generations by cultural transmission, about the relationship of living beings (including humans) with one another and with their environment" (Berkes, 2008:7). The conclusion of this study indicates that hydrologic changes are occurring in the Yukon River Basin (YRB), including alterations in temperature, precipitation, permafrost, annual hydrograph, river ice, and sediment regimes. The study found that Indigenous knowledge can help with the scientific understanding of hydrologic change in three ways: 1) it can provide valuable data in the absence of substantive Western scientific observations related to specific areas of hydrologic change; 2) it can indicate new areas of inquiry by contributing observations not previously considered by Western scientific studies; and 3) it can be used simultaneously with Western scientific methods of observation in long-term monitoring projects.

Keywords: climate change, Indigenous knowledge of water, socio-hydrology, river dynamics, water resources

Available Online: Full Document http://dx.doi.org/10.14430/arctic4459

Citation: Wilson, N.J., Walter, M.T. and Waterhouse, J., 2014. Indigenous Knowledge of Hydrologic Change in the Yukon River Basin: A Case Study of Ruby, Alaska. ARCTIC, vol. 68, no. 1, p. 93-106

2. HYDROLOGY

2.1 YUKON RIVER BASIN

Effects of Disturbance and Climate Change on Ecosystem Performance in the Yukon River Basin Boreal Forest

Research Location: Yukon River Basin

Publication Type: Journal Article

Publication Date: 2014

Abstract: A warming climate influences boreal forest productivity, dynamics, and disturbance regimes. We used ecosystem models and 250 m satellite Normalized Difference Vegetation Index (NDVI) data averaged over the growing season (GSN) to model current, and estimate future, ecosystem performance. We modeled Expected Ecosystem Performance (EEP), or anticipated productivity, in undisturbed stands over the 2000–2008 period from a variety of abiotic data sources, using a rule-based piecewise regression tree. The EEP model was applied to a future climate ensemble A1B projection to quantify expected changes to mature boreal forest performance. Ecosystem Performance Anomalies (EPA), were identified as the residuals of the EEP and GSN relationship and represent performance departures from expected performance conditions. These performance data were used to monitor successional events following fire.

Results suggested that maximum EPA occurs 30–40 years following fire, and deciduous stands generally have higher EPA than coniferous stands. Mean undisturbed EEP is projected to increase 5.6% by 2040 and 8.7% by 2070, suggesting an increased deciduous component in boreal forests. Our results contribute to the understanding of boreal forest successional dynamics and its response to climate change. This information enables informed decisions to prepare for, and adapt to, climate change in the Yukon River Basin forest

Local Relevance: Ecosystem productivity in the boreal forest is often constrained by short growing seasons, lack of winter sunlight, temperature, permafrost, low soil nutrient levels and disturbance. The Yukon is predicted to continue warming throughout the 21st century, and climatic changes over the last century have already resulted in warmer spring temperatures accompanied by an earlier start to the growing season, as well as warmer summers and winter. Furthermore, ecosystem productivity is increasingly limited by stresses on mid-summer moisture causing increased wildfire danger. This paper supports the notion that the strength and direction of future productivity patterns in the boreal forest depends largely on changes to the quantity and timing of precipitation. In Yukon, this information will enable informed decisions to prepare for, and adapt to, climate change in the Yukon River Basin's boreal forest. For example, a shift is predicted to occur from a predominantly coniferous boreal forest to a forest having an increased deciduous component due to an increase in fire severity and burned areas. The study concludes that low precipitation impacts are especially apparent in the Yukon Flats region in the north-central part of the Yukon River Basin and in east-central Yukon, which has some of the lowest site potentials in the basin due to their continentality and rain shadows that reduce precipitation. Results broadly suggest increased estimated ecosystem performance (EEP) in undisturbed forests in the west; in the east (i.e., the drier portions of Yukon), there will be reduced EEP by 2040 followed by a reverse in direction to a net positive undisturbed EEP by 2070, following precipitation contours.

Keywords: boreal, climate change, fire, succession, forest composition, future

Available Online: Full Document http://www.mdpi.com/2072-4292/6/10/9145/htm

Citation: Wylie, B., Rigge, M., Brisco, B., Murnaghan, K., Rover, J. and Long, J., 2014. Effects of Disturbance and Climate Change on Ecosystem Performance in the Yukon River Basin Boreal Forest. Remote Sensing, vol. 6, issue 10, p. 9145-9169. doi: 10.3390/rs6109145

Modelled sensitivity of the snow regime to topography, shrub fraction and shrub height

Research Location: Granger Basin (GB), Yukon

Publication Type: Journal Article

Publication Date: 2014

Abstract: Recent studies show that shrubs are colonizing higher latitudes and altitudes in the Arctic. Shrubs affect the wind transport, accumulation and melt of snow, but there have been few sensitivity studies of how shrub expansion might affect snowmelt rates and timing. Here, a three-source energy balance model (3SOM), which calculates vertical and horizontal energy fluxes – thus allowing within-cell advection – between the atmosphere, snow, snow-free ground and vegetation, is introduced. The three-source structure was specifically adopted to investigate shrub–tundra processes associated with patchy snow cover that single- or two-source models fail to address. The ability of the model to simulate the snow regime of an upland tundra valley is evaluated; a blowing snow transport and sublimation model is used to simulate pre-melt

snow distributions and 3SOM is used to simulate melt. Some success at simulating turbulent fluxes in point simulations and broad spatial pattern in distributed runs is shown even if the lack of advection between cells causes melt rates to be underestimated. The models are then used to investigate the sensitivity of the snow regime in the valley to varying shrub cover and topography. Results show that, for domain average shrub fractional cover < 0.4, topography dominates the pre- and early melt energy budget but has little influence for higher shrub cover. The increase in domain average sensible heat fluxes and net radiation with increasing shrub cover is more marked without topography where shrubs introduce wind-induced spatial variability of snow and snow-free patches. As snowmelt evolves, differences in the energy budget between simulations with and without topography remain relatively constant and are independent of shrub cover. These results suggest that, to avoid overestimating the effect of shrub expansion on the energy budget of the Arctic, future large-scale investigations should consider wind redistribution of snow, shrub bending and emergence, and sub-grid topography as they affect the variability of snow cover.

Local Relevance: The effects of shrub expansion or retreat on tundra surface energy balance have garnered much attention over the past decade. The tundra in the Yukon Territory is the vast, rocky plain in the arctic regions, where the extreme climate has stunted vegetation located in the northern regions. This study looks at the increasing evidence from field observations suggesting that warming in the arctic regions have led to a "greening" that is partly due to the densification and expansion of shrub patches. The paper states that the differences and changes in shrub cover also affect the snow mass balance of tundra because the height, density and location of shrubs affect snow distribution by reducing near-surface wind speeds within and downwind of shrub patches. Shrub cover may also trap wind-blown snow around isolated patches or at the edges of large patches thus increasing or decreasing water retention and exposure to wind. This can affect migration routes of wild game thus disturbing hunting patterns of the local peoples of the north altering their way of life and adding to concerns about food security. Further, this study suggests that the expansion and densification of tundra shrub patches in a warming climate will have a positive feedback on warming through decreases in surface albedo and increases in sensible heat fluxes to the atmosphere.

Keywords: tundra, higher latitudes, Arctic, shrub expansion, snow melt, long-wave radiation, energy balance

Available Online: Full Document www.hydrol-earth-syst-sci.net/18/2375/2014/

Citation: Ménard, C.B., Essery, R. and Pomeroy, J., 2014. Modelled sensitivity of the snow regime to topography, shrub fraction and shrub height. Hydrology and Earth System Sciences, vol. 18, issue 6, p. 2375-2392, 2014. doi: 10.5194/hess-18-2375-2014

Arctic Climate and Water Change: Model and Observation Relevance for Assessment and Adaptation

Research Location: Circumpolar Regions

Publication Type: Journal Article

Publication Date: 2013

Abstract: The Arctic is subject to growing economic and political interest. Meanwhile, its climate and water systems are in rapid transformation. In this paper, we review and extend a set of studies on climate model results, hydro-climatic change, and hydrological monitoring systems. Results indicate that general circulation model (GCM) projections of drainage basin

temperature and precipitation have improved between two model generations. However, some inaccuracies remain for precipitation projections. When considering geographical priorities for monitoring or adaptation efforts, our results indicate that future projections by GCMs and recent observations diverge regarding the basins where temperature and precipitation changes currently are the most pronounced and where they will be so in the future. Regarding late twentieth-century discharge changes in major Arctic rivers, data generally show excess of water relative to precipitation changes. This indicates a possible contribution to sea-level rise of river water that was previously stored in permafrost or groundwater. The river contribution to the increasing Arctic Ocean freshwater inflow is similar in magnitude to the separate contribution from glaciers, which underlines the importance of considering all possible sources of freshwater when assessing sea-level change. We further investigate monitoring systems and find a lack of harmonized water chemistry data, which limits the ability to understand the origin and transport of nutrients, carbon and sediment to the sea. To provide adequate information for research and policy, Arctic hydrological and hydro-chemical monitoring needs to be extended, better integrated and made more accessible. Further water-focused data and modeling efforts are required to resolve the source of excess discharge in Arctic rivers. Finally, improvements in climate model parameterizations are needed, in particular for precipitation projections.

Local Relevance: In the Arctic, surface temperatures over the last half-century have increased at a rate that is 50% higher than that of the Northern Hemisphere average, and where future climate change is expected to be the most pronounced. Consequently, climate-related changes in the Arctic have the potential to affect the entire Earth system. This study reviews the following with respect to societal adaptation: 1) the reliability of general circulation models (GCM) on the scale of main Arctic river basins; 2) the recently observed changes to water flow and water budgets in the Arctic; and 3) the representativeness, accessibility and relevance of hydrological and hydrochemical observation systems for assessing changes to water, sediment and hydrochemical fluxes in the Arctic hydrological cycle. Several conclusions were made for the Pan-Arctic Drainage Basin (PADB); however, one of the most notable observations was that deviations in precipitation do not translate into similar deviations in discharge, i.e., there is an excess in discharge compared to available precipitation. This discrepancy may be explained by changes in permafrost or groundwater storage.

Keywords: hydrology, monitoring, Arctic, climate change, adaptation

Available Online: Full Document http://link.springer.com/article/10.1007/s10712-013-9267-6/fulltext.html

Citation: Bring, A. and Destouni, G., 2014. Arctic Climate and Water Change: Model and Observation Relevance for Assessment and Adaptation. Surveys in Geophysics, vol. 35, issue 3, p. 853-877. doi: 10.1007/s10712-013-9267-6

Hydrological sensitivity of a northern mountain basin to climate change

Research Location: Yukon River

Publication Type: Journal Article

Publication Date: 2014

Abstract: The hydrological sensitivity of a northern Canadian mountain basin to change in temperature and precipitation was examined. A physically based hydrological model was created and included important snow and frozen soil infiltration processes. The model was discretized into hydrological response units in order to simulate snow accumulation and melt regimes and basin discharge. Model parameters were drawn from scientific studies in the basin

except for calibration of routing and drainage. The model was able to simulate snow surveys and discharge measurements with very good accuracy. The forcing inputs of the hourly air temperatures and daily precipitation were scaled linearly to examine the model sensitivity to conditions included in a range of climate change scenarios: warming of up to 5 °C and change in precipitation of ±20%. The results show that peak seasonal snow accumulation, snow season length, evapotranspiration, runoff, peak runoff, and the timing of peak runoff have a pronounced sensitivity to both warming and precipitation change, where the impact of warming is partly compensated for by increased precipitation and dramatically enhanced by decreased precipitation. The snow regime, including peak snow accumulation, snow-free period, intercepted snow sublimation, and blowing snow transport, was most sensitive to temperature, and the impact of a warming of 5 °C could not be compensated for by a precipitation increase of 20%. However, basin discharge was more sensitive to precipitation, and the impact of warming could be compensated for by a slight increase in precipitation. The impacts of 5 °C warming with a ±20% change in precipitation resulted in snow accumulation, runoff, and peak stream flow decreasing by from one half to one fifth and the snow-free period lengthening by from 46 to 60 days; in both cases, the smaller change is associated with increased precipitation and the larger change with decreased precipitation. These results show that mountain hydrology in Northern Canada is extremely sensitive to warming, that snow regime is more sensitive to warming than stream flow and that changes in precipitation can partly modulate this response.

Local Relevance: Air temperatures in northern latitudes in general and specifically in the Yukon Territory, Canada have increased significantly within the last decades; however, precipitation has been variable showing increases in summer precipitation throughout Yukon, whereas winter precipitation has decreased in southern Yukon and increased in central and northern parts of the territory. These temperature and precipitation changes ultimately affect the hydrological cycle. This study attempts to estimate components of the hydrological cycle using a physically based model created using the Cold Regions Hydrological Modelling (CRHM) platform that will in turn be able to assess the sensitivity of the hydrological response to climate change in a Yukon mountain basin. This research aims to highlight the combination of changes in temperature and precipitation that are necessary to induce significant changes in basin hydrology. The simulated changes in this research demonstrate that snow packs are very sensitive to warming in wet years and less sensitive in drier years; this is mostly due to spring contributions to wet year precipitation and the phase sensitivity of relatively warm spring snowfall. Although the research clearly shows that warming will have an undeniable impact on cold regions hydrological processes (e.g., reduced snow contribution to streamflow, shorter snow-covered period, and greater evapotranspiration), the magnitude and direction of the impact of warming on streamflow hydrology will depend on changes to precipitation. Consequently, both warming and changes to precipitation must be considered when evaluating future hydrology in Yukon. Results from this study may be used to inform the early development of adaptation strategies such as improving flood forecasting and warning systems, infrastructure design modification, land zoning changes, as well as changes to policy, regulation and legislation.

Keywords: climate change impact, Yukon, sensitivity analysis, snow hydrology, cold regions, hydrological modelling

Available Online: Full Document http://onlinelibrary.wiley.com/doi/10.1002/hyp.10244/full

Citation: Rasouli, K., Pomeroy, J.W., Janowicz, J.R., Carey, S.K. and Williams, T.J., 2014. Hydrological sensitivity of a northern mountain basin to climate change. Hydrological Processes, Canadian Geophysical Union Special Issue 2014, vol. 28, issue 14, p. 4191-4208. doi: 10.1002/hyp.10244

2.2 NORTHERN LAKES

Potential Influence of Climate Change on the Acid-Sensitivity of High-Elevation Lakes in the Georgia Basin, British Columbia

Project Location: British Columbia (Coast Mountains)

Publication Type: Journal Article

Publication Date: 2015

Abstract: Global climate models predict increased temperature and precipitation in the Georgia Basin, British Colombia; however, little is known about the impacts on high-elevation regions. In the current study, fifty-four high-elevation lakes (754–2005m a.s.l.) were studied to investigate the potential influence of climate change on surface water acid-sensitivity. Redundancy analysis indicated that the concentration of nitrate, dissolved organic carbon, and associated metals was significantly influenced by climate parameters. Furthermore, these components differed significantly between biogeoclimatic zones. Modelled soil base cation weathering for a subset of the study lakes (n = 11) was predicted to increase by 9% per 1°C increase in temperature. Changes in temperature and precipitation may potentially decrease the pH of surface waters owing to changes in anthropogenic deposition and organic acid production. In contrast, increased soil base cation weathering may increase the critical load (of acidity) of high-elevation lakes. Ultimately, the determining factor will be whether enhanced base cation weathering is sufficient to buffer changes in natural and anthropogenic acidity. Mountain and high-elevation regions are considered early warning systems to climate change; as such, future monitoring is imperative to assess the potential ramifications of climate change on the hydrochemistry and acid-sensitivity of these surface waters.

Local Relevance: The high central Yukon Plateau, at an average elevation of 1200 m, is interrupted frequently by local mountain areas and deep valleys and there are over 600 km of interconnected lakes in the Yukon Territory. It is widely accepted that changes in climate may significantly alter the biological, physical, and chemical systems of mountainous regions and Yukon is no exception. This study monitored lakes whereby the elevations ranged between 754 and 2005 m a.s.l. with 72% of the lakes having elevations ≥1000 m a.s.l. The lakes were characterized by low conductivity (median = 6.0 μS cm−1 at 25°C) and low base cation and nutrient concentrations which are typical of the dilute nature of high-elevation lakes. The research concludes that the ratio between increased transport of base cations into surface waters, deposition levels, and increased acidifying components from organic anion production will ultimately determine whether lakes will continue to be susceptible to acidification.

Keywords: increased temperature, precipitation, climate change, soil base cation, high-elevation

Available Online: Full Document http://www.hindawi.com/journals/amete/2015/536892/

Citation: Strang, D. and Aherne, J., 2015. Potential Influence of Climate Change on the Acid-Sensitivity of High-Elevation Lakes in the Georgia Basin, British Columbia. Advances in Meteorology, vol. 2015, Article ID 536892, 11 p. doi: 10.1155/2015/536892

Pronounced chemical response of Subarctic lakes to climate-driven losses in surface area

Research Location: Alaska

Publication Type: Journal Article

Publication Date: 2014

Abstract: Losses in lake area have been observed for several Arctic and Subarctic regions in recent decades, with unknown consequences for lake ecosystems. These reductions are primarily attributed to two climate-sensitive mechanisms, both of which may also cause changes in water chemistry: (i) increased imbalance of evaporation relative to inflow, whereby increased evaporation and decreased inflow act to concentrate solutes into smaller volumes; and (ii) accelerated permafrost degradation, which enhances sub lacustrine drainage while simultaneously leaching previously frozen solutes into lakes. We documented changes in nutrients [total nitrogen (TN), total phosphorus (TP)] and ions (calcium, chloride, magnesium, sodium) over a 25 year interval in shrinking, stable, and expanding subarctic lakes of the Yukon Flats, Alaska. Concentrations of all six solutes increased in shrinking lakes from 1985–1989 to 2010–2012, while simultaneously undergoing little change in stable or expanding lakes. This created a present-day pattern, much weaker or absent in the 1980s, in which shrinking lakes had higher solute concentrations than their stable or expanding counterparts. An imbalanced evaporation-to-inflow ratio (E/I) was the most likely mechanism behind such changes; all four ions, which behave semi conservatively and are prone to evapoconcentration, increased in shrinking lakes and, along with TN and TP, were positively related to isotopically derived E/I estimates. Moreover, the most conservative ion, chloride, increased >500% in shrinking lakes. Conversely, only TP concentration was related to probability of permafrost presence, being highest at intermediate probabilities. Overall, the substantial increases of nutrients (TN >200%, TP >100%) and ions (>100%) may shift shrinking lakes towards overly eutrophic or saline states, with potentially severe consequences for ecosystems of northern lakes.

Local Relevance: Lakes are in important part of Yukon's ecology and support many species that add to the lush biodiversity of the Territory. This research looks at the impacts of increased evaporation and decreased inflow in subarctic lakes. Accelerated permafrost degradation, which enhances sublacustrine drainage, is a major issue facing the northern regions of Yukon especially in the Old Crow Flats region where many lakes are contained by permafrost. The study documented changes in nutrients [total nitrogen (TN), total phosphorus (TP)] and ions (calcium, chloride, magnesium, sodium) over a 25 year interval in shrinking, stable, and expanding subarctic lakes. Lastly, the results show of the 55 lakes >1 ha, 18 were classified as shrinking, 33 as stable, and 4 as expanding, in which shrinking lakes have markedly higher solute concentrations than their stable and expanding counterparts.

Keywords: aquatic nutrients, eutrophication, evapoconcentration, permafrost, shrinking lakes, subarctic, water chemistry

Available Online: Abstract http://www.ncbi.nlm.nih.gov/pubmed/25294238

Citation: Lewis, T.L., Lindberg, M.S., Schmutz, J.A., Heglund, P.J., Rover, J., Koch, J.C. and Bertram, M.R., 2014. Pronounced chemical response of Subarctic lakes to climate-driven losses in surface area. Global Change Biology, vol. 21, issue 3, p. 1140-1152. doi: 10.1111/gcb.12759

Proximity to ice fields and lake depth as modulators of paleoclimate records: a regional study from southwest Yukon, Canada

Research Location: southwest Yukon Territory

Publication Type: Journal Article

Publication Date: 2014

Abstract: Pronounced climate warming during the past century has been well documented in high latitude regions. Nonetheless, considerable heterogeneity exists in northern climate trends. We examined the roles of cryospheric landscape and lake depth in modulating the rate and magnitude of local climate responses through a paleolimnological study of lakes from southwest Yukon, Canada. By sampling lakes at varying distances from the Wrangell-St. Elias ice fields, we hypothesized that, for lakes of similar maximum depth, sites closest to the ice fields would be relatively complacent in terms of their chironomid and diatom assemblage changes over the past ~200 years. This hypothesis is based on the moderating effect of the glaciers on local climate, which would be most pronounced in the lakes nearest to the ice fields. However, given the known ecological differences between deep and shallow lakes, we further predicted that, for a given distance from the ice fields, a sediment record from a shallower lake would show the greatest change in stratigraphic subfossil assemblages. Because of the complicated shape of the ice fields, we applied the longitude for each site (which decreases from west to east) to approximate the proximity of our study lakes to the ice fields. Consistent with our predictions, we observed a space-transgressive pattern in the chironomid assemblage turnover that was associated with their proximity to the ice fields ($r = -0.75$, $P = 0.034$, $n = 8$) across lakes of similar depth (mean maximum depth ± 1, SE = 18.1 ± 2.6 m). Considering a broader network of lakes that represented a greater range in maximum depth (4.9–29 m), we found that differences in subfossil chironomid assemblages between the modern and ca. AD 1800 sediment layers were strongly related to lake depth ($r = -0.77$, $P < 0.001$, $n = 15$), but failed to detect a significant relationship with latitude or longitude (i.e. our proxy for proximity to the ice fields). Similarly, our comparative high-resolution analyses of two lakes with distinct lake morphometries, but similar proximities to the ice fields, demonstrated the predicted contrasting pattern: we observed pronounced post-1880 changes in the biotic assemblages in the shallow lake and a muted and delayed response (i.e. ~1970s) in the deeper lake. Our findings confirm that cryospheric landscape features can strongly modulate regional climate. Furthermore, our work shows that investigators need to be conscious of how climate change affects the structure and functioning of lakes of different typologies, which influences the way in which paleoclimate signals are recorded and interpreted.

Local Relevance: High-latitude regions have experienced pronounced warming over the past ~150 years and in Yukon this trend is expected to continue into the future. Given the limited spatial and temporal coverage of instrumental climate records in northern regions, paleoenvironmental reconstructions have been key to defining the rate and magnitude of past climate change. This study achieves this by analyzing lake sediments because they are natural archives of environmental change, since the biological, chemical and physical indicators preserved can be used to infer past climate, watershed and limnological conditions. The results of this research shows a total of 61 chironomid taxa were recovered from the sediments of 18 lakes, with 50 taxa observed in at least two samples with a relative abundance ≥2 %. This research has demonstrated that proximity to glaciers structured the subfossil assemblages and their responses to past environmental change over broad spatial coverage. Furthermore, there exists a clear pattern of temporal taxonomic turnover that significantly correlates with distance from cryospheric landscapes (i.e., St. Elias ice fields).

Keywords: cryospheric landscape, lake depth, paleolimnology, chironomids, climate change, spatial heterogeneity

Available Online: Full Document http://link.springer.com/article/10.1007%2Fs10933-014-9787-1

Citation: Chen, G., Selbie, D.T., Griffiths, K., Sweetman, J.N., Botral, M., Taranu, Z.E., Knops, S., Bondy, J., Michelutti, N., Smol, J.P. and Gregory-Eaves, I., 2014. Proximity to ice fields and lake depth as modulators of paleoclimate records: a regional study from southwest Yukon, Canada. Journal of Paleolimnology, vol., 52, p. 185-200 DOI 10.1007/s10933-014-9787-1

Observing a Catastrophic Thermokarst Lake Drainage in Northern Alaska

Research Location: Arctic Coastal Plain, Alaska

Publication Type: Journal Article

Publication Date: 2015

Abstract: The formation and drainage of thermokarst lakes have reshaped ice-rich permafrost lowlands in the Arctic throughout the Holocene. North of Teshekpuk Lake, on the Arctic Coastal Plain of northern Alaska, thermokarst lakes presently occupy 22.5% of the landscape, and drained thermokarst lake basins occupy 61.8%. Analysis of remotely sensed imagery indicates that nine lakes (>10 ha) have drained in the 1,750 km^2 study area between 1955 and 2014. The most recent lake drainage was observed using *in situ* data loggers providing information on the duration and magnitude of the event, and a nearby weather station provided information on the environmental conditions preceding the lake drainage. Lake 195 (L195), an 80 ha thermokarst lake with an estimated water volume of ~872 000 m^3, catastrophically drained on 05 July 2014. Abundant winter snowfall and heavy early summer precipitation resulted in elevated lake water levels that likely promoted bank overtopping, thermo-erosion along an ice-wedge network, and formation of a 9 m wide, 2 m deep, and 70 m long drainage gully. The lake emptied in 36 hours, with 75% of the water volume loss occurring in the first ten hours. The observed peak discharge of the resultant flood was 25 m^3/s, which is similar to that in northern Alaska river basins whose areas are more than two orders of magnitude larger.

