NORTHERN CLIMATE EXCHANGE, Yukon Research Centre



COMPENDIUM OF YUKON CLIMATE CHANGE SCIENCE

2003-2011

Northern Climate ExChange
YUKON RESEARCH CENTRE · Yukon College

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Front cover photograph: Aerial photo of the Klutlan Glacier, St. Elias Mountains, Yukon. Photo courtesy of Jeff Bond, Yukon Geological Survey.

Foreword

The Compendium is intended to provide an overview of recent (2003-2011) climate change work involving Yukon. 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 Infosources Database and 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
- INAC 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 period 2003-2011. A greater emphasis was placed on studies dated between 2007 and 2011 and information that is available online. That being said, we 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" part of each entry highlights information directly related to Yukon climate change. The term "Affiliation" refers to the university, government, or organization to which the principal author belonged at the time of publication. The principal author was used as the point of contact except for cases in which there was a contact person identified or information for the principal author could not be found.

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

I would like to thank Lia Johnson, John Streicker, Bob Van Dijken, Rebecca World, Ryan Hennessey, Lacia Kinnear, Darcie Matthiessen, and Aynslie Ogden for their assistance. I am also grateful to all of the Yukon First Nations that responded to my request for information involving studies conducted in their respective traditional territories.

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August 2011

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I. COMPENDIUM

1. Changing Climate

Climatic Conditions in Northern Canada: Past and Future

Research Location: *Yukon; Northwest Territories; Nunavut*
Publication Date: *2009*
Publication Type: *Journal Article*

Affiliation: *Environment Canada; University of Victoria*
Contact: *Terry D. Prowse, University of Victoria/Environment Canada*

Abstract: This article reviews the historical, instrumental, and future changes in climate for the northern latitudes of Canada. Discussion of historical climate over the last 10 000 years focuses on major climatic shifts including the Medieval Warm Period and the Little Ice Age, and how these changes compare with those most recently experienced during the period of instrumental records. In reference to the latter, details are noted about observed trends in temperature and precipitation that have been recorded over the last half century, which exhibit strong west to east and north to south spatial contrasts. A comprehensive review of future changes is also provided based on outputs from seven atmosphere–ocean global climate models and six emission scenarios. Discussion focuses on annual, seasonal, and related spatial changes for three 30-year periods centered on the 2020s, 2050s, and 2080s. In summary, substantial changes to temperature and precipitation are projected for the Canadian North during the twenty-first century. Although there is considerable variability within the various projections, all scenarios show higher temperature and, for the most part, increasing precipitation over the entire region.

Local Relevance: During the period of 1948-2005, the Yukon experienced an annual average warming of 2.2°C and a winter warming of 4.5°C, the greatest rate of temperature increase in Canada. The period 1950-1998 saw fewer extremely cold days and more extremely warm days, accompanied by more intense and more frequent precipitation events. Temperatures have warmed and precipitation has increased across Canada, and the rate of warming exceeds anything seen since the onset of the Holocene 10,000 years ago. Climate projections predict increasing temperatures (most pronounced during winter and fall) and generally agree that precipitation will increase. Rates of predicted warming increase further north, an effect that would act to equilibrate temperatures across the North and may affect north-flowing rivers.

Keywords: *air temperature, climate modelling, precipitation, Yukon-wide*

Available Online: Full Article

Citation: Prowse, T.D., Furgal, C., Bonsal, B.R., Edwards, T.W.D. 2009. "Climatic Conditions in Northern Canada: Past and Future." *Ambio* 38(5): 257-265.

Northern Canada in a Changing Climate: Major Findings and Conclusions

Research Location: *Yukon; Northwest Territories; Nunavut*
Publication Date: *2009*
Publication Type: *Journal Article*
Affiliation: *University of Victoria; Environment Canada*
Contact: *Terry D. Prowse, University of Victoria/Environment Canada*

Excerpt: The papers in this and a subsequent Special Issue of the international journal Ambio are directly based on a Northern Canada chapter (1, 2) that formed part of a broader regional assessment of Canada's vulnerability to climate change led by the government of Canada (3). For the purposes of this national assessment, the ''North'' of Canada refers to the area north of latitude 60°N that contains three large territorial administrative units: Yukon, Northwest Territories, and Nunavut. The issues also include manuscripts which draw from work conducted for a chapter on the health implications of climate change in Canada's North (4) conducted as part of a health assessment of climate vulnerabilities in the country led by Health Canada (5). The following summarizes the major conclusion and key findings contained in the various papers that comprise these Special Issues…

Local Relevance: This paper summarizes the key findings of multiple papers on climate change in the north, based on an assessment of climate change vulnerability conducted by the Government of Canada. Permafrost degradation may damage infrastructure as well as leach contaminants from waste retention areas that rely on underlying permafrost as a barrier. Changes in river hydrology will effect hydroelectric power generation while rising sea-levels and more storms will damage coastal areas. Aboriginal peoples practicing their traditional way of life in remote communities are the most vulnerable, yet may benefit from new economic opportunities as northern Canada becomes less remote.

Keywords: *coastal erosion, economic development, hydroelectricity, impacts, permafrost, vegetation, wildlife, Yukon-wide*

Available Online: Full Article

Citation: Prowse, T.D., Furgal, C. 2009. "Northern Canada in a Changing Climate: Major Findings and Conclusions." *Ambio* 38(5): 290-292.

From Impacts to Adaptation: Canada in a Changing Climate 2007, Chapter 3—Northern Canada

Research Location: *Yukon; Northwest Territories; Nunavut*
Publication Date: *2008*
Publication Type: *Government Publication*
Affiliation: *Trent University*
Contact: *Chris Furgal, Trent University*

Excerpt: The climate of the Arctic has shown an unprecedented rate of change during the past 50 years. Over the last half century, the Canadian Arctic has experienced significant increases in both temperature and precipitation, consistent with trends in other circumpolar regions. Increases in air temperature have resulted in many of the most extreme warm years throughout the entire Canadian North being recorded in the last decade, with the greatest temperature increases observed over the western Arctic. All global climate models project continued increases in temperature and precipitation over the Canadian Arctic, with greatest temperature changes at higher latitudes. As a result, there will continue to be significant changes in the physical environment, particularly in the cryosphere (snow, glaciers, permafrost and river/lake/sea ice).

There is increasing evidence that changes in climate are already having impacts on ecological, economic and human systems in northern regions, and that some individuals, communities and institutions are already taking action to reduce harmful impacts. Current levels of exposure to climate-related changes and sensitivities, as well as limitations in adaptive capacity, make some northern systems and populations particularly vulnerable to the effects of climate change…

Local Relevance: Climate change will affect physical, biological, ecological, and social systems in the North because northern stability is directly dependent on the cryosphere (ice, snow, glaciers, permafrost, etc.). Melt of the Yukon-Alaska glaciers has contributed approximately 9% of the sea-level rise in the past 50 years. Yukon is predicted to experience the largest increases in permafrost active-layer depth in Canada. Drought in southern Yukon forests is preventing forest regeneration following forest fires. Remote communities worry that climate change if affecting their relationship with the natural environment. The Council of Yukon First Nations has highlighted food security, community health and well-being, resource-use conflicts, and emergency preparedness as key issues associated with climate change.

Keywords: *adaptation, impacts, Yukon First Nations, Yukon-wide*

Available Online: Full Article

Citation: Furgal, C., and Prowse, T.D. (2008): Northern Canada; *in* From Impacts to Adaptation: Canada in a Changing Climate 2007, edited by D.S. Lemmen, F.J. Warren, J. Lacroix and E. Bush; Government of Canada, Ottawa, ON, p. 57-118.

Maximum June–July Temperatures in the Southwest Yukon over the Last 300 Years Reconstructed from Tree Rings

Research Location: *southwest Yukon*
Publication Date: *2008*
Publication Type: *Journal Article*

Affiliation: *University of Western Ontario*
Contact: *Brian Luckman, University of Western Ontario*

Abstract: A network of seven high-elevation white spruce tree-ring chronologies from the southwest Yukon is used to reconstruct June–July maximum temperatures (T_{max}) back to 1684 AD, explaining 46.6% of the climatic variation over the 1946–1995 calibration period. The chronologies are characterised by low interannual ring-width variability and display similar patterns of ring-width

variation across the sample area over the last 300 years. The driving force of this common signal appears to be a tree growth response to summer temperatures across the region. The reconstruction compares well with regional records of temperature variability derived from annual ring-width and maximum density data. Periods of cooler temperatures correspond with solar minima and glacier advances, particularly during the early 18th and the early 19th centuries. The maximum reconstructed temperatures are in the 1940s with 20th century values averaging 0.46 °C higher than the 1684–1899 period. In contrast to several regional studies, there does not appear to be a reduction in the sensitivity of tree growth to temperature at these sites during the late 20th century. Instead, a slight increase in the strength of the temperature–tree growth relationship is observed during recent decades. A possible explanation for this difference is the absence of significant summer season warming in the southwest Yukon region in comparison to other areas that have demonstrated this response change. This research is part of an ongoing project aimed at assessing the spatial and temporal potential of dendroclimatic reconstructions from the Yukon Territory.

Local Relevance: A tree-ring chronology was created to infer maximum June-July temperatures across the southwest Yukon over the last 300 years. The tree rings showed a consistent response across the study area, most highly correlated with summer temperature. Reconstructed temperatures from the 20th century average was 0.46°C higher than the average temperature from 1684-1899, and the highest temperatures occurred in the 1940s. In this study, there was no discrepancy between tree-ring width and temperature beginning in the late 20th century; the researchers hypothesize that this is due to insignificant summer warming in the southwest Yukon as compared to areas that have shown a decreased tree-growth response to summer temperatures.

Keywords: *air temperature, climate reconstruction, south Yukon, tree ring*

Available Online: Abstract

Citation: Luckman, B., Youngblut, D. 2008. "Maximum June–July Temperatures in the Southwest Yukon over the Last 300 Years Reconstructed from Tree Rings." *Dendrochronologia* 25(3): 153-166.

Climatic Change and Permafrost Stability in the Eastern Canadian Cordillera

Research Location: *Eastern Canadian Cordillera*
Publication Date: *2008*
Publication Type: *Conference Proceedings*

Affiliation: *University of Calgary*
Contact: *Stuart A. Harris, University of Calgary*

Abstract: Permafrost is the result of cold climatic conditions, so the stability of the climate is crucial to permafrost stability. It has been predicted by modeling that Alaska and the Yukon Territory should exhibit the maximum degree of climatic warming in the next century (Anisomov & Poliakov 2003), but Harris (2007) and Sergeev (2007) found that the available climatic data from the most reliable government sources indicated no strong warming trends in large parts of these areas. This paper explores the matter further by extending the study south along the Canadian Cordillera and relating the results to the evidence of associated permafrost stability.

Local Relevance: By analyzing weather records, it was determined that the Arctic coast of Alaska and Yukon, the Mackenzie Valley, northern British Columbia, and the eastern side of the Canadian Cordillera have experienced substantial warming since 1980. This warming is illustrated by permafrost degradation in these areas. Temperatures in central Yukon and Alaska have remained stable, supported by lack of permafrost thaw—except where processes other than climate are responsible (beavers, development). Weather patterns related to the mountains in this area act to shelter central Yukon and Alaska from climatic changes.

Keywords: *air temperature, permafrost, Yukon-wide*

Available Online: Full Article

Citation: Harris, S.A., 2008. Climatic Change and Permafrost Stability in the Eastern Canadian Cordillera. *In*: Ninth International Conference on Permafrost, Extended Abstracts, D.L. Kane and K.M. Hinkel (eds.), Fairbanks, Alaska, June 29-July 3, 2008, p. 93-94.

Diatom Responses to 20th Century Climate-Related Environmental Changes in High-Elevation Mountain Lakes of the Northern Canadian Cordillera

Research Location: *southern Yukon; northern British Columbia*
Publication Date: *2005*
Publication Type: *Journal Article*

Affiliation: *Queen's University*
Contact: *Michael F.J. Pisaric, Carleton University*

Abstract: Diatom responses to 20th century climate-related environmental change were assessed from three high-elevation lakes in the northern Canadian Cordillera. Dominance of small benthic *Fragilaria* diatoms reflect the generally cold conditions with long periods of ice cover that have characterized these mountain lakes over at least the last ~300 years until the period of recent warming. At the turn of the 20th century, salient shifts in the diatom assemblages reveal individualistic limnological responses with the onset of climate warming trends in northwest Canada. At YK3 Lake, an oligotrophic, chemically dilute, alpine lake, increased representation of the planktonic *Cyclotella pseudostelligera* may reflect longer ice-free conditions and/or more stable thermal stratification. By contrast, in the more productive, alkaline lakes (BC2 and Deadspruce lakes), changes to more diverse assemblages of periphytic diatoms suggest greater benthic habitat availability, most likely associated with the enhanced growth of aquatic plants with lengthening of the growing seasons. In addition, diatom assemblages from these lakes suggest less alkaline conditions following the onset of 20th century climate warming. Continued alkalinity reduction throughout the 20th century is qualitatively inferred at the lower elevation, treeline lake (Deadspruce Lake), while greater representation of alkaliphilous *Fragilaria* diatoms after ~1950 suggested increased alkalinity at the alpine BC2 Lake. Our results confirm the sensitivity of diatoms from high-elevation mountain lakes to regional climate change in northwest Canada. Individualistic limnological responses to 20th century warming are potentially attributed to differences in their

physical setting (e.g., bedrock geology, elevation, catchment vegetation) in this complex mountain environment.

Local Relevance: Diatom assemblages from two northern British Columbia lakes and one southern Yukon lake were analyzed over approximately the last 300 years to identify climate-induced changes in sedimentary organisms. In all three lakes, the diatom assemblages showed a significant change at the beginning of the 1900s in response to climate warming following the Little Ice Age. Throughout the 1900s, continued abundance changes of certain diatoms are thought to illustrate longer growing seasons and less ice cover on the lakes. Over this time, the thermal regime of the Yukon lake became more stratified in response to warmer climatic conditions, as evident from changes in the abundance of specific diatoms.

Keywords: *climate reconstruction, diatom, south Yukon, water temperature*

Available Online: Full Article

Citation: Karst-Riddoch, T.L., Pisaric, M.F.J., Smol, J.P. 2005. "Diatom Responses to 20th Century Climate-Related Environmental Changes in High-Elevation Mountain Lakes of the Northern Canadian Cordillera." *Journal of Paleolimnology* 33: 265-282.

Climate Change in Northern Canada

Research Location: *Yukon; Northwest Territories; Nunavut*
Publication Date: *2007*
Publication Type: *Discussion Paper*

Affiliation: *Arctic Athabaskan Council*
Contact: *Arctic Athabaskan Council*

Excerpt: That the world's climate is changing rapidly is no longer a subject of serious debate. A very small number of scientists demur but an overwhelming majority accept that increased level of greenhouse gases (GHG) in the atmosphere—380ppm in 2005 from a pre-industrial level of 280ppm—is altering the world's climate. The vast majority of scientists also accept that rising GHG concentrations is caused by burning of fossil fuels, and land and resource use changes, primarily deforestation, that reduce the natural environment's ability to absorb and store (sequester) carbon…

Local Relevance: This paper was drafted by the Arctic Athabaskan Council to highlight the issues that climate change presents to northern Canada. Impacts noted by the Intergovernmental Panel on Climate Change and the Arctic Climate Impact Assessment are discussed, followed by perspectives of northern residents related to climate change impacts and adaptation. In general, low adaptive capacity is noted and a desire for government leadership is expressed.

Keywords: *adaptation, impacts, policy, traditional knowledge, Yukon-wide*

Available Online: Full Article

Citation: AAC. 2007. *Climate Change in Northern Canada.* Arctic Athabaskan Council: Whitehorse, Yukon.

Climate Change in Our Backyard

Research Location: *Champagne and Aishihik Traditional Territory*
Publication Date: *2006*
Publication Type: *Conference Report*
Affiliation: *Champagne and Aishihik First Nations*
Contact: *Champagne and Aishihik First Nations*

Excerpt: The Climate Change in Our Backyard conference, held in the spring of 2006, was the first of its kind in the Yukon. It brought together scientific and local experts to share common concerns about climate change and work together on solutions. Outcomes will be used by local managers to guide ongoing management.

The first section of this report, "Presentation Summaries" is made up of summaries of all the formal presentations made at the conference. The second section, "Local Observations of Change," is a summary of the changes observed by residents recorded during the round table discussions. Section Three, "Local Directions: Impacts of Change and Adapting to Change," summarizes round table discussions of future impacts of climate change and acceptable ways of dealing with those impacts…

Local Relevance: Information was gathered and shared by scientists and local community members in Haines Junction in order to gain a better understanding of climate change and plausible adaptive strategies. Locals noted many changes regarding fish, wildlife, weather, landscape features, and the boreal forest and they provided ideas for adaptation, many of which called for community involvement. Concerns included warm water affecting fish, snow-crusting making it difficult for big game species to access food, and raining and melting in winter harming small mammals. With respect to forest management, a cautious approach was suggested as the best approach.

Keywords: *adaptation, Champagne and Aishihik First Nations, fish, forest management, Haines Junction, impacts, local knowledge, south Yukon, wildlife, Yukon First Nations*

Citation: Champagne and Aishihik First Nations and Alsek Renewable Resource Council. 2006. "Climate Change in our Backyard." Conference Report, Haines Junction, Yukon, 34 p.

Climate Change in the Mayo Area: Observations of Long-Term Local Residents

Research Location: *Mayo, Yukon*
Publication Date: *2005*
Publication Type: *Workshop Report*
Affiliation: *Unknown*
Contact: *First Nation of Na-Cho Nyäk Dun*

Excerpt: This report summarises the results of a workshop that was the first step towards documenting the observations of Mayo-area residents about climate change. It is a part of a larger Mayo Community Ecological Monitoring Project (CEMP), which was started in 2004 with funding from Environment Canada's Northern Ecosystems Initiative. CEMP has three main parts in Mayo: 1) this workshop, aimed at giving us a historical background about local climate change and its effects on subsistence activities, 2) annual interviews with local residents most active on the land aimed at monitoring current influences of weather and environmental conditions on subsistence activities, and 3) monitoring of key components of the boreal forest food web (e.g., berries, spruce cones, small mammals, snowshoe hares, carnivores) using technical methods on selected sites around Mayo…

Local Relevance: It was noted that summer and winter temperatures have increased with fewer periods of extreme cold and there has been increased snow and rain in winter. There have been changes to the freeze-thaw cycle with earlier thaw of water bodies in spring and later freeze-up in fall. Permafrost conditions have also changed, resulting in damage to overlying houses and drainage of lakes into the ground. Vegetative changes noticed include larger trees and poorer crop yields from berry bushes. There has also been an increase in the number of forest fires, attributed to higher temperatures, less precipitation, and more lightening. These climatic changes have resulted in changes to fish and wildlife. The contribution of climate change to altered patterns of subsistence activities is hard to ascertain because social changes and participant aging has also affected the way people interact with the land.

Keywords: *central Yukon, First Nation of Na-Cho Nyäk Dun, fish, impacts, local knowledge, Mayo, wildlife, Yukon First Nations*

Citation: 2005. "Climate Change in the Mayo Area: Observations of Long-Term Local Residents." Workshop Report, 9-10 Feb. 2005, Mayo, Yukon, 16 p.

Climate and other Sources of Change in the St. Elias Region

Research Location: *St. Elias region, Yukon*
Publication Date: *2003*
Publication Type: *Book Chapter*

Affiliation: *Wilfrid Laurier University*
Contact: *Scott Slocombe, Wilfrid Laurier University*

Abstract: Climate change is hypothesized to have both a greater effect and/or to be more visible in high latitudes and/or elevations. This is significant for both the peoples who live in these regions and scientists seeking evidence about the nature and magnitude of climate change. The Kluane National Park region of southwest Yukon and adjoining parks in Alaska and British Columbia, is one high-latitude, mountainous region well-suited to such studies. Many factors cause change and disturbance in mountainous regions. Thus important questions for research and management are distinguishing and understanding the interaction of climate related changes and changes due to other factors. This paper reviews the literature on the interaction of climate-related and other environmental change. It provides an initial assessment of the causes, nature and magnitude of environmental change in the broader St. Elias region as a basis for distinguishing climate-related

changes. Key sources of change include resource management policies and practices, land use change, wildlife population fluctuations, long-range transport of pollutants, forestry and mining, and tourism activities.

Local Relevance: This study documents both climatic and environmental changes in the St. Elias region in order to understand the interaction between these two types of change. This paper investigates ways to distinguish climate change from a broad array of other environmental changes, including: resource management; land use; wildlife population changes; pollutants, and; the forestry, mining, and tourism industries.

Keywords: *economic development, forestry, south Yukon, wildlife*

Available Online: Abstract

Citation: Slocombe, D.S. 2003. "Climate and other Sources of Change in the St. Elias Region." In *Global Change and Protected Areas*, edited by G. Visconti *et. al*, 61-69. Netherlands: Kluwer Academic Publishers.

Climate Change Adaptation

Community Adaptation Project: Atlin Climate Change Adaptation Plan

Research Location: *Atlin British Columbia*
Publication Date: *2011*
Publication Type: *Project Publication*

Affiliation: *Northern Climate ExChange*
Contact: *Ryan Hennessey, Northern Climate ExChange*

Executive Summary: The Atlin Adaptation Plan documents the community-led process of evaluating and addressing disaster mitigation and climate change in Atlin, British Columbia. The plan is the final report of the Atlin Adaptation Project, a three-year study of the projected impacts of climate change on the community of Atlin. Earlier work in the project indicated the following: i) the community was vulnerable to climate change; and ii) the primary limiting factor inhibiting adaptation in the community was the capacity of residents to take action.

Work on the adaptation plan was undertaken with the vision to address community vulnerability to those environmental hazards exacerbated by climate change through community capacity development. While initial results indicated that capacity development for climate change adaptation would entail actions to reduce community vulnerability by addressing infrastructure needs and building community resources for disaster mitigation in the community, it became apparent over the course of the planning process that residents were concerned with the potential impact of climate change on the human and social capital of the community. Specifically, the community was concerned with the added stress climate change would place on their ability to collaborate. Concern in the community also existed with regard to the increased collaboration, which would result in a subsequent strain on the predominantly volunteer labour force responsible for responding to emergency situations…

Local Relevance: Atlin community members identified four hazards they believed could be exacerbated by climate change—namely, forest fire, power outage, disease outbreak, and isolation. The next step was to develop scenarios in which climate change interacted with each hazard and to determine how this could be addressed. This report identifies organizations that are responsible for disaster mitigation in Atlin and calls for increased communication and collaboration between these organizations and members of the community. Five goals intended to decrease Atlin's vulnerability to said hazards and ways to achieve these goals are described as well as a timeline for implementing the adaptations suggested in the Plan.

Keywords: *adaptation, Atlin, climate modelling, hazards, impacts, local knowledge, south Yukon, Taku River Tlingit First Nation*

Available Online: Atlin Climate Change Adaptation Plan

Atlin Workshop: Preparing for Change—Managing Climate Change Risks in the Atlin Area

Atlin Adaptive Capacity Assessment

Further Information

Citation: Hennessey, R., Love, N., Kinnear, L. and Duerden, F., 2011. *Atlin Climate Change Adaptation Plan*. Northern Climate ExChange, Yukon Research Centre, Yukon College, Whitehorse, YT, 55 p.

Community Adaptation Project: Whitehorse Climate Change Adaptation Plan (Draft Plan)

Research Location: *Whitehorse, Yukon*
Publication Date: *2011*
Publication Type: *Project Publication*
Affiliation: *Northern Climate ExChange*
Contact: *Ryan Hennessey, Northern Climate ExChange*

Executive Summary: Climate has been changing in Whitehorse. It is clear from weather data going back to the 1940's that temperature has been warming, especially in winters. Spring break up has been arriving earlier, freeze up later and frost free days have been increasing.

The Whitehorse Community Adaptation Project, or WhiteCAP, funded by the Northern Strategy Trust, begins the process of preparing Whitehorse for climate change. WhiteCAP consists of two distinct phases: planning and implementation.

The WhiteCAP plan assesses how climate change may positively or negatively affect the community over the next forty years, to 2050. The first half of the planning process focuses on exploring multiple scenarios of how the community may change by 2050, and is presented in the companion document for this plan: *Future Histories of Whitehorse: Scenarios of Change.* The second half of the planning process assesses the risks of climate change impacts and then the priorities of climate change adaptations. Portions of the plan have been implemented in the second year of the WhiteCAP project…

Local Relevance: Whitehorse is expected to experience a winter temperature increase of 3.3°C to 5.4°C, increased precipitation (especially in winter), and a growing season lengthened by 18-25 days by 2050. Impacts of climate change are expected to be the most pronounced regarding natural hazards (flooding, fires), infrastructure, food and energy security, and the environment. Opportunities resulting from climate change are also noted, including an opportunity for increased local agriculture and a heightened need for Whitehorse to be a hub for the north. High priority risks and adaptations are identified and a structure for implementing adaptation strategies is suggested.

Keywords: *air temperature, climate modelling, impacts, Kwanlin Dün First Nation precipitation, south Yukon, Ta'an Kwäch'än Council, Whitehorse, Yukon River*

Available Online: Whitehorse Climate Change Adaptation Plan

Future Histories of Whitehorse: Scenarios of Change

Further Information

Citation: Hennessey, R. and Streicker, J., 2011. *Community Adaptation Project: Whitehorse Climate Change Adaptation Plan.* Northern Climate ExChange, Yukon Research Centre, Yukon College, Whitehorse, YT.

Climate Change and Institutional Capacity in an 'Arctic Gateway' City: A CAVIAR Case Study of Whitehorse

Research Location: *Whitehorse, Yukon*
Publication Date: *2010*
Publication Type: *Book Chapter*

Affiliation: *University of British Columbia*
Contact: *Ralph Matthews, University of British Columbia*

Abstract: Throughout the north, the majority of residents live in sub-Arctic administrative centres south of the Arctic Circle. These 'Arctic Gateways' are critical administrative and service centres through which pass most goods and services to and from the Arctic. Although not Arctic communities in the strict sense, they still must deal with issues of environmental change such as melting permafrost, and threats from flooding and forest fires. While doing so, they also must cope with expanding economic development, tourism, and growing demands for services throughout the Arctic region. Findings are presented from a CAVIAR case study of adaption and vulnerability of one such 'Arctic Gateway' carried out in partnership with the staff and Council of the City of Whitehorse, Yukon Territory. The study is based on extensive, in-depth interviews with elected officials and senior and operational staff of the City of Whitehorse, as well as with representatives of the Yukon Territory Government (YTG), First Nations, inter-governmental bodies, and NGOs responsible for administrative and resource management throughout southern Yukon. We explore key decision processes, institutional linkages and relationships within the civic government structure of the City of Whitehorse as well as with other jurisdictions and levels of government, including two First Nations upon whose traditional territory the City is situated. We find that existing adaptive strategies regarding climate change reside frequently in the processes of decision-making, planning and organizational culture as they are applied in the context of other changes facing the City and Yukon

Territory. Thus, we explore the processes by which policies, decisions and adaptive responses take shape in both routine and uncommon or surprise situations around key areas of civic concern related to infrastructure, public health and safety, land-use planning, emergency preparedness and the environment. The case study is linked to the City's ongoing Integrated Community Sustainability Planning process which provides the temporal basis for exploration of future changes and exposure-sensitivities as defined by various governance institutions. The focus on the application of governance as process and context provides a glimpse of the potential (institutional) capacity of Whitehorse to manage and cope with complex social-ecological changes taking place in the north now and in the future.

Local Relevance: This paper addresses the findings of a case study investigating Whitehorse's adaptive capacity and vulnerability to climatic and economic changes. Policy adaptations to climate change are investigated as well as partnerships between governmental bodies. This study was based on interviews conducted with a variety of organizations including City of Whitehorse, Government of Yukon, and First Nations.

Keywords: *adaptation, Kwanlin Dün First Nation, policy, south Yukon, Ta'an Kwäch'än Council, local knowledge, Whitehorse*

Available Online: Abstract

Citation: Matthews, R., Sydneysmith, R. 2010. "Climate Change and Institutional Capacity in an 'Arctic Gateway' City: A CAVIAR Case Study of Whitehorse." In *Community Adaptation and Vulnerability in Arctic Regions*, edited by G.K. Hovelsrud and B. Smit, 239-261. Springer Science + Business Media.

Dawson Climate Change Adaptation Project Final Project Report

Research Location: *Dawson, Yukon*
Publication Date: *2010*
Publication Type: *Project Report*

Affiliation: *Northern Climate ExChange*
Contact: *Ryan Hennessey, Northern Climate ExChange*

Abstract: Following the successful application by the Northern Climate ExChange (NCE) to the Northern Strategy Trust for Adaptation Planning in three Yukon Communities, Dawson was selected as the first community to attempt this level of adaptation planning. Sebastian Jones was hired as the local coordinator; he led a local advisory committee (LAC) that gave direction to the Plan. The Adaptation Plan was developed through a series of local workshops, validated by a technical committee, which identified the impacts of climate change to the Dawson area, how it is vulnerable to these impacts and what would be the best ways to live with and take advantage of these changes. An unusual and valuable aspect of this project was the setting aside of $120,000 with which to fund projects to implement the Plan. Five projects that worked towards implementing the recommendations were funded through the project. The projects improved the community's ability to provide its own food, reduced its dependence on imported food and fuel and increased its ability to adapt into the future. The project ended on June 30th 2010. This report will focus primarily on the implementation projects.

Local Relevance: This project report addresses four projects initiated in Dawson in response to the recommendations listed in the Northern Climate ExChange's Dawson Climate Change Adaptation Plan. The first project involves promoting growing and purchasing local produce through community gardens and greenhouse. In the future, cold storage options will be explored. A second project is aimed at establishing selective salmon fishing techniques. An electric vehicle was created by the Conservation Klondike Society which is used for daily Society operations. The last project is intended to establish a network for communicating scientific and local knowledge in Dawson.

Keywords: *adaptation, central Yukon, Dawson, fish, salmon, Tr'ondëk Hwëch'in First Nation*

Available Online: Dawson Climate Change Adaptation Project Final Project Report

Further Information

Citation: Jones, S. 2010. "Dawson Climate Change Adaptation Project Final Project Report." Report prepared for: the Northern Climate ExChange, City of Dawson, and Tr'ondëk Hwëch'in First Nation.