Local Relevance: Thermokarst lakes in Yukon play a key role in hydrology, permafrost, carbon, and habitat dynamics in the continuous permafrost zone in the northern regions of the territory. Their formation, expansion, and drainage have actively reshaped ice-rich permafrost lowlands since the onset of the Holocene. This study is the first of its kind to provide valuable *in situ* observations of a natural catastrophic drainage of Lake 195 (L195) located on the younger outer coastal plain of northern Alaska. The 80 ha thermokarst lake drained on July 5, 2014 over a course of 36 hours, and 75% of the 871 990 m^3 volume of water loss occurred in the first 10 hours after the onset of drainage. Peak discharge was observed to be 25 m^3/s and the estimated, peak instantaneous discharge was 29.4 m^3/s. The research indicates that thermokarst lakes may be primed for drainage in early summer, when cold and wet weather conditions prevail, and that drainage may result from bank overtopping and thermo-erosion along an ice wedge networks. The current observations from a natural, thermokarst lake drainage event may provide useful information for predicting future catastrophic lake drainage events and their broader impacts.

Keywords: arctic, catastrophic drainage, lakes, permafrost, thermokarst

Available Online: Full Document http://onlinelibrary.wiley.com/doi/10.1002/ppp.1842/full

Citation: Jones, B.M. and Arp, C.D., 2015. Observing a Catastrophic Thermokarst Lake Drainage in Northern Alaska. Permafrost and Periglacial Processes, vol. 26, issue 2, p. 119-128. doi: 10.1002/ppp.1842

Modelled present and future thaw lake area expansion/contraction trends throughout the continuous permafrost zone

Research Location: Artic Coastal Plain

Publication Type: Journal Article

Publication Date: 2014

Abstract: Thaw lakes and drained lake basins are a dominant feature of Arctic lowlands. Thaw lakes are a source of the greenhouse gas methane (CH_4), which is produced under anaerobic conditions, while drained lake basins are carbon sinks due to sedimentation. Besides feedbacks on climate, the development of thaw lakes due to the melt-out of ground ice and subsequent ground subsidence can have significant impacts on the regional morphology, hydrology, geophysics and biogeochemistry.

Permafrost degradation as a result of climate warming, which is proceeding considerably faster in high latitude regions than the global average, could lead to either an increase in lake area due to lake expansion, or decrease due to lake drainage. However, which process will dominate is elusive. Therefore understanding thaw lake dynamics and quantifying the feedbacks related to thaw lake expansion and contraction are urgent questions to solve.

We apply a stochastic model, THAWLAKE, on four representative Arctic sites, to reproduce recent lake dynamics (1963–2012) and predict for the future changes under various anticipated climate scenarios. The model simulations of current thaw lake cycles and expansion rates are comparable with data. Future lake expansions are limited by lake drainage. We suggest further improvements in the area of enhancing the hydrology component, and operation on larger scales to gauge the impacts on lacustrine morphology and greenhouse gas emissions.

Local Relevance: The northern Yukon is a vast area located in the continuous permafrost zone and which contains an integrated network of thermokarst lakes as seen in the crow flats and Vuntut National Park. The development and evolution of thaw lakes can alter the permafrost carbon budget by releasing methane (CH_4) to the atmosphere and CH_4 is known to have a significantly positive feedback on global warming. In northern high latitudes, rising temperatures are being felt at an accelerated pace, that is faster than any other region in the world. This study looks at understanding thaw lake dynamics and quantifying the feedbacks related to thaw lake expansion and contraction in continuous permafrost zones. The research employs THAWLAKE (a stochastic model) to quantify the evolution of thaw lake area over the last 50 years and subsequently predict future changes under various anticipated climate scenarios. The results of the study demonstrate that under current climate conditions, the model captures realistic thaw lake growth-drainage cycles, and lake expansion and contraction rates are comparable with the data. Additionally, future changes in air temperature and precipitation lead to a significant decline in lake coverage due to lake drainage which has the potential to negatively feedback on the climate system.

Keywords: thawlake, thermokarst lake, permafrost, expansion/contraction, sequestration, drainage

Available Online: Full Document www.the-cryosphere-discuss.net/8/3603/2014/

Citation: Mi, Y., van Huissteden, J. and Dolman, A.J., 2014. Modelled present and future thaw lake area expansion/contraction trends throughout the continuous permafrost zone. The Cryosphere Discussions, vol. 8, issue 4, p. 3603–3627. doi: 10.5194/tcd-8-3603-2014

Methane and carbon dioxide emissions from 40 lakes along a north–south latitudinal transect in Alaska

Research location: Northern Alaska

Publication Type: Journal Article

Publication Date: 2015

Abstract: Uncertainties in the magnitude and seasonality of various gas emission modes, particularly among different lake types, limit our ability to estimate methane (CH_4) and carbon dioxide (CO_2) emissions from northern lakes. Here we assessed the relationship between CH_4 and CO_2 emission modes in 40 lakes along a latitudinal transect in Alaska to lakes' physicochemical properties and geographic characteristics, including permafrost soil type surrounding lakes. Emission modes included direct ebullition, diffusion, storage flux, and a newly identified ice-bubble storage (IBS) flux. We found that all lakes were net sources of atmospheric CH_4 and CO_2, but the climate warming impact of lake CH_4 emissions was 2 times higher than that of CO_2. Ebullition and diffusion were the dominant modes of CH_4 and CO_2 emissions respectively. IBS, ~10% of total annual CH_4 emissions, is the release to the atmosphere of seasonally ice-trapped bubbles when lake ice confining bubbles begins to melt in spring. IBS, which has not been explicitly accounted for in regional studies, increased the estimate of springtime emissions from our study lakes by 320%. Geographically, CH_4 emissions from stratified, mixotrophic interior Alaska thermokarst (thaw) lakes formed in icy, organic-rich yedoma permafrost soils were 6-fold higher than from non-yedoma lakes throughout the rest of Alaska. The relationship between CO_2 emissions and geographic parameters was weak, suggesting high variability among sources and sinks that regulate CO_2 emissions (e.g., catchment waters, pH equilibrium). Total CH_4 emission was correlated with concentrations of soluble reactive phosphorus and total nitrogen in lake water, Secchi depth, and lake area, with yedoma lakes having higher nutrient concentrations, shallower Secchi depth, and smaller lake areas. Our findings suggest that permafrost type plays important roles in determining CH_4 emissions from lakes by both supplying organic matter to methanogenesis directly from thawing permafrost and by enhancing nutrient availability to primary production, which can also fuel decomposition and methanogenesis.

Local Relevance: In lakes, CH_4 and CO_2 have contrasting patterns of production, consumption, and ex-change with the atmosphere. Despite recycling of CH_4 and CO_2 internally in lakes, a significant quantity of these greenhouse gases is released from lakes to the atmosphere, hence accelerating the warming of the atmosphere in northern high latitudes. This research considers why it is important to understand how changes in nutrient availability and temperature influence CO_2 and CH_4 cycling in lakes. The goal was to assess the magnitude, variability and seasonality of individual modes of emission among a wide range of geographic lake settings in Alaska. Researchers concluded that CH_4 and CO_2 emissions were dominated by ebullition (bubbling) and diffusion, respectively, and that the climate warming impact of CH_4 emissions was twice that of CO_2. Furthermore, the study revealed that the type of permafrost, that is containing yedoma soils versus non-yedoma soils, was the geographical parameter most closely related to CH_4 and CO_2 emissions. In much of northern Yukon where permafrost is continuous and thermokarst lakes are pervasive, regional assessments of lake CH_4 and CO_2 emissions should take into account the many emission modes and geographic characteristics, such as lake and permafrost types.

Keywords: ice-bubble storage, emissions, diffusion, CH_4, CO_2, nutrients, Secchi depth, decomposition

Available Online: Abstract http://www.biogeosciences.net/12/3197/2015/bg-12-3197-2015.html

Citation: Sepulveda-Jauregui, A., Walter Anthony, K.M., Martinez-Cruz, K., Greene, S. and Thalasso, F., 2015. Methane and carbon dioxide emissions from 40 lakes along a north–south latitudinal transect in Alaska. Biogeosciences, vol. 12, issue 11, p. 3197-3223. doi:10.5194/bgd-11-13251-2014

Surface water inundation in the boreal- Arctic: potential impacts on regional methane emissions

Research Location: boreal-Arctic

Publication Type: Journal Article

Publication Date: 2014

Abstract: Northern wetlands may be vulnerable to increased carbon losses from methane (CH_4), a potent greenhouse gas, under current warming trends. However, the dynamic nature of open water inundation and wetting/drying patterns may constrain regional emissions, offsetting the potential magnitude of methane release. Here we conduct a satellite data driven model investigation of the combined effects of surface warming and moisture variability on high northern latitude (≥45° N) wetland CH_4 emissions, by considering (1) sub-grid scale changes in fractional water inundation (Fw) at 15 day, monthly and annual intervals using 25 km resolution satellite microwave retrievals, and (2) the impact of recent (2003–11) wetting/drying on northern CH_4 emissions. The model simulations indicate mean summer contributions of 53 Tg CH_4 yr^{-1} from boreal-Arctic wetlands. Approximately 10% and 16% of the emissions originate from open water and landscapes with emergent vegetation, as determined from respective 15 day Fw means or maximums, and significant increases in regional CH_4 efflux were observed when incorporating satellite observed inundated land fractions into the model simulations at monthly or annual time scales. The satellite Fw record reveals widespread wetting across the Arctic continuous permafrost zone, contrasting with surface drying in boreal Canada, Alaska and western Eurasia. Arctic wetting and summer warming increased wetland emissions by 0.56 Tg CH_4 yr^{-1} compared to the 2003–11 mean, but this was mainly offset by decreasing emissions (−0.38 Tg CH_4 yr^{-1}) in sub-Arctic areas experiencing surface drying or cooling. These findings underscore the importance of monitoring changes in surface moisture and temperature when assessing the vulnerability of boreal-Arctic wetlands to enhanced greenhouse gas emissions under a shifting climate.

Local Relevance: Wetlands and lakes cover approximately 2-8% of the boreal-Arctic region (including Yukon) and over 50% of the global soil organic carbon pool is stored in these regions. The Old Crow Flats region in northern Yukon has as many as 2,000 lakes. Methane gas is a potent greenhouse gas and northern wetlands may be more susceptible to methane emissions when the extent and duration of surface wetness is sustained or increasing. This study looks at the potential implications of recent (2003-2011) variability in surface wetness on methane emissions from northern high latitudes such as northern Yukon. Additionally, researchers examined the contrasting influence of regional changes in moisture and temperature on summer (May – September) emission budgets using satellite remote sensing and reanalysis information. In conclusion, it was found that areas of significant increase in surface water extent were more prevalent in the Arctic Rim and may coincide with increases in summer precipitation or permafrost thaw in these high latitudes. In order to reduce the uncertainty in regional and global methane emissions, an improved quantification of regional patterns and temporal dynamics in surface environmental conditions are required. The study concludes that northern boreal-Arctic ecosystems may be especially vulnerable to methane emissions given climate warming, abundant soil carbon stocks, and a predominately wet landscape.

Keywords: arctic, wetlands, permafrost, inundation, methane, microwave remote sensing, carbon

Available Online: Full Document http://iopscience.iop.org/article/10.1088/1748-9326/9/7/075001/pdf

Citation: Watts, J.D., Kimball, J.S., Bartsch, A. and McDonald, K.C., 2014. Surface water inundation in the boreal-Arctic: potential impacts on regional methane emissions. Environmental Research Letters, vol. 9, art. 075001, 13 p. doi:10.1088/1748-9326/9/7/075001

3. PERMAFROST

3.1 MODELLING AND MAPPING TECHNIQUES

High-Resolution Permafrost Modeling in Denali National Park and Preserve

Research Location: Alaska

Publication Type: Technical Report

Publication Date: 2014

Abstract: We used the CRU (1950-59 and 2000-09) and projected 5-GCM composite (2001-10, 2051-60, and 2091-00) decadal climate forcing, ecotype (Stevens 2001), soil landscape (Clark and Duffy 2006), and snow (unpublished) maps of DENA to model the presence or absence of near-surface permafrost, temperature at the bottom of seasonal freeze-thaw layer and it thickness within DENA. We produced permafrost temperature and active-layer/ seasonally-frozen-layer thickness distribution maps through this modeling effort at a pixel spacing of 28 m, i.e. at the resolution of DENA ecotype map. This is a big improvement over the spatial resolution of existing permafrost maps on any part of Alaska, whether produced through the spatially explicit thermal modeling of ground temperatures or by visual interpretation of satellite images/ aerial photos using indirect surface evidences of permafrost or by compilation of information from detailed field soil/geology/ecotype surveys. The accuracy tests of the modeled permafrost and active-layer or seasonally-frozen-layer maps by comparing them against the field observations of permafrost presence/absence and thaw depth (at 1965 sites within DENA) suggest 89% agreement.

Local Relevance: Permafrost is defined as “ground (soil or rock and included ice and organic material) that remains at or below 0 °C for at least two consecutive years, for natural climatic reasons”. The whole of Yukon falls within the discontinuous or continuous permafrost zones. Much of this permafrost is vulnerable to major changes due to climatic warming because 1) it has temperatures within a few degrees of freezing, such that relatively minor warming could destabilize it entirely; and/or 2) it contains ice-rich material near the surface that could thaw with climatic warming, leading to major reconfiguration of the landscape through the development of thermokarst. Thawing permafrost is second only to wildfires as a major disturbance to boreal forests. The project was designed to obtain improved and higher-resolution maps for Alaska’s National Park Service which also lies within the zone of discontinuous to continuous permafrost. The maps provide permafrost distribution, temperature, and active-layer thickness under various climate scenarios, including present conditions, the recent past (e.g. 1950, prior to recently observed warming), and the future. Permafrost has been identified by the Arctic and Central Alaska Network as one of the “vital signs” of ecosystem health and this can also be applied to the Yukon’s permafrost zones.

Keywords: permafrost, thermokarst, organic layer thickness, modelling, mapping, active layer

Available Online: Full Report http://permafrost.gi.alaska.edu/sites/default/files/High-resolution%20permafrost%20modeling%20in%20DENA.pdf

Citation: Panda, S.K., Marchenko, S.S. and Romanovsky, V.E., 2014. High-Resolution Permafrost Modeling in Denali National Park and Preserve. Natural Resource Technical Report, Geophysical Institute, University of Alaska Fairbanks, AK, USA, 44 p.

A new approach to mapping permafrost and change incorporating uncertainties in ground conditions and climate projections

Research Location: Northern Canada (Arctic tundra)

Publication Type: Journal Article

Publication Date: 2014

Abstract: Spatially detailed information on permafrost distribution and change with climate is important for land use planning, infrastructure development, and environmental assessments. However, the required soil and surficial geology maps in the North are coarse, and projected climate scenarios vary widely. Considering these uncertainties, we propose a new approach to mapping permafrost distribution and change by integrating remote sensing data, field measurements, and a process-based model. Land cover types from satellite imagery are used to capture the general land conditions and to improve the resolution of existing permafrost maps. For each land cover type, field observations are used to estimate the probabilities of different ground conditions. A process-based model is used to quantify the evolution of permafrost for each ground condition under three representative climate scenarios (low, medium, and high warming). From the model results, the probability of permafrost occurrence and the most likely permafrost conditions are determined. We apply this approach at 20 m resolution to a large area in Northwest Territories, Canada. Mapped permafrost conditions are in agreement with field observations and other studies. The data requirements, model robustness, and computation time are reasonable, and this approach may serve as a practical means to mapping permafrost and changes at high resolution in other regions.

Local Relevance: About a quarter of the land in the northern hemisphere is underlain by permafrost. Gaining a better understanding of permafrost distribution and the change in climate will help government and land-use planners to better anticipate building conditions prior to investing dollars into a project, while also providing valuable information relevant to environmental assessments (e.g., Yukon Environmental and Socio-economic Assessment Board). The climate in northern high latitudes, including the Yukon Territory, has warmed at about twice the rate of the global average during the 20th century, and continued warming is projected for the 21st century. This study proposes a new way of permafrost mapping by integrating remote sensing data, field measurements, and a process-based model. This research used a new approach to mapping permafrost and change in an objective, replicable, and quantitative way while incorporating uncertainties in ground conditions and climate projections. The study concludes that this approach may serve as a practical means to map permafrost evolution at a high resolution in other high-latitude regions.

Keywords: Arctic tundra, climate warming, mapping, permafrost, remote-sensing, wildfires

Available Online: Abstract www.the-cryosphere.net/8/2177/2014/

Citation: Zhang, Y., Olthof, I., Fraser, R. and Wolfe, S.A. 2014. A new approach to mapping permafrost and change incorporating uncertainties in ground conditions and climate projections. The Cryosphere, vol. 8, issue 6, p. 2177-2194. doi: 10.5194/tc-8-2177-2014

Effect of permafrost thaw on CO_2 and CH_4 exchange in a western Alaska peatland chronosequence

Research Location: Alaska

Publication Type: Journal Article

Publication Date: 2014

Abstract: Permafrost soils store over half of global soil carbon (C), and northern frozen peat lands store about 10% of global permafrost C. With thaw, inundation of high latitude lowland peatlands typically increases the surface-atmosphere flux of methane (CH_4), a potent greenhouse gas. To examine the effects of lowland permafrost thaw over millennial timescales, we measured carbon dioxide (CO_2) and CH_4 exchange along sites that constitute a ~1000 yr thaw chronosequence of thermokarst collapse bogs and adjacent fen locations at Innoko Flats Wildlife Refuge in western Alaska. Peak CH_4 exchange in July (123 ± 71 mg CH_4–Cm^{-2} d^{-1}) was observed in features that have been thawed for 30 to 70 (<100) yr, where soils were warmer than at more recently thawed sites (14 to 21 yr; emitting 1.37 ± 0.67 mg CH_4–Cm^{-2} d^{-1} in July) and had shallower water tables than at older sites (200 to 1400 yr; emitting 6.55 ± 2.23 mg CH_4–Cm^{-2} d^{-1} in July). Carbon lost via CH_4 efflux during the growing season at these intermediate age sites was 8% of uptake by net ecosystem exchange. Our results provide evidence that CH_4 emissions following lowland permafrost thaw are enhanced over decadal time scales, but limited over millennia. Over larger spatial scales, adjacent fen systems may contribute sustained CH_4 emission, CO_2 uptake, and DOC export. We argue that over timescales of decades to centuries, thaw features in high latitude lowland peat lands, particularly those developed on poorly drained mineral substrates, are a key locus of elevated CH_4 emission to the atmosphere that must be considered for a complete understanding of high latitude CH_4 dynamics.

Local Relevance: Over half of global belowground carbon (C) is stored in permafrost soils, largely at high latitudes. The Yukon Territory is underlain almost entirely by continuous and discontinuous permafrost. The peat lands that we have in Yukon have acted as sinks for atmospheric carbon (C) since at least the late Pleistocene, and possibly even since the last interglacial period (i.e., for the last 126,000 years). These peat lands are now subject to increased thaw and potential C release due to climate warming. This study examines the thaw dynamics of lowland permafrost over millennial timescales. They examined trace gas fluxes, C stocks, temperature, inundation, and topographic effects of thermokarst bogs and an adjacent fen system. The study concludes that thawing of ice-rich peat results in water impoundment, soil saturation, and both vertical and lateral thaw propagation. As a result, if permafrost peatland thaw progression increases the hydrologic connection with flow systems through extensive landscape lowering (i.e., transformation from bog to fen environment), sustained CH_4 production may develop, particularly in poorly drained areas (e.g., deposits of lacustrine silts).

Keywords: carbon dioxide, climate change, methane, permafrost, wetlands

Available Online: Full Document http://iopscience.iop.org/article/10.1088/1748-9326/9/8/085004/pdf

Citation: Johnston, C.E., Ewing, S.A., Harden, J.W., Varner, R.K., Wickland, K.P., Koch, J.C., Fuller, C.C., Maines, K. and Jorgenson, M.T., 2014. Effect of permafrost thaw on CO_2 and CH_4 exchange in a western Alaska peatland chronosequence. Environmental Research Letters, vol. 9, no. 8, 12 p. doi:10.1088/1748-9326/9/8/085004

The Last Permafrost Maximum (LPM) map of the Northern Hemisphere: permafrost extent and mean annual air temperatures, 25–17 ka BP

Research Location: Northern Hemisphere

Publication Type: Journal Article

Publication Date: 2014

Abstract: This paper accompanies a map that shows the extent of permafrost in the Northern Hemisphere between 25 and 17 thousand years ago. The map is based upon existing archival data, common throughout the Northern Hemisphere, that include ice-wedge pseudomorphs, sand wedges and large cryoturbations. Where possible, a distinction is made between areas with continuous permafrost and areas where permafrost is either spatially discontinuous or sporadic. The associated mean annual palaeo-temperatures that are inferred on the basis of present-day analogues increase understanding of the possible changes in permafrost extent that might accompany current global warming trends. Areas with relict permafrost and areas that were formerly exposed due to lower sea level (submarine permafrost) are also mapped. Mapping is mostly limited to lowland regions (areas approximately <1000 m a.s.l.). Striking features that appear from the map are (i) the narrow permafrost zone in North America, which contrasts with the broader LPM permafrost zone in Eurasia (that may be related to different snow thickness or vegetation cover), (ii) the zonal extent of former LPM permafrost (that may reflect sea-ice distribution), which contrasts with the present-day pattern of permafrost extent (especially in Eurasia) and (iii) the relatively narrow zones of LPM discontinuous permafrost (that may indicate strong temperature gradients).

Local Relevance: The Yukon Territory is entirely underlain by discontinuous and continuous permafrost. A large portion of central to northern Yukon remained unglaciated during the Pleistocene, creating the ice-free landmass known as Beringia. The impacts of climate change on permafrost development can best be discussed starting from the period of maximum cold-climate conditions that occurred towards the end of the last ice age. This time likely coincides with the maximum extent of permafrost, or 'Last Permafrost Maximum' (LPM). This information is important since any prediction of current global climate change and permafrost extent requires knowledge of both present-day permafrost as well as the inferred extent of permafrost during the LPM. This study uses both published and unpublished literature as well as newly observed field data to reconstruct the LPM permafrost distribution in the Northern Hemisphere. The study concludes that permafrost may be underestimated especially in areas where data are lacking. The relatively narrow zones of LPM discontinuous permafrost indicate strong air temperature gradients; until now, this has not been considered by palaeoclimate models. Having a better understanding of the extent of the permafrost can help planners develop more robust designs capable of withstanding permafrost loss and/or degradation from future climate warming.

Keywords: archival data, cryoturbations, discontinuous, global-warming, permafrost, sporadic, surface-warming

Available Online: Full Document http://onlinelibrary.wiley.com/doi/10.1111/bor.12070/full

Citation: Vandenberghe, J., French, H.M., Gorbunov, A., Marchenko, S., Velichko, A.A., Jin, H., Cui, Z., Zhang, T. and Wan, X., 2014. The Last Permafrost Maximum (LPM) map of the Northern Hemisphere: permafrost extent and mean annual air temperatures, 25–17 ka BP. Boreas, vol. 43, issue 3, p. 652-666. doi: 10.1111/bor.12070

Permafrost thaw and soil moisture driving CO_2 and CH_4 release from upland tundra

Research Location: Alaska

Publication Type: Journal Article

Publication Date: 2015

Abstract: As permafrost degrades, the amount of organic soil carbon (C) that thaws during the growing season will increase, but decomposition may be limited by saturated soil conditions common in high-latitude ecosystems. However, in some areas, soil drying is expected to accompany permafrost thaw as a result of increased water drainage, which may enhance C release to the atmosphere. We examined the effects of ecosystem warming, permafrost thaw, and soil moisture changes on C balance in an upland tundra ecosystem. This study was conducted at a water table drawdown experiment, established in 2011 and located within the Carbon in Permafrost Experimental Heating Research project, an ecosystem warming and permafrost thawing experiment in Alaska. Warming and drying increased cumulative growing season ecosystem respiration by ~20% over 3 years of this experiment. Warming caused an almost twofold increase in decomposition of a common substrate in surface soil (0–10 cm) across all years, and drying caused a twofold increase in decomposition (0–20 cm) relative to control after 3 years of drying. Decomposition of older C increased in the dried and in the combined warmed + dried plots based on soil pore space $^{14}CO_2$. Although upland tundra systems have been considered CH_4 sinks, warming and ground thaw significantly increased CH_4 emission rates. Water table depth was positively correlated with monthly respiration and negatively correlated with CH_4 emission rates. These results demonstrate that warming and drying may increase loss of old permafrost C from tundra ecosystems, but the form and magnitude of C released to the atmosphere will be driven by changes in soil moisture.