Community Adaptation Project: Dawson Climate Change Adaptation Plan

Research Location: *Tr'ondëk Hwëch'in Traditional Territory*
Publication Date: *2009*
Publication Type: *Project Publication*
Affiliation: *Northern Climate ExChange*
Contact: *Ryan Hennessey, Northern Climate ExChange*

Executive Summary: The Dawson Adaptation Plan is based on a collaborative process that draws on the experience and knowledge of residents and integrates it with scientific expertise. The plan is primarily intended as a resource for community use and to support other planning and decision-making processes in the study area, the Tr'ondëk Hwëch'in Traditional Territory. The Dawson Adaptation project team itself is made up by members of the International Polar Year Dawson Community Adaptation and Vulnerability in Arctic Regions (CAVIAR) team, and the Northern Climate ExChange (NCE).

The Tr'ondëk Hwëch'in Traditional Territory was selected as the study area boundary because it allowed a broad area from which to assess potential environmental changes that may affect the community. However, this study focused on how climate change may affect the community. The community in turn focused on those aspects of their environment that affects them the most; the infrastructure and townsite of Dawson…

Local Relevance: Temperature in Dawson is expected to increase by 2.5°C to 3.5°C and precipitation is expected to increase (especially in winter) by the 2050s. Based on workshops with local residents and input from science experts, vulnerabilities and opportunities stemming from climate change were noted for Dawson and the Tr'ondëk Hwëch'in Traditional Territory. Areas in which Dawson is expected to experience negative consequences of climate change are all related to alterations to weather, forest fires, and flooding, while possible opportunities may result from changes to weather,

forest fires, tourism and recreation, permafrost, and the economy. The importance of these consequences and opportunities was determined based on the likelihood of occurrence, the level of impact, and the community's capacity to respond. Resulting from the high priority consequences is a list of recommended actions to be implemented both immediately and by 2020.

Keywords: *adaptation, air temperature, central Yukon, climate modelling, Dawson, impacts, precipitation, local knowledge, Tr'ondëk Hwëch'in First Nation*

Available Online: Dawson Climate Change Adaptation Plan

Further Information

Citation: Hennessey, R., Jones, S., Duerden, F. and Swales, S., 2009. *Community Adaptation Project: Dawson Climate Change Adaptation Plan*. Northern Climate ExChange: Whitehorse, Yukon.

Dawson City Community Action Plan on Climate Change Forum Report

Research Location: *Dawson, Yukon*
Publication Date: *2006*
Publication Type: *Project Report*
Affiliation: *Yukon Fish and Wildlife Management Board*

Abstract: In November 2005, Sebastian Jones, the Dawson Community Steward for the Yukon Fish and Wildlife Management Board (YFWMB), organized a Climate Change Forum. A Community Steward has a number of objectives, one of which is to assist communities to identify local stewardship priorities and help develop related plans. The overriding purpose of the forum was to develop a community driven Action Plan on adapting to and mitigating for Climate Change. The plan was developed by working through a series of workshops and meetings. Advantage was taken of the opportunity resulting from the presence of outside resources to undertake related activities consistent with reducing energy consumption. 50 people contributed to the plan which provides a framework of actions and recommendations for a number of existing organizations to help make Dawson a more sustainable and healthy community.

Local Relevance: As part of a project to promote climate change awareness in Canadian communities, 50 people attended a forum hosted in Dawson in 2006. Forum participants separated into groups to discuss key issues and current and potential programs to mitigate these issues for six broad categories: energy, buildings, transportation, land and wildlife, air and water, and waste management. The issues and solutions raised by participants are listed and organized by topic. In addition, the participants noted which organizations should be responsible for each of the strategies proposed. This report concludes with priority actions and recommendations.

Keywords: *adaptation, central Yukon, Dawson, impacts, infrastructure, local knowledge, Tr'ondëk Hwëch'in First Nation*

Available Online: Dawson City Community Action Plan on Climate Change Forum Report

Dawson Climate Change Action Plan

Citation: Jones, S. 2006. "Dawson City Community Action Plan on Climate Change Forum Report." Report prepared for: the Yukon Fish and Wildlife Management Board *et al*.

Pelly Crossing Landscape Hazards: Geological Mapping for Climate Change Adaptation Planning

Research Location: *Pelly Crossing, Yukon*
Publication Date: *2011*
Publication Type: *Project Publication*

Affiliation: *Northern Climate ExChange*
Contact: *Lacia Kinnear, Northern Climate ExChange*

Excerpt: Vulnerability, at a local level, is conditioned by social, economic, cultural, political and biophysical conditions and processes operating at multiple temporal and spatial scales and in turn affects community exposure and adaptive capacity. To understand vulnerabilities within the landscape, we must assess the environmental conditions that may be affected by climate change and may therefore pose hazards to safe and sustainable development. Factors to be considered include permafrost and ground ice, surface water drainage, groundwater dynamics, surficial geology and slope stability. These factors combine to create landscape hazards that can pose risks to infrastructure, and may be exacerbated in a changing climate. Insights related to these hazards can be used to direct investigations that will support future adaptation and town planning processes.

The objective of this project is to identify landscape hazards in the Village of Pelly Crossing and nearby surroundings (Figure 1) by gathering and mapping geoscience data (surficial geology and hydrology). This data is used to create a map of landscape hazards based on geotechnical properties that suggest low, moderate and high-risk areas in the Pelly Crossing region. Potential impacts of a changing climate are incorporated in the identification of these three hazard zones. This report is prepared as a guide and not as a document upon which to base planning decisions. It should not be used for site selection for development, but rather treated as a guide in identifying areas that would require additional engineering studies, should development be desired…

Local Relevance: A detailed assessment of landforms, ground materials, permafrost and hydrological conditions, vegetation, and projected climate change impacts was undertaken to identify areas vulnerable to climatic changes near Pelly Crossing. The potential climate-induced changes are based upon modelling which projects increases in temperature (2.5°C to 3.7°C warmer) and precipitation by 2050. These areas are presented in map form and are ranked as low, medium, or high based on the likelihood that projected changes will affect each area. This report describes in detail the hydrological characteristics and surficial geology of the Pelly Crossing region and possible climate-induced changes.

Keywords: *climate modelling, hazards, hydrology, Pelly Crossing, Pelly River, permafrost, Selkirk First Nation, south-central Yukon, streamflow, surficial geology, vegetation*

Available Online: Full Report

Citation: Northern Climate Exchange, 2011. *Pelly Crossing Landscape Hazards: Geological Mapping for Climate Change Adaptation Planning.* Yukon Research Centre, Yukon College, 48 p. and 2 maps.

Mayo Landscape Hazards: Geological Mapping for Climate Change Adaptation Planning

Research Location: *Mayo, Yukon*
Publication Date: *2011*
Publication Type: *Project Publication*

Affiliation: *Northern Climate ExChange*
Contact: *Lacia Kinnear, Northern Climate ExChange*

Excerpt: Vulnerability, at a local level, is conditioned by social, economic, cultural, political and biophysical conditions and processes operating at multiple temporal and spatial scales and in turn affects community exposure and adaptive capacity. To understand vulnerabilities within the landscape, we must assess the environmental conditions that may be affected by climate change and may therefore pose hazards to safe and sustainable development. Factors to be considered include permafrost and ground ice, surface water drainage, groundwater dynamics, surficial geology and slope stability. These factors combine to create landscape hazards that can pose risks to infrastructure, and may be exacerbated in a changing climate. Insights related to these hazards can be used to direct investigations that will support future adaptation and town planning processes.

The objective of this project is to identify landscape hazards in the Village of Mayo and nearby surroundings (Figure 1) by gathering and mapping geoscience data (surficial geology, permafrost conditions and hydrology). This data is used to create a map of landscape hazards based on geotechnical properties that suggest low, moderate and high-risk areas in the Mayo region. Potential impacts of a changing climate are incorporated in the identification of these three hazard zones.

Local Relevance: A detailed assessment of landforms, ground materials, permafrost and hydrological conditions, vegetation, and projected climate change impacts was undertaken to identify areas vulnerable to climatic changes near Mayo. The potential climate-induced changes are based upon modelling which projects increases in temperature (2.1°C to 3.2°C warmer) and precipitation by 2050. These areas are presented in map form and are ranked as low, medium, or high based on the likelihood that projected changes will affect each area. Specific climate-induced changes to the hydrological regime and permafrost conditions in the Mayo region that could occur are highlighted.

Keywords: *central Yukon, climate modelling, First Nation of Na-Cho Nyäk Dun, hazards, hydrology, Mayo, Mayo River, permafrost, streamflow, Stewart River, surficial geology*

Available Online: Full Report

Citation: Northern Climate Exchange, 2011. *Mayo Landscape Hazards: Geological Mapping for Climate Change Adaptation Planning.* Yukon Research Centre, Yukon College, 64 p. and 2 maps.

Adapting to Climate Change in the Circumpolar North: The Role of the Northern Climate ExChange

Research Location: *Canada and United States*
Publication Date: *2004*
Publication Type: *Project Publication*

Affiliation: *Northern Climate ExChange*
Contact: *Lacia Kinnear, Northern Climate ExChange*

Excerpt: The mandate of the Northern Climate ExChange is, in part, to develop precisely the kinds of linkages that will be vital to the creation of adaptation strategies. In its short history, the NCE has already undertaken initiatives addressing both sides of the adaptation coin: assessment of vulnerability and discussion of adaptation options at the local level, and development of information and expertise from the wider scientific, technical and governmental community to support local action. In February 2001, for example, the NCE joined with the Yukon village of Mayo and the Na-Cho Ny'a'k Dun First Nation in hosting a workshop to discuss climate change and its impacts on the central Yukon. On the broader stage, the NCE partnered with Environment Canada and several academic and independent researchers in the NCE Gap Analysis Project, mentioned earlier, a multi-year undertaking to assess the current state of knowledge about climate change in northern Canada (NCE, 2002). Both cases highlight the potential value of an organization like the NCE in facilitating the kind of cooperation between regions, disciplines, and institutions that will be required to deal with the impacts of climate change…

Local Relevance: This paper addresses the part the Northern Climate ExChange (NCE) plays regarding climate change adaptation in the North. According to the authors, northerners should respond to climate change with both mitigative and adaptive strategies. Both of these responses are based on behavioural changes, and a behavioural change must be motivated by knowledge. Expanding knowledge is where NCE fits in—NCE helps to acquire and disseminate knowledge across the various political and social boundaries of the Canadian north. This paper highlights numerous projects and accomplishments of NCE in its first few years of operation after being established in 2000.

Keywords: *adaptation, Yukon-wide*

Available Online: Full Article

Citation: Eamer, C., and Ogden, A.E. 2003. "Adapting to Climate Change in the Circumpolar North: The Role of the Northern Climate ExChange." Northern Climate ExChange, Occasional Paper # 5.

Climate Impacts on Northern Canada: Regional Background

Research Location: *Yukon; Northwest Territories; Nunavut*
Publication Date: *2009*
Publication Type: *Journal Article*
Affiliation: *Environment Canada; University of Victoria*
Contact: *Terry D. Prowse, University of Victoria/Environment Canada*

Abstract: Understanding the implications of climate change on northern Canada requires a background about the size and diversity of its human and biogeophysical systems. Occupying an area of almost 40% of Canada, with one-third of this contained in Arctic islands, Canada's northern territories consist of a diversity of physical environments unrivaled around the circumpolar north. Major ecozones composed of a range of landforms, climate, vegetation, and wildlife include: Arctic, boreal and taiga cordillera; boreal and taiga plains; taiga shield; and northern and southern Arctic. Although generally characterized by a cold climate, there is an enormous range in air temperature with mean annual values being as high as −5°C in the south to as low as −20°C in the high Arctic islands. A similar contrast characterizes precipitation, which can be >700 mm y^{-1} in some southern alpine regions to as low as 50 mm y^{-1} over islands of the high Arctic. Major freshwater resources are found within most northern ecozones, varying from large glaciers or ice caps and lakes to extensive wetlands and peat lands. Most of the North's renewable water, however, is found within its major river networks and originates in more southerly headwaters. Ice covers characterize the freshwater systems for multiple months of the year while permafrost prevails in various forms, dominating the terrestrial landscape. The marine environment, which envelops the Canadian Arctic Archipelago, is dominated by seasonal to multiyear sea ice often several meters thick that plays a key role in the regional climate. Almost two-thirds of northern Canadian communities are located along coastlines with the entire population being just over 100 000. Most recent population growth has been dominated by an expansion of non-aboriginals, primarily the result of resource development and the growth of public administration. The economies of northern communities, however, remain quite mixed with traditional land-based renewable resource-subsistence activities still being a major part of many local economies.

Local Relevance: This paper identifies the physical, biological, geological, and human systems present in Canada in an attempt to better understand and predict the impacts of climate change. Temperature and precipitation regimes vary greatly between regions, as do ecosystems. The North has a vast freshwater supply, available in renewable form in the river networks. Resource development and evolving public administration has led to recent population growth.

Keywords: *air temperature, economic development, environment, precipitation, Yukon-wide*

Available Online: Abstract

Citation: Prowse, T.D., Furgal, C., Bonsal, B.R., Peters, D.L. 2009. "Climate Impacts on Northern Canada: Regional Background." *Ambio* 38(5): 248-256.

Implications of Climate Change for Northern Canada: The Physical Environment

Research Location: *Yukon; Northwest Territories; Nunavut*
Publication Date: *2009*
Publication Type: *Journal Article*

Affiliation: *University of Victoria; Environment Canada*
Contact: *Terry D. Prowse, University of Victoria/Environment Canada*

Abstract: The physical environment of the Canadian North is particularly sensitive to changes in climate because of a large concentration of cryospheric elements including both seasonal and multiyear forms of freshwater and sea ice, permafrost, snow, glaciers, and small ice caps. Because the cryosphere responds directly to changes in air temperature and precipitation, it is a primary indicator of the effects of climate variability and change. This article reviews the major changes that have occurred in the recent historical record of these cryospheric components at high latitudes in Canada. Some changes have been less pronounced in the Canadian North than elsewhere, such as changes in sea-ice coverage, whereas others have been potentially more significant, such as ablation of the extensive alpine and high-Arctic small glaciers and ice caps. Projections of future changes are also reviewed for each cryospheric component. Discussion about two other physical components of the North intrinsically linked to the cryosphere is also included, specifically: i) freshwater discharge to the Arctic Ocean via major river networks that are fed primarily by various forms of snow and ice, and ii) the related rise in sea level, which is strongly influenced by ablation of the cryosphere, and coastal stability, which also depends on the thermal integrity of coastal permafrost.

Local Relevance: Northern Hemisphere snow-cover extent has decreased in recent decades and continuing changes are expected to be most pronounced during fall and spring, affecting spring runoff. Of glaciers in northern Canada, the Yukon-Alaska glaciers have experienced the most melting, causing approximately 9% of the global sea-level rise observed over the past 50 years. It is estimated that recent melt of the Yukon-Alaska glaciers contributed two times more to sea-level rise than melt of the Greenland ice sheet. With respect to permafrost, Yukon is expected to experience the largest percentage increase in active layer depth over the coming 50 years. Northern Hemisphere lakes and rivers are displaying a trend toward earlier ice breakup and later freeze-up by about 6 days per century each.

Keywords: *hydrology, impacts, Yukon-wide*

Available Online: Full Article

Citation: Prowse, T.D., Furgal, C., Melling, H., Smith, S.L. 2009. "Implications of Climate Change for Northern Canada: The Physical Environment." *Ambio* 38(5): 266-271.