Local Relevance: Soil moisture and temperature are the main environmental drivers of tundra carbon (C) exchange; however, the form of C released (i.e., CO_2 or methane CH_4) is highly dependent on soil moisture changes. This study examines the effects of temperature and soil moisture on ecosystem C balance in an upland tundra ecosystem located in the discontinuous permafrost zone in Alaska. Subarctic tundra was experimentally warmed, thawed and dried. Soils at the study site comprise an organic horizon, 0.35–0.45 m thick, above a cryoturbated mineral soil that is a mixture of glacial till and loess. The vegetation is dominated by the tussock-forming sedge, *Eriophorum vaginatum*, and deciduous shrub, *Vaccinium uliginosum* all species natural to the northern regions of Yukon's tundra ecosystem. The researchers have also considered that in some areas, soil drying is expected to accompany permafrost thaw as a result of increased water drainage, which may enhance C release to the atmosphere. Researchers found that warming and drying increased ecosystem respiration and common substrate decomposition and resulted in older CO_2 respired from soils. Furthermore, drying decreased plant C uptake, and led to significant losses of CO_2 from the ecosystem. Warmed and wetter plots within the study site had significantly higher rates of CH_4 release. As Yukon is entirely underlain by discontinuous and continuous permafrost, studies such as these are will become increasingly important in determining the changes in ground thaw and soil moisture on both the magnitude if C losses as well as the form of C released as permafrost thaws.

Keywords: carbon cycling, permafrost, Arctic, tundra, NEE, climate change

Available Online: Full Document http://onlinelibrary.wiley.com/doi/10.1002/2014JG002872/full

Citation: Natali, S.M., Schuur, E.A.G., Mauritz, M., Schade, J.D., Celis, G., Crummer, K.G., Johnston, C., Krapek, J., Pegoraro, E., Salmon, V.G. and Webb, E.E., 2015. Permafrost thaw and soil moisture driving CO_2 and CH_4 release from upland tundra. Journal of Geophysical Research, Biogeosciences, vol. 120, issue 3, p. 525-537. doi: 10.1002/2014JG002872.

Determining Hillslope Diffusion Rates in a Boreal Forest: Quaternary Fluvial Terraces in the Nenana River Valley, Central Alaska Range

Research Location: Alaska

Publication Type: MSc thesis

Publication Date: 2014

Abstract: The subarctic boreal forest biome is predicted to experience higher magnitudes of warming than other biomes due to climate change. The effects of this warming will be pronounced in areas underlain by discontinuous permafrost where melting permafrost and distinct changes in vegetation patterns are expected. To better understand rates of hill slope diffusion in the boreal forest I have used a geomorphic process modeling approach, using data from a sequence of Quaternary fluvial terraces located in the Nenana River valley of central Alaska. I hypothesized that diffusion rates here would be slower when compared to the mid-latitudes, and faster on north versus south-facing slopes. Calculated diffusion rates do support the hypothesis as they fall on the lower end of the global spectrum of documented hill slope diffusion rates. However, a significant difference in diffusion rates is not seen between the predominantly northeast and southwest facing slopes used in this study.

Local Relevance: This study uses a geomorphic process modeling approach to determine hillslope diffusion rates for a boreal forest site in central Alaska. The author also examines how these rates may change over time with climate, and if slope aspect affects hillslope diffusion. The study site comprises fluvial terraces that correspond to three main glacial advances. Results from this research can be correlated to areas in southern Yukon which were heavily glaciated and are also situated in boreal forest. Furthermore, the study sites in Alaska are comparable to Yukon because both regions experienced Pleistocene summers during the most recent glacial period which kept these areas relatively warm and dry. This study will help to better understand landscape evolution in Yukon.

Keywords: Alaska Range, boreal forest, hillslope diffusion, Nenana River Valley, Optically Stimulated Quartz Luminescence

Available Online: Full Document http://uknowledge.uky.edu/ees_etds/16

Citation: Walker, L.A., 2014. Determining Hillslope Diffusion Rates in a Boreal Forest: Quaternary Fluvial Terraces in the Nenana River Valley, Central Alaska Range. Theses and Dissertations, MSc thesis, Earth and Environmental Sciences. Paper 16.

A geosystems approach to permafrost investigations for engineering applications, an example from a road stabilization experiment, Beaver Creek, Yukon, Canada

Research Location: Yukon

Publication Type: Journal Article

Publication Date: 2013

Abstract: The Alaska Highway crosses numerous terrain units underlined by warm and ice-rich discontinuous permafrost highly susceptible to thermal degradation. For years, this infrastructure, which is essential to transportation in northwestern Canada and Alaska, has been showing signs of road damage induced by permafrost degradation. In 2008, Yukon Highways and Public Works, and its international collaborators, implemented a road experimental site near Beaver Creek (Yukon) to test mitigation techniques aiming to control permafrost degradation. Permafrost investigations were done accordingly to a geo system approach based on the hypothesis that permafrost has a distinctive sensitivity to climate and terrain conditions at a local scale and that changes (dynamics) in the system must be integrated in the analysis to obtain a holistic understanding of permafrost conditions and consequences of potential changes through time. Therefore, permafrost assessment at BC-RES came along with other components assessment such as local climate, natural terrain and embankment conditions.

Four main units identified were typically ice-rich, with the exception of one shallow sub-unit (2B) that was ice-poor, but which contained the top of inactive ice-wedges, and Unit 3 at depth. The extent of the syngenetic ice wedges was not encountered, but reached at least a depth of 10.7 m. Units 1 and 2 (likely eolian periglacial deposits) were fine grained soils characterized by a potential to liquefy, if soils thaw and maintain their natural moisture content, and to differential thaw-settlement. Unit 3 (likely interglacial deposit) was mainly made of peat, while Unit 4 (likely glacial deposit) was a diamicton with a fine-grained matrix containing abundant excess ice. Impact from road embankment was measured at many locations in permafrost below the infrastructure. Isothermal profile under the road and embankment subsidence, assessed from core-drilling combination with GPR and ground temperatures, reflected the thermal impact of embankment and its interaction with other geo system components (e.g. snow, groundwater) on the underlying ice-rich cryostratigraphic units. Thaw depth below embankment side slopes had mostly reached sub-unit 2B, exposing now excess ground ice from the underlying very ice-rich sub-unit 2C and ice wedge to melting. In this context, an increase in permafrost degradation is expected in the near future, regardless of the mitigation technique performance.

Application of the geosystem approach for road infrastructure in permafrost regions was beneficial at the BC-RES to identify the comprehensive critical engineering conditions that should be considered at the infrastructure spatial scale for road sustainability through timescale of its life. This approach emphasized the importance of changes in properties and processes, including their variability and dynamic related to interactions within the system. Overall, engineering studies in permafrost regions, which are typically sensitive to changes in conditions, would clearly benefit from applications of the geo system approach, which can be adapted to spatial and time scales of these studies.

Local Relevance: The Alaska Highway is a crucial transportation infrastructure for northwestern Canada and the United States and crosses areas underlain by discontinuous permafrost. The continuous thaw of the permafrost is causing road damage and this in turn is putting stress on the Yukon government's budget to maintain Yukon highways and main corridors. This study explores the use of an experimental road site in an area where permafrost occurs; the site is known as the Beaver Creek Road Experimental Site (BC-RES). The site was designed for

testing a range of techniques for mitigating permafrost degradation along the highway. Ground Penetrating Radar (GPR) and drilling operations showed that the road embankment has sunk in the natural ground since its construction in the 90s due to thaw consolidation of ice-rich soils. By combining various techniques used in the field of climatology, geomorphology, geophysics and geotechnical engineering, a comprehensive characterization of permafrost conditions can be achieved. Measurements of the environmental factors allowed the identification of local terrain processes that interacts with the road embankment to affect permafrost conditions. Finally, knowing permafrost temperature distribution within the cryostratigraphic units, and the embankment volumes for heat fluxes calculation, provide a basis for interpreting the permafrost thermal response to implementation of the mitigation techniques.

Keywords: cryostratigraphy, ground ice, mitigation techniques, permafrost geotechnical properties, roads, thermal regime

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Citation: Stephani, E., Fortier, D., Shur, Y., Fortier, R. and Doré, G., 2014. A geosystems approach to permafrost investigations for engineering applications, an example from a road stabilization experiment, Beaver Creek, Yukon, Canada. Cold Regions Science and Technology, vol. 100, p. 20-35. doi: 10.1016/j.coldregions.2013.12.006

Microbial Functional Potential and Community Composition in Permafrost-Affected Soils of the NW Canadian Arctic

Research Location: Herschel Island, Yukon Coast and Western Canadian Arctic

Publication Type: Journal Article

Publication Date: 2014

Abstract: Permafrost-affected soils are among the most obvious ecosystems in which current microbial controls on organic matter decomposition are changing as a result of global warming. Warmer conditions in polygonal tundra will lead to a deepening of the seasonal active layer, provoking changes in microbial processes and possibly resulting in exacerbated carbon degradation under increasing anoxic conditions. To identify current microbial assemblages in carbon rich, water saturated permafrost environments, four polygonal tundra sites were investigated on Herschel Island and the Yukon Coast, Western Canadian Arctic. Ion Torrent sequencing of bacterial and archaeal 16S rRNA amplicons revealed the presence of all major microbial soil groups and indicated a local, vertical heterogeneity of the polygonal tundra soil community with increasing depth. Microbial diversity was found to be highest in the surface layers, decreasing towards the permafrost table. Quantitative PCR analysis of functional genes involved in carbon and nitrogen-cycling revealed a high functional potential in the surface layers, decreasing with increasing active layer depth. We observed that soil properties driving microbial diversity and functional potential varied in each study site. These results highlight the small-scale heterogeneity of geomorphological comparable sites, greatly restricting generalizations about the fate of permafrost-affected environments in a warming Arctic.

Local Relevance: Warming temperatures in northern latitudes is resulting in thawing permafrost and a deepening of the active layer. Changes to active-layer thickness can create altered conditions in polygonal tundra and cause major shifts in microbial community composition and their functional potential. More specifically, a thickening active layer can cause the release of previously stored organic matter and stimulate microbial decomposition of this organic carbon, resulting in a positive feedback loop for global warming. Results demonstrate that within each

polygon, water content did not significantly correlate with depth. Total organic carbon content (TOC) was high at all sites, ranging from 20 to 40%. Lastly, the researchers determined that soil water content does not have the expected influence on microbial communities, but that depth-related changes in soil parameters have a strong influence in shaping microbial abundance and distribution.

Keywords: active layer, anoxic conditions, arctic, carbon degradation, permafrost, polygonal tundra soil

Available Online: Full Document http://www.plosone.org

Citation: Frank-Fahle, B.A., Yergeau, É., Greer, C.W., Lantuit, H. and Wagner, D., 2014. Microbial Functional Potential and Community Composition in Permafrost-Affected Soils of the NW Canadian Arctic. PLoS ONE, vol.9, issue 1: e84761. doi:10.1371/journal.pone.0084761

Permafrost and Thermokarst Lake Dynamics in the Old Crow Flats, Northern Yukon, Canada

Research Location: Old Crow Flats

Publication Type: PhD thesis

Publication Date: 2014

Abstract: Aspects of the thaw lake cycle were investigated in Old Crow Flats (OCF). OCF is a 5600 km^2 peat land with thousands of thermokarst lakes in the continuous permafrost of northern Yukon. It is located in the traditional territory of the Vuntut Gwich'in, who expressed concern that climatic change may be affecting the permafrost and lakes of OCF.

Field data collected in 2008-2011 provided the first assessment of spatial variability in permafrost temperatures across the tree line ecotone in OCF. Lake-bottom temperatures were recorded near the shores of four thermokarst lakes and talik configuration was defined beneath the lakes by jet-drilling to determine conditions controlling permafrost degradation in the area. Analytical and thermal models were used to relate field observations to current theory. Surface and subsurface conditions were examined in three drained lake basins and four expanding lakes to investigate how shore recession, talik development, and sediment deposition during lake expansion control the topography in lake basins after drainage.

Permafrost temperature at the depth of zero annual amplitude varied between -5.1°C and -2.6°C on the Flats. Within the forest-tundra transition, spatial variability in permafrost temperatures appeared to be controlled by the snow-holding capacity of vegetation and the configuration of land covers in the surrounding landscape, which controlled snow supply. Annual mean lake-bottom temperatures close to shorelines were unaffected by spatial variations in on-ice snow depth, but accumulation of freezing degree-days at the lake bottom varied sufficiently to affect rates of permafrost degradation beneath the lake. Where ice reached the lake bottom, talik development rates were controlled by the ratio of freezing degree days to thawing degree days and the thermal offset in the lake sediment. After lake drainage and permafrost aggradation, thermokarst lake basins in OCF commonly develop depressed margins and raised centres. An elevation difference of up to 2 m was recorded between the margins and centres of drained basins, but this elevation difference was not associated with increased ice-wedge density or increased segregated ice content. A conceptual model based on sediment deposition patterns during lake expansion was proposed to explain the topography of drained lake basins in OCF.

Local Relevance: In 2007, Zelma Lake, a traditional hunting and gathering place for the Vuntut Gwich'in people for thousands of years, vanished overnight in an unprecedented event that

devastated the people of the small, northern Yukon community. This thesis investigates the links between permafrost conditions, talik geometry, and drained basin topography in Old Crow Flats (OCF), an Arctic peatland containing thousands of thermokarst lakes. This research is accomplished through three main objectives: 1) the examination of spatial variation in ground temperatures within the forest-tundra ecotone; 2) the investigation of talik development near thermokarst lake shores; and 3) the recommendation of a landform development model adapted to conditions of OCF by investigating the genesis of the topography of drained basins. It is well known that thawing permafrost has the potential to create a positive feedback to climate warming through the release of stored organic carbon in frozen ground. Carbon release in the form of methane has a much greater impact compared to CO_2 release and is directly linked to permafrost degradation and the development of thermokarst lakes. This thesis provides detailed observations that will contribute to a better understanding of thermokarst lake dynamics and the associated changes to permafrost conditions.

Keywords: decomposition, lake bottom, permafrost, recession, talik, thermokarst lake

Available Online: Full Document https://curve.carleton.ca/system/files/etd/e0fe1f04-5de1-41b2-92eb-fb4495f715af/etd_pdf/59bbb0fad37714064248c67dc90c3431/roy-leveillee-permafrostandthermokarstlakedynamicsinthe.pdf

Citation: Roy-Léveillée, P., 2014. Permafrost and Thermokarst Lake Dynamics in the Old Crow Flats, Northern Yukon Canada. PhD thesis, Carleton University, Ottawa, ON, 224 p.

Permafrost soils and carbon cycling

Research Location: Alaska and the Yukon Territory

Publication Type: Journal Article

Publication Date: 2014

Abstract: Knowledge of soils in the permafrost region has advanced immensely in recent decades, despite the remoteness and inaccessibility of most of the region and the sampling limitations posed by the severe environment. These efforts significantly increased estimates of the amount of organic carbon organic carbon stored in permafrost-region soils and improved understanding of how pedogenic processes unique to permafrost environments built enormous OC stocks during the Quaternary. This knowledge has also called attention to the importance of permafrost-affected soils to the global C cycle and the potential vulnerability of the region's soil organic carbon (SOC) stocks to changing climatic conditions. In this review, we briefly introduce the permafrost characteristics, ice structures, and cryopedogenic processes that shape the development of permafrost-affected soils and discuss their effects on soil structures and on organic matter distributions within the soil profile. We then examine the quantity of organic carbon stored in permafrost-region soils, as well as the characteristics, intrinsic decomposability, and potential vulnerability of this organic carbon to permafrost thaw under a warming climate. Overall, frozen conditions and cryopedogenic processes, such as cryoturbation, have slowed decomposition and enhanced the sequestration of organic carbon in permafrost-affected soils over millennial timescales. Due to the low temperatures, the organic matter in permafrost soils is often less humified than in more temperate soils, making some portion of this stored organic carbon relatively vulnerable to mineralization upon thawing of permafrost.

Local Relevance: The Yukon Territory is underlain by over 75% continuous and discontinues permafrost rich in organic soils that act as a carbon sink. Permafrost and permafrost-affected soils have received greater attention because of their large organic carbon stocks and the potential, with warming, for releasing significant amounts of this carbon as the greenhouse

gases carbon dioxide (CO_2) and methane (CH_4). This study examines the important factors affecting the patterns, processes, and carbon stocks of permafrost soils and provides a summary of current research. One of the most significant consequences to permafrost thaw in Yukon and other circumpolar regions is the subsequent changes to soil hydrology and the associated changes to the permafrost landscape (e.g., increased thermokarsting). With permafrost thaw and degradation, there will be a shifting of proportional releases of CO_2 and CH_4, and increased methane emissions are expected in areas where the spatial extent of wetland soils increase. The complicated and dynamic systems related to permafrost thaw with a warming climate will require detailed assessments through a combination of laboratory studies, integrated observational and manipulative field studies, geospatial upscaling and mapping of soil organic carbon stocks and their decomposability, in addition to ecosystem, regional, and Earth system modelling studies.

Keywords: Old Crow Flats, organic carbon, permafrost, positive feed-back, warming climate

Available Online: Full Document http://www.soil-journal.net/1/147/2015/soil-1-147-2015.pdf

Citation: Ping, C.L., Jastrow, J.D., Jorgenson, M.T., Michaelson, G.J. and Shur, Y.L., 2014. Permafrost soils and carbon cycling. SOIL, vol. 1, issue 1, p. 147-171. doi: 10.5194/soil-1-147-2015

4. FORESTRY

4.1 FOREST GROWTH

Climate Variation and Disturbance Regime Affect Stand Composition and Structure of the Boreal Forests in Southwest Yukon of Canada

Research Location: Southwest Yukon

Publication Type: Journal Article

Publication Date: 2015

Abstract: The cold and dry boreal forests of the Southwest Yukon are dominated by white spruce (*Picea glauca*), trembling aspen (*Populus tremuloides*) and balsam poplar (*Populus balsamifera*), and the variability in structure and composition of stands depends on the favourability of disturbance, climate and site conditions for stimulating regeneration. In this study, we investigated relationships between stand structure and ecological, climatic and disturbance factors in the southwest Yukon. We found that white spruce dominates mature forests across the landscape, but it is regenerating proportionately less than trembling aspen. Nevertheless, regeneration of all the three species was abundant following any type or severity of disturbance. Height and diameter of both species varied with several environmental variables, particularly site physiography. Mixed stands of aspen and white spruce were more productive than pure stands of aspen or spruce. However, overall productivity in mixed stand decreased when density of aspen was more than 1000 stems/ ha. These results suggested that mixed stands of deciduous and coniferous species where appropriate should be promoted maintaining aspen density below 1000 stems/ha as the productivity declined beyond this threshold. Similarly, we suggest carrying out selection harvesting of co-dominant trees and regular thinning of intermediate trees to promote the height and diameter growth of the remaining trees.

Local Relevance: Stand structure is an important attribute of forest ecosystems, with implications for forest health, biodiversity conservation and forest management for the Yukon

Territory. The purpose of this study was to assess the variability in structure and composition of the boreal forests of southwest Yukon. Researchers examined several parameters including stand structure variables (i.e., diameter, density in stems per hectare, and basal area), as well as forest composition and productivity. Several conclusions were made that are significant in terms of future forest management practices. The following recommendations were made: 1) promote mixed stands of coniferous and deciduous species where appropriate, but maintain stand density below 1000 stem/ha in mixed stands as the productivity declined beyond this threshold; 2) perform selection harvesting of co-dominant trees and regular thinning of intermediate trees to promote the height and diameter growth of the remaining trees; and 3) focus commercial harvesting to lower elevations where average basal diameter of white spruce is higher as these areas are more accessible and will reduce operational costs while increasing productivity.

Keywords: basal area, climate variability, composition, density, disturbance, ecosystem, stand structure

Available Online: Full Document http://dx.doi.org/10.4236/ojf.2015.54029

Citation: Paudel, S.K., Simard, S.W., Nitschke, C.R. and Innes, J.L., 2015. Climate Variation and Disturbance Regime Affect Stand Composition and Structure of the Boreal Forests in Southwest Yukon of Canada. Open Journal of Forestry, vol. 5, no. 4, p. 337-352. doi: 10.4236/ojf.2015.54029

Fire effects on seedling establishment success across treeline: implications for future tree migration and flammability in a changing climate

Research Location: Alaska

Publication Type: Journal Article

Publication Date: 2014

Abstract: Understanding the complex mechanisms controlling treeline advance or retreat in the arctic and subarctic has important implications for projecting ecosystem response to changes in climate. Changes in land cover due to a treeline biome shift would alter climate feedbacks (carbon storage and energy exchange), ecosystem services such as wildlife and berry habitat, and landscape flammability. Wildfire frequency and extent has increased in the last half-century in the boreal forest and tundra in response to warmer weather and lower precipitation. Invasion of tundra by trees may be facilitated by wildfire disturbance, which exposes new seedbeds, increases nutrient availability immediately post-fire, and creates opportunities for establishment in an ecosystem where tree recruitment is otherwise rare. Coupled with projects specifically investigating biotic factors influencing tree seedling establishment, we evaluated the regional abiotic factors governing seedling performance and establishment success across treeline after fire. Addressing the Joint Fire Science Program (JFSP) Graduate Research INnovation (GRIN) topic of climate change and fire effects, we investigated regional controls on seedling growth across a latitudinal treeline gradient post-fire in Alaska. We used samples from a tree seedling out-plant experiment and an observational study of naturally established tree seedlings to investigate how establishment success and physiological performance is limited by drought stress and nutrient acquisition across the treeline ecotone. We developed a conceptual model of the abiotic and biotic factors that govern seedling performance at treeline and tundra. This conceptual model has been implemented in ALFRESCO, a landscape-level model of vegetation-fire-climate dynamics. Using ALFRESCO we are investigating the potential for fire-initiated tree migration.

Local Relevance: This study looks at the advancing arctic treeline and the implications that the trees and shrubs may have on ecosystems where trees are historically rare. A warming climate

promotes disturbances such as fire thus creating new habitat and opportunities for accelerated growth. High-severity fires expose mineral soils, which are favourable to seedling germination, net seedling establishment, and growth of transplanted seedlings. This project links mechanistic investigation of regional patterns of seedling establishment to model projects of continental biome shifts after fire using a novel suite of analytical tools in order to address fire effects on treeline successional trajectories and future flammability. This model may be used to inform land managers about treeline sensitivity to fire in order to evaluate the vulnerability of forest ecotones to the influences of future climate change.

Keywords: boreal forest, climate change, shrubs, treeline, tundra, wildfire

Available Online: Full Document http://digitalcommons.unl.edu/jfspresearch/82

Citation: Chapin, F.S. III, Hollingsworth, T.N. and Hewitt, R.E., 2014. Fire effects on seedling establishment success across treeline: implications for future tree migration and flammability in a changing climate. JFSP Research Project Reports, Paper 82, 20 p.

A Review of the Effects of Climate and Weather on Mountain Pine Beetle Population Dynamics and Impacts of Climate Change on Range Expansion in Canada

Research Location: British Columbia

Publication Type: BSc thesis

Publication Date: 2014

Abstract: The recent past and future range expansion of mountain pine beetle, *Dendroctonus ponderosae* Hopkins (Coleoptera: Curculionidae: Scolytinae), are reviewed on the basis of the review of the direct and indirect effects of climate and weather on beetle population dynamics. The recent warming has resulted in decreased cold-induced mortality, increased adaptive seasonality, and reduced host-tree defense, and has increased climatically benign habitats for the beetle. There has been a significant range expansion of mountain pine beetle in western Canada in the recent decades, posing a risk of future infestation in the adjacent boreal jack pine (*Pinus banksiana* Lamb.) forests.