Five Year Compendium: Status of Climate Change Impacts and Adaptation from the Perspective of C-CIARN North – Yukon Node

Research Location: *Yukon*
Publication Date: *2006*
Publication Type: *Compendium*
Affiliation: *C-CIARN North*
Contact: *Lacia Kinnear, Northern Climate ExChange*

Excerpt: Hosted by the Northern Research Institute at Yukon College the Yukon office of C-CIARN North serves as a networking and coordination hub for research and information sharing related to climate impacts and adaptation in the Yukon and also serves as the coordination centre for the CCIARN North network…

Drawing on outcomes from C-CIARN North Workshops and stakeholder meetings in the past, we were able to synthesize gathered information into three distinct key impacts…

The C-CIARN North – Yukon Node maintains one-on-one contact with over 2000 stakeholders and researchers. Many of these contacts stand out as key individuals that must be engaged in order for appropriate decisions be made to reduce risks to the Yukon. In particular, for the above listed key impacts to be addressed, certain contacts should play a crucial role…

Local Relevance: This document summarizes the main accomplishments of the Yukon node of C-CIARN North and identifies prominent climate change impacts in three broad categories: hydrological shifts; species distribution, and; impacts on people. Key stakeholders and best-practice strategies for stakeholder involvement are outlined. Research questions that need to be answered are proposed as well as a call for further research on impacts and adaptations specific to individual regions and sectors.

Keywords: *adaptation, impacts, policy, research needs, Yukon-wide*

Available Online: Full Article

Citation: C-CIARN North. 2006. "Five Year Compendium: Status of Climate Change Impacts and Adaptation from the Perspective of C-CIARN North – Yukon Node." C-CIARN North: Whitehorse, Yukon.

Evidence and Implications of Recent Climate Change in Northern Alaska and Other Arctic Regions

Research Location: *Arctic, focus on Alaska*
Publication Date: *2005*
Publication Type: *Journal Article*
Affiliation: *University of Alaska Fairbanks*
Contact: *Larry D. Hinzman, University of Alaska Fairbanks*

Abstract: The Arctic climate is changing. Permafrost is warming, hydrological processes are changing and biological and social systems are also evolving in response to these changing conditions. Knowing how the structure and function of arctic terrestrial ecosystems are responding to recent and persistent climate change is paramount to understanding the future state of the Earth

system and how humans will need to adapt. Our holistic review presents a broad array of evidence that illustrates convincingly; the Arctic is undergoing a system-wide response to an altered climatic state. New extreme and seasonal surface climatic conditions are being experienced, a range of biophysical states and processes influenced by the threshold and phase change of freezing point are being altered, hydrological and biogeochemical cycles are shifting, and more regularly human sub-systems are being affected. Importantly, the patterns, magnitude and mechanisms of change have sometimes been unpredictable or difficult to isolate due to compounding factors. In almost every discipline represented, we show how the biocomplexity of the Arctic system has highlighted and challenged a paucity of integrated scientific knowledge, the lack of sustained observational and experimental time series, and the technical and logistic constraints of researching the Arctic environment. This study supports ongoing efforts to strengthen the interdisciplinarity of arctic system science and improve the coupling of large scale experimental manipulation with sustained time series observations by incorporating and integrating novel technologies, remote sensing and modeling.

Local Relevance: Peak runoff has declined in most of the interior and northern Yukon river basins analysed, while peak streamflow has increased in the western, glacierized river basins. Contrary to a steady increasing trend of Alaskan caribou herd populations, the Porcupine caribou herd has both increased and decreased since the 1970s. The period of decreasing is correlated with a greater frequency of ice-crusts on top of snow which can effect foraging, energy output, and ability to escape predators. This implies that negative effects of climate change for caribou may be greater than the positive benefits of increased spring food availability and June calf survival. In this paper, the implications of changes to caribou on the community of Old Crow are addressed.

Keywords: *caribou, hydrology, impacts, Old Crow, streamflow, Vuntut Gwitchin First Nation, wildlife, Yukon-wide*

Available Online: Full Article

Citation: Hinzman, L.D., Bettez, N.D., Bolton, W.R., Chapin, F.S., Dyurgerov, M.B., Fastie, C.L., Griffith, B., Hollister, R.D., Hope, A., Huntington, H.P., Jensen, A.M., Jia, G.J., Jorgenson, T., Kane, D.L., Klein, D.R., Kofinas, G., Lynch, A.H., Lloyd, A.H., McGuire, A.D., Nelson, F.E., Oechel, W.C., Osterkamp, T.E., Racine, C.H., Romanovsky, V.E., Stone, R.S., Stow, D.A., Sturm, M., Tweedie, C.E., Vourlitis, G.L., Walker, M.D., Walker, D.A., Webber, P.J., Welker, J.M., Winker, K.S., Yoshikawa, K. 2005. "Evidence and Implications of Recent Climate Change in Northern Alaska and Other Arctic Regions." *Climatic Change* 72: 251-298.

Translating Climate Change Impacts at the Community Level

Research Location: *northern Canada*
Publication Date: *2004*
Publication Type: *Journal Article*
Affiliation: *Ryerson University*
Contact: *Frank Duerden, Ryerson University*

Abstract: It is well recognized that climate change will have considerable impact on the physical landscapes of northern Canada. How these impacts will be transmitted to the level of human activity

is not clear, but it needs to be understood by governments and other decision makers to help them identify and implement appropriate approaches to ameliorate the effects of climate change. Translating physical changes into human impacts is not a simple task; communities are not passive players that will respond to changes in the physical environment in easily predictable ways. While many prognoses about change are made on a large scale, human activity is highly localized, and impacts and responses will be conditioned by local geography and a range of endogenous factors, including demographic trends, economic complexity, and experience with "change" in a broad sense. More and more studies are yielding important information about community-level experience, both past and current, with environmental shifts in the North, but research effort by social scientists falls short of what is required to reduce the level of uncertainty, and it compares unfavourably with the physical sciences' dedication to the climate change problem. A pan-northern research effort, building on a long legacy of social science research in the North, would go some way towards translating the promise of change into probable community impacts.

Local Relevance: In order to effectively adapt to climate change, governments and decision-makers must be aware of the impacts of climate change at the level of individual communities. Climate change impacts are affected by a range of geographic and endogenous factors that vary between localities. This paper suggests that impacts at the local level can best be predicted by an analysis of previously-determined community characteristics and use of traditional knowledge and perspectives of local populations.

Keywords: *impacts, Yukon-wide*

Available Online: Full Article

Citation: Duerden, F. 2004. "Translating Climate Change Impacts at the Community Level." *Arctic* 57(2): 204-212.

2. Hydrology

Yukon Water Availability Analysis

Research Location: *Yukon*
Publication Date: *2011*
Publication Type: *Project Report*

Affiliation: *Scenarios Network for Alaska and Arctic Planning (SNAP)*
Contact: *Ryan Hennessey, Northern Climate ExChange*

Executive Summary: The high-latitude ecosystems of the Yukon are vulnerable to climate change, including hydrologic changes. In order to predict potential changes in growing season water balance in the Yukon, the Scenarios Network for Alaska and Arctic Planning (SNAP) and Yukon College collaborated to develop a modeling tool for mapping future growing-season water availability. The model focused on estimating the growing-season balance between precipitation (P) and potential evapotranspiration (PET), a term used to describe the likely amount of water that could be returned

to the atmosphere through the combination of evaporation and transpiration. Results showed that much of the Yukon is likely to remain water-limited during summer months, with the balance between P and PET remaining negative. Subtle changes were predicted in this balance, with some regional drying, particularly in the boreal regions. However, the greatest impacts to ecosystem hydrology may stem for associated climate-driven changes such as increases in growing season length and growing degree days and associated vegetation shifts; changing drainage from permafrost loss; and altered fire cycles.

Local Relevance: Currently, the amount of water lost from most Yukon ecosystems (with the exception of the Pacific Maritime ecoregion in the southwest) through evapotranspiration (ET) during the summer months is greater than water added to the ecosystem through precipitation, resulting in a water deficit. Based on climate modelling, this deficit is expected to continue, with central and southern areas becoming slightly dryer. However, the exact balance between precipitation and ET as the climate warms will depend on changes to growing season length, permafrost, forest fires, and ecosystems. Potential contribution of these factors to future water balance in Yukon is discussed.

Keywords: *evapotranspiration, hydrological modelling, hydrology, precipitation, Yukon-wide*

Available upon Request

Citation: Scenarios Network for Alaska and Arctic Planning. 2011. "Yukon Water Availability Analysis." Report prepared for: the Northern Climate ExChange. SNAP: University of Alaska Fairbanks.

Modeled Continual Surface Water Storage Change of the Yukon River Basin

Research Location: *Yukon River Basin*
Publication Date: *2008*
Publication Type: *Conference Proceedings*

Affiliation: *University of Alaska Fairbanks*
Contact: *Rena Bryan, University of Alaska Fairbanks*

Excerpt: Climate change in high latitudes, occurring at an observable pace, provides a window into changes the rest of the earth may experience over a longer time scale (Shaver et al. 1992). Large-scale datasets of surface water, groundwater, and permafrost dynamics serve as prerequisites in a variety of other analyses and applications (Lehner et al. 2008). This study models continual surface water storage change in the Yukon River Basin. The project is the underpinning for carbon dioxide and methane flux; taiga-tundra shift; regional surface energy balance; regional weather pattern; migratory waterfowl habitat availability; and infrastructure, building, and community stability studies…

Local Relevance: As temperatures increase, soil dehydration will allow oxygen from the air to penetrate further into the ground, potentially resulting in increased output of carbon dioxide from the ground. Increased release of methane into the atmosphere may also occur as a result of permafrost thaw occurring in lake bottoms. It is possible that areas with low precipitation may evolve

into grassy tundra as permafrost thaws, soils dry out, and surface water drains into the groundwater table. This may reduce the habitat available for migratory waterfowl.

Keywords: *carbon, climate modelling, methane, permafrost, precipitation, hydrology, wildlife, Yukon River Basin*

Available Online: Full Article

Citation: Bryan, R., Hinzman, L. D., Busey, R. C., 2008. Modeled Continual Surface Water Storage Change of the Yukon River Basin. *In*: Ninth International Conference on Permafrost, Extended Abstracts, D.L. Kane and K.M. Hinkel (eds.), Fairbanks, Alaska, June 29-July 3, 2008, p. 35-36.

Yukon Water: An Assessment of Climate Change Vulnerabilities

Research Location: *Yukon*
Publication Date: *2011*
Publication Type: *Government Publication*
Affiliation: *Environment Yukon*
Contact: *Holly Goulding, Government of Yukon*

Executive Summary: The need to monitor and respond to climate change—including its impacts on water—is an emerging national and territorial priority. Climate change is already altering, and will continue to alter, the hydrologic cycle in Yukon, affecting not only water-course flows, volumes, and timing, but also the quality of the water. These changes will inevitably affect every aspect of Yukon life, from day-to-day household practices to industrial development and energy generation. This report provides a snapshot of current and forecasted water resource issues in Yukon related to climate change. It documents current and future Yukon water uses and practices, reviews our knowledge about possible climate change impacts on Yukon water, and provides a list of existing programs that collect water-related data. The report was produced through the Adaptive Management for Water Users Responding to Climate Change project (the Water Adaptation Project), led by Environment Yukon's Water Resources Branch and funded by Indian and Northern Affairs Canada…

Local Relevance: Increased winter and summer temperatures have resulted in a thinner snowpack and earlier spring snowmelt, resulting in earlier peak river flows. As permafrost thaws, the influence of groundwater on streamflow increases and water chemistry can be affected as groundwater interacts with deeper soils. Permafrost disintegration likely caused the drainage of two lakes in the Old Crow flats in 2007. River ice break up is affected by air temperature; for example, the break up date of the Yukon River at Dawson City has moved earlier by five days over the last 100 years as air temperatures have warmed. Our hydroelectricity generation, fisheries and aquaculture and oil and gas industries, and agriculture and mining sectors are all impacted by water and changes that may result from climate change.

Keywords: *hydrology, impacts, streamflow, Yukon-wide*

Available Online: Full Report

Summary Report

Citation: Yukon. Dept. of Environment. *Yukon Water: An Assessment of Climate Change Vulnerabilities*. Whitehorse: 2011.

Changes in Past Hydro-Climatology and Projected Future Change—for the City of Whitehorse (Summary Report)

Research Location: *Whitehorse, Yukon*
Publication Date: *2008*
Publication Type: *Project Report*
Affiliation: *Pacific Climate Impacts Consortium*
Contact: *Arelia T. Werner, University of Victoria*

Executive Summary: The North in general and Whitehorse (Yukon Territory) in particular are highly susceptible to climate change. Warming is taking place faster in this region than many others. Because of the potential for major disruptions to systems that humans rely on, it is important that planners are provided with information that they can use to initiate the development and implementation of relevant adaptation and mitigation measures.

The Pacific Climate Impacts Consortium (PCIC) participated in the City of Whitehorse Sustainability Charrette, October 22nd -25th 2007. For this event, PCIC conducted analysis and created graphics to demonstrate the influence of climate change and variability on air temperature, precipitation, and streamflow in the past for the Whitehorse region. Projections of future changes in these variables were presented as well as impacts such as, forest fire severity, growing degree days, and spruce bark beetle infestations.

PCIC Staff (Arelia Werner and Trevor Murdock) made presentations at the Charrette and participated in the planning process over the four days. They were on hand to interact with the Charrette participants and met one-on-one with municipal planners and engineers to discuss the implications of the climate change impacts presented. From this interaction a few key ideas for future work were identified. This brief report summarizes the findings for the historical changes in hydro-climatology for the Whitehorse region and projections for the future. Recommendations for future work will also be outlined.

Local Relevance: From 1950-2003, temperatures in Whitehorse increased by 1.5°C to 2.5°C and precipitation increased by up to 30% in some regions (albeit mostly statistically insignificant). Climate models predict average temperature increases of 3°C to 6°C and precipitation increases between 10% and 45% by the 2050s. Streamflow trends were documented for many major rivers in Yukon. For the Yukon River, the current trend of increasing winter flows and decreasing summer flows is expected to continue. This may assist winter hydroelectric power production while having adverse impacts on some ecosystems.

Keywords: *air temperature, Arctic Oscillation, climate modelling, El Niño/Southern Oscillation, hydroelectricity, hydrology, Kwanlin Dün First Nation, Pacific Decadal Oscillation, precipitation, streamflow, south Yukon, Ta'an Kwäch'än Council, Whitehorse, Yukon River*

Available Online: Full Report

Citation: Werner, A.T., and Murdock, T.Q. 2008. "Changes in Past Hydro-Climatology and Projected Future Change—for the City of Whitehorse." Pacific Climate Impacts Consortium, University of Victoria.