Local Relevance: The mountain pine beetle is the most significant agent of mortality in lodgepole pine forests in North America. The expansion in the geographical range of the mountain pine beetle into southwest Yukon in recent decades has been tremendous, affecting a vast area and increasing the fire danger for the region. This essay is a review of the direct and indirect effects of climate and weather on beetle population dynamics, and the impacts of climate change on range expansion. The report concludes that climate warming has resulted in milder winters with less lethal temperatures for the beetle thus an expansion of their geographical range.

Keywords: climate change, climatic suitability, global warming, mountain pine beetle, range expansion

Available Online: Full Document https://open.library.ubc.ca/cIRcle/collections/undergraduateresearch/1037/items/1.0075587

Citation: Zhang, Z., 2014. A review of the effects of climate and weather on mountain pine beetle population dynamics and impacts of climate change on the range expansion in Canada. BSc thesis, University of British Columbia, Vancouver, BC, 27 p.

Effects of Disturbance and Climate Change on Ecosystem Performance in the Yukon River Basin Boreal Forest

Research Location: Yukon River Basin

Publication Type: Journal Article

Publication Date: 2014

Abstract: A warming climate influences boreal forest productivity, dynamics, and disturbance regimes. We used ecosystem models and 250 m satellite Normalized Difference Vegetation Index (NDVI) data averaged over the growing season (GSN) to model current, and estimate future, ecosystem performance. We modeled Expected Ecosystem Performance (EEP), or anticipated productivity, in undisturbed stands over the 2000–2008 period from a variety of abiotic data sources, using a rule-based piecewise regression tree. The EEP model was applied to a future climate ensemble A1B projection to quantify expected changes to mature boreal forest performance. Ecosystem Performance Anomalies (EPA), were identified as the residuals of the EEP and GSN relationship and represent performance departures from expected performance conditions. These performance data were used to monitor successional events following fire. Results suggested that maximum EPA occurs 30–40 years following fire, and deciduous stands generally have higher EPA than coniferous stands. Mean undisturbed EEP is projected to increase 5.6% by 2040 and 8.7% by 2070, suggesting an increased deciduous component in boreal forests. Our results contribute to the understanding of boreal forest successional dynamics and its response to climate change. This information enables informed decisions to prepare for, and adapt to, climate change in the Yukon River Basin forest.

Local Relevance: In the Yukon Territory what defines the ecosystem's productivity in the boreal forest is often constrained by short growing seasons, lack of winter sunlight, temperature, permafrost, low soil nutrient levels and disturbance. Furthermore, climatic changes over the last century have already resulted in warmer springs accompanied by an earlier start of growing season, warmer summers, and much warmer winters. This paper discusses the effects less precipitation may have on the boreal forest eco-systems including "browning" and increased severity and frequency of wildfires. Average annual precipitation varies geographically from 150 to 565 mm and precipitation generally decreases from west to east. The researchers replaced contemporary weather conditions with the future climate projections of a 14-model average composite in order to develop a future ecosystem performance of the years 2040 and 2070. Lastly, the study produced two major findings. First, peak ecosystem performance and landscape diversity occurred in stands that are 30–40 years old. Second, minor increases in productivity for future undisturbed boreal forest are expected (5.6% by 2040 and 8.7% by 2070) and are anticipated to be related to an increasing deciduous forest species composition. This study provides valuable information to land managers and users making adaptive management decisions that relate to climate, feedback and mitigation at global scales.

Keywords: boreal, climate change, fire, forest composition, future, succession

Available Online: Full Document http://www.mdpi.com/2072-4292/6/10/9145/htm

Citation: Wylie, B., Rigge, M., Brisco, B., Murnaghan, K., Rover, J. and Long, J., 2014. Effects of disturbance and climate change on ecosystem performance in the Yukon River Basin boreal forest. Remote Sensing, vol. 6, issue 10, p. 9145-9169. doi: 10.3390/rs6109145

Climate change vulnerability and adaptation in the managed Canadian boreal forest

Research Location: Boreal Forest Regions

Publication Type: Journal Article

Publication Date: 2014

Abstract: Climate change is affecting Canada's boreal zone, which includes most of the country's managed forests. The impacts of climate change in this zone are expected to be pervasive and will require adaptation of Canada's forest management system. This paper reviews potential climate change adaptation actions and strategies for the forest management system, considering current and projected climate change impacts and their related vulnerabilities. These impacts and vulnerabilities include regional increases in disturbance rates, regional changes in forest productivity, increased variability in timber supply, decreased socioeconomic resilience, and increased severity of safety and health issues for forest communities. Potential climate change adaptation actions of the forest management system are categorized as those that reduce non climatic stressors, those that reduce sensitivity to climate change, or those that maintain or enhance adaptive capacity in the biophysical and human subsystems of the forest management system. Efficient adaptation of the forest management system will revolve around the inclusion of risk management in planning processes, the selection of robust, diversified, and no-regret adaptation actions, and the adoption of an adaptive management framework. Monitoring is highlighted as a no-regret action that is central to the implementation of adaptive forest management.

Local Relevance: This study reviews potential climate change adaptation actions and strategies for the forest management system, considering current and projected climate change impacts and their related vulnerabilities. This will be important to the management of the boreal forest in Yukon and allow policy and law makers to make informed decisions. As northern regions become warmer, it is anticipated that forest management will need to adjust and adapt to a changing climate, particularly those changes to temperature and precipitation. The implementation of a monitoring system is recommended which will identify vulnerabilities and put into place systems to acquire information in an experimental set-up at the appropriate temporal and spatial scales; these systems should also be maintained over the long term. The results of the study have identified the increase in disturbance frequency and severity as one of the major vulnerabilities for the forest management system. Adaptation of the forest management system should generate multiple benefits by adding intelligence to the system and enabling responses to multiple sources of stress in addition to climate change.

Keywords: adaptation, adaptive capacity, boreal forest, climate change, resilience, vulnerability

Available Online: Full Document http://www.nrcresearchpress.com/doi/pdfplus/10.1139/er-2013-0064

Citation: Gauthier, S., Bernier, P., Burton, P.J., Edwards, J., Isaac, K., Isabel, N., Jayen, K., Héloïse, L.G. and Nelson, E.A., 2014. Climate change vulnerability and adaptation in the managed Canadian boreal forest. Environmental Reviews, vol. 22, no. 3, p. 256-285. doi: 10.1139/er-2013-0064

Forestry under Climate Change. Is Time a Tool for Sustainable Forest Management?

Research Location: Apennine Alps

Publication Type: Journal Article

Publication Date: 2015

Abstract: Changing climate conditions are known to influence forest tree growth response and the CO_2 cycle. Dendroclimatological research has shown that the climate signal, species composition, and growth trends have changed in different types of forest ecosystems during the last century. Under current and demonstrated changes in climate variability at the geographic, regional, and local levels tree growth shows also variability and trends that can be non-stationary during time even at relatively short distance between sites. In forest planning and management, yield tables, site quality indices, age class, rate of growth, and spatial distribution are some of the most used tools and parameters. However, these methods do not involve climate variability during time although climate is the main driver in trends of forest and tree growth. Previous research warns about the risk that forest management under changing climatic conditions could amplify their negative effects. For example, changing climate conditions may impact on temperature and/or precipitation thresholds critical to forest tree growth. Forest biomass, resilience, and CO_2 storage may be damaged unless forest planning and management implement the relationships between climate variability and trends of tree growth. A positive aspect is that, periods of favorable climate conditions may allow harvesting higher amount of wood mass and storing more CO_2 than traditional planning methods. And, the average length of both favorable and adverse periods appears to occur within the validity period of a forest management plan. Here, we show a conceptual development to implement climate variability in forest management in the view of continuing the research.

Local relevance: It is well known that the mean global temperature is rising and in the north, it is happening at an accelerated rate. In order to better understand the changes in the boreal forest composition in the Yukon Territory, it is important to consider what is occurring in other forested, mountainous regions. This study looks at tree growth response and CO_2 cycling with respect to changes in climate variability. The researchers look at forest biomass, resilience, and CO_2 storage and how it may be damaged unless forest planning and management implement the relationships between climate variability and trends of tree growth. The results of this study have shown that once the range of temperature and/or rainfall within which tree growth responds is identified, it is relatively easy to identify the periods when growth increases or decreases in correspondence with historical series of climate variables. To attain sustainable forest management practices, further research is needed to identify which climate variables and the relative thresholds drive growth response by species, forest type and ecoregion.

Keywords: climate change, forestry, sustainability, time factor, management

Available Online: Full Document http://www.scirp.org/journal/ojf

Citation: D'Aprile, F., Tapper, N. and Marchetti, M. 2015. Forestry under Climate Change. Is Time a Tool for Sustainable Forest Management? Open Journal of Forestry, vol. 5, no. 4, p. 329-336. http://dx.doi.org/10.4236/ojf.2015.54028

Tree Rings for the Assessment of the Potential Impact of Climate Change on Forest Growth

Research Location: boreal forest in North America (Alaska to Quebec)

Publication Type: Journal Article

Publication Date: 2014

Abstract: The Earth's climate is changing rapidly and while human influence on the same is an inconvenient truth, it is important to assess the likely impacts of climate change on vulnerable ecosystems across the globe. Forests contain the world's largest terrestrial carbon pool and constitute a major sink that reduces the build-up of atmospheric carbon dioxide. Climate change is likely to result in substantial changes in the structure and function of forests. The effects of climate variability on forests can be best estimated from tree rings which are highly sensitive to changes in environmental conditions. However, there is conflicting evidence as regards the response of forests to climate change. Will climate change accelerate tree growth and mitigate CO_2 release from fossil fuels and land-use change? Or would the outbreak of forest fires, insect attacks and storms negate any increase in forest carbon storage from faster growth, the 'divergence problem', as propounded by some researchers? Climatic variations in recent decades and in the years to come may pose grave threats to the world's forests and their role as potential carbon sinks, hence concerted research is needed in the future to validate the claims of forest growth dynamics in relation to climate change.

Local Relevance: The boreal forest is one of the largest ecosystems that reduce the input and build-up of atmospheric CO_2. Managing these resources takes money and time and governments are constantly looking for new science and technology that will help develop a sustainable resource that is adapted to climate change. Forests are particularly sensitive to climate change, because the long life-span of trees does not allow for rapid adaptation to environmental changes. This study looks at the growth of tree rings as they are sensitive to changes in environmental conditions and can be used as a fingerprint of recent climate change as well as provide a natural archive of past climate. This study provides an overview of key studies on the impact of climatic changes on the growth of forests as estimated through tree ring analysis.

Keywords: climate, forests, tree rings, growth, carbon

Available Online: Full Document http://www.aloki.hu

Citation: Shah, S. and Shah, C. 2014. Tree rings for the assessment of the potential impact of climate change on forest growth. Applied Ecology and Environmental Research, vol. 13, no. 1, p. 277-288. doi: 10.15666/aeer/1301_277288

Response of southwest Yukon forests to spruce beetle: 2010 plot re-assessment

Research Location: southwest Yukon Territory

Publication Type: Report

Publication Date: 2014

Abstract: In 2000 and 2002, 27 Forest Assessment plots were established within the area infested by spruce bark beetle, *Dendroctonus rufipennis* Kirby (Coleoptera: Scolytidae) in southwest Yukon. The study objective was to document long-term changes in white spruce (*Picea glauca* (Moench) Voss) mortality, stand structure, regeneration, surface vegetation, and surface woody fuel load (Garbutt et al. 2006). A partial re-measurement was conducted in 2010,

which included 22 of the original 27 FA plots. Eight of the 22 FA plots were sampled to determine growth release of spruce overstorey and understorey, and establishment of regeneration. A number of plot maintenance activities were completed to ensure future re-measurements. Forest assessment plots were prioritized and buffered for long-term protection from forest management activities. Field sampling methodology followed the protocol used in Garbutt et al. (2006) except for spruce advanced regeneration and seedlings.

Overstorey spruce and deciduous species diameter-at-breast height increased from 18.2 cm to 18.9 cm. Overstorey spruce stand density (live and dead) increased from 1059 to 1124 stems per ha and volume from 184.4 to 198.7 m^3/ha. The volume of healthy overstorey spruce declined from 65.9 to 49.4 m^3/ha. Growth responses in live residual overstorey spruce were detected in four of eight plots. Fifty-nine percent of the spruce seedlings sampled were established between 2000 and 2008. Establishment dates of understorey and advanced regeneration suggested continuous spruce regeneration with a few decadal pulses detected in the 1820s and 1980s. Spot fire potential increased due to loose bark on the dead spruce. Coarse woody debris load remained similar to that reported in Garbutt et al. (2006) because few dead spruce had fallen over. A complete plot re-measurement should be considered starting in 2015 and include all attributes measured in Garbutt et al. (2006) and the 2010 re-measurement.

Local Relevance: Since 1994, a record-breaking spruce bark beetle epidemic has been killing large areas of white spruce forests in southwest Yukon. The spruce beetle has engulfed the landscapes of the Alsek River drainage within Kluane National Park as well as public forest lands and First Nations settlement lands in the Shakwak Trench. The spruce beetle outbreak was a key driver in the development of a Strategic Forest Management Plan for the Champagne and Aishihik First Nation (CAFN) Territory. The extensive spruce mortality is expected to affect the CAFN traditional economy, potential commercial forest operations, and community fire risk. In early 2000, researchers from Natural Resources Canada created Forest Assessment (FA) plots within the infestation area. In order to monitor the spread of the outbreak, researchers re-assessed 22 of the original 27 plots in 2010. This report presents data measured in 2010, and outlines the changes within the spruce beetle-impacted forest from mature trees to tree seedling establishment. A priority rating system for plot protection was also established to ensure that potential future land management activities (e.g., firewood cutting, logging and agricultural leases) do not compromise plot integrity for future re-assessments. The results of the study show that the plots in immature stands of white spruce with edge effects were assigned a moderate rating while those that already had been partially impacted by harvesting were assigned a low rating; all FA plots located in Kluane National Park were assigned a high priority for retention. The knowledge gained from the FA plots on spruce beetle impacts will inform programs directed at fire prevention and hazard abatement, sustainable forest management, reforestation, and public education. It was recommended that all plots be considered for re-measurement beginning in 2015.

Keywords: coarse woody debris, forest health, forest assessment, growth and mortality of trees, risk of fire, seedling establishment, spruce beetle, stand structure

Available Online: Full Document http://cfs.nrcan.gc.ca/publications?id=35443

Citation: Hawkes, B., Alfaro, R., Waring, V. and Berg, J., 2014. Response of southwest Yukon forests to spruce beetle: 2010 plot re-assessment. Natural Resources Canada, Canadian Forest Service, Pacific Forestry Centre, Information Report BC-X-435, 38 p.

Greater shrub dominance alters breeding habitat and food resources for migratory songbirds in Alaskan arctic tundra

Research Location: Alaska

Publication Type: Journal Article

Publication Date: 2014

Abstract: Climate warming is affecting the Arctic in multiple ways, including via increased dominance of deciduous shrubs. Although many studies have focused on how this vegetation shift is altering nutrient cycling and energy balance, few have explicitly considered effects on tundra fauna, such as the millions of migratory songbirds that breed in northern regions every year. To understand how increasing deciduous shrub dominance may alter breeding songbird habitat, we quantified vegetation and arthropod community characteristics in both graminoid and shrub dominated tundra. We combined measurements of preferred nest site characteristics for Lapland longspurs (*Calcarius lapponicus*) and Gambel's White-crowned sparrows (*Zonotrichia leucophrys gambelii*) with modeled predictions for the distribution of plant community types in the Alaskan arctic foothills region for the year 2050. Lapland longspur nests were found in sedge-dominated tussock tundra where shrub height does not exceed 20 cm, whereas White-crowned sparrows nested only under shrubs between 20 cm and 1 m in height, with no preference for shrub species. Shrub canopies had higher canopy-dwelling arthropod availability (i.e. small flies and spiders) but lower ground-dwelling arthropod availability (i.e. large spiders and beetles). Since flies are the birds' preferred prey, increasing shrubs may result in a net enhancement in preferred prey availability. Acknowledging the coarse resolution of existing tundra vegetation models, we predict that by 2050 there will be a northward shift in current White-crowned sparrow habitat range and a 20–60% increase in their preferred habitat extent, while Lapland longspur habitat extent will be equivalently reduced. Our findings can be used to make first approximations of future habitat change for species with similar nesting requirements. However, we contend that as exemplified by this study's findings, existing tundra modeling tools cannot yet simulate the fine-scale habitat characteristics that are critical to accurately predicting future habitat extent for many wildlife species.

Local Relevance: This study strives to understand how the increasing dominance of deciduous shrubs may alter breeding songbird habitat; the researchers quantified vegetation and arthropod community characteristics in both graminoid and shrub dominated tundra. Millions of migratory songbirds migrate to the arctic tundra biome every year due in part to the abundant summer food resources, long day length, and fewer predators and parasites. Songbirds are important prey for many tundra predators, and also provide essential ecosystem services – such as seed dispersal and insect control. The results of the research showed the majority (80%) of nests were placed directly in the sides of tussocks formed by the sedge *Eriophorum vaginatum* (cottongrass), with the remaining 20% of nests placed amongst other vascular species.

Keywords: arthropods, climate change, Gambel's White-crowned sparrow (*Zonotrichia leucophrys gambelii*), habitat, Lapland longspur (*Calcarius lapponicus*), migratory songbirds, shrubs

Available Online: Abstract http://onlinelibrary.wiley.com/doi/10.1111/gcb.12761/abstract

Citation: Boelman, N.T., Gough, L., Wingfield, J., Goetz, S., Asmus, A., Chmura, H.E., Krause, J.S., Perez, J.H., Sweet, S.K. and Guay, K.C., 2014. Greater shrub dominance alters breeding habitat and food resources for migratory songbirds in Alaskan arctic tundra. Global Change Biology, vol. 21, issue 4, p. 1508-1520. doi: 10.1111/gcb.12761

Northernmost North American Pinus contorta var. latifolia (lodgepole pine) sociations and vegetation diversity relative to its central range east of the Rocky Mountains

Research Location: central Yukon Territory

Publication Type: Journal Article

Publication Date: 2013

Abstract: Lodgepole pine (*Pinus contorta* var. *latifolia*) stands were sampled in central Yukon, Canada (61.5 – 64°N latitude), which represented the northernmost 9% of the tree's North American range. Within this area, lodgepole pine occupied only ~2% of the landscape. This study determined: 1) what forest sociations occurred (i.e. structural dominance-types); 2) how plant growth form composition and richness differed from the central portion of the species' geographical range; and 3) if stands were biased towards occurring on more thermally favorable south-facing slopes. Five lodgepole pine sociations were recognized among 100 relevés: *Rhododendron groenlandicum* (Labrador tea); *Cladonia arbuscula* (green reindeer lichen); *Calamagrostis purpurascens* (purple reedgrass); *Hylocomium splendens* (stairstep moss) and *Alnus viridis* (green alder, n = 4 relevés). *Rhododendron* stands were proportionally more common on low gradient sites and had more total plant cover than the other sociations. *Cladonia* and *Calamagrostis* stands were typically associated with dry coarse-textured soils and warm dry sites, respectively; whereas the composition of the *Hylocomium* sociation reflected the detrimental influences of atypically dense forest canopies on understory vascular plants. Only the *Calamagrostis* sociation was unique to the study region. Species richness among common northern lodgepole pine sociations averaged 16 – 19 taxa per relevé ($p > 0.05$). Northern compared to central range (n = 1394) relevés were compositionally different based on little overlap of their datasets in the ordination space. Northern vegetation had less ($p < 0.001$) total plant (129% vs 184%), deciduous shrub (9% vs 26%), broad-leaved herb (5% vs 25%), and bryophyte (27% vs 54%) cover; had greater macro-lichen cover (13% vs 5%) and lower floristic richness (11 vs 24 taxa) and was less than half as phytosociological diverse. Lodgepole pine stands in the northernmost portion of their range were not biased towards occurring on south-facing slopes, which suggested an ecological potential for range expansion.

Local Relevance: This study considers the presence of a plant at or near the limits of its geographical range. Using the range of lodgepole pine advancement north would provide an indicator for climate change related impacts to ecosystems not currently dominated by the species. The results show that there is no significant difference in dominance concentration occurred between datasets that employed the standardized sampling design. Lastly, if outward migration occurs, northward migration would likely be blocked by the cold higher elevation climates of the Mackenzie Mountains with some expansion to the northeast into east central Yukon. More rapid and extensive expansion would more likely occur northwest of the study area at lower elevations into east – central Alaska.

Keywords: canopy, dispersal, lodgepole pine, over-growth, tundra, under-growth

Available Online: Abstract http://onlinelibrary.wiley.com/doi/10.1111/j.1756-1051.2013.00126.x/abstract

Citation: Strong, W.L., 2013. Northernmost North American *Pinus contorta* var. *latifolia* (lodgepole pine) sociations and vegetation diversity relative to its central range east of the Rocky Mountains. Nordic Journal of Botany, vol. 32, issue 2, p. 222-232. doi: 10.1111/j.1756-1051.2013.00126.x

5. GLACIOLOGY

Projected Future Changes in Glaciers and their Contribution to Discharge of the Yukon River at Whitehorse

Research Location: Yukon Territory

Publication Type: Report

Publication Date: 2014

Abstract: This study was carried out by the Northern Climate ExChange (NCE), Yukon Research Centre, Yukon College for the Yukon Energy Corporation (YEC) in order to understand the hydrological role of glaciers, and their future potential response to climate change, in the Upper Yukon River Basin above Whitehorse. There is presently uncertainty in both the contribution that glaciers provide to the flow volume of this river, as well as how future climate change will affect this contribution and alter the balance of runoff from glacial sources and non-glacial sources. To accomplish this research and attempt to resolve these issues, this study used a variety of approaches, including: 1) field-based, ice-penetrating radar measurements over a sample of glaciers within the basin to obtain information on their current thickness and volume; 2) compilation of a remotely sensed, image-based inventory of the present area and distribution of glaciers within the basin, together with an analysis of recent changes in glacier extent over the past several decades (and back to 1948 for some selected regions); 3) calibration and validation of a hydrological model (HBV-EC model within the Green KenueTM platform) for the simulation of seasonal hydrographs and glacier contributions for two tributary rivers (Fantail and Wheaton rivers) of the Yukon River, as well as for the Yukon River at Whitehorse; and 4) the application of various climate scenarios within the model to evaluate the potential response of glacier area and mass balance, river discharge, and glacier contributions to runoff over the next 60 years.

Local Relevance: Climate change in Arctic and sub-Arctic areas, including Yukon Territory, are having an impact on the hydrological cycle through changes in temperature and precipitation. An increase in volume from melt water run-off added to the river systems will put extra stressors on current dam infrastructure on the Yukon and other rivers. Future warming trends in northern regions are expected to occur at a relatively greater rate than most other parts of the world and this will cause our local governments and utility providers to adapt to a changing environment. The purpose of the study is to assess climate-induced changes to the contribution of glacially sourced waters to Yukon's hydroelectric power generation. The report concludes with several recommendations on adaptations, including future research and monitoring needs.

Keywords: discharge, glaciers, hydrology, ice-penetrating radar, non-glacial, volume, Yukon River

Available Online: Full Document https://yukoncollege.yk.ca/index.php/research/abstracts/projected_future_changes_in_glaciers_and_their_contribution_to_discharge_of

Citation: DeBeer, C.M., Kavanaugh, J.L. and Laxton, S., 2014. Projected future changes in glaciers and their contribution to discharge of the Yukon River at Whitehorse. Northern Climate ExChange, Yukon Research Centre, Yukon College, Whitehorse, YT, 44 p.

Evolution of seasonal variations in motion of the Kaskawulsh Glacier, Yukon Territory

Research Location: Yukon Territory

Publication Type: MSc thesis

Publication Date: 2014

Abstract: Differential GPS data from 2007-2014 are used to assess horizontal and vertical velocity variations of the Kaskawulsh Glacier at interannual and intra-annual timescales. These indicate that an upglacier propagating high velocity event occurs every spring at the onset of melt, and that a downglacier propagating high velocity event occurs every fall or winter after melt has finished. These events suggest that the subglacial drainage system alternates between a distributed system in the winter and channelized system in the summer and fall. In addition, there is a strong negative correlation between summer melt and velocity the following fall and winter, with strong melt years resulting in low velocities. For each additional metre of summer melt, an 8.6% average decrease in velocity is observed on the glacier the following fall-winter.

These results suggest that changes in the subglacial drainage system limit the sensitivity of glacier motion to increased meltwater inputs. Glacier motion will likely show a net decrease under a warming climate due to the negative correlation between surface melt rates and ice motion and a decrease in driving stresses as a result of reduced ice thicknesses. In addition, future fall-winter velocity patterns could be accurately predicted from only a month or two of summer melt data, with May-June melt providing the best indication of fall-winter motion. This study also suggests that the common assumption that glaciers are 'stable' in the late fall and winter is incorrect.