Apparent Recent Trends in Hydrologic Response in Permafrost Regions of Northwest Canada

Research Location: *Yukon*
Publication Date: *2008*
Publication Type: *Journal Article*

Affiliation: *Environment Yukon*
Contact: *Richard Janowicz, Government of Yukon*

Abstract: Yukon air temperature trends have been observed to change over the last several decades with an increase in both summer and winter air temperatures. An assessment of streamflow response was carried out to determine if there are apparent trends in permafrost regions as a result of the observed temperature changes. Degrading permafrost places a greater reliance on the interaction between surface and subsurface processes. Annual mean, maximum and minimum flows were assessed using the Mann–Kendall test to statistically validate observed trends. Annual mean flows are observed to have slight positive trends over the last three decades within continuous and discontinuous permafrost zones, with variable results within sporadic permafrost regions. These results are generally in keeping with similar trends in annual precipitation, which has increased slightly. Though not generally statistically significant, annual peak flows have largely decreased within continuous permafrost regions, and lesser so within discontinuous regions. Results are variable within sporadic permafrost zones. These trends are likely associated with increased annual precipitation; however, it is conceivable that there may be increased infiltration amounts as a result of degrading permafrost. Winter low flows have experienced significant apparent changes over the last three decades. The greatest changes in winter low flows appear to be occurring within the continuous permafrost zone, where flows from the majority of sampled streams have increased. Winter low flows trends in streams within the discontinuous permafrost zone generally exhibit positive significant trends, but are more variable. Winter streamflow trends within the sporadic permafrost zone are not consistent.

Local Relevance: This study investigates whether permafrost thaw as a result of warming air temperatures has affected streamflow in Yukon waterways over the last three decades. Streamflow changes in the sporadic permafrost zone are inconsistent; however, within the discontinuous and continuous permafrost zones, annual mean flows have increased slightly and minimum winter flows have also increased. The increase in annual flows may be the result of increased precipitation over the same time period. The increase in minimum winter flows has been the most pronounced in the continuous permafrost zone and less so in the discontinuous zone. Also, peak flows have shown a decrease (albeit not statistically significant) in both continuous and discontinuous zones. This is likely the result of increased precipitation, but may also be due to increased penetration of the water into the ground as permafrost thaws.

Keywords: *hydrology, streamflow, Yukon-wide*

Available Online: Abstract

Citation: Janowicz, R. 2008. "Apparent Recent Trends in Hydrologic Response in Permafrost Regions of Northwest Canada." *Hydrology Research* 39(4): 267-275.

Climate Change Impacts on Boundary and Transboundary Water Management

Research Location: *Canada*
Publication Date: *2003*
Publication Type: *Project Report*

Affiliation: *Global Change Strategies International*
Contact: *Global Change Strategies International*

Excerpt: This report, funded in part through the Climate Change Action Fund, Natural Resources Canada, deals with the climate-change related issues of water management in boundary and transboundary areas. Climate change is now happening and the projected climate change over this century is unprecedented in thousands of years. As part of climate change, there will be changes to the water cycles and increases, in some areas, and decreases, in others, in the flows in rivers in Canada and around the world. W\River flows naturally cross boundaries, both within Canada and between Canada and the United States. The management of these water resources is governed by a series of agreements between the provinces, territories and the federal government, within Canada and between Canada and the United States for international boundaries. Climate change will test these agreements and the management of water resources within the North American context. In recognition of these potential difficulties, a contract was let by the CCAF, Natural Resources Canada, to the partnership of Global Change Strategies International (GCSI) and the Institute for Catastrophic Loss Reduction. The Meteorological Service of Environment Canada became a partner in the project. Professors D. Shrubsole, J. McDougall and J. Whalley of The University of Western Ontario and R. Halliday of R Halliday & Associates became participants with the ICLR. The combined team held three meetings, in Burlington, Winnipeg and London, and several information meetings and discussions. An Advisory Board for the Project was created and met once formally to provide advice…

Local Relevance: The Yukon River Basin did not experience statistically significant annual streamflow changes over the period 1970-2000. However, maximum and summer flows decreased while winter flows increased. There may be political issues between Yukon and Alaska regarding the potential effects of warming water on salmon populations. The Mackenzie River Basin is susceptible to climatic changes and responding to these changes will have to be a joint effort between Yukon and the Northwest Territories.

Keywords: *hydrology, Mackenzie River Basin, policy, water management, Yukon River Basin*

Available Online: Full Report

Citation: Bruce, J.P., Martin, H., Colucci, P., McBean, G., McDougall, J., Shurbsole, D., Whalley, J., Halliday, R., Alden, M., Mortsch, L., Mills, B. 2003. "Climate Change Impacts on Boundary and Transboundary Water Management." Report submitted to the Climate Change Action Fund (Project A458/402), Natural Resources Canada, 161 pp.

Glacial and Nival Rivers

Detection of Changes in Glacial Run-off in Alpine Basins: Examples from North America, the Alps, central Asia and the Andes

Research Location: *Canada; Switzerland; Austria; central Asia; Peru; Chile*
Publication Date: *2009*
Publication Type: *Journal Article*

Affiliation: *Centro de Estudios Científicos*
Contact: *Gino Casassa, Centro de Estudios Científicos*

Abstract: Atmospheric warming and enhanced melting of glaciers is already resulting in changes in the glacial contribution to run-off in mountain basins around the world. The enhanced melting of glaciers leads at first to increased run-off and discharge peaks and an increased melt season, while in the longer time frame glacier wasting can be so severe that it results in decreased run-off. Glacier basins with a decreasing run-off trend have been observed in south-central British Columbia, at low elevations in the Swiss Alps and in the central Andes of Chile, which is probably a combined effect of reduced melt from seasonal snow cover as the snow line rises, and relevant glacier area losses. In contrast, significant run-off increases are reported in Alberta, north-western British Columbia and Yukon in Canada, in highly glacierized basins in the Swiss and Austrian Alps, the Tianshan Mountains and Tibet in central Asia and in the tropical Andes of Peru. The run-off increase within these basins is closely related to observed temperature rise, indicating that there is an unequivocal signal of enhanced glacier melting under the present warming trends. In future warming scenarios, glacier run-off should start to decrease even in high-altitude basins, affecting water availability.

Local Relevance: Glacierized river basins located in the southwest Yukon and northwest British Columbia show an increase in runoff which is attributed to glacier thinning as a result of climate warming. However, basins in south and central British Columbia and southwest Alberta show a decrease in runoff. According to the researchers, this runoff decrease is because the southern glaciers have passed the threshold at which increased runoff from glacier thinning no longer compensates for decreased runoff due to glacier area loss. The authors hypothesize decreased runoff in glacierized basins will become increasingly common as glaciers approach a point of significant area loss.

Keywords: *glaciers, hydrology, south Yukon, streamflow*

Available Online: Full Article

Citation: Casassa, G., López, P., Pouyaud, B., Escobar, F. 2009. "Detection of Changes in Glacial Run-off in Alpine Basins: Examples from North America, the Alps, central Asia and the Andes." *Hydrological Processes* 23(1): 31-41.

Glacier-Mediated Streamflow Teleconnections to the Arctic Oscillation

Research Location: *White, Big Creek, Kluane, Dezadeash, Alsek, M'Clintock, and Wheaton Rivers, Yukon; Wann River, British Columbia*
Publication Date: *2006*
Publication Type: *Journal Article*

Affiliation: *University of British Columbia; Aquatic Informatics Inc.*
Contact: *Sean Fleming, Environment Canada*

Abstract: We investigated the potential for glacier- and snowmelt-fed rivers to respond differently to the Arctic Oscillation (AO) by applying nonparametric statistical techniques to standardized and deseasonalized monthly hydrometric data from eight watersheds in southwest Yukon and northwest British Columbia, Canada. We first extracted regionally coherent glacial and nival hydroclimatic signals from the station data using empirical orthogonal function analysis. The annually averaged glacial and nival principal component time series were mutually uncorrelated, suggesting a decoupling of interannual streamflow variability between the two fluvial regimes. Moreover, glacial and nival rivers showed selective teleconnectivity to the AO; the annual glacial signal was significantly positively correlated to the AO index, whereas the nival signal was not. Composite analyses of annual hydrographs, performed using data from individual hydrometric stations, were consistent with the EOF-correlation results and provided details of related changes in hydrologic seasonality. In particular, positive-phase AO events are associated with positive glacial streamflow anomalies in late spring and early summer and an earlier freshet in nival rivers with little or no net change in annual flow. Parallel composite analyses of locally available homogeneous temperature and precipitation station data suggested that the hydrologic behaviour largely arises from the combination of AO-related late spring to early summer temperature anomalies and the presence or absence of a glacial reservoir potentially available for melting. Synoptic-scale correlation mapping of sea-level pressure fields reinforced these inferences. The results provide significant additional evidence that watershed glacierization can control the fundamental nature and patterns of regional-scale spatiotemporal water resource variability resulting from low-frequency climatic forcing.

Local Relevance: This study investigates the effects of the Arctic Oscillation (AO) on streamflow trends in both snowmelt- and glacier-fed rivers. In the southwest Yukon and northwest British Columbia, the positive phase of the AO correlates with above-average temperatures from late spring to early summer. Therefore, the positive phase of the AO is correlated with increased glacial melt and results in higher flows in glacier-fed rivers. Whereas the positive phase of the AO creates more water availability in glacier-fed rivers, the positive phase of the AO results in an earlier spring freshet in snowmelt-fed rivers but does not affect overall annual water availability.

Keywords: *Alsek River, Arctic Oscillation, Big Creek, Dezadeash River, glaciers, hydrology, Kluane River, M'Clintock River, south Yukon, streamflow, Wheaton River, White River*

Available Online: Full Article

Citation: Fleming, S.W., Moore, R.D., Clarke, G.K.C. 2006. "Glacier-Mediated Streamflow Teleconnections to the Arctic Oscillation." *International Journal of Climatology* 26: 619-636.

Comparative Analysis of Glacial and Nival Streamflow Regimes with Implications for Lotic Habitat Quantity and Fish Species Richness

Research Location: *southwest Canadian subarctic*
Publication Date: *2005*
Publication Type: *Journal Article*

Affiliation: *University of British Columbia*
Contact: *Sean Fleming, Environment Canada*

Abstract: Growing interest in the differential responses of glacial and nival rivers to climatic forcing, and in ecological distinctions between the two streamflow regimes, suggests the need for a better comparative understanding of how the annual hydrologic cycle differs with presence or absence of catchment glacial cover. In this study, timing and magnitude characteristics of the average annual hydrographs of five glacierized and four nival catchments in the southwestern Canadian subarctic are empirically identified and compared. Likely effects upon fish habitat are qualitatively assessed, and net fisheries potential is tentatively investigated using taxa richness data. The chief hydrological conclusions at $P<0.05$ using Kolmogorov-Smirnov and empirical function analyses are: (1) catchment glacial cover results in freshets that are longer, larger, and peak later than those experienced by the nival regime; (2) the winter baseflows of glacial rivers are also much higher on a unit-catchment-area basis; and (3) basin scale and degree of catchment glacial cover are of comparable importance in determining the magnitude of the annual hydrologic cycle. These differences arise from the greater availability, both in volume and over time, of meltwater in glacial catchments, which in part reflects the consistently negative alpine glacial mass balances observed both in the present study area and globally under historical climatic warming. Such regime distinctions result in increased spawning season and winter aquatic habitat availability, which may in turn offset negative habitat characteristics previously identified for glacial river ecosystems. While previous studies have suggested that glacial influences tend to decrease macroinvertebrate diversity and increase salmon populations, preliminary analysis of available fish species presence/absence data from the current study area tentatively appears to suggest similar or, perhaps, slightly higher fish taxa richness relative to nival streams; in all three cases, however, catchment lake cover may play a key hydroecological modifying role. The results strongly confirm and extend existing understanding of glacial–nival regime differences with respect to both streamflow and fisheries ecology, and raise new questions for future research.

Local Relevance: Glacier- and snowmelt-fed rivers were analysed with respect to timing and magnitude of streamflow patterns. Major conclusions include: glacier-fed rivers have spring freshets that last longer and are of greater magnitude (but occur later) than snowmelt-fed rivers, and; glacier-fed rivers have higher winter flows. The influence of hydrological conditions on fish abundance and fisheries potential are discussed—evidence suggests greater fish-species richness in glacier-fed waterways. This study enhances understanding of these river systems, and therefore allows for greater accuracy in making climate change predictions.

Keywords: *glaciers, hydrology, fish, salmon, south Yukon, streamflow*

Available Online: Abstract

Citation: Fleming, S.W. 2005. "Comparative Analysis of Glacial and Nival Streamflow Regimes with Implications for Lotic Habitat Quantity and Fish Species Richness." *River Research and Applications* 21(4): 363-379.

Glacial Control of Water Resource and Related Environmental Responses to Climatic Warming: Empirical Analysis Using Historical Streamflow Data from Northwestern Canada

Research Location: *White, Kluane, Takhini, M'Clintock, Alsek, Big Creek, Dezadeash, and Wheaton Rivers, Yukon; Wann River, British Columbia*
Publication Date: *2003*
Publication Type: *Journal Article*

Affiliation: *University of British Columbia*
Contact: *Sean Fleming, Environment Canada*

Abstract: We applied nonparametric statistical techniques to historical streamflow data from five glacierized and four nonglacierized watersheds in southwest Yukon and northwestern British Columbia, Canada, to determine whether rivers with and without catchment glacial cover respond in significantly different ways to a warming climate. The analysis was posed in terms of contrasts between the two groups with respect to long-term trends in annual time series of total river flow volume. We found that glacier-fed rivers grew larger and nival streams progressively smaller over the historical record under an observed regional warming trend. Although some of these trend effects are subtle, the overall result was statistically significant at restrictive confidence levels. Combined consideration of hydrological, meteorological and glaciological trends suggests that the streamflow consequences of increasing temperature exceed those from a concurrent rise in precipitation in the study area, causing increases in both glacial meltwater production and evapotranspiration; the former appears to have the dominant net hydrologic effect in glacierized catchments, and the latter in glacier-free watersheds. By empirically demonstrating that catchment glacial cover can result in opposite trends in total annual flow volume from river to river within an other hydroclimatologically uniform area, the analysis presents strong evidence that climate warming can materially affect downstream water resources specifically via glaciological pathways, and also implies that regional generalizations of interpreted or projected hydrologic trends may not be tenable in variably-glacierized regions.

Local Relevance: Over the time period investigated, regional temperatures, glacial melt, and precipitation increased. These trends were translated into increasing flow volumes in glacier-fed rivers and decreasing volumes in non-glacial rivers. Glacier-fed rivers experienced a streamflow increase because water added through glacial melt was greater than water removed via evapotranspiration. Rivers without glacial input experienced decreased streamflow because water removed via evapotranspiration was greater than water added through increased precipitation.

Keywords: *Alsek River, Big Creek, Dezadeash River, evapotranspiration, glaciers, hydrology, Kluane River, M'Clintock River, precipitation, south Yukon, streamflow, Takhini River, Wheaton River, White River*

Available Online: Full Article

Citation: Fleming, S.W., Clarke, G.K.C. 2003. "Glacial Control of Water Resource and Related Environmental Responses to Climatic Warming: Empirical Analysis Using Historical Streamflow Data from Northwestern Canada." *Canadian Water Resources Journal* 28(1): 69-86.

Yukon River Basin

Trends in Streamflow in the Yukon River Basin from 1944 to 2005 and the Influence of the Pacific Decadal Oscillation

Research Location: *Yukon River Basin*
Publication Date: *2010*
Publication Type: *Journal Article*
Affiliation: *U.S. Geological Survey*
Contact: *Timothy P. Brabets, U.S. Geological Survey*

Abstract: Streamflow characteristics in the Yukon River Basin of Alaska and Canada have changed from 1944 to2005, and some of the change can be attributed to the two most recent modes of the Pacific Decadal Oscillation (PDO). Seasonal, monthly, and annual stream discharge data from 21 stations in the Yukon River Basin were analyzed for trends over the entire period of record, generally spanning 4–6 decades, and examined for differences between the two most recent modes of the PDO: cold-PDO (1944–1975) and warm-PDO (1976–2005) subsets. Between 1944 and 2005, average winter and April flow increased at 15 sites. Observed winter flow increases during the cold-PDO phase were generally limited to sites in the Upper Yukon River Basin. Positive trends in winter flow during the warm-PDO phase broadened to include stations in the Middle and Lower Yukon River drainage basins. Increases in winter streamflow most likely result from groundwater input enhanced by permafrost thawing that promotes infiltration and deeper subsurface flow paths. Increased April flow may be attributed to a combination of greater baseflow (from groundwater increases), earlier spring snowmelt and runoff, and increased winter precipitation, depending on location. Calculated deviations from long-term mean monthly discharges indicate below-average flow in the winter months during the cold PDO and above-average flow in the winter months during the warm PDO. Although not as strong a signal, results also support the reverse response during the summer months: above-average flow during the cold PDO and below-average flow during the warm PDO. Changes in the summer flows are likely an indirect consequence of the PDO, resulting from earlier spring snowmelt runoff and also perhaps increased summer infiltration and storage in a deeper active layer.

Annual discharge has remained relatively unchanged in the Yukon River Basin, but a few glacier-fed rivers demonstrate positive trends, which can be attributed to enhanced glacier melting. A positive trend in annual flow during the warm PDO near the mouth of the Yukon River suggests that small increases in flow throughout the Yukon River Basin have resulted in an additive effect manifested in the downstream-most streamflow station.

Many of the identified changes in streamflow patterns in the Yukon River Basin show a correlation to the PDO regime shift. This work highlights the importance of considering proximate climate forcings as well as global climate change when assessing hydrologic changes in the Arctic.

Local Relevance: Streamflow data was collected from 21 stations in the Yukon River Basin (YRB) (9 in Alaska and 12 in Yukon). There has been a strong trend of increasing streamflow in the winter and early spring, somewhat balanced by a weaker trend of decreasing summer streamflow. Increases in average winter streamflow were observed throughout both the positive and negative Pacific Decadal Oscillation (PDO) phases, while individual areas experienced streamflow changes related to reversals of the PDO. For example, decreased streamflow in the northern Porcupine River may be the result of less precipitation caused by a PDO shift. This lends support to both global climate change and regional climate conditions as having an impact on streamflow in the YRB.

Keywords: *hydrology, Pacific Decadal Oscillation, Porcupine River, streamflow, Yukon River Basin*

Available Online: Full Article

Citation: Brabets, T.P., Walvoord, M.A. 2009. "Trends in Streamflow in the Yukon River Basin from 1944 to 2005 and the Influence of the Pacific Decadal Oscillation." *Journal of Hydrology* 371: 108-119.

Yukon River Streamflow Response to Seasonal Snow Cover Changes

Research Location: *Yukon River Basin*
Publication Date: *2009*
Publication Type: *Journal Article*

Affiliation: *University of Alaska Fairbanks*
Contact: *Daqing Yang, University of Alaska Fairbanks*

Abstract: We used remotely sensed weekly snow water equivalent (SWE) and snow cover extent (SCE) data to investigate streamflow response to seasonal snowcover change over the Yukon watershed. We quantified the seasonal cycles and variations of snowcover (both SWE and SCE) and river streamflow, and identified a clear correspondence of river discharge to seasonal snowcover change. We also examined and compared the weekly mean streamflow with the weekly basin SWE and SCE. The results revealed a strong relation between the streamflow and snowcover change during the spring melt season. This relationship provides a practical procedure of using remotely sensed snowcover information for snowmelt runoff estimation over the large northern watersheds. Analyses of extreme (high/low) streamflow cases (years) and basin snowcover conditions indicate an association of high (low) flood peak with high (low) maximum SWE. Comparative analyses of weekly basin SWE versus SCE, peak snowmelt floods, and climatic variables (temperature and winter precipitation) indicate consistency among basin SWE, SCE, and temperature, but there is some incompatibility between basin SWE and winter precipitation. The inconsistency suggests uncertainties in determination of basin winter snowfall amounts and limitations in applications of the SWE retrieval algorithm over large watersheds/regions with different physical characteristics. Overall, the results of this study demonstrate that the weekly SWE and SCE data/products derived from remote sensing technology are useful in understanding seasonal streamflow changes in the northern regions.

Local Relevance: This study used remote sensing of snow water equivalent and snow-cover extent in the Yukon River Basin to examine the relationship between streamflow and snow cover changes. A

greater amount of snow results in more runoff and vice versa. The amount of snow in the Basin is highest near the beginning of the year and decreases quickly in spring when the mean temperature hovers around freezing. This decrease in snow amount is significantly correlated with increased river flows. One uncertainty is that there is a lack of agreement between the remotely sensed snow amount and the total winter precipitation for a given year, which may be due to inaccurate precipitation records for the region.

Keywords: *hydrology, precipitation, streamflow, Yukon River Basin*

Available Online: Full Article

Citation: Yang, D., Zhao, Y., Armstrong, R., Robinson, D. 2009. "Yukon River Streamflow Response to Seasonal Snow Cover Changes." *Hydrological Processes* 23: 109-121.

Rainfall-Runoff Hydrograph Characteristics in a Discontinuous Permafrost Watershed and Their Relation to Ground Thaw

Research Location: *Granger Basin and Wolf Creek Basin, Yukon*
Publication Date: *2008*
Publication Type: *Conference Proceedings*

Affiliation: *Carleton University*
Contact: *Sean K. Carey, Carleton University*

Abstract: Rainfall-runoff hydrographs were analyzed for 49 rainstorms over 5 years in a 7.6 km^2 alpine discontinuous permafrost watershed to assess the effect of seasonal thawing on hydrograph parameters. Hydrographs were analyzed for 11 common characteristics including runoff ratio, initial abstraction, recession coefficient, and several parameters related to shape of the hydrograph. Runoff ratios varied between 0 and 0.33 (average 0.09) and declined throughout the summer, reflecting increased active layer storage. Hydrograph recessions were steeper immediately post-freshet and flattened as the summer progressed, as flow pathways descended into soils with lower transmissivities. There was no relation between antecedent wetness and timing response, indicating that saturated areas of the catchment exist near the stream throughout the season, facilitating rapid runoff. Results indicate that at this scale, permafrost and active layer depth exert a strong influence on the stormflow hydrograph.

Local Relevance: This study illustrates that headwater streamflow response characteristics throughout the summer season in the discontinuous permafrost zone portray changes in the underlying permafrost. For example, heavy rainfall in the late summer produces less runoff than it would in the earlier in the year because the ground has a greater water-storage capacity due to increased active layer thickness and ground dryness. Findings support the belief that runoff is controlled by the relationship between the position of the groundwater and frost tables.

Keywords: *Granger Basin, groundwater table, hydrology, permafrost, south Yukon, streamflow, Wolf Creek Basin*

Available Online: Full Article

Citation: Carey, S. K., DeBeer, C. M., 2008. Rainfall-Runoff Hydrograph Characteristics in a Discontinuous Permafrost Watershed and Their Relation to Ground Thaw. *In*: Ninth International Conference on Permafrost, Vol. 1, D.L. Kane and K.M. Hinkel (eds.), Fairbanks, Alaska, June 29-July 3, 2008, p. 233-238.

Hydrologic Effects of Climate Change in the Yukon River Basin

Research Location: *Yukon River Basin (at Pilot Station, Alaska)*
Publication Date: *2010*
Publication Type: *Journal Article*

Affiliation: *U.S. Geological Survey*
Contact: *Lauren E. Hay, U.S. Geological Survey*

Abstract: A monthly water balance (WB) model was developed for the Yukon River Basin (YRB). The WB model was calibrated using mean monthly values of precipitation and temperature derived from the Precipitation-elevation Regression on Independent Slopes Model (PRISM) data set and by comparing estimated mean monthly runoff with runoff measured at Pilot Station, Alaska. The calibration procedure used the Shuffled Complex Evolution global search. Potential hydrologic effects of climate change were assessed for the YRB by imposing changes in precipitation and temperature derived from selected Inter-governmental Panel for Climate Change (IPCC) climate simulations. Scenarios from five general circulation model (GCM) simulations were used to provide a range of potential changes. Results from the scenarios indicate an increase in annual runoff in the twenty-first century for the YRB with simulated increases in precipitation having the greatest effect on increases in runoff. Simulated increases in temperature were found to alter the timing of snow accumulation and melt.

Local Relevance: A climate model was used to predict the effects of increased temperature and precipitation on Yukon River Basin (YRB) runoff. Runoff is expected to increase throughout the 21st century, mostly as a result of increased precipitation. Increased winter precipitation will result in increased snowpack available for spring melt, and increased summer precipitation will add to river flows. The model predicts the majority of increased runoff to occur from May through July, as a result of an increase in the ratio of rain to snow as well as increased snowmelt. Increased temperature is expected to delay snow accumulation and promote earlier snowmelt, which will affect the timing of spring runoff.

Keywords: *hydrological modelling, hydrology, precipitation, Yukon River Basin*

Available Online: Full Article

Citation: Hay, L.E., McCabe, G.J. 2010. "Hydrologic Effects of Climate Change in the Yukon River Basin." *Climatic Change* 100: 509-523.

Impact of Doubled CO_2 on the Interaction between the Global and Regional Water Cycles in Four Study Regions

Research Location: *Yukon, Ob, St. Lawrence, and Colorado River Basins*
Publication Date: *2008*
Publication Type: *Journal Article*

Affiliation: *University of Alaska Fairbanks*
Contact: *Nicole Mölders, University of Alaska Fairbanks*

Abstract: Results from a suite of 30-year simulations (after spin-up) of the fully coupled Community Climate System Model version 2.0.1 are analyzed to examine the impact of doubling CO_2 on interactions between the global water cycle and the regional water cycles of four similar-size, but hydrologically and thermally different study regions (the Yukon, Ob, St Lawrence, and Colorado river basins and their adjacent land). A heuristic evaluation based on published climatological data shows that the model generally produces acceptable results for the control 1x CO_2 concentration, except for mountainous regions where it performs like other modern climate models. After doubling CO_2, the Northern Hemisphere receives significantly (95% confidence level) more moisture from the Southern Hemisphere during the boreal summer than under 1x CO_2 conditions, and the phase of the annual cycle of net moisture transport to areas north of 60°N shifts to a month later than in the reference simulation. Precipitation and evapotranspiration in the doubled CO_2 simulation increase for the Yukon, Ob, and St Lawrence, but decrease, on average, for the Colorado region compared to the reference simulation. For all regions, interaction between global and regional water cycles increases under doubled CO_2, because the amount of moisture entering and leaving the regions increases in the warmer climate. The degree of change in this interaction depends on region and season, and is related to slight shifts in the position/strength of semi-permanent highs and lows for the Yukon, Ob, and St Lawrence; in the Colorado region, higher temperatures associated with doubling CO_2 and the anticyclone located over the region increase the persistence of dry conditions.

Local Relevance: Compared to the control scenario (355 ppm CO_2), doubling CO_2 results in a temperature increase of 5°C in winter and 2°C in summer in the Yukon River Basin region. In the doubled CO_2 scenario, winter snowfall starts later, evapotranspiration increases, snowmelt occurs earlier, monthly precipitation increases for more than half the year, the spring runoff peak commences earlier and ends more quickly, and a greater proportion of total precipitation falls in the form of rain. The interaction between the Yukon River Basin and the global water cycle increases under the doubled CO_2 conditions, and the region has a decreased role in the regional water cycle due to an increase in precipitation that is greater than the increase in evapotranspiration.

Keywords: *air temperature, climate modelling, evapotranspiration, hydrological modelling, hydrology, precipitation, streamflow, Yukon River Basin*

Available Online: Full Article

Citation: Li, Z., Bhatt, U. S., Mölders, M. 2008. "Impact of Doubled CO_2 on the Interaction between the Global and Regional Water Cycles in Four Study Regions." *Climate Dynamics* 30: 255-275.

Canadian RCM Projected Climate-Change Signal and Its Sensitivity to Model Errors

Research Location: *Yukon, Mackenzie, Fraser, Nelson, Churchill, and Mississippi River Basins*
Publication Date: *2006*
Publication Type: *Journal Article*

Affiliations: *Université du Québec à Montréal; Ouranos Consortium*
Contact: *Laxmi Sushama, Université du Québec à Montréal*

Abstract: Climate change is commonly evaluated as the difference between simulated climates under future and current forcings, based on the assumption that systematic errors in the current-climate simulation do not affect the climate-change signal. In this paper, we investigate the Canadian Regional Climate Model (CRCM) projected climate changes in the climatological means and extremes of selected basin-scale surface fields and its sensitivity to model errors for Fraser, Mackenzie, Yukon, Nelson, Churchill and Mississippi basins, covering the major climate regions in North America, using current (1961–1990) and future climate simulations (2041–2070; A2 and IS92a scenarios) performed with two versions of CRCM.

Assessment of errors in both model versions suggests the presence of nonnegligible biases in the surface fields, due primarily to the internal dynamics and physics of the regional model and to the errors in the driving data at the boundaries. In general, results demonstrate that, in spite of the errors in the two model versions, the simulated climate-change signals associated with the long-term monthly climatology of various surface water balance components (such as precipitation, evaporation, snow water equivalent (SWE), runoff and soil moisture) are consistent in sign, but differ in magnitude. The same is found for projected changes to the low-flow characteristics (frequency, timing and return levels) studied here. High-flow characteristics, particularly the seasonal distribution and return levels, appear to be more sensitive to the model version.

CRCM climate-change projections indicate an increase in the average annual precipitation for all basins except Mississippi, while annual runoff increases in Fraser, Mackenzie and Yukon basins. A decrease in runoff is projected for Mississippi. A significant decrease in snow cover is projected for all basins, with maximum decrease in Fraser. Significant changes are also noted in the frequency, timing and return levels for low flows.

Local Relevance: Two versions of the Canadian Regional Climate Model (3.6 and 3.7) are used to evaluate the differences between each prediction of future climate. This study simulated annual precipitation increases for the Yukon River Basin (YRB); however, it should be noted that both models overestimate summer rain in the YRB. The YRB experiences reduced snow cover and delayed snow buildup resulting in higher fall/winter runoff and earlier and weaker spring runoff peaks. Fall, winter, and spring streamflows are expected to increase. The timing of low winter flows does not change but the magnitude increases. It is noted that both models make the same general projections; these projections just differ in magnitude.

Keywords: *hydrological modelling, hydrology, precipitation, streamflow, Yukon River Basin*

Available Online: Full Article

Citation: Sushama, L., Laprise, R., Caya, D., Frigon, A., Slivitzky, M. 2006. "Canadian RCM Projected Climate-Change Signal and Its Sensitivity to Model Errors." *International Journal of Climatology* (in press).