Local Relevance: Glacier hydrological processes play an important role in glacier motion. Many glaciers in the Yukon are experiencing a reduction in mass due to a warmer climate leading to an increase in melt water volume entering the receiving environment and inducing movement. Englacial and subglacial conduits are important in glacier motion as they route meltwater to the glacier bed, lubricating it and reducing friction, leading to glacier motion via basal sliding or bed deformation. This research examines the connections between surface melt and the velocity patterns of the Kaskawulsh Glacier, southwest Yukon. Velocity patterns are determined through the use of differential global positioning system (dGPS) data and water inputs are derived from meteorological data. Results from the study found that annual motion of the Kaskawulsh Glacier is slower in years with higher melt due to the increased efficiency of the subglacial drainage system (i.e., lower basal water pressures) above a critical rate of water input. The study also found that by using only one month or two of summer melt data (e.g., May-June), future fall-winter velocity patterns could be accurately predicted. The evolution of patterns of glacier motion in response to changing melt and mass balance conditions can provide valuable insight into how large valley glaciers may respond to climate warming.

Keywords: glaciers, horizontal and vertical velocity variations, interannual and intra-annual timescales

Available Online: Full Document https://www.ruor.uottawa.ca/bitstream/10393/31835/1/Herdes_Emilie_2014_thesis.pdf

Citation: Herdes, É., 2014. Evolution of seasonal variations in motion of the Kaskawulsh Glacier, Yukon Territory. MSc thesis, Department of Geography Faculty of Arts, University of Ottawa, Ottawa, ON, 105 p.

Investigating absolute chronologies of glacial advances in the NW sector of the Cordilleran Ice Sheet with terrestrial in situ cosmogenic nuclides

Research Location: Yukon Territory

Publication Type: Journal Article

Publication Date: 2014

Abstract: Geologic mapping in Yukon Territory, Canada, over the past 100 years has revealed a consistent pattern of diminishing Cordilleran Ice Sheet (CIS) extent during successively younger glaciations. Although this pattern is generally accepted, there is still much uncertainty about the number of glaciations, their ages, and the dynamics of the different lobes that constituted the digitate ice sheet margin, their subglacial thermal regimes, and ice thicknesses. We address uncertainties in the timing of glaciation using cosmogenic nuclide exposure dating at key localities that straddle several major lobes of the CIS in west-central Yukon Territory. Differences in exposure duration within what are thought to be the same map units are perhaps due to inheritance (older than expected), but more likely result from postglacial shielding (younger than expected) or surface erosion. Despite a significant spread in exposure durations on moraines and within map units, and tending to rely on longest exposure durations on moraines due to postglacial degradation and shielding, our results indicate that the McConnell glacial advance occurred during Marine Oxygen Isotope Stage (MIS) 2, judging from oldest minimum apparent exposure ages of 15.7 $\pm$ 1.5 and 17.7 $\pm$ 1.6 ka, a Gladstone glacial advance occurred before 51.8 $\pm$ 4.7 ka (MIS 4) and Reid glacial advances before 79.8 $\pm$ 7.3 and 82.8 $\pm$ 7.5 ka (consistent with MIS 6). Traces of even older glacial advances predate 100 ka (107.5 $\pm$ 9.9 to 154.3 $\pm$ 14.2 ka).

Local Relevance: Much progress has been made in reconstructing the growth and decay of ice sheets and alpine glaciers with the help of radiocarbon dating methods on various sediments. However, there is a limited understanding of the knowledge and behaviour of older ice sheets due to the fact that they are less well preserved and the events of interest are beyond the range of radiocarbon dating. Little is known about the continental record of Pleistocene glaciation prior to Marine Oxygen Isotope Stage (MIS) 2 (i.e., prior to 29 thousand years ago). This study uses a relatively new dating technique known as terrestrial cosmogenic nuclide (TCN) dating to refine the chronology of Pleistocene glacial events along the northwestern margin of the Cordilleran Ice Sheet in southern and central Yukon. Researchers found that exposure durations of boulders and cobbles on moraine are more reliable age indicators than exposure durations of erratics or bedrock. Furthermore, throughout much of central Yukon where there existed highly active periglacial environments, suitable, large, glacially transported boulders are rare and surface exposure dating produces results with large uncertainties. As TCN dating techniques improve and methodological uncertainties are reduced, a clearer picture of the geographic past will emerge, ultimately providing more insight into future changes to glacial environments with climate change.

Keywords: Cordilleran Ice sheet, exposure dating, Pleistocene glaciations, Yukon Territory

Available Online: Full Document www.elsevier.com/locate/quascirev

Citation: Stroeven, A.P., Fabel, D., Margold, M., Clague, J.J. and Xu, S., 2013. Investigating absolute chronologies of glacial advances in the NW sector of the Cordilleran Ice Sheet with terrestrial in situ cosmogenic nuclides. Quaternary Science Reviews, vol. 92, p. 429-443. doi: 10.1016/j.quascirev.2013.09.026

Risks and Benefits of Global Warming and the Loss of Mountain Glaciers and Ice Patches to Archeological, Paleoclimate, and Paleoecology Resources

Research Location: Rocky Mountain National Park

Publication Type: Journal Article

Publication Date: 2014

Abstract: Scientific documentation of global warming, despite disagreement on its ultimate causes, includes measurable rises in sea levels, more frequently stronger and more violent weather patterns, and accelerating melting of Arctic and Antarctic ice sheets, long-existing glaciers, and "permanent" snow fields. In recent years, there have been numerous discoveries of ancient human, animal, and plant remains melted from long-frozen snow and ice, finds which recently led to development of a new subfield of archaeology known as ice patch or glacial archaeology. Ice patch organic remains, once exposed, are subject to rapid deterioration and destruction. Both cultural and natural remains, if identified and collected prior to extended surface exposure can provide extraordinary evidence about past societies, climates, and ecosystems. This article provides a short background and discussion on the nature and history of the emerging science of glacier/ice patch archaeology and describes results of an on-going study in the United States' southern Rocky Mountains where ice patch evidence for climate change is integrated with more traditional paleoclimate and archaeological research to reconstruct several millennia of cultural, climate, and ecological landscape evolution.

Local Relevance: Both cultural and natural remains, if identified and collected prior to extended surface exposure can provide extraordinary evidence about past societies, climates, and ecosystems. There have been many recent discoveries of archaeological objects and faunal remains in southern Yukon as ice patches melt. This study introduces a relatively new field of archeology in which the researchers hope to reconstruct several millennia of cultural, climate, and ecological landscape evolution. Remains uncovered from the melting of mountain glaciers and permanent snowfields (i.e., ice patches) provide unparalleled opportunities to better understand long-term climate change effects and past human adaptations to those changes.

Keywords: global warming, ice patch archaeology, Rocky Mountain National Park

Available Online: Full Document http://dx.doi.org/10.12775/EQ.2014.022

Citation: Brunswig, R.H., 2014. Risks and Benefits of Global Warming and the Loss of Mountain Glaciers and Ice Patches to Archeological, Paleoclimate, and Paleoecology Resources. Ecological Questions, vol. 20, p. 99-108.

A Short and Somewhat Personal History of Yukon Glacier Studies in the Twentieth Century

Research Location: Yukon Territory

Publication Type: Journal Article

Publication Date: 2014

Abstract: Glaciological exploration of Yukon for scientific purposes began in 1935, with the National Geographic Society's Yukon Expedition led by Bradford Washburn and the Wood Yukon Expedition led by Walter Wood. However, Project "Snow Cornice," launched by Wood in 1948, was the first expedition to have glacier science as its principal focus. Wood's conception of the "Icefield Ranges Research Project" led the Arctic Institute of North America (AINA) to

establish the Kluane Lake Research Station on the south shore of Kluane Lake in 1961. Virtually all subsequent field studies of Yukon glaciers were launched from this base. This short history attempts to document the trajectory of Yukon glacier studies from their beginnings in 1935 to the end of the 20th century. It describes glaciological programs conducted from AINA camps at the divide between Hubbard Glacier and the north arm of Kaskawulsh Glacier and at the confluence of the north and central arms of Kaskawulsh Glacier, as well as the galvanizing influence of the 1965 – 67 Steele Glacier surge and the inception and completion of the long-term Trapridge Glacier study. Excluded or minimized in this account are scientific studies that were conducted on or near glaciers, but did not have glaciers or glacier processes as their primary focus.

Local Relevance: In Europe, the scientific study of glaciers was well established by the 1840s. The scientific study of Yukon glaciers began almost a century later beginning with the 1935 expedition sponsored by the American Geographical Society. In 1941, a more scientific study was initiated that focused on the glacial history and glacial geomorphology of the "Wolf Creek" glaciers (now Steele Glacier). This study laid the scientific foundation for subsequent studies of glaciers in southern Yukon. In 1945, the Arctic Institute of North America (AINA) was established and has remained committed to Yukon scientific research to this day. In 1961, AINA built the Kluane Lake Research Station on the south shore of Kluane Lake which was originally constructed as a base camp for the Icefield Ranges Research Project. This study attempts to document the trajectory of Yukon glacier studies from their beginnings in 1935 to the end of the 20th century. The study reveals a significant knowledge gap with the lack of measurements of subglacial topography. Such information is necessary to estimate the contribution of glacier melt to sea level rise and as input to simulation models of ice dynamics that can be used to project the effects of climate-forced deglaciation on the water cycle.

Keywords: glacier studies, Icefield Ranges Research Project, Kluane Lake Research Station, St. Elias Mountains, Yukon

Available Online: Full Document http://arctic.journalhosting.ucalgary.ca/arctic/index.php/arctic/article/view/4355/4510

Citation: Clarke, G.K.C., 2014. A Short and Somewhat Personal History of Yukon Glacier Studies in the Twentieth Century. Arctic, vol. 67, no. 5, p. 1-21. doi: http://dx.doi.org/10.14430/arctic4355

6. WILDLIFE

6.1 MAMMALS

Influence of shrub canopies on growth rate and pre-hibernation mass of juvenile arctic ground squirrels

Research Location: Ruby Range, southwest Yukon

Publication Type: Journal Article

Publication Date: 2014

Abstract: The wide-spread encroachment of canopy-forming shrubs into northern and alpine tundra communities is likely to alter many plants – animal interactions, with direct and indirect impacts on herbivore populations. Specifically, shrub encroachment may impact habitat quality for herbivores by changing predation risk as a result of reduced visibility. We investigated the association between visibility and growth of juvenile arctic ground squirrels *Urocitellus parryii*

across an alpine tundra eco-tone with varying shrub cover. Marked individuals were weighed throughout the period following emergence from natal burrows in early summer until just prior to hibernation. Both males and females showed a positive association between habitat-specific visibility and post-emergence growth rate. There was a positive relationship between post-emergence juvenile growth rate and pre-hibernation mass for females but not males. As shrubs increase, ground squirrel populations may be adversely affected by reductions in habitat-scale visibility.

Local Relevance: Canopy-forming shrubs are becoming more abundant in tundra ecosystems as the climate warms and this may affect habitat quality for many arctic species that are adapted to more open landscapes. This study examines how shrub encroachment may affect ground squirrel population dynamics by determining what role visibility plays on post-emergence juvenile growth rate and prehibernation mass. The investigation was carried out across an alpine tundra ecotone with varying shrub cover. In Yukon, as the climate warms, the advancement of shrubs can indirectly and directly affect local herbivore species as more time is spent looking for predators in a decreased open environment (i.e., decreased visibility); this may lead to a loss in body mass as the animal spends less time foraging. Alterations in environment for species that usually prefer open landscapes can cause extirpation of the species form an area leading to loss of genetics and biodiversity. Researchers found a variation in juvenile growth rates associated with visibility related to shrub cover, indicating that the consequences of increases in shrub cover could negatively affect juvenile growth rates.

Keywords: ground squirrels, predator-prey relationships, shrub cover, tundra, visibility, *Urocitellus parryii*

Available Online: Full Document http://www.bioone.org/doi/full/10.2981/wlb.00038

Citation: Wheeler, H.C. and Hik, D.S., 2014. Influence of shrub canopies on growth rate and pre-hibernation mass of juvenile arctic ground squirrels. Wildlife Biology vol. 20, p. 253-258. doi: 10.2981/wlb.00038

Simulation of maintenance, growth and reproduction of caribou and reindeer as influenced by ecological aspects of nutrition, climate change and industrial development using an energy-protein model

Research Location: northern Canada

Publication Type: Report

Publication Date: 2014

Introduction: Northern caribou populations typically make seasonal migrations between lichen rich taiga forests in the winter and open tundra in the spring for calving (Kelsall, 1968; Bergerud et al., 2008). Caribou and wild reindeer are adapted to characteristically high seasonal and annual variability that is typical of the higher latitudes. Variability includes accumulation and structure of winter snow, spring snow melt and linked plant phenological dynamics (Klein, 1990; Albon & Langvatn, 1992), quality and accessibility of summer forage and disruptive impacts of biting and parasitic insects in the summer (Klein, 1990; Russell et al., 1993; Witter et al., 2011; Cuyler et al., 2012). Thus habitat characteristics and variability in risk (Kie, 1999) influence reproductive allocation patterns (Munns, 2006; Bårdsen et al., 2008; 2009; Monteith et al., 2013). Caribou have adapted to these ecological characteristics through evolutionary strategies that include trade-offs between survival and reproduction...

Local Relevance: The ability for managers and users of caribou to predict caribou responses to climate change will provide valuable insight into the key requirements for assessing incremental and cumulative impacts of climate change and industrial development (e.g., mining in the territory). Meta-modelling has been developed in recent years to recognize and capture environmental complexity in assessing risks on biodiversity. This study provides a detailed description of a meta-model for caribou that is based on energy-protein interactions of individuals that can be done to typify cohorts of a caribou population in order to project on the cohorts the variable impacts of climate change and development. This model is complex, and with that complexity come advantages and disadvantages. The biggest disadvantage is the data requirements needed to run the model. One of the most recent advantages is the modification of the model to allow for up to 1000 animals to be run through the model concurrently under the same scenario. This will allow users for example, to summarize results that will provide mean and variance for use in a population model. Furthermore, the user can simulate an animal for up to 10 years allowing the comparison of model outputs for different time periods, e.g., when the heard was increasing compared to when it was decreasing.

Keywords: caribou, disturbances, energy, impacts, latitudes, protein, variability, wild reindeer

Available Online: Full Document http://septentrio.uit.no/index.php/rangifer/article/view/3269/3139

Citation: White, R.G., Russell, D.E. and Daniel, C.J., 2014. Simulation of maintenance, growth and reproduction of caribou and reindeer as influenced by ecological aspects of nutrition, climate change and industrial development using an energy-protein model. Rangifer, vol. 34, Special Issue No. 22, 126 p.

Cold truths: how winter drives responses of terrestrial organisms to climate change

Research Location: temperate, polar and alpine habitats

Publication Type: Journal Article

Publication Date: 2014

Abstract: Winter is a key driver of individual performance, community composition, and ecological interactions in terrestrial habitats. Although climate change research tends to focus on performance in the growing season, climate change is also modifying winter conditions rapidly. Changes to winter temperatures, the variability of winter conditions, and winter snow cover can interact to induce cold injury, alter energy and water balance, advance or retard phenology, and modify community interactions. Species vary in their susceptibility to these winter drivers, hampering efforts to predict biological responses to climate change. Existing frameworks for predicting the impacts of climate change do not incorporate the complexity of organismal responses to winter. Here, we synthesize organismal responses to winter climate change, and use this synthesis to build a framework to predict exposure and sensitivity to negative impacts. This framework can be used to estimate the vulnerability of species to winter climate change. We describe the importance of relationships between winter conditions and performance during the growing season in determining fitness, and demonstrate how summer and winter processes are linked. Incorporating winter into current models will require concerted effort from theoreticians and empiricists, and the expansion of current growing-season studies to incorporate winter.

Local Relevance: In Yukon, as in other high, northern latitudes, climate warming is happening at a much higher rate compared to other parts of the globe. Current climate change research tends to focus on the growing season; however, winter conditions vary geographically and extreme

winter low temperatures constrain the geographic distribution of many species. The interaction between a species' traits and their environment will determine the success or failure in a changing climate. Therefore predictions on species vulnerability would ideally use information on species traits combined with climate models. This study looks at the alterations that can coincide with a changing climate beyond changes in growing seasons. The researchers present a multi-component framework for predicting the impact of change in abiotic winter drivers on terrestrial organisms. The researchers make comparison between overwintering strategies and how they are being challenged by an increase in winter temperatures. The study made several conclusions as follows: 1) Overwintering is a key component of the biology of organisms that live in temperate, polar and alpine habitats, and has driven the evolution of extreme phenotypes (i.e., dormancy and migration). 2) The main abiotic drivers of biological responses to winter are the mean and variability of air temperatures and the extent and timing of snow cover. 3) An understanding of the links between abiotic change and organismal performance is required for determining organismal vulnerability to climate change. 4) Responses to winter conditions are not isolated from growing-season responses to climate. 5) Inter- and intra-specific interactions strongly influence responses to winter climate change at the population and community levels.

Keywords: average temperatures, cold, energetics, extreme events, freeze-thaw cycles, frost, hibernation, snow, sub-lethal impacts

Available Online: Full Document http://onlinelibrary.wiley.com/doi/10.1111/brv.12105/full

Citation: Williams, C.M., Henry, H.A.L. and Sinclair, B.J., 2014. Cold truths: how winter drives responses of terrestrial organisms to climate change. Biological Reviews, vol. 90, issue 1, p. 214-235. doi: 10.1111/brv.12105

Collared Pika (Ochotona Collaris) Occupancy in Tombstone Territorial Park, Yukon: 2013 Survey Results

Research Location: Yukon Territory

Publication Type: Report

Publication Date: 2014

Summary:

- The Collared Pika (*Ochotona collaris*) is considered an indicator species for climate change, because of their sensitivity to climatic fluctuations and the natural isolation of suitable habitat. Given their susceptibility to climate change, Collared Pika is listed as Special Concern in the federal *Species at Risk Act*.
- During late-summer 2013, we conducted occupancy surveys for Collared Pika in Tombstone Territorial Park. Our aim was to provide occupancy estimates for Collared Pika in the park, and compare the results with the survey done in 2009.
- Collared Pikas were observed on 50.7% of 73 sites surveyed.
- Occupancy of the 46 sites surveyed in both 2009 and 2013 suggested a 15% decline in site occupancy between the 2 surveys. The reason for the apparent decline is unknown.
- Because Collared Pika populations may naturally fluctuate between years, multi-year surveys would be required to assess the annual variability in site occupancy and identify population trends.

- Population trend monitoring by means of occupancy surveys can assist in determining the conservation status of Collared Pikas, and serve as a window into the potential impact of climate change on alpine ecosystems in Yukon.

Local Relevance: The Collared Pika (*Ochotona collaris*) is a cold-adapted lagomorph that lives in talus slopes in alpine environments. It is considered an excellent indicator species for changes in climate due to their susceptibility to climatic fluctuations and the natural isolation of suitable habitat. About 60% of the species' range is in Canada; most of it in Yukon. The north is warming at an accelerated pace and Pikas tolerate heat poorly; they escape high daytime temperatures by sheltering under rocks. This report considers in its findings that pikas are a cold-adapted species, and climate change is expected to cause a reduction in population or local extirpation in lower latitudes and altitudes. Researchers conducted a site occupancy survey of 46 sites surveyed in both 2009 and 2013. The study suggests a 15% decline in site occupancy from 2009 to 2013, however the reason for decline is unknown.

Keywords: climate change, collared Pika, indicator species, special concern, Tombstone National Park

Available Online: Full Document www.env.gov.yk.ca

Citation: Kukka, P.M.K., McCulley, A., Suitor, M., Eckert, C.D. and Jung, T.S., 2014. Collared pika (*Ochotona collaris*) occupancy in Tombstone Territorial Park, Yukon: 2013 survey results. Fish and Wildlife Branch Report SR-14-01. Whitehorse, Yukon, Canada, 18 p.

Influence of hybridization on niche shifts in expanding coyote populations

Research Location: North America

Publication Type: Journal Article

Publication Date: 2014

Abstract: The degree to which niches of species change over time or space has important implications for ecology and evolutionary biology. However, conditions that give rise to niche shifts remain poorly understood. In particular, the relative influence of release from predation or competition (change in realized niche) vs. genetically based alterations (change in fundamental niche) has received little attention. We studied niche shifts in expanding coyote (*Canis latrans*) populations. During expansion from their historic range, coyotes experienced marked changes in competitive regimes and also genetic changes (i.e. hybridization), and these alterations occurred unevenly across the expanding front. The goal of this study was to determine the presence and degree of niche shifts in expanding coyote populations and the potential influence of hybridization on these patterns.

Local Relevance: In order to better understand the range and distribution of species in Yukon considerations on changes to ecosystems from climate change needs to be taken into account to better inform decision makers. This study looks at species distribution models and compares climatic niche overlap between historic and expanding coyote populations with different levels of genetic introgression with wolves. The researchers also developed harvest models to examine differences in how coyote and coyote hybrids responded to human disturbance and land use. Results show that niche differentiation is most pronounced for expanding coyote populations that have experienced substantial hybridization with wolves. Niche conservatism also has important implications for our ability to understand and model species response to global change processes.

Keywords: coyote, harvest, hybridization, invasive, niche shift, species distribution model

Available Online: Full Document http://wileyonlinelibrary.com/journal/ddi

Citation: Thornton, D.H. and Murray, D.L., 2014. Influence of hybridization on niche shifts in expanding coyote populations. Diversity and Distributions, vol. 20, issue 11, p. 1355–1364. doi: 10.1111/ddi.12253

Climate-Driven Effects of Fire on Winter Habitat for Caribou in the Alaskan-Yukon Arctic

Research Location: Alaskan – Yukon Arctic

Publication Type: Journal Article

Publication Date: 2014

Abstract: Climatic warming has direct implications for fire-dominated disturbance patterns in northern ecosystems. A transforming wildfire regime is altering plant composition and successional patterns, thus affecting the distribution and potentially the abundance of large herbivores. Caribou (*Rangifer tarandus*) are an important subsistence resource for communities throughout the north and a species that depends on terrestrial lichen in late-successional forests and tundra systems. Projected increases in area burned and reductions in stand ages may reduce lichen availability within caribou winter ranges. Sufficient reductions in lichen abundance could alter the capacity of these areas to support caribou populations. To assess the potential role of a changing fire regime on winter habitat for caribou, we used a simulation modeling platform, two global circulation models (GCMs), and a moderate emissions scenario to project annual fire characteristics and the resulting abundance of lichen-producing vegetation types (i.e., spruce forests and tundra >60 years old) across a modeling domain that encompassed the winter ranges of the Central Arctic and Porcupine caribou herds in the Alaskan-Yukon Arctic. Fires were less numerous and smaller in tundra compared to spruce habitats throughout the 90-year projection for both GCMs. Given the more likely climate trajectory, we projected that the Porcupine caribou herd, which winters primarily in the boreal forest, could be expected to experience a greater reduction in lichen-producing winter habitats (-21%) than the Central Arctic herd that wintered primarily in the arctic tundra (-11%). Our results suggest that caribou herds wintering in boreal forest will undergo fire-driven reductions in lichen-producing habitats that will, at a minimum, alter their distribution. Range shifts of caribou resulting from fire-driven changes to winter habitat may diminish access to caribou for rural communities that reside in fire-prone areas.

Local Relevance: Many people that reside in Yukon depend on country foods and wild game to meet some or most of their dietary and nutritional needs. In the northern regions of Yukon, the local indigenous groups have maintained a relationship with the porcupine caribou for thousands of years. As the climate becomes warmer due to global warming, severe wild fires will become more frequent. Ecosystem structure and function are being affected by a transforming wildfire regime thus altering plant composition and successional patterns. These shifts in vegetation alter the distribution and abundance of northern herbivores such as caribou. This study examines the potential effects on barren-ground and woodland caribou from an increase in fire severity and intensity. Fire disrupts migration patterns, foraging and habitat suitable for large ungulates. The researchers used a simulation modeling platform, two global circulation models (GCMs), and a moderate emissions scenario to project annual fire characteristics. The results showed that caribou herds wintering in boreal forest will undergo fire-driven reductions in lichen-producing habitats that will, at a minimum, alter their distribution.

Keywords: Arctic tundra, caribou, distribution, forest fire, foraging, migration, simulation modeling platform

Available Online: Full Document www.plosone.org

Citation: Gustine, D.D., Brinkman, T.J., Lindgren, M.A., Schmidt, J.I, Rupp, T.S. and Adams, L.G., 2014. Climate-Driven Effects of Fire on Winter Habitat for Caribou in the Alaskan-Yukon Arctic. PLoS ONE, vol. 9, issue 7, p. 1-11. doi:10.1371/journal.pone.0100588

Climate change and mammals: evolutionary versus plastic responses

Research Location: Research compilation of 19 studies

Publication Type: Journal Article

Publication Date: 2013

Abstract: Phenotypic plasticity and microevolution are the two primary means by which organisms respond adaptively to local conditions. While these mechanisms are not mutually exclusive, their relative magnitudes will influence both the rate of, and ability to sustain, phenotypic responses to climate change. We review accounts of recent phenotypic changes in wild mammal populations with the purpose of critically evaluating the following: (i) whether climate change has been identified as the causal mechanism producing the observed change; (ii) whether the change is adaptive; and (iii) the relative influences of evolution and/or phenotypic plasticity underlying the change. The available data for mammals are scant. We found twelve studies that report changes in phenology, body weight or litter size. In all cases, the observed response was primarily due to plasticity. Only one study (of advancing parturition dates in American red squirrels) provided convincing evidence of contemporary evolution. Subsequently, however, climate change has been shown to not be the causal mechanism underlying this shift. We also summarize studies that have shown evolutionary potential (i.e. the trait is heritable and/or under selection) in traits with putative associations with climate change and discuss future directions that need to be undertaken before a conclusive demonstration of plastic or evolutionary responses to climate change in wild mammals can be made.

Local Relevance: Climate change in northern Canada is happening at a faster rate compared to other regions in the country. Yukon is home to many species of birds, fish and animals and it is important to understand the potential effects and phenotypic change that rapid climate change may have on these individuals. To date, there is little actual evidence that these phenotypic changes are due to climate-driven evolution. This paper reviews 19 recent studies in order to examine the evidence for a causative link between climate change and phenotypic changes in mammals. The authors also evaluate whether the changes are adaptive and the relative influences that evolution and/or phenotypic plasticity have on these changes. The main phenotypic changes considered were reproductive timing, emergence from hibernation, and body mass and litter size. This review concludes that current evidence for microevolution of mammal populations in response to recent climate change is negligible.

Keywords: adaptation, climate change, contemporary evolution, ecological genetics, natural selection, phenotypic plasticity, quantitative genetics

Available Online: Full Document http://onlinelibrary.wiley.com/doi/10.1111/eva.12121/pdf

Citation: Boutin, S. and Lane, J.E., 2013. Climate change and mammals: evolutionary versus plastic responses. Evolutionary Applications, vol. 7, issue 1, p. 29-41. doi:10.1111/eva.12121

Climate change and the increasing impact of polar bears on bird populations

Research Location: Svalbard and Greenland

Publication Type: Journal Article

Publication Date: 2015

Abstract: The Arctic is becoming warmer at a high rate, and contractions in the extent of sea ice are currently changing the habitats of marine top-predators dependent on ice. Polar bears (*Ursus maritimus*) depend on sea ice for hunting seals. For these top-predators, longer ice-free seasons are hypothesized to force the bears to hunt for alternative terrestrial food, such as eggs from colonial breeding birds. We analyzed time-series of polar bear observations at four locations on Spitsbergen (Svalbard) and one in east Greenland. Summer occurrences of polar bears, measured as the possibility of encountering bears and the number of days with bear presence, has increased significantly from the 1970/80s to the present. The shifts in polar bear occurrence coincide with trends for shorter sea ice seasons and less sea ice during the spring in the study area. This resulted in a strong inverse relationship between the probability of bear encounters on land and the length of sea ice season. Within 10 years after the first appearance on land, polar bears had advanced their arrival dates by almost 30 days. Direct observations of nest predation showed that polar bears may severely affect reproductive success of the barnacle goose (*Branta leucopsis*), common eider (*Somateria mollissima*) and glaucous gull (*Larus hyperboreus*). Nest predation was strongest in years when the polar bears arrived well before hatch, with more than 90% of all nests being predated. The results are similar to findings from Canada, and large-scale processes, such as climate and subsequent habitat change, are pinpointed as the most likely drivers in various parts of the Arctic. We suggest that the increasing, earlier appearance of bears on land in summer reflects behavioral adaptations bya small segment of the population to cope with a reduced hunting range on sea ice. This exemplifies how behavioral adaptations may contribute to the cascading effects of climate change.

Local Relevance: This study looks at the adaptations of polar bears in a changing climate and how they might be adjusting their feeding behaviour as a result of sea ice reduction. Evidence is accumulating that polar bears are suffering from a warming climate and associated loss of sea ice habitat. Several studies have documented that polar bears on land can potentially have a large Impact on their prey, in particular when bears feed on bird eggs. This study documents the summer ranges of polar bears and how the changes in sea ice conditions are related to bear incursions on land. The researchers also explore the effects of polar bears on the reproductive success of three colonial breeding birds: barnacle goose (*Branta leucopsis*), common eider (*Somateria mollissima*) and glaucous gull (*Larus hyperboreus*). Two of these species of birds (common eider and glaucous gull) occur on the north coast of Yukon. The results of the study show that the highest predation occurred in the years when the first bears appeared in June, well before bird eggs hatched. Furthermore, polar bear predation will lower the reproductive outputs during favourable years.

Keywords: cascading effects, colonial breeding birds, depredation, global warming, polar bear, seabirds, sea ice

Available Online: Full Document http://journal.frontiersin.org/article/10.3389/fevo.2015.00033/full

Citation: Prop, J., Aars, J., Bårdsen, B-J., Hanssen, S.A., Bech, C., Bourgeon, S., de Fouw, J., Gabrielsen, G.W., Lang, J., Noreen, E., Oudman, T., Sittler, B., Stempniewicz, L., Tombre, I., Wolters, E. and Moe, B., 2015. Climate change and the increasing impact of polar bears on bird populations. Frontiers in Ecology and Evolution, 3:33. doi: 10.3389/fevo.2015.00033

Natal den selection by sympatric arctic and red foxes on Herschel Island, Yukon, Canada

Research Location: Herschel Island, Yukon

Publication Type: Journal Article

Publication Date: 2013

Abstract: In the twentieth century, red fox (*Vulpes vulpes*) expanded into the Canadian Arctic, where it competes with arctic fox (*Vulpes lagopus*) for food and shelter. Red fox dominates in physical interactions with the smaller arctic fox, but little is known about competition between them on the tundra. On Hershel Island, north Yukon, where these foxes are sympatric, we focused on natal den choice, a critical aspect of habitat selection. We tested the hypothesis that red fox displaces arctic fox from dens in prey-rich habitats. We applied an approach based on model comparisons to analyze a 10-year data set and identify factors important to den selection. Red fox selected dens in habitats that were more prey-rich in spring. When red foxes reproduced, arctic fox selected dens with good springtime access, notably many burrows unblocked by ice and snow. These provided the best refuge early in the reproductive season. In the absence of red foxes, arctic foxes selected dens offering good shelter (i.e. large isolated dens). Proximity to prey-rich habitats was consistently less important than the physical aspects of dens for arctic fox. Our study shows for the first time that red foxes in the tundra select dens associated primarily with prey-rich areas, while sympatric arctic foxes do not. These results fit a model of red fox competitively interfering with arctic fox, the first detailed study of such competition in a true arctic setting.

Local Relevance: Artic and red foxes are viewed as ecological equivalents and thus direct competitors for food and shelter. The red foxes dominate physical interactions with the smaller arctic fox, however in north Yukon there are cases of coexistence at the local and regional scales; however, it is not known whether there are negative consequences to the arctic foxes. The researchers studied den selection by red and arctic foxes on Herschel Island in northern Yukon, using 10 years of repeated observations of a set of 25 dens. The study found that arctic foxes bred yearly on the island, whereas red foxes only bred in four out of 10 years. Results of the study found that not only do the arctic and red fox occupy the same habitat, but also the same den locations. Red fox, which are larger and have a higher energetic burden, select dens primarily on the basis of proximity to food sources. The arctic fox, which are dominated by the red fox, choose good shelter over proximity to good hunting grounds and that the need for early springtime access to shelter is increased when they share the landscape with the red fox. However, in the absence of reproducing red foxes, the arctic fox may occupy dens previously used by the red fox.

Keywords: competition, den, reproduction, habitat selection, Herschel Island, *Vulpes lagopus*, *Vulpes vulpes*, Yukon

Citation: Gallant, D., Reid, D.G., Slough, B.G. and Berteaux, D., 2013. Natal den selection by sympatric arctic and red foxes on Herschel Island, Yukon, Canada. Polar Biology, vol. 37, p. 333-345. doi: 10.1007/s00300-013-1434-1

Origin of Dermacentor Albipictus (Acari: Ixodidae) on Elk in the Yukon, Canada

Research Location: Yukon Territory

Publication Type: Journal Article

Publication Date: 2014

Abstract: Winter ticks (*Dermacentor albipictus*) on elk (*Cervus elaphus canadensis*) have recently increased in numbers in the Yukon, Canada, potentially posing risks to other indigenous host species in the region. To evaluate the regional source of winter ticks in the Yukon, we sequenced one nuclear (ITS-2) and two mitochondrial (16SrRNA and COI) genes, and genotyped 14 microsatellite loci from 483 winter tick specimens collected across North America. We analyzed genetic variation across the geographic and host ranges of this tick species with the use of variance partitioning, Bayesian clustering, and standard population genetic analyses. Based on our results, winter ticks on elk in the Yukon could have originated either by translocation from central Alberta or by northward range expansion of more geographically proximate populations in northern Alberta and British Columbia. Although there was some genetic structuring of winter ticks on different hosts in the same region, we found little evidence of host specificity in winter ticks from five ungulate host species, suggesting that the winter ticks on elk in the Yukon could potentially become established on other locally available host species such as moose (*Alces alces*).

Local Relevance: Elk is an introduced species to the Yukon. This study looks at the potential ability of winter ticks to transfer from elk to other ungulates such as moose. Moose are an important big game species in Yukon for both First Nation and non-First Nation resident hunters. Climate change is occurring at an accelerated pace in the north and this study will provide wildlife managers and local researchers new data on the potential for winter ticks to advance and become established on other host species. The tick is a wildlife management concern because of its association with hair loss and mortality in various cervid species, particularly moose. This research suggests that the presence of winter ticks in Yukon could be the result of natural northward range expansion due to spatial movement by ungulate host species in response to ecologic factors like climate change.

Keywords: *Dermacentor albipictus*, genetics, host specificity, invasive species, parasites

Available Online: Abstract http://www.bioone.org/doi/abs/10.7589/2013-03-078

Citation: Leo, S.S.T., Samuel, W.M., Pybus, M.J. and Sperling, F.A.H., 2014. Origin of *Dermacentor albipictus* (acri: ixodiae) on elk in the Yukon, Canada. Journal of Wildlife Diseases, vol. 50, issue 3, p. 544-551. doi: 10.7589/2013-03-078

Trophic Dynamics of the Boreal Forests of the Kluane Region

Research Location: Kluane Lake Research Station

Publication Type: Journal Article

Publication Date: 2014

Abstract: The trophic dynamics of the Yukon boreal forest have been under investigation at the Kluane Lake Research Station since 1973. We monitored and conducted experiments on the major species in this ecosystem, except the large mammals (for logistic reasons). The central problem has been to determine the causes of the 9 – 10 year cycle of snowshoe hares, and to achieve this we carried out several large-scale experiments manipulating food supplies, predator pressure, and soil nutrient availability to test hypotheses that food, predation, or habitat quality regulate populations. The hare cycle is driven top-down by predators, and most hares die because they are killed by predators. Predators also cause stress in female hares, and the stress response seems to be responsible for the loss of reproductive potential in the decline and low phases of the hare cycle. Many of the specialist predators and some herbivores in this ecosystem fluctuate with the hare cycle. Arctic ground squirrels do, but red squirrels do not, being linked closely to white spruce seed masting years. Small rodents fluctuate in numbers in two patterns. Red-backed voles and four species of *Microtus* voles have a 3 – 4 year cycle that seems to be driven by food supplies and social behaviour. Deer mice, in contrast, have fluctuated dramatically in the 38 years we have monitored them, but not cyclically. White spruce seed production varies with temperature and rainfall, but was not affected by adding nutrients in fertilizer. Global warming and reduced hare browsing in the last 20 years have helped to increase the abundance of shrubs in these forests. It will be challenging to predict how this system will change as climatic warming proceeds, because even closely related species in the same trophic level respond differently to perturbations. We recommend continued monitoring of the major species in these boreal forests.

Local Relevance: Early research on trophic dynamics in the boreal forest of southwest Yukon discovered that small rodent biodiversity was among the highest in North America and the most dominant mammalian species was found to be the snowshoe hare. This study uses data that has been collected from the Kluane Lake Research Station since 1973 in an effort to determine the causes of the 9-10 year cycle of the snowshoe hare – an important secondary producer and a staple food source for specialized predators such as Lynx. The hares can be considered a keystone species as many species are dependent on them for food in the northern boreal forest and a reduction in hare productivity is felt throughout the trophic system of the forest. In conclusion, it is recommended that monitoring continue to provide a continuous record of the response of key ecosystem components to changes over time since changes in trophic dynamics are impossible to predict as the climate shifts, even within relatively simple ecosystems such as the boreal forest.

Keywords: boreal forest, snowshoe hares (*Lepus americanus*), red-backed voles (*Myodes rutilus*), *Microtus* spp., Arctic ground squirrels (*Urocitellus parryi*), red squirrels (*Tamiasciurus hudsonicus*), grouse, fertilization, predation

Available Online: Full Document http://arctic.journalhosting.ucalgary.ca/arctic/index.php/arctic/article/view/4350/4513

Citation: Krebs, C.J., Boonstra, R., Boutin, S., Sinclair, A.R.E., Smith, J.N.M., Gilbert, B.S., Martin, K., O'Donoghue, M. and Turkington, R., 2014. Trophic Dynamics of the Boreal Forests of the Kluane Region. Arctic, vol. 67, no. 5, p. 71-81. http://dx.doi.org/10.14430/arctic4350

6.2 AVES

Stacked species distribution models and macroecological models provide congruent projections of avian species richness under climate change

Research Location: Canada and USA

Publication Type: Journal Article

Publication Date: 2015

Abstract:

Aim: Using survey data for North American birds, we assess how well historical patterns of species richness are explained by stacked species distribution models and macroecological models. We then describe the degree to which projections of future species richness differ, employing both modelling approaches across multiple emissions scenarios.

Methods: We use Audubon Christmas Bird Count and North American Breeding Bird Survey data to estimate current and future species richness of birds using two distinct approaches. In the first, we model richness by stacking predictions from individual species distribution models. In the second, we model richness directly, ignoring the contributions of specific taxa to richness estimates.

Results: The two modelling approaches show similar accuracies when validated with historical observations, particularly winter observations, and result in similar patterns of richness when projected onto current and future climate spaces. Patterns of projected change in species richness differed markedly between winter and summer seasons regardless of modelling approach. Our models suggest that bird species richness in winter will increase or remain stable across much of North America. In contrast, species richness in summer is projected to decrease over much of North America, except part of northern Canada, suggesting that climate may constrain many breeding bird species and communities in the future.

Main conclusions: Stacked species distribution models and macroecological models produce similar estimates of current and future species richness for each of two seasons despite being built on different concepts of community assembly. Our results suggest that, although the mechanisms that shape geographical variation in biodiversity remain uncertain, these limitations do not impede our ability to predict patterns of species richness at broad scales. Congruence of species richness projections across modelling approaches is encouraging for conservation planning efforts that focus on retaining biodiversity into the future.

Local Relevance: Recent climate change has already caused shifts in the geographical ranges of myriad species and ongoing climate change is expected to result in even greater redistributions of taxa. In the Yukon many indigenous cultures depend and rely on the historical migration and distribution routes for their harvesting activities and gathering techniques. This study is one of the first of its kind that predicts the potential impacts of climate change on avian species in the United States and Canada across the seasons and for all species where standardized survey data exists. This research has shown that stacked individual species distribution models and macroecological models produced strikingly similar estimates of both current and future species richness, despite being built on very different concepts of community assembly. Based on the models, species richness in winter is expected to increase over much of Canada and the US, whereas summer species richness is expected to decline. This is important in Yukon because changes in patterns of species richness have important implications for systematic conservation planning.

Keywords: biodiversity, birds, climate change, conservation, macroecology, North America, seasonality, species distribution models

Available Online: Full Document http://onlinelibrary.wiley.com/doi/10.1111/jbi.12479/pdf

Citation: Distler, T., Schuetz, J.G., Velásquez-Tibatá, J. and Langham, G.M., 2015. Stacked species distribution models and macroecological models provide congruent projections of avian species richness under climate change. Journal of Biogeography, vol. 42, issue 5, p. 976–988. doi:10.1111/jbi.12479

Breeding habitat associations and predicted distribution of an obligate tundra-breeding bird, Smith's Longspur

Research Location: Alaska

Publication Type: Journal Article

Publication Date: 2015

Abstract: Smith's Longspur (*Calcarius pictus*) is a species of conservation concern which breeds in Arctic habitats that are expected to be especially vulnerable to climate change. We used bird presence and habitat data from point-transect surveys conducted at 12 sites across the Brooks Range, Alaska, 2003–2009, to identify breeding areas, describe local habitat associations, and identify suitable habitat using a predictive model of Smith's Longspur distribution. Smith's Longspurs were observed at seven sites, where they were associated with a variety of sedge–shrub habitats composed primarily of mosses, sedges, tussocks, and dwarf shrubs; erect shrubs were common but sparse. Nonmetric multidimensional scaling ordination of ground cover revealed positive associations of Smith's Longspur presence with sedges and mosses and a negative association with high cover of shrubs. To model predicted distribution, we used boosted regression trees to relate landscape variables to occurrence. Our model predicted that Smith's Longspurs may occur in valleys and foothills of the northeastern and southeastern mountains and in upland plateaus of the western mountains, and farther west than currently documented, over a predicted area no larger than 15% of the Brooks Range. With climate change, shrubs are expected to grow larger and denser, while soil moisture and moss cover are predicted to decrease. These changes may reduce Smith's Longspur habitat quality and limit distribution in the Brooks Range to poorly drained lowlands and alpine plateaus where sedge–shrub tundra is likely to persist. Conversely, northward advance of shrubs into sedge tundra may create suitable habitat, thus supporting a northward longspur distribution shift.

Local Relevance: With climate change, shrubs are expected to grow larger and denser, while soil moisture and moss cover are predicted to decrease and this will negatively affect some species and positively affect others in the Yukon Territory. The warming climate sets the stage for the advancement of southern shrub and plant species and the subsequent dispersal of species that may benefit from an altered environment. This study's primary goal was to collect presence and absence data in a systematic manner to best inform our models of predicted distribution. The results show that Smith's Longspurs were patchily distributed at both the landscape and local scale

Keywords: Alaska, Brooks Range, *Calcarius pictus*, climate change, sub-Arctic, predictive distribution model

Available Online: Full Document www.cooper.org

Citation: Wild, T.C., Kendall, S.J., Guldagar, N. and Powell, A.N., 2015. Breeding habitat associations and predicted distribution of an obligate tundra-breeding bird, Smith's Longspur. The Condor, vol. 117, issue 1, p. 3-17. doi: 10.1650/CONDOR-14-77.1

Projecting boreal bird responses to climate change: the signal exceeds the noise

Research Location: Alaska

Publication Type: Journal Article

Publication Date: 2015

Abstract: For climate change projections to be useful, the magnitude of change must be understood relative to the magnitude of uncertainty in model predictions. We quantified the signal-to-noise ratio in projected distributional responses of boreal birds to climate change, and compared sources of uncertainty. Boosted regression tree models of abundance were generated for 80 boreal-breeding bird species using a comprehensive data set of standardized avian point counts (349 629 surveys at 122 202 unique locations) and 4-km climate, land use, and topographic data. For projected changes in abundance, we calculated signal-to-noise ratios and examined variance components related to choice of global climate model (GCM) and two sources of species distribution model (SDM) uncertainty: sampling error and variable selection. We also evaluated spatial, temporal, and interspecific variation in these sources of uncertainty. The mean signal-to noise ratio across species increased over time to 2.87 by the end of the 21st century, with the signal greater than the noise for 88% of species. Across species, climate change represented the largest component (0.44) of variance in projected abundance change. Among sources of uncertainty evaluated, choice of GCM (mean variance component = 0.17) was most important for 66% of species, sampling error (mean = 0.12) for 29% of species, and variable selection (mean = 0.05) for 5% of species. Increasing the number of GCMs from four to 19 had minor effects on these results. The range of projected changes and uncertainty characteristics across species differed markedly, reinforcing the individuality of species' responses to climate change and the challenges of one size- fits-all approaches to climate change adaptation. We discuss the usefulness of different conservation approaches depending on the strength of the climate change signal relative to the noise, as well as the dominant source of prediction uncertainty.

Local Relevance: Climate change within the boreal region has already led to increased drought- and insect-induced tree mortality, wetland drying, and wildfire activity in the Yukon Territory. This drastic alteration is visible in the beetle killed boreal forest of southwest Yukon near Haines Junction. Therefore, bird species presently restricted to boreal regions may experience range reductions if those biomes shift northward and decrease in area, as projected for North America; however, concurrent northward range expansions of breeding birds have been documented and attributed to climate change in temperate North America. With systematic conservation planning efforts, there is growing interest in forecasting the potential ecological impacts of climate change with an understanding of the associated uncertainties. This study uses an extensive boreal bird data set for North America to evaluate the signal-to-noise ratio (i.e., magnitude of change vs. estimates of uncertainty) for projected changes in boreal bird abundance over the next century. The results of this study showed that the climate-only model was significantly better for only one species. Lastly, the researchers concluded that species with the most northerly distributions often had high sampling uncertainty, due to sparse data, but also had large projected declines, leading to high signal-to-noise ratios that increased over time.

Keywords: avian density, boosted regression trees, boreal birds, boreal forest, climate change, global climate models, signal-to-noise ratio, species distribution models, uncertainty, variance partitioning

Available Online: Full Document http://www.esajournals.org/doi/full/10.1890/13-2289.1

Citation: Stralberg, D., Matsuoka, S.M., Hamann, A., Bayne, E.M., Sólymos, P., Schmiegelow, F.K.A., Wang, X., Cumming, S.G. and Song, S.J., 2015. Projecting boreal bird responses to climate change: the signal exceeds the noise. Ecological Applications, vol. 25, issue 1, p. 52–69. http://dx.doi.org/10.1890/13-2289.1

Wetland issues affecting waterfowl conservation in North America

Research Location: Canadian northern boreal forest

Publication Type: Journal Article

Publication Date: 2014

Abstract: This paper summarizes discussions by invited speakers during a special session at the 6th North American Duck Symposium on wetland issues that affect waterfowl, highlighting current ecosystem challenges and opportunities for the conservation of waterfowl in North America. Climate change, invasive species, U.S. agricultural policy (which can encourage wetland drainage and the expansion of row-crop agriculture into grasslands), cost and competition for water rights, and wetland management for non-waterfowl species were all considered to pose significant threats to waterfowl populations in the near future. Waterfowl populations were found to be faced with significant threats in several regions, including: the Central Valley of California, the Playa Lakes Region of the south-central U.S., the Prairie Pothole Region of the northern U.S. and western and central Canada, the boreal forest of northern Canada, the Great Lakes region and Latin America. Apart from direct and indirect threats to habitat, presenters identified that accurate and current data on the location, distribution and diversity of wetlands are needed by waterfowl managers, environmental planners and regulatory agencies to ensure focused, targeted and cost-effective wetland conservation. Although populations of many waterfowl species are currently at or above long-term average numbers, these populations are thought to be at risk of decline in the near future because of ongoing and predicted nesting habitat loss and wetland destruction in many areas of North America.

Local Relevance: In Yukon and northern Canada wetlands are sensitive to climate changes; threats include drainage and loss of wetlands due to increased agriculture supported by a warming climate. The main objectives of this study are to: 1) outline the growing threats to wetlands and waterfowl in North America; 2) generally highlight current research and management that addresses these issues; and 3) provide recommendations for future actions that may benefit wetland and waterfowl conservation in North America. Wetlands comprise 6% of the earth's land cover, yet Canada alone has 25% of the world's wetlands; more than 85% of Canada's wetlands are in the form of bogs, fens, swamps, marshes and open water basins in the Boreal. However, in Boreal Canada, there is almost no broad wetland protection either at the federal or provincial/territorial level. In Yukon, the Old Crow Flats region is undergoing changes due to climate warming; thermokarst lakes are draining due to permafrost degradation and thaw. Waterfowl managers and scientists must focus increased efforts on providing information that can influence the future of wetland conservation policies.