Impact of Climate Change on River Discharge Projected by Multimodel Ensemble

Research Location: *worldwide*
Publication Date: *2006*
Publication Type: *Journal Article*

Affiliations: *Meteorological Research Institute, Tsukuba; Japan Science and Technology Agency*
Contact: *Japan Meteorological Agency*

Abstract: This study investigates the projections of river discharge for 24 major rivers in the world during the twenty-first century simulated by 19 coupled atmosphere–ocean general circulation models based on the Special Report on Emissions Scenarios A1B scenario. To reduce model bias and uncertainty, a weighted ensemble mean (WEM) is used for multimodel projections. Although it is difficult to reproduce the present river discharge in any single model, the WEM results produce more accurate reproduction for most rivers, except those affected by anthropogenic water usage. At the end of the twenty-first century, the annual mean precipitation, evaporation, and runoff increase in high latitudes of the Northern Hemisphere, southern to eastern Asia, and central Africa. In contrast, they decrease in the Mediterranean region, southern Africa, southern North America, and Central America. Although the geographical distribution of the changes in precipitation and runoff tends to coincide with that in the river discharge, it should be emphasized that the change in runoff at the upstream region affects the river flow in the downstream region. In high-latitude rivers (Amur, Lena, MacKenzie, Ob, Yenisei, and Yukon), the discharge increases, and the peak timing shifts earlier because of an earlier snowmelt caused by global warming. Discharge tends to decrease for the rivers in Europe to the Mediterranean region (Danube, Euphrates, and Rhine), and southern United Sates (Rio Grande).

Local Relevance: Precipitation, evaporation, and river runoff are expected to increase for the Yukon River Basin. The model, which reproduces accurate discharge simulations for the Yukon River with the exception of peak discharge, predicts an increase in discharge with climate change. In addition, peak discharge is expected to occur earlier in the year as a result of earlier onset of snowmelt.

Keywords: *evaporation, hydrological modelling, hydrology, precipitation, Yukon River, Yukon River Basin*

Available Online: Full Article

Citation: Nohara, D., Kitoh, A., Hosaka, M., Oki, T. 2006. "Impact of Climate Change on River Discharge Projected by Multimodel Ensemble." *Journal of Hydrometeorology* 7: 1076-1089.

Mobilization Pathways of Organic Carbon from Permafrost to Arctic Rivers in a Changing Climate

Research Location: *Yukon, Mackenzie, and Sag River Basins*
Publication Date: *2007*
Publication Type: *Journal Article*

Affiliation: *University of Southern Mississippi*
Contact: *Laodong Guo, University of Southern Mississippi*

Abstract: Arctic warming may cause the release of vast amounts of soil organic carbon (SOC) from permafrost, which will manifest itself in the fluxes and composition of organic carbon in northern rivers and Arctic coastal regions. To elucidate the transport pathways of SOC, radiocarbon composition was measured for dissolved organic carbon (DOC), particulate organic carbon (POC), sediments and SOC from the Mackenzie, Sagavanirktok, and Yukon river basins, and soil leaching experiments were conducted. The radiocarbon ages of riverine suspended POC and sediments ranged from 4430 to ~7970 yr BP, while DOC was much younger (390–1440 yr BP) except samples from the Sag River. Soil leaching experiments released <1% of SOC as DOC. The decoupling in age and partitioning between POC and DOC indicates that POC in these rivers is dominated by old SOC derived from permafrost thawing and river-bank erosion in contrast to DOC, which is more readily influenced by modern terrestrial biomass, especially in large river basins which also drain subarctic regions. These observations imply that melting of permafrost will be manifest in the age and amounts of POC in arctic rivers whereas change in DOC will reflect altered plant ecology.

Local Relevance: This study investigates the radiocarbon signatures of dissolved organic carbon (DOC) and particulate organic carbon (POC) in order to better understand the relationship between climate warming and carbon dynamics of arctic rivers. For the Yukon River Basin, POC is mainly derived from soil organic carbon (SOC) in permafrost, while DOC is largely supplied by biomass productivity on land. Evidence suggests that there is limited release of DOC from permafrost into the river. It is hypothesized that warming will result in higher DOC levels in arctic rivers mainly due to increased primary production and POC release from permafrost.

Keywords: *carbon, hydrology, permafrost, primary production, Yukon River Basin*

Available Online: Full Article

Citation: Guo, L., Ping, C.-L., Macdonald, R.W. 2007. "Mobilization Pathways of Organic Carbon from Permafrost to Arctic Rivers in a Changing Climate." *Geophysical Research Letters* 34(13): 1-5.

Increased Groundwater to Stream Discharge from Permafrost Thawing in the Yukon River Basin: Potential Impacts on Lateral Export of Carbon and Nitrogen

Research Location: *Yukon River Basin*
Publication Date: *2007*
Publication Type: *Journal Article*

Affiliation: *U.S. Geological Survey*
Contact: *Michelle A. Walvoord, U.S. Geological Survey*

Abstract: Arctic and subarctic watersheds are undergoing climate warming, permafrost thawing, and thermokarst formation resulting in quantitative shifts in surface water–groundwater interaction at the basin scale. Groundwater currently comprises almost one fourth of Yukon River water discharged to the Bering Sea and contributes 5–10% of the dissolved organic carbon (DOC) and nitrogen (DON) and 35–45% of the dissolved inorganic carbon (DIC) and nitrogen (DIN) loads. Long-term streamflow records (>30 yrs) of the Yukon River basin indicate a general upward trend in groundwater contribution to streamflow of 0.7–0.9%/yr and no pervasive change in annual flow. We propose that the increases in groundwater contributions were caused predominately by climate warming and permafrost thawing that enhances infiltration and supports deeper flowpaths. The increased groundwater fraction may result in decreased DOC and DON and increased DIC and DIN export when annual flow remains unchanged.

Local Relevance: It was determined that winter flows in the Yukon River Basin have been increasing without a corresponding increase in annual flows. Only two rivers, Kluane and Atlin, have showed an increase in annual flows, likely because they are glacier-fed. The researchers attribute the trend of increasing winter flows to melting permafrost that results in increased groundwater contribution to winter flows. Groundwater has higher concentrations of dissolved inorganic carbon and nitrogen and lower concentrations of dissolved organic carbon and nitrogen; therefore, this trend is expected to decrease the export of organic molecules while increasing the export of inorganic molecules.

Keywords: *Atlin River, carbon, hydrology, Kluane River, nitrogen, permafrost, Yukon River Basin*

Available Online: Full Article

Citation: Walvoord, M.A., Striegl, R.G. 2007. "Increased Groundwater to Stream Discharge from Permafrost Thawing in the Yukon River Basin: Potential Impacts on Lateral Export of Carbon and Nitrogen." *Geophysical Research Letters* 34: L12402, doi:10.1029/2007GL030216.

A Decrease in Discharge-Normalized DOC Export by the Yukon River during Summer through Autumn

Research Location: *Yukon River Basin*
Publication Date: *2005*
Publication Type: *Journal Article*

Affiliation: *U.S. Geological Survey*
Contact: *Robert G. Striegl, U.S. Geological Survey*

Abstract: Climate warming is having a dramatic effect on the vegetation distribution and carbon cycling of terrestrial subarctic and arctic ecosystems. Here, we present hydrologic evidence that warming is also affecting the export of dissolved organic carbon and bicarbonate (DOC and HCO_3^-) at the large basin scale. In the 831,400 km^2 Yukon River basin, water discharge (Q) corrected DOC export significantly decreased during the growing season from 1978 - 80 to 2001 - 03, indicating a major shift in terrestrial to aquatic C transfer. We conclude that decreased DOC export, relative to total summer through autumn Q, results from increased flow path, residence time, and microbial mineralization of DOC in the soil active layer and groundwater. Counter to current predictions, we

argue that continued warming could result in decreased DOC export to the Bering Sea and Arctic Ocean by major subarctic and arctic rivers, due to increased respiration of organic C on land.

Local Relevance: Using the Yukon River Basin as a case study, the researchers state that when large amounts of dissolved organic carbon (DOC) are released from thawing permafrost, this DOC is no longer carried away by river and streams but instead infiltrates the active layer of permafrost or the groundwater table. This reduces DOC export by rivers and streams—most noticeably during the spring and summer months when the depth of the active layer is greatest. Supporting this statement, summer DOC export in the Yukon River Basin decreased from 1978-1980 to 2001-2003. Reduced DOC export is not observed during spring runoff because the active layer is still frozen. It is expected that the ratio of bicarbonate to DOC will increase and that DOC export to the Arctic Ocean and Bering Sea will decrease with continued warming.

Keywords: *bicarbonate, carbon, hydrology, permafrost, Yukon River Basin*

Available Online: Full Article

Citation: Striegl, R.G., Aiken, G.R., Dornblaser, M.M., Raymond, P.A., Wickland, K.P. 2005. "A Decrease in Discharge-Normalized DOC Export by the Yukon River during Summer through Autumn." *Geophysical Research Letters* 32: LXXXXX, doi:10.1029/2005GL024413.

Old Crow Flats

Environmental Change and Traditional Use of the Old Crow Flats in Northern Canada: An IPY Opportunity to Meet the Challenges of the New Northern Research Paradigm

Research Location: *Old Crow, Yukon*
Publication Date: *2011*
Publication Type: *Journal Article*

Affiliation: *Wilfrid Laurier University*
Contact: *Brent B. Wolfe, Wilfrid Laurier University*

Excerpt: The Old Crow Flats (OCF), northern Yukon Territory, is homeland to the Vuntut Gwitchin First Nation (VGFN) and is a Ramsar Wetland of International Importance. This vast northern area encompasses 5600 km^2 and approximately 2700 shallow thermokarst lakes, creating a freshwater landscape that has long been an important refuge for Arctic wildlife, while also supporting the traditional lifestyle of the VGFN. Observations and traditional knowledge of the VGFN indicate that the OCF is undergoing pronounced changes in temperature, precipitation, vegetation cover, lake and river water levels, and ice integrity, along with changes in diversity and distribution of wildlife. Of even greater concern to the VGFN is the apparent rate at which these changes are occurring. Placing these changes within the context of recent environmental change (decades to centuries) and within the perspective of previous change under conditions similar to those projected for the future is necessary to formulate an effective strategy of stewardship for the OCF, and to ensure future food security for the residents of Old Crow…

Local Relevance: Community members have noticed thawing permafrost, changes in wildlife abundance and vegetation, and shallower water levels in lakes and rivers. According to Old Crow's1930-2000 temperature records, all seasons, with the exception of fall, experienced a mean temperature increase. A tree-ring width chronology resulting from this IPY project illustrates that temperature increases during the last two to three decades were much more rapid than at any other time during the previous 300 years. This project provided community members with an opportunity to share their knowledge as well as to learn from skilled researchers. Locals were hired as field research assistants, one researcher engaged local youth in a Science Camp, and the research team regularly shared their findings and progress with the community.

Keywords: *air temperature, impacts, north Yukon, Old Crow, Old Crow Flats, traditional knowledge, tree ring, Vuntut Gwitchin First Nation, Yukon First Nations*

Available Online: Full Article

Citation: Wolfe, B.B., Humphries, M.M., Pisaric, M.F.J., Balasubramaniam, A.M., Burn, C.R., Chan, L., Cooley, D., Froese, D.G., Graupe, S., Hall, R.I., Lantz, T., Porter, T.J., Roy-Leveillee, P., Turner, K.W., Wesche, S.D., William, M. 2011. "Environmental Change and Traditional Use of the Old Crow Flats in Northern Canada: An IPY Opportunity to Meet the Challenges of the New Northern Research Paradigm." *Arctic* 64(1): 127-135.

Characterizing the Role of Hydrological Processes on Lake Water Balances in the Old Crow Flats, Yukon Territory, Canada, Using Water Isotope Tracers

Research Location: *Old Crow Flats, Yukon*
Publication Date: *2010*
Publication Type: *Journal Article*

Affiliation: *Wilfrid Laurier University*
Contact: *Kevin W. Turner, Wilfrid Laurier University*

Abstract: We employ water isotope tracers to assess hydrological processes controlling lake water balances in the Old Crow Flats (OCF) landscape, northern Yukon Territory, Canada. Fifty-six lakes were sampled in June and July 2007 and 26 of these were re-sampled in September 2007. Based on patterns of isotopic evolution in $\delta^{18}O$–$\delta^{2}H$ space, calculations of input water compositions (δ_I) and evaporation-to-inflow (E/I) ratios, and field observations we identify *snowmelt-dominated*, *rainfall-dominated*, *groundwater-influenced*, *evaporation-dominated* and *drained* lake types, which represent the dominant hydrological process influencing the lake water balance. These results highlight the diversity in lake water balance conditions in the OCF, which are strongly associated with landscape characteristics. *Snowmelt-dominated* lakes are located where more dense vegetation cover entraps snow transported by prevailing northeasterly winds. *Rainfall-dominated* lakes occupy areas of sparse tundra vegetation cover where less snow accumulates. *Groundwater-influenced* oxbow lakes are located along the floodplain of higher-order river and creek channels and receive input throughout the ice-free season from snowmelt-recharged channel fens and sub-surface flow. Only one basin became evaporation-dominated during the 2007 open-water season probably because extremely high precipitation during the preceding late summer, late winter and early spring offset vapour loss. However, *rainfall-dominated* lakes appear to be more susceptible to evaporative drawdown

than *snowmelt-dominated* and *groundwater-influenced* lakes, and many would likely evolve to *evaporation-dominated* during drier summers. *Drained* lakes are commonly observed throughout the landscape and in most cases likely result from elevated water levels and channel erosion between water-bodies. Unusually high amounts of snowmelt and/or rainfall triggered the drainage of two lakes in early June 2007 in which overflow led to rapid erosion of outlet channels. Our classification of lake types and corresponding isotopic evolution patterns are likely typical of other thermokarst landscapes and their identification could be used to better predict hydrological responses to ongoing climate change.

Local Relevance: Lakes in the Old Crow Flats were classified based on the primary process that controls each lake's water balance. The lakes are classified as snowmelt-*dominated*, *rainfall-dominated*, *groundwater-influenced*, *evaporation-dominated*, or *drained*. The researchers state that *drained* lakes are usually caused by erosion of the land separating one water body from another. This research could be used to identify possible responses of these lakes and other thermokarst lakes to future climatic change.

Keywords: *hydrology, north Yukon, Old Crow, Old Crow Flats, Vuntut Gwitchin First Nation*

Available Online: Abstract

Citation: Turner, K.W., Wolfe, B.B., Edwards, T.W.D. 2010. "Characterizing the Role of Hydrological Processes on Lake Water Balances in the Old Crow Flats, Yukon Territory, Canada, Using Water Isotope Tracers." *Journal of Hydrology* 386(1-4): 103-117.

Contemporary (1951–2001) Evolution of Lakes in the Old Crow Basin, Northern Yukon, Canada: Remote Sensing, Numerical Modeling, and Stable Isotope Analysis

Research Location: *Old Crow Flats, Yukon*
Publication Date: *2009*
Publication Type: *Journal Article*

Affiliation: *Meteorological Service of Canada*
Contact: *Sylvain Labrecque, Environment Canada*

Abstract: This study reports on changes in the distribution, surface area, and modern water balance of lakes and ponds located in the Old Crow Basin, northern Yukon, over a 50-year period (1951–2001), using aerial photographs, satellite imagery, a numerical lake model, and stable O-H isotope analysis. Results from the analysis of historical air photos (1951 and 1972) and a Landsat-7 Enhanced Thematic Mapper (ETM+) image (2001) show an overall decrease (-3.5%) in lake surface area between 1951 and 2001. Large lakes typically decreased in extent over the study period, whereas ponds generally increased. Between 1951 and 1972, approximately 70% of the lakes increased in extent; however, between 1972 and 2001, 45% decreased in extent. These figures are corroborated by a numerical lake water balance simulation (P-E index) and stable O-H isotope analysis indicating that most lakes experienced a water deficit over the period 1988–2001. These observed trends towards a

reduction in lake surface area are mainly attributable to a warmer and drier climate. The modern decrease in lake levels corresponds well to changes in regional atmospheric teleconnection patterns (Arctic and Pacific Decadal oscillations). In 1977, the climate in the region switched from a predominantly cool and moist regime, associated with the increase in lake surface area, to a hot and dry one, thus resulting in the observed decrease in lake surface area. Although some lakes may have drained catastrophically by stream erosion or bank overflow, it is not possible to determine with certainty which lakes experienced such catastrophic drainage, since an interval of two decades separates the two air photo mosaics, and the satellite image was obtained almost 30 years after the second mosaic of air photos.

Local Relevance: It was determined that the changing water balance of lakes and ponds in the Old Crow Basin could be best explained by the Pacific Decadal and Arctic Oscillations. In 1977, the regional climate switched from a cool, moist regime to a hot, dry regime, which correlates with a switch from increasing lake surface area to decreasing surface area. As far as climate change effects, permafrost thaw causes ground subsidence that can increase or decrease lake areal extent depending on whether new drainage paths are formed. Greater precipitation may facilitate the formation of new drainage paths and higher temperatures increase evaporation from the basin.

Keywords: *Arctic Oscillation, hydrology, north Yukon, Old Crow, Old Crow Flats, Pacific Decadal Oscillation, Vuntut Gwitchin First Nation*

Available Online: Full Article

Citation: Labrecque, S., Lacelle, D., Duguay, C.R., Lauriol, B., Hawkings, J. 2009. "Contemporary (1951–2001) Evolution of Lakes in the Old Crow Basin, Northern Yukon, Canada: Remote Sensing, Numerical Modeling, and Stable Isotope Analysis." *Arctic* 62(2): 225-238.

Near-Record Precipitation Causes Rapid Drainage of Zelma Lake, Old Crow Flats, Northern Yukon Territory

Research Location: *Old Crow Flats, Yukon*
Publication Date: *2008*
Publication Type: *Journal Article*

Affiliation: *Wilfrid Laurier University*
Contact: *Brent B. Wolfe, Wilfred Laurier University*

Abstract: While conducting the first phase of hydrological fieldwork in June 2007 for the Government of Canada International Polar Year project, Environmental change and traditional use of the Old Crow Flats in northern Canada, we observed the rapid overland drainage of Zelma Lake. The Old Crow Flats (OCF), a 5300 km^2 freshwater ecosystem in the northern Yukon, is internationally recognized for its ecological significance and is closely linked to the cultural identity of the Vuntut Gwitchin community of Old Crow. Zelma Lake stands out among the more than 2000 lakes in the OCF because of its large size, its accessibility by boat, and because local residents have long used it for hunting, trapping and fishing. We used aerial photographs from a later survey in July 2007 as well as water depth measurements to estimate that water loss of approximately 5.8 million cubic metres

(the equivalent of about 2300 Olympic-size swimming pools) exposed about 5.2 square kilometres of lake bed, corresponding to 43% reduction in lake area and over 80% reduction in lake volume. Precipitation in the month of May prior to our fieldwork totalled 44.4 mm, the highest recorded since measurements began in 1951; this followed above-average cumulative precipitation during the previous two months. Analysis of lake water isotope composition from Zelma Lake indicates that substantial rainfall likely increased lake levels and ultimately triggered rapid erosion of an outlet leading to the channel network that exports water from the Flats.

Local Relevance: It was determined from analyzing water isotope composition that the drainage of Zelma Lake, Old Crow Flats was likely the result of a period of record rainfall which caused rapid erosion of a land barrier separating the lake from the water network that removes water from the Flats. Zelma Lake drained in June 2007, after the largest May precipitation recorded since 1951 and above-average total precipitation from the previous two months. The lake experienced a volume loss of 80% and an area reduction of 43%.

Keywords: *hydrology, north Yukon, Old Crow, Old Crow Flats, Vuntut Gwitchin First Nation*

Available Online: Abstract

Citation: Wolfe, B. B., Turner, K. W. 2008. "Near-Record Precipitation Causes Rapid Drainage of Zelma Lake, Old Crow Flats, Northern Yukon Territory." *Meridian*: 7-12.

3. Permafrost

Historic, Recent & Projected Change

Permafrost Response to Last Interglacial Warming: Field Evidence from Non-Glaciated Yukon and Alaska

Research Location: *Ch'ijee's Bluff and Thistle Creek, Yukon; Palisades, Alaska*
Publication Date: *2010*
Publication Type: *Journal Article*

Affiliation: *University of Alberta*
Contact: *Alberto V. Reyes, University of Wisconsin-Madison*

Abstract: We present stratigraphic observations from three sites in eastern Beringia—Ch'ijee's Bluff in northern Yukon and nearby exposures on the Old Crow River, the Palisades on the Yukon River in Alaska, and placer mining exposures at Thistle Creek in west-central Yukon—which provide insight into the response of permafrost to regional warming during the last interglaciation. Chronology is based on the presence of Old Crow tephra, an important regional stratigraphic marker that dates to late Marine Isotope Stage 6, supplemented by paleoecology and non-finite ^{14}C ages on wood-rich organic silts. Old Crow tephra overlies several relict ice wedges at the Palisades and Thistle Creek, indicating that permafrost at these sites did not thaw completely during the last interglaciation. Prominent deposits of last interglacial wood-rich organic silt are present at multiple sites in eastern

Beringia, and probably represent accumulations of reworked forest vegetation due to thaw slumping or deposition into thermokarst ponds or depressions. Consistent stratigraphic relations between these deposits, Old Crow tephra, and ice wedge pseudomorphs at our three study sites, and at least six other sites in eastern Beringia, suggest that thaw of shallow permafrost was widespread during the last interglaciation. Limited stratigraphic evidence suggests that thaw was probably on the order of meters, rather than 10s of meters. The ubiquity of shallow permafrost degradation during the last interglaciation suggests that current ground warming may foreshadow widespread near-surface thaw under even modest future warming scenarios. However, the persistence of relict pre-last interglacial ice wedges highlights the potential for the regional antiquity of discontinuous permafrost, and provides compelling field evidence for the long-term resilience of deep permafrost during sustained periods of warmer-than-present climate.

Local Relevance: It was determined that there was widespread thaw of shallow permafrost during the last interglacial period (likely less than tens of metres) with deeper permafrost persisting. Since the last interglacial was a period of warmer-than-current temperatures that lasted for multiple centuries, the researchers hypothesize that deep permafrost will be resilient to future climate warming, at least for the next couple of centuries. It should be noted that the previous interglacial period is not a perfect analog for the current Holocene period, and that the permafrost sites studied contained ice-rich permafrost which is more resistant to thaw.

Keywords: *central Yukon, Ch'ijee's Bluff, north Yukon, permafrost, Thistle Creek*

Available Online: Full Article

Citation: Reyes, A.V., Froese, D.G., Jensen, B.J.L. 2010. "Permafrost Response to Last Interglacial Warming: Field Evidence from Non-Glaciated Yukon and Alaska." *Quaternary Science Reviews* (in press).

Historic Change in Permafrost Distribution in Northern British Columbia and Southern Yukon

Research Location: *Alaska Highway corridor, from Whitehorse, Yukon to Fort St. John, British Columbia*
Publication Date: *2008*
Publication Type: *Conference Proceedings*

Affiliation: *University of Ottawa*
Contact: *Antoni G. Lewkowicz, University of Ottawa*

Abstract: As a largely climatically-controlled phenomenon, permafrost conditions are impacted by air temperature and precipitation, as well as other local surface and subsurface factors (Smith & Riseborough 1996, 2002). Numerous studies have shown that permafrost should diminish in extent with rising air and ground temperatures (ACIA 2004). However, most of these predictions are based on modeling, and there are very few field-based studies of long-term permafrost change in Canada. The objective of this study is to directly evaluate the impact of recent climate change on permafrost distribution. We were able to conduct it due to the availability of early baseline permafrost data,

which are rare in Canada. In August 2007, we repeated a 1964 permafrost survey undertaken by the late Roger Brown along the Alaska Highway from Whitehorse, YT, to Fort St. John, BC (Brown 1967).

Local Relevance: In 2007, the researchers investigated permafrost extent and distribution at sites along the Alaska Highway from Whitehorse to Fort St. John that had previously been studied in 1964. Of the original sites located, over half of the places where permafrost was present in 1964 no longer contained permafrost. In areas where permafrost was still intact, the active layer had deepened. It is suggested that this permafrost thaw is related to the 1.5-2.0°C rise in air temperature since the previous study as well as changes in precipitation. Preliminary results also suggest that permafrost boundaries may have moved northward.

Keywords: *air temperature, Alaska Highway, permafrost, south Yukon*

Available Online: Full Article

Citation: Bryan, R., Hinzman, L.D., Busey, R.C., 2008 Historic Change in Permafrost Distribution in Northern British Columbia and Southern Yukon. *In*: Ninth International Conference on Permafrost, Extended Abstracts, D.L. Kane and K.M. Hinkel (eds.), Fairbanks, Alaska, June 29-July 3, 2008, p. 115-116.

Cryostratigraphic Record of Permafrost Degradation and Recovery following Historic Surface Disturbances, Klondike Area, Yukon

Research Location: *Dominion Creek area, Klondike Goldfields, Yukon*
Publication Date: *2009*
Publication Type: *Journal Article*
Affiliation: *University of Alberta*
Contact: *Fabrice Calmels, University of Alberta*

Abstract: Cryostratigraphic investigation of near-surface permafrost at a site in the southern Klondike goldfields has revealed three ages of permafrost disturbance and recovery which potentially span the last century. In an undisturbed forest, the base of the modern active layer is stable with a suspended ice/sediment cryofacies at the contact. A recently burned site (2004) shows that the degrading contact has not yet stabilized. An earlier disturbance from the 1970s shows evidence of aggradation (upward shift) of the permafrost table following limited vegetation succession. Underlying all three sites is an older disturbance corresponding to a thaw depth of ~2 m, predating the 1970s disturbance; it is likely that this represents an early 20th century disturbance associated with the deforestation of the valley during the gold rush era. Permafrost has recovered significantly since that time as the boreal forest and understory vegetation was re-established, underscoring the role of vegetation cover in permafrost disturbance and recovery.

Local Relevance: Permafrost condition was identified at sites with various disturbance histories, including forest fire, deforestation, and land clearing. The disturbance areas all show a characteristic pattern: initially, the active layer increases over a couple of decades, the height of the permafrost table stabilizes and then slowly rises as the overlying vegetation recovers. Based on the history of

these various sites, the researchers hypothesize that changes in vegetation cover will have a more profound impact on permafrost than future changes in temperature. The effects of temperature on permafrost decay will be moderated by the type of vegetation cover that is present.

Keywords: *central Yukon, Dominion Creek, permafrost, vegetation*

Available Online: Full Article

Citation: Calmels, F. and Froese, D.G., 2009. Cryostratigraphic Record of Permafrost Degradation and Recovery following Historic Surface Disturbances, Klondike area, Yukon. *In*: Yukon Exploration and Geology 2008, L.H. Weston, L.R. Blackburn and L.L. Lewis (eds.), Yukon Geological Survey, p. 85-97.

Simulating the Effects of Wildfire on Permafrost and Soil Carbon Dynamics of Black Spruce over the Yukon River Basin Using a Terrestrial Ecosystem Model

Research Location: *Yukon River Basin*
Publication Date: *2008*
Publication Type: *Conference Proceedings*

Affiliation: *University of Alaska Fairbanks*
Contact: *David McGuire, U.S. Geological Survey*

Excerpt: Wildfire is considered an important disturbance agent in boreal forest ecosystems (Kasischke et al. 2006). It can affect high latitude carbon dynamics directly through combustion emissions, and indirectly through vegetation succession and removal of the surface organic layer, which might accelerate the degradation of permafrost and, hence, the release of soil carbon. At the regional scale, the direct effects of fire have received a lot of attention, but the evaluation of the indirect effects has been more limited because the appropriate tools have not yet been developed for application at the regional scale.

In this study, we implemented a dynamic soil layer module in the Terrestrial Ecosystem Model (hereafter DSL-TEM) to answer the following questions: (1) What is the change of permafrost over the Yukon River Basin for periods before and after year 1976, when there was a shift in the Pacific Decadal Oscillation? (2) What is the effect of fire on permafrost? and (3) What is the effect of fire on carbon fluxes between the land surface and the atmosphere? …

Local Relevance: According to the climate model implemented, Yukon River Basin temperatures increased consistently over the period 1950-2000, accompanied by increased precipitation at the eastern and western ends of the basin and decreased precipitation in the centre. The depth of unfrozen ground decreased in the central basin and increased at both the eastern and western ends, illustrating that the amount of snowfall played a greater role in determine ground temperature characteristics than temperature. Forest fire had little effect on the ground temperature, partially due to a small burn area and to decreased snow cover in areas with high fire activity. Fire was important in determining the net transfer of carbon between the surface and the atmosphere; however, the indirect effect of fire on carbon transfer via stimulating soil decomposition was small.

Keywords: *air temperature, carbon, climate modelling, forest fire, ground temperature, Pacific Decadal Oscillation, permafrost, precipitation, Yukon River Basin*

Available Online: Full Article

Citation: Yi, S., McGuire, A.D., Harden, J., 2008. Simulating the Effects of Wildfire on Permafrost and Soil Carbon Dynamics of Black Spruce over the Yukon River Basin Using a Terrestrial Ecosystem Model. *In*: Ninth International Conference on Permafrost, Extended Abstracts, D.L. Kane and K.M. Hinkel (eds.), Fairbanks, Alaska, June 29-July 3, 2008, p.357-358.

Permafrost and Climate Change at Herschel Island (Qikiqtaruq), Yukon Territory, Canada

Research Location: *Herschel Island, Yukon*
Publication Date: *2009*
Publication Type: *Journal Article*
Affiliation: *Carleton University*
Contact: *Chris R. Burn, Carleton University*

Abstract: Herschel Island, in the southern Beaufort Sea, is dominantly a glacier ice thrust feature composed of ice-rich, perennially frozen sediments. Climate data are available for Herschel Island from 1899 to 1905 and 1995–2006. Air temperatures at Herschel Island are similar to sites on the adjacent mainland. Late winter snow depth is only about 20 cm, or half the depth on the mainland, and local topography defines the sites of annually recurring snowdrifts. Near-surface ground temperatures, thaw depths, and ground ice contents have been investigated over a 750-m transect leading up Collinson Head, the easternmost part of the island. The ground temperature profile to 42-m depth indicates recent warming of permafrost because the temperature decreases with depth. The temperature at 15-m depth is –8.0°C, the same as the annual mean temperature at 1-m depth at windswept sites along the transect. A simulation of the ground thermal regime, calibrated with local ground properties, equilibrated with the climate of 1899–1905, and driven by the climate of the region during the 20th century reproduces the present ground temperature profile and the annual temperature cycle for 1-m depth at windswept sites. The model indicates that the mean annual temperatures at the top of permafrost and at 20-m depth have increased by 2.6 and 1.9°C, respectively, since 1899–1905, and the perturbation in ground temperature has reached about 120-m depth. Active layer thickness measured in the terrain types studied on Herschel Island is about 55 cm, 15 to 25 cm greater than field data from these units collected in 1985.

Local Relevance: The ground temperature