Keywords: agriculture, climate change, dabbling duck, national wetlands inventory, playa, policy, prairie pothole.

Available Online: Full Document http://wildfowl.wwt.org.uk/index.php/wildfowl/article/view/2612/1728

Citation: Hagy, H.M., Yaich, S.C., Simpson, J.W., Carrera, E., Haukos, D.A., Johnson, W.C., Loesch, C.R., Reid, F.A., Stephens, S.E., Tiner, R.W., Werner, B.A. and Yarris, G.S., 2014. Wetland issues affecting waterfowl conservation in North America. Wildfowl Special Issue No. 4, p. 343–367.

Habitat selection and nest success of the Upland Sandpiper (Bartramia longicauda) in Ivvavik National Park, Yukon, Canada

Research Location: northern Yukon

Publication Type: Journal Article

Publication Date: 2014

Abstract: The Upland Sandpiper (*Bartramia longicauda*) is a grassland shorebird species associated primarily with prairie habitats in central North America. A disjunct and poorly studied population also occurs in Yukon, Canada, and Alaska, United States. We studied habitat selection of nesting Upland Sandpipers in Ivvavik National Park, Yukon, at the scales of microhabitat (1-m radius around nest) and putative home range (11.3-m radius plots at nests and within 50 m of nest). At the microhabitat scale, the Upland Sandpiper selected nest sites with lower visibility from above than that of their home range (median 91.5%, range 70–98% versus median 99.0%, range 85–100%) and less-variable composition of vegetation than at random sites within the home range. Vegetation adjacent to the nest in the eastern quadrat was significantly shorter (mean ± standard error: 10.6 ± 1.55 cm) than that in other directions around the nest (> 13 cm); nest sites and microsites within home ranges were more often hummocky than random sites in the park. At the mesohabitat scale, Upland Sandpipers selected sites within home ranges with fewer trees than random sites within the park (10.3 ± 3.0 trees per 11.3-m-radius plot around nest versus 32.9 ± 5.9 trees per 11.3-m-radius plot in the park) and greater herbaceous cover (70.7% ± 3.0% versus 56.2% ± 3.7%). Despite the disproportionate use of sites with fewer trees, more herbaceous cover, and lower vertical visibility, these factors did not relate to nest success in our sample. Of the 24 nests found in 2010 and 2011, 22 contained four eggs and 2 contained three eggs. Upland Sandpipers at this high latitude site had a nesting success rate of 0.85 ± 0.01 and 0.56 ± 0.01 in 2010 and 2011, respectively, for a 21-day incubation period. Further assessment of the selected characteristics of nesting sites will improve our ability to predict the effects of northward shrub and tree encroachment on this grassland species.

Local Relevance: The population of Upland Sandpiper is poorly studied and therefore little information is documented. Upland Sandpipers selected sites within home ranges with fewer trees and high visibility. This study looks at the effects of northward shrub and tree encroachment on the nest habitat selection of the Upland Sandpiper. Vegetation characteristics are typically important features of nest-site selection for birds and the Upland Sandpiper prefers to nest in large open grasslands with flowering herbaceous vegetation and avoids woody and tall, dense vegetation. As climate warms, there is an expected advancement of treeline and a shifting in biomes. The study concluded that Upland Sandpipers nested in home ranges with fewer trees and greater herbaceous cover. Additionally, Upland Sandpipers nest in flat valleys and shallow slopes, as the mountains are too rocky and the south-facing slopes have dense spruce cover. Habitat loss for the Upland Sandpiper in Ivvavik National Park is believed to be a real threat due to the already small openings (<0.1 ha) in the sparsely forested landscape.

Keywords: *Bartramia longicauda*, Ivvavik National Park, mesohabitat, microhabitat, nest-site selection, northern limit, shorebirds, Upland Sandpiper, Yukon

Available Online: Full Document http://canadianfieldnaturalist.ca/index.php/cfn/article/view/1627/1630

Citation: Miller, V., Nol, E., Nguyen, L.P. and Turner, D.M., 2014. Habitat selection and nest success of the Upland Sandpiper (*Bartramia longicauda*) in Ivvavik National Park, Yukon, Canada. The Canadian Field-Naturalist, vol. 128, no. 4, p. 341–349.

6.3 INSECTS

Phenology of high-arctic butterflies and their floral resources: Species-specific responses to climate change

Research Location: high arctic, northeast Greenland

Publication Type: Journal Article

Publication Date: 2014

Abstract: Current global warming is particularly pronounced in the Arctic and arthropods are expected to respond rapidly to these changes. Long-term studies of individual arthropod species from the Arctic are, however, virtually absent. We examined butterfly specimens collected from yellow pitfall traps over 14 years (1996–2009) at Zackenberg in high-arctic, north-east Greenland. Specimens were previously sorted to the family level. We identified them to the species level and examined long-term species-specific phenological responses to recent summer warming. Two species were rare in the samples (Polaris fritillary *Boloria polaris* and Arctic blue *Plebejus glandon*) and statistical analyses of phenological responses were therefore restricted to the two most abundant species (Arctic fritillary, *B. chariclea* and Northern clouded yellow *Colias hecla*). Our analyses demonstrated a trend towards earlier flight seasons in *B. chariclea*, but not in *C. hecla*. The timing of onset, peak and end of the flight season in *B. chariclea* were closely related to snowmelt, July temperature and their interaction, whereas onset, peak and end of the flight season in *C. hecla* were only related to timing of snowmelt. The duration of the butterfly flight season was significantly positively related to the temporal overlap with floral resources in both butterfly species. We further demonstrate that yellow pitfall traps are a useful alternative to transect walks for butterfly recording in tundra habitats. More phenological studies of Arctic arthropods should be carried out at the species level and ideally be analysed in context with interacting species to assess how ongoing climate change will affect Arctic biodiversity in the near future

Local Relevance: Phenology is a key indicator of species response to climate change and butterflies are model organisms to use in phenological studies as they respond rapidly to environmental change. Since global warming is particularly pronounced in the Arctic, many species are responding rapidly to these changes. Butterflies in Yukon are an important food source for many species of breeding birds. This study examines species-specific estimates of onset, peak and end of flight season for butterflies in the high-arctic of northeast Greenland and how it may be associated with recent rapid warming. The researchers have found that over a 14-year period, there is a direct correlation with snowmelt and movement patterns of some arctic butterfly species. Furthermore, the duration of the flight season varied by a factor of two over the study period for both butterfly species examined and was related to the duration of overlap with relevant floral resources. The strong phenological response by high-arctic butterflies to

climate variation clearly demonstrates that species-specific studies of populations of arctic arthropods should be a research priority in regions like Yukon.

Keywords: Arctic, arthropod, flight period, Greenland, pitfall trap, Zackenberg

Available Online: Full Document http://www.currentzoology.org/temp/%7B977A363E-6392-4112-995A-8458A2A536B4%7D.pdf

Citation: Høye, T.T., Eskildsen, A., Hansen, R.R., Bowden, J.J., Schmidt, N.M. and Kissling, W.D., 2014. Phenology of high-arctic butterflies and their floral resources: Species-specific responses to climate change. Current Zoology, vol. 60, issue 2, p. 243–251.

Middle Pleistocene (MIS 7) to Holocene fossil insect assemblages from the Old Crow basin, northern Yukon, Canada

Research Location: Old Crow region

Publication Type: Journal Article

Publication Date: 2014

Abstract: The Old Crow basin, northern Yukon, provides a key record of environmental change in northwestern North America from the late-Middle Pleistocene through the Early Holocene. Site chronologies are based on the presence of the Old Crow tephra (OCt: 124 ± 10 ka) at three sites, and provide a stratigraphic framework for observations. Ecological affinities of fossil insects indicate that Pleistocene environments were dominated by dry tundra and steppe-tundra. Forest insect species are relatively rare even during the last inter-glaciation (MIS 5e), and it is only by considering the total insect assemblages that interglacial beds can be recognized. Last interglacial insects from these sites indicate a relatively wet and warm tundra environment with evidence for sparse forest vegetation. Rare taxa with strong affinities to warmer temperatures are present and could suggest a warmer than modern climate. Early Holocene deposits yield a greater abundance of forest insects relative to MIS 5 or 7 interglacial deposits. Fossil insect assemblages reflect the position of the sites above the Arctic Circle, and in contrast to central Yukon sites, steppe insects are less common during cold stages and forest insects are less common during warm stages. These data suggest overall that the contrast between cold and warm stages was less pronounced than in other regions of Yukon and Alaska, and may indicate influence of persistent large regional lakes during the Pleistocene.

Local Relevance: The focus of this research was to identify the last interglaciation at previously studied sites along the lower Old Crow River on the basis of the insect fossil assemblages and stratigraphic position. The objectives of this paper are to: (1) establish the stratigraphic setting of interglacial units in the lower Old Crow basin; (2) identify fossil insect assemblages from these deposits and adjacent units; and (3) establish the paleoenvironmental significance of these units for our understanding of glacial, interglacial and interstadial environments of northern Yukon. The Old Crow area remains a significant region for paleoenvironmental research since it remained unglaciated during the Pleistocene, and that combined with the presence of permafrost has preserved an exceptional record of Beringian paleoenvironments extending into the Pliocene. Understanding the nature of past periodic climate change through paleoenvironmental reconstruction is important for developing a model of the mechanisms that drive global climate change. Knowledge of the ecological and physical responses to these changes provides critical information about the sensitivity of ecosystems to climate variability.

Keywords: insects, interglaciation, Old Crow, Pleistocene, tephra, tundra

Available Online: Abstract http://www.sciencedirect.com/science/article/pii/S1040618213007970

Citation: Kuzmina, S., Froese, D.G., Jensen, B.J.L., Hall, E. and Zazula, G.D., 2014. Middle Pleistocene (MIS 7) to Holocene fossil insect assemblages from the Old Crow basin, northern Yukon, Canada. Quaternary International, vol. 341, p. 216-242. doi: 10.1016/j.quaint.2013.10.025

Climate-associated tundra thaw pond formation and range expansion of boreal zooplankton predators

Research Location: Alaska

Publication Type: Journal Article

Publication Date: 2015

Abstract: Most of the freshwater component of the Earth 's surface is composed of shallow tundra ponds. These high latitude ecosystems have been exposed to a variety of abiotic disturbances associated with recent environmental change. However, the biological significance of these changes remains poorly understood. Here, we characterize the abiotic disturbance to the shallow tundra ponds of northwest Alaska. We used historical aerial imagery to determine that up to 53% of the sampled ponds have formed during the recent warmer decades (since the 1970s). We discovered that two top predator species (phantom midges of the genus *Chaoborus*) of the freshwater zooplankton have recently undergone range expansion, forming widespread (a scale of hundreds of km) stable tundra populations. We assessed the population persistence of these boreal predators by longitudinal sampling over 14 yr. Recent thaw ponds had significantly dissimilar zooplankton communities to communities of ponds that formed before 1950. Both predator and herbivore species differed by age of pond. Younger pond ages and warmer surface temperatures were the significant predictors of the presence of temperate *Chaoborus americanus* in tundra ponds. Ponds containing tundra populations of *C. americanus* and *C.* cf. *flavicans* were associated with recent formation (83 – 90%). Recent ponds in river valleys appeared more important than recent ponds near roads as colonization corridors for *C. americanus*. Only 24% of the tundra keystone predator, *Heterocope septentrionalis*, populations were from recent ponds. Our results suggest that climate-associated disturbance can lead to a widespread stable range expansion of boreal species despite the propinquity of older ponds with top-down control exerted by an endemic keystone predator.

Local Relevance: In Yukon, the biotic effects of persistent disturbances remain poorly studied in tundra ecosystems. This is important data for the Yukon because high latitude regions have been exposed to recent climate warming at a higher rate than the global average. Countless small ponds have been formed under recent warming at high latitudes with the thawing of frost wedges. This study examines how climate change has affected the distributions of many species, specifically temperate predators in tundra waters such as the phantom midge. The researchers studied 345 shallow persistent ponds from 2000 to 2014 and results showed that the number of persistent ponds more than doubled in recent decades. Lastly, the results also demonstrated the successful invasion of typically boreal predators into novel tundra thaw ponds, partially due to weak dispersal barriers.

Keywords: *C. americanus*, dispersal, *Heterocope septentrionalis*, permafrost, tundra, tundra ponds

Available Online: Abstract http://onlinelibrary.wiley.com/doi/10.1111/ecog.01514/abstract

Citation: Taylor, D.J., Ballinger, M.J., Medeiros, A.S. and Kotov, A.A., 2015. Climate-associated tundra thaw pond formation and range expansion of boreal zooplankton predators. Ecography, vol. 38: 001–011, 2015. doi: 10.1111/ecog.01514

6.4 FISH

Design considerations for community-based stream monitoring to detect changes in Pacific salmon habitats

Research Location: Namu and Koeye watersheds, British Columbia

Publication Type: Journal Article

Publication Date: 2014

Abstract: Communities in the Great Bear Rainforest of British Columbia, Canada are highly dependent on Pacific salmon (*Oncorhynchus* spp.) and the watersheds that support them, yet current monitoring efforts are likely inadequate for detecting changes in stream habitats that may affect salmon populations. The Coastal First Nations Regional Monitoring System is attempting to address these information gaps through a new stream assessment program that collects baseline information and tracks changes in stream habitats. Using the program's monitoring protocol, we assessed the habitat characteristics of eight streams within the Koeye and Namu watersheds, then used a statistical power simulation to determine within-stream sampling requirements for detecting changes in substrate composition that may affect salmon habitat suitability. We also assessed resource constraints and perceived threats to stream habitats via questionnaires to coastal First Nations' stewardship staff. Results suggest that the current recommended sample size of 6 within-stream transects has low statistical power for detecting biologically significant changes in fine sediment. Given limited monitoring resources, we recommend higher transect sampling intensities within productive riffle-pool streams, but an emphasis on monitoring site level characteristics, such as large woody debris and pool volume, in less productive, high gradient cascade-pool streams. Questionnaire results highlight the need for flexibility and local adaptation in monitoring efforts because of differences in resource constraints among First Nations communities. If successfully implemented, the stream assessment program can integrate local knowledge with western science to inform ecosystem-based management of watersheds within the Great Bear Rainforest.

Local Relevance: Communities in Yukon, especially Yukon First Nation communities, have a high dependence on Pacific salmon for food and traditional pursuit activities. In British Columbia, a number of First Nations have begun monitoring streams within their own territories as part of a broader Coastal First Nations Regional Monitoring System (RMS). The RSM has developed a habitat assessment component for their stream monitoring program that collects baseline information on stream habitat quality and monitors for changes over time. Apart from overharvesting other threats to stream ecosystems include: (1) vegetation removal and road construction from forest harvesting; (2) other watershed developments such as from liquefied natural gas, mining, or crude oil projects; and (3) climate change. In this study, the researchers collect information on stream physical properties of the Koeye and Namu rivers, BC to provide advice on optimizing monitoring protocols in consideration of threats to stream habitats, statistical power, and community resource constraints. This study looks at changes in substrate composition (i.e., percent fine sediments and mean particle size) that may affect salmon habitat suitability. Results from the research suggest that the current recommended sample size of 6 within-stream transects has low statistical power for detecting biologically significant changes

in fine sediment. Several recommendations were made to improve the quality of monitoring systems for stream habitats.

Keywords: adaptive governance, ecosystem-based management, First Nations management, Great Bear Rainforest, Pacific salmon, power analysis, stream monitoring

Available Online: Full Document http://www.ecologyandsociety.org/vol19/iss4/art19/

Citation: Lagasse, C.R., Ou, W., Honka, L.D., Atlas, W.I., Hutton, C.N., Kotaska, J. and Hocking, M.D., 2014. Design considerations for community-based stream monitoring to detect changes in Pacific salmon habitats. Ecology and Society, vol. 19, no. 4, art. 19. http://dx.doi.org/10.5751/ES-06976-190419

7. HAZARDS

7.1 INFRASTRUCTURE AND DEVELOPMENT

Ice Loss and Slope Stability in High-Mountain Regions

Research Location: European Alps

Publication Type: Chapter in Series

Publication Date: 2015

Abstract: The present time is one significant stage in the adjustment of mountain slopes to climate change, and specifically atmospheric warming. This review examines the state of understanding of the responses of mid-latitude alpine landscapes to recent cryospheric change, and summarizes the variety and complexity of documented landscape responses involving glaciers, moraines, rock and debris slopes, and rock glaciers. These indicate how a common general forcing translates into varied site-specific slope responses according to material structures and properties, thermal and hydrological environments, process rates, and prior slope histories. Warming of permafrost in rock and debris slopes has demonstrably increased instability, manifest as rock glacier acceleration, rock falls, debris flows, and related phenomena. Changes in glacier geometry influence stress fields in rock and debris slopes, and some failures appear to be accelerating toward catastrophic failure. Several sites now require expensive monitoring and modeling to design effective risk-reduction strategies, especially where new lakes as multipliers of hazard potential form, and new activities and infrastructure are developed.

Local Relevance: Mountain glaciers have been shrinking worldwide since the end of the Little Ice Age (about 1870). In recent decades, with climate warming, the extent of glaciers has decreased at an accelerated rate. Additionally, there has been an apparent increase in slope failures in steep rock walls as a result of permafrost degradation. This study examines slope instability and mass movements related to ice loss in areas that have less frequent events, as these events tend to be higher in magnitude. In Yukon, there has been a recorded mean annual increase in temperature of 3°C over the past 50 years, increasing the potential loss of perennial ice, both at the surface (glaciers) and in the subsurface (permafrost). Changes in glacier geometry and slope topography as well as the thermal regime of steep ice can have a severe impact on the stability of hanging glaciers and eventually lead to ice avalanches. The researchers found that the rapid shrinking of glaciers in recent decades influences slope instability at different spatial and temporal scales through glacial debuttressing, stress-release fracturing, and crustal rebound. Furthermore, mountain permafrost is strongly affected by atmospheric warming causing rock

temperature increases and water percolation leading to changes in hydraulic permeability and mechanical strength that alter the stress field in steep rock walls. This process is leading to more frequent rock falls and debris slides.

Keywords: debuttressing, deep-seated gravitational slope deformation, glacier shrinkage, ice unloading, moraine instability, permafrost degradation, rock fall, rock glacier, rock slide

Available Online: Abstract http://dx.doi.org/10.1016/B978-0-12-394849-6.00015-9

Citation: Deline, P., Gruber, S., Delaloye, R., Fischer, L., Geertsema, M., Giardino, M., Hasler, A., Kirkbride, M., Krautblatter, M., Magnin, F., McColl, S., Ravanal, L. and Schoeneich, P., 2015. Ice loss and slope stability in high-mountain regions. *In:* Snow and Ice-Related Hazards, Risks and Disasters, W. Haeberli, C. Whiteman and J.F. Shroder (eds.), Elsevier, p. 521-561. doi: 10.1016/B978-0-12-394849-6.00015-9

Towards Net Zero: An Evaluation of Building Orientation in the Reduction of Energy Load Requirements in High Latitudes

Research Location: Whitehorse, Yukon

Publication Type: MSc thesis

Publication Date: 2014

Abstract: A net-zero energy community localizes its energy creation and distribution. Such a community does not rely on outside influences to power itself. Further, through new design techniques, at both the individual home and neighborhood scale, the load requirements needed to power itself can be significantly reduced, while increasing the comfort level of living in an extreme environment. These elements would have profound effects in the improvements of the well-being of communities in high latitudes. This paper is an investigation of what the literature deemed to be the most effective means of achieving a net zero community: reduction of a buildings energy load. Specifically it focuses on the effects of passive solar and uses simulation modeling to measure the effects that building orientation has in the reduction of energy load requirements in high latitudes. The results indicate that orientation does effect a building's energy load reduction especially in newer, better insulated homes. However, it is shown to be relatively minimal from a cost savings perspective.

Local Relevance: Whitehorse's population of 28,872 (Yukon Bureau of Statistics, 2015) has traditionally relied on hydroelectric energy but now is facing energy deficits that require diesel generators to meet the demand of the residents. The cost of shipping diesel to Whitehorse is very high due to its relative remoteness. This study examines the concept of 'net-zero energy' for northern communities which would reduce the cost of living for its residents, as well as provide economic and food security by having a community in which one's inputs equal one's outputs (i.e., having a zero carbon footprint). Current research has shown that a significant amount of energy in Canada is used to run our homes (17%) and in the US, this figure jumps to 40% when combined with the energy consumption of commercial buildings. Presently, the most effective way to achieve a net zero community is by reducing a building's energy load. The focus of this research is to test whether using building orientation to optimize passive solar gains will have the same significant reduction in heating loads when compared to southern communities in Canada. The researcher concluded that if buildings are orientated to face the south then that will reduce energy load requirements, however it provides little cost savings. Furthermore, geographic location is significant and is very site specific, and it is important to evaluate the effects of orientation on a building's energy performance on a case-by-case basis.

Keywords: energy-modeling, building orientation in high latitudes, net-zero communities

Available Online: Full Document https://atrium.lib.uoguelph.ca/xmlui/bitstream/handle/10214/8002/Barrett_Jeffrey_201403_MLA.pdf?sequence=3

Citation: Barrett, J., 2014. Towards Net Zero: An Evaluation of building Orientation in the Reduction of Energy Load Requirements in High Latitudes. MSc thesis, The University of Guelph, ON, 60 p.

Distribution and landscape controls of organic layer thickness and carbon within the Alaskan Yukon River Basin

Research Location: Yukon River Basin, Alaska

Publication Type: Journal Article

Publication Date: 2014

Abstract: Understanding of the organic layer thickness (OLT) and organic layer carbon (OLC) stocks in subarctic ecosystems is critical due to their importance in the global carbon cycle. Moreover, post-fire OLT provides an indicator of long-term successional trajectories and permafrost susceptibility to thaw. To these ends, we 1) mapped OLT and associated uncertainty at 30 m resolution in the Yukon River Basin (YRB), Alaska, employing decision tree models linking remotely sensed imagery with field and ancillary data, 2) converted OLT to OLC using a nonlinear regression, 3) evaluate landscape controls on OLT and OLC, and 4) quantified the post-fire recovery of OLT and OLC. Areas of shallow (<10 cm), moderate (≥10 cm and <20 cm), moderately thick (≥20 cm and <30 cm), and thick (≥30 cm) OLT, composed 34, 20, 14, and 18% of the YRB, respectively; the average OLT was 19.4 cm. Total OLC was estimated to be 3.38 Pg. A regional chronosequence analysis over 30 years revealed that OLT and OLC increased with stand age (OLT: R^2 = 0.68; OLC: R^2 = 0.66),where an average of 16 cm OLT and 5.3 kg/m^2 OLC were consumed by fires. Strong predictors of OLT included climate, topography, near-surface permafrost distributions, soil wetness, and spectral information. Our modeling approach enabled us to produce regional maps of OLT and OLC, which will be useful in understanding risks and feedbacks associated with fires and climate feedbacks.

Local Relevance: It is estimated that the northern circumpolar regions contain 50% of the global below-ground organic carbon pool. The increase in frequency and severity of forest fires in subarctic regions in recent decades is affecting permafrost and processes of vegetation succession post-fire; this in turn has direct implications to future global warming and represents a potential feedback to regional and global-scale climate and carbon cycles. In 2014, the Yukon experienced only 32 fires but in 2015, this number was surpassed as Yukon wild land fire management reported 123 forest fires up to June 22. Forest fires will affect organic layer thickness (OLT) and organic layer carbon (OLC); understanding the spatial distribution of OLC stocks in Arctic/subarctic ecosystems is essential due to their importance in the global carbon cycle and potential contribution to climate feedbacks. Furthermore, mapping organic layer thickness (OLT) post-fire will provide long-term successional trajectories and susceptibility of permafrost to thaw. This study uses remote sensing technology to map the distribution of OLT and OLC stocks in the Yukon River Basin in Alaska and assesses the landscape-scale factors controlling the spatial variation. This research is highly relevant to Yukon where most of the territory is underlain by discontinuous and continuous permafrost and covered by boreal forest. Studies such as these will inform resource managers and modelers on the responses and feedbacks associated with fires and climate changes, as well as provide a better understanding of carbon dynamics in organic layers.

Keywords: boreal forest, chronosequence, machine learning, soil carbon, organic layer thickness, remote sensing, succession, tundra, wetlands

Available Online: Full Document http://dx.doi.org/10.1016/j.geoderma.2014.04.008

Citation: Pastick, N.J., Rigge, M., Wylie, B.K., Jorgenson, M.T., Rose, J.R., Johnson, K.D. and Ji, L., 2014. Distribution and landscape controls of organic layer thickness and carbon within the Alaskan Yukon River Basin. Geoderma, vols. 230–231, p. 79-94. doi: 10.1016/j.geoderma.2014.04.008

8. FOOD SECURITY

Prevalence and severity of household food insecurity of First Nations people living in an on-reserve, sub-Arctic community within the Mushkegowuk Territory

Research Location: sub-Arctic Ontario, Canada

Publication Type: Journal Article

Publication Date: 2013

Abstract:

Objective: To measure and describe the prevalence and severity of household food insecurity in a remote on-reserve First Nations community using the Household Food Security Survey Module (HFSSM) and to evaluate the perceived relevance of the HFSSM for this population.

Design: Household food security status was determined from the eighteen-item HFSSM following the classifications developed by Health Canada for the Canadian Community Health Survey, Cycle 2·2 Nutrition. One adult from each household in the community was invited to complete the HFSSM and to comment on its relevance as a tool to measure food security for First Nations communities.

Setting: Sub-Arctic Ontario, Canada.

Subjects: Households (*n* = 64).

Results: Seventy per cent of households were food insecure, 17% severely and 53% moderately. The prevalence of food insecurity in households with children was 76%. Among respondents from homes rated as having severe food insecurity, all (100%) reported worrying that food would run out, times when food didn't last and there wasn't money to buy more, and times when they couldn't afford to eat balanced meals. The majority of respondents felt the HFSSM did not capture an accurate picture of food security for their situation. Aspects missing from the HFSSM included the high cost of market food and the incorporation of traditional food practices.

Conclusions: A high prevalence of household food insecurity was reported in this community. On-reserve remote First Nations communities may be more susceptible to food insecurity than off-reserve Aboriginal populations. Initiatives that promote food security for this vulnerable population are needed.

Local Relevance: Current research has demonstrated that people living in remote, isolated communities are particularly vulnerable to high levels of food insecurity, such as those northern communities found in Canada's territories. This study found that in a small community in sub-Arctic Ontario, there existed a high prevalence of food insecurity particularly in households with children; furthermore, on-reserve remote First Nations communities may be more susceptible to food insecurity compared with off-reserve Aboriginal populations. Food insecurity has been

described as an urgent and pervasive public health issue for Aboriginal people. In Yukon, there are many small, remote communities with significant populations of First Nations. In a recent Canadian Community Health Survey, food insecurity rates for Yukon were reported at 21%, which is 6.3% above the national average.

Keywords: Canada, First Nations, household food insecurity, nutrition surveys, population surveillance, vulnerable populations

Available Online: Full Document http://journals.cambridge.org/download.php?file=%2FPHN%2FS1368980013001705a.pdf&code=13a53ddbf1a473e04786ecfec8f757c2

Citation: Skinner, K., Hanning, R.M. and Tsuji, L.J.S., 2013. Prevalence and severity of household food insecurity of First Nations people living in an on-reserve, sub-Arctic community within the Mushkegowuk Territory. Public Health Nutrition, p. 1-9. doi:10.1017/S1368980013001705

9. GENERAL

Lessons from Scenario Planning for Wildlife Management in the Southwest Yukon

Research Location: Yukon Territory

Publication Type: Master of Environmental Sustainability

Publication Date: 2014

Abstract: The southwest Yukon social-ecological system (SES) is marked by complex changes, including a climate induced directionally changing landscape, an increasing shift away from traditional subsistence lifestyles, and changing species composition. The addition of “new” ungulate species through human and non-human introductions has spawned many management questions. This study developed qualitative scenarios through a participatory process, utilizing scientific and traditional knowledge from within the social-ecological system’s local context. The study worked with local management groups to address two main objectives: 1.) Collaboratively envision alternate future scenarios with management groups from which to collaboratively develop management goals for wood bison, elk, and mule deer to cope with the changing social and ecological landscape of the southwest Yukon and 2.) Discover resource managers’ and local stakeholders’ perceptions of scenario planning as a method identify wildlife management goals. A series of three workshops with the Alsek Renewable Resource Council, the Yukon Wood Bison Technical Team, and the Yukon Elk Management Planning Team addressed the first objective, while two surveys addressed the second objective. Major findings included southwest Yukon-specific wildlife management goals and considerations for using scenario planning in a wildlife management context. The scenarios themselves warn of plausible events that might unfold, such as novel disease and pest outbreaks. Several participants mentioned that the value attributed to different species will change based on scenario context. This prompts warnings for wildlife managers not to “shut the door” on a species today that may be highly valuable for solving food security challenges of the future. Findings suggest that one of scenario planning’s most significant contribution is a forum for people to share perspectives and develop trust and understanding of one another. All participants valued the holistic and long-term thinking aspects of scenario planning, seeing it as a complementary tool to enhance existing planning processes. Major resource management plans and/or resource development projects in the future should consider using a scenarios approach to better articulated goals in terms of whole system impacts.

Local Relevance: Current research has suggested that with a rapidly changing climate, conventional wildlife management practices may not be meeting their intended goals. This research examines the changes of the southwest Yukon social-ecological system as it relates to the reintroduction of the Aishihik wood bison herd, the introduction of the Braeburn and Takhini elk herds, as well as the naturally dispersing mule deer. The focus of the study was to test a more holistic and potentially adaptive approach to wildlife management planning through two main objectives: (1) create possible future scenarios and management goals for wood bison, elk and mule deer in response to the social-ecological system of the southwest Yukon; and (2) explore resource managers' and local stakeholders' perceptions of scenario planning as a method to identify management goals. In conclusion, the researcher demonstrated that scenario planning is a powerful planning tool that can improve practitioners' adaptive capacity under changing conditions and uncertainties.

Keywords: adaptive capacity, change, elk, mule deer, participatory, qualitative, scenario planning, social-ecological system (SES), wildlife management, wood bison, Yukon Territory

Available Online: Full Document http://ecommons.usask.ca/bitstream/handle/10388/ETD-2014-01-1405/BEACH-THESIS.pdf?sequence=4

Citation: Beach, D.M., 2014. Lessons from Scenario Planning for Wildlife Management in the Southwest Yukon. Master of Environmental Sustainability, University of Saskatchewan, Saskatoon, SK, 161 p.

9.1 RESEARCH NEEDS

Socio-Economic Drivers of Change in the Arctic

Research Location: The Arctic

Publication Type: Report

Publication Date: 2014

Executive Summary: The Arctic is undergoing rapid and fundamental change. Recent decades have seen rising temperatures and reduced sea ice, and these present substantial uncertainties to local communities. Overlaid on these climatic shifts are changes in other factors such as resource demand, globalization, transportation, economic development, and demographics, factors which are to varying degrees themselves affected by the changing climate…

This report presents an overview of the potential directions of non-climate drivers affecting the Arctic, and explicitly excludes discussion of potential impacts and responses. In this report, the non-climate drivers have been split into two perspectives: global and Arctic. Global drivers set the wider context within which the Arctic is changing. How is the global economy expected to develop? What might the world's population be in 2050? How will global demand for mineral resources change over time? What are the expectations for future energy demand? These global factors – represented by large numbers and considerable momentum – come with large uncertainty, especially several decades out, yet they set the scene for change in the Arctic…

Local Relevance: The Arctic, including Yukon, is already changing as a result of a warming climate which is occurring at an unprecedented rate; these changes are expected to be substantial over the coming decades. Some of these changes will be direct results of climate change, while others will be indirect or even unrelated to climate change. This report focuses mainly on the non-climate drivers of change at both the global and Arctic level. This research is carried out through the investigation of two main themes. The first part discusses key drivers of global change and

presents sources of information for these drivers, along with discussion of the robustness and uncertainties associated with this information. The second part is divided into key Arctic drivers: population, oil and gas, mining, marine transportation, tourism, and food security, which are all issues that affect Yukoners. This report looks at the Arctic and the changes that it may experience up to the year 2100 such as oil and gas exploration and mining. Although the future situation for Arctic regions is highly complex and there is considerable uncertainty, some predictions can be made. Oil and gas exploration and mining is expected to grow and the main drivers of this growth include increased accessibility, high commodity prices and sovereignty issues; constraints on this growth will be high production costs and the volatility of commodity prices. Arctic tourism is also expected to increase potentially resulting in substantial negative impacts to the environment and northern culture. Food insecurity in Arctic Canada is already high and is a complex and diverse issue that will require highly specific studies. It is clear from this report that the Arctic is certainly facing continued change from a number of angles and its resilience will be tested.

Keywords: Arctic, climate shifts, demographics globalization, economic development, transportation

Available Online: Full Document http://www.amap.no/documents/doc/Socio-Economic-Drivers-of-Change-in-the-Arctic/1115

Citation: Andrew, R., 2014. Socio-economic Drivers of Change in the Arctic. AMAP Technical Report No. 9, Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway, 33 p.

The State of Northern Knowledge in Canada

Research Location: northern Canada

Publication Type: Technical Report

Publication Date: 2014

Mandate of Canadian Polar Commission: Established in 1991, the Canadian Polar Commission is Canada's primary polar knowledge agency and has responsibility for:

- Monitoring polar knowledge in Canada and around the world;
- Working with Canadian and international institutions to determine scientific and other priorities;
- Encouraging support for Canadian polar research;
- Communicating polar research information to Canadians; and,
- Fostering international cooperation in the advancement of polar knowledge.

In carrying out its mandate the Commission builds and maintains polar knowledge networks, hosts conferences and workshops, publishes information regarding the polar regions, and works closely with other governmental and non-governmental partners to promote and support Canadian polar knowledge.

The Commission serves as Canada's primary point of contact with the circumpolar knowledge community, and is Canada's adhering body to the International Arctic Science Committee (IASC) and the Scientific Committee for Antarctic Research (SCAR). In addition, the Commission maintains liaison with research organizations and institutes throughout the circumpolar world, providing guidance into bi-lateral and multi-lateral scientific projects relevant to Canadian interests.

Local Relevance: The focus of this report is the Canadian North, comprising Yukon, Northwest Territories, Nunavut, Nunavik in northern Quebec, and Nunatsiavut in northern Newfoundland and Labrador. This report is to inform Yukoners and others living in the north about the state of northern research so they can better influence its direction. This report focuses on the need for science and technology to support sound decision-making since Northerners have the greatest vested interest in northern research; the focus of this report is also on knowledge gains and opportunities that align with the priorities of Northerners. The study recognizes the Yukon is undergoing significant change driven by a number of complex factors, some global in nature, others rooted in the dynamics of the region's unique history, and others stemming from the increased empowerment of Aboriginal peoples through settled comprehensive land claims. The study concludes that if research is to be successful then it must reflect the elegant complexity inherent in the North and in its peoples.

Keywords: Arctic council, Canada's north, northern peoples, polar knowledge, research

Available Online: Full Document http://www.polarcom.gc.ca/eng/content/download-northern-knowledge-report

Citation: Abele, F., Beaulieu, J.M., Relf, C., Scott, D.J. and Sheldon, T., 2014. The State of Northern Knowledge in Canada. A report prepared by the Canadian Polar Commission for the Third International Conference on Arctic Research Planning (ICARP III), Aboriginal Affairs and Northern Development, Canada, 42 p.

Pathogens, herbivores, and phenotypic plasticity of boreal Vaccinium vitis-idaea experiencing climate change

Research Location: Fairbanks, Alaska

Publication Type: Journal Article

Publication Date: 2014

Abstract: Climate warming is occurring at a rapid rate in the boreal forest; mean winter temperature has increased about 4°C in Alaska over the last 40 years and about the same increase is predicted over the next 40 years. Warming temperatures tend to increase the number and kinds of herbivores and pathogens. How will boreal plants respond to these abiotic and biotic changes? To address these questions we used common gardens and reciprocal transplants of *Vaccinium vitis-idaea* at sites with contrasting abiotic conditions near Fairbanks, Alaska. Plant morphology, chemistry, resistance to pathogens and herbivores, and survival were all strongly influenced by the destination environment (planting site and block within site), and less by the site of origin for the seed. Overall, seedlings survived significantly better at the summer cold site, which was buffered from drought as a result of its northern aspect, presence of sphagnum moss and permafrost (86.4% survival versus 48.5%). However, this cool damp site had more stem-killing consumers, the pathogens *Phomopsis columnaris* and *Exobasidium vaccinii* and mammalian browse, all of which became more common over the three years of the study as the plants became larger. Taken together, these results suggest that the seedling stage is likely to be vulnerable to droughts, except at sites with thick moss cover, which results in greater duration of summer moisture. Thus, as the climate warms, seedling growth will be restricted to those sites where the adult stages will later suffer from more stem-killing pathogen attack and mammalian browse.

Local Relevance: The boreal forest biome is the second largest on the planet and covers most of Yukon. The Yukon has experienced an increase in mean annual temperature leading to an

increase in the length of the growing season. Projections for the future are for 4-7°C increase by 2100 in neighbouring Fairbanks, Alaska. It is predicted that cold-adapted plant species, such as those found in Yukon, are likely to experience drought stress as the climate warms due to increased transpiration. Furthermore, herbivores and pathogens will increase in both species richness and in the amount of damage they cause. This study explores the relationships between the abiotic environment, plants and their pathogens, as well as herbivores. The researchers set up common gardens and reciprocal transplants of *Vaccinium vitis-idaea* L. (lingonberry or lowbush cranberry, Ericaceae) at two sites near Fairbanks, Alaska which differed in environmental characteristics, including temperature. The researchers were particularly interested in whether there was evidence of local adaptation to the sites. *Vaccinium vitis-idaea* is a very common species within the boreal forest and tussock tundra and is an important food plant for many animals including humans. The researchers conclude that *Vaccinium vitis-idaea* exhibits a range of plastic responses to differing abiotic and biotic environments and favour phenotypic plasticity but not local adaptation. Additionally, the seedling stage is vulnerable to droughts unless they are at sites with thick moss cover and the resulting longer duration of summer moisture. Therefore, with climate change and the likelihood of increased duration and frequency of droughts, seedling growth will be progressively restricted to mossy sites. These mossy sites, albeit favourable to seedlings, have more stem-killing consumers and are worse for adult growth and reproduction.

Keywords: Alaska, climate change, *Exobasidium vaccinii*, global warming, herbivory, local adaptation, lingonberry, phenolic, *Phomopsis columnaris*, plasticity, reciprocal transplant, *Vaccinium vitis-idaea*

Available Online: Full Document http://creativecommons.org/licenses/by/3.0/

Citation: Roy, B.A. and C.P.H., Mulder, 2014. Pathogens, herbivores, and phenotypic plasticity of boreal *Vaccinium vitisidaea* experiencing climate change. Ecosphere, vol. 5, issue 3, http://dx.doi.org/10.1890/ES13-00271.1

Public Health Adaptation to Climate Change in Canadian Jurisdictions

Research Location: Canada

Publication Type: Journal Article

Publication Date: 2015

Abstract: Climate change poses numerous risks to the health of Canadians. Extreme weather events, poor air quality, and food insecurity in northern regions are likely to increase along with the increasing incidence and range of infectious diseases. In this study we identify and characterize Canadian federal, provincial, territorial and municipal adaptation to these health risks based on publically available information. Federal health adaptation initiatives emphasize capacity building and gathering information to address general health, infectious disease and heat-related risks. Provincial and territorial adaptation is varied. Quebec is a leader in climate change adaptation, having a notably higher number of adaptation initiatives reported, addressing almost all risks posed by climate change in the province, and having implemented various adaptation types. Meanwhile, all other Canadian provinces and territories are in the early stages of health adaptation. Based on publically available information, reported adaptation also varies greatly by municipality. The six sampled Canadian regional health authorities (or equivalent) are not reporting any adaptation initiatives. We also find little relationship between the number of initiatives reported in the six sampled municipalities and their provinces, suggesting that municipalities are adapting (or not adapting) autonomously.

Local Relevance: Current research has identified climate change as a major risk to human health. Extreme weather events, poor air quality, and food insecurity are all connected our changing climate and are expected to increase in the future. The annual average surface temperature over Canada's landmass has increased by 1.7°C since 1948, a rate almost twice the global average; in northern Canada (including Yukon) this rate is even higher experiencing the most rapid climate change globally. This report provides a systematic review of Canadian health adaptation at the federal, provincial, territorial and municipal levels; it also documents jurisdictional patterning and outlines gaps in health adaptation. This study provides a baseline for future monitoring of adaptation progress in Canada. In this study, Yukon is reported as having three or fewer health adaptation initiatives that address few or none of the identified regional health risks, and provide limited detail. The study concludes that the territories need vulnerability assessments to plan appropriate adaptation strategies. The province of Quebec has a reported five times more health adaptation initiatives than the Yukon Territory.

Keywords: climate change, adaptation, Canada, public health, adaptation tracking

Available Online: Full Document www.mdpi.com/journal/ijerph

Citation: Austin, S.E., Ford, J.D., Berrang-Ford, L., Araos, M., Parker, S. and Fleury, M.D., 2015. Public Health Adaptation to Climate Change in Canadian Jurisdictions. International Journal of Environmental Research and Public Health, vol. 12, issue 1, p. 623-651. doi: 10.3390/ijerph120100623

10. POLLUTANTS

Mercury in freshwater ecosystems of the Canadian Arctic: Recent advances on its cycling and fate

Research Location: Canadian Arctic

Publication Type: Journal Article

Publication Date: 2014

Abstract: The Canadian Arctic has vast freshwater resources, and fish are important in the diet of many Northerners. Mercury is a contaminant of concern because of its potential toxicity and elevated bioaccumulation in some fish populations. Over the last decade, significant advances have been made in characterizing the cycling and fate of mercury in these freshwater environments. Large amounts of new data on concentrations, speciation and fluxes of Hg are provided and summarized for water and sediment, which were virtually absent for the Canadian Arctic a decade ago. The biogeochemical processes that control the speciation of mercury remain poorly resolved, including the sites and controls of methylmercury production. Food web studies have examined the roles of Hg uptake, trophic transfer, and diet for Hg bioaccumulation in fish, and, in particular, advances have been made in identifying determinants of mercury levels in lake-dwelling and sea-run forms of Arctic char. In a comparison of common freshwater fish species that were sampled across the Canadian Arctic between 2002 and 2009, no geographic patterns or regional hotspots were evident. Over the last two to four decades, Hg concentrations have increased in some monitored populations of fish in the Mackenzie River Basin while other populations from the Yukon and Nunavut showed no change or a slight decline. The different Hg trends indicate that the drivers of temporal change may be regional or habitat-specific. The Canadian Arctic is undergoing profound environmental change, and preliminary evidence suggests that it may be impacting the cycling and bioaccumulation of mercury. Further research is needed to investigate climate change impacts on the Hg cycle as well as biogeochemical

controls of methylmercury production and the processes leading to increasing Hg levels in some fish populations in the Canadian Arctic.

Local Relevance: Fresh water covers approximately 140 000 km^2 of land north of 60° latitude and contain many fish species that are an important part of the diet of many northerners. For First Nation populations, fish is an iatrical part of their heritage and woven into their customs and traditions. This review summarizes our current state of knowledge on mercury in freshwater ecosystems of the Canadian Arctic, including Yukon. In this study, concentrations of total mercury (THg) and methylmercury (MeHg) are sampled and measured in waters of the upper Yukon River Basin; three samples were taken from stations on the Yukon River, and 14 samples from stations on its tributaries. For the Yukon River Basin, the study reported on average, THg concentrations were equally partitioned between the dissolved and particulate fractions (49 ± 28%, *n*=32). However, the observed range in particulate THg (<0.06–26.3 ng L^{-1}) was much higher than for the dissolved fraction (0.3–6.4 ng L^{-1}), and elevated THg levels in river water were primarily associated with particulates.

Keywords: Arctic, mercury, fresh water, bioaccumulation, biogeochemistry, temporal trends

Available Online: Full Document http://www.sciencedirect.com/science/article/pii/S0048969714008535

Citation: Chételat, J., Amyot, M., Arp, P., Blais, J.M., Depew, D., Emmerton, C.A., Evans, M., Gamberg, M., Gantner, N., Girard, C., Graydon, J., Kirk, J., Lean, D., Lehnherr, I., Muir, D., Nasr, M., Poulain, A.J., Power, M., Roach, P., Stern, G., Swanson, H. and van der Velden, S., 2014. Mercury in freshwater ecosystems of the Canadian Arctic: Recent advances on its cycling and fate. Science of the Total Environment, vol. 509-510, Special Issue: Mercury in Canada's North, p. 41-66. doi: 10.1016/j.scitotenv.2014.05.151

Ice Cores from the St. Elias Mountains, Yukon, Canada: Their Significance for Climate, Atmospheric Composition and Volcanism in the North Pacific Region

Research Location: Yukon Territory

Publication Type: Journal Article

Publication Date: 2014

Abstract: A major achievement in research supported by the Kluane Lake Research Station was the recovery, in 2001 – 02, of a suite of cores from the icefields of the central St. Elias Mountains, Yukon, by teams of researchers from Canada, the United States, and Japan. This project led to the development of parallel, long (10^3 – 10^4 year) ice-core records of climate and atmospheric change over an altitudinal range of more than 2 km, from the Eclipse Icefield (3017 m) to the ice-covered plateau of Mt. Logan (5340 m). These efforts built on earlier work recovering single ice cores in this region. Comparison of these records has allowed for variations in climate and atmospheric composition to be linked with changes in the vertical structure and dynamics of the North Pacific atmosphere, providing a unique perspective on these changes over the Holocene. Owing to their privileged location, cores from the St. Elias Icefields also contain a remarkably detailed record of aerosols from various sources around or across the North Pacific. In this paper we review major scientific findings from the study of St. Elias Mountain ice cores, focusing on five main themes: (1) The record of stable water isotopes ($\delta^{18}O$, δD), which has unique characteristics that differ from those of Greenland, other Arctic ice cores, and even among sites in the St. Elias; (2) the snow accumulation history; (3) the record of pollen, biomass burning aerosol, and desert dust deposition; (4) the record of long-range air pollutant deposition

(sulphate and lead); and (5) the record of paleo-volcanism. Our discussion draws on studies published since 2000, but based on older ice cores from the St. Elias Mountains obtained in 1980 and 1996.

Local Relevance: The St. Elias Mountains (Yukon, Canada) and Wrangell Mountains (Alaska USA) are a major orographic obstacle to westerly air flow across the subarctic Pacific Ocean and are located at the end-point of extratropical Pacific storm tracks (Orlanski, 2005). Ice core research conducted in 1980 and 1996 on the St. Elias Mountains provided over 300 years of information on climate and atmospheric composition and highlighted the role of El Niño-Southern Oscillation (ENSO) in modulating snow fall rates. Ice core research uses stable isotope ratios of water ($\delta^{18}O$ and δD) to reconstruct the precipitation-weighted mean air temperature history of high-latitude sites. In this study, the researchers were operating from the Arctic Institute of North America's Kluane Lake Research Station over the course of two field seasons (2001 – 02). The expedition recovered more than 900 m of new firn and ice cores from three separate locations: Prospector-Russell Col (PRC) at 5340 m on the Mt. Logan high plateau; King Col at 4135 m on the western flank of the massif; and the Eclipse Icefield northwest of Mt. Logan. This recent core research significantly extends the previous records (1980 and 1996 expeditions) and the comparison of these records allowed for the variations in climate and atmospheric composition to be linked with changes in the vertical structure and dynamics of the North Pacific atmosphere. This research has contributed greatly to our improved understanding and knowledge of climate and atmospheric variability in the northeastern Pacific region and its connections to other parts of the globe. Several key findings were made which could have important implications for predicting the future climate evolution of western North America.

Keywords: aerosols, air pollution, climate change, Holocene, ice cores, North Pacific, volcanism

Available Online: Full Document http://arctic.journalhosting.ucalgary.ca/arctic/index.php/arctic/article/view/4352/4516

Citation: Zdanowicz, C., Fisher, D., Bourgeois, J., Demuth, M., Zheng, J., Mayewski, P., Kreutz, K., Osterberg, E., Yalcin, K., Wake, C., Steig, E.J., Froese, D. and Goto-Azuma, K., 2014. Ice Cores from the St. Elias Mountains, Yukon, Canada: Their Significance for Climate, Atmospheric Composition and Volcanism in the North Pacific Region. ARCTIC, vol. 67, no. 5, p. 35-57. http://dx.doi.org/10.14430/arctic4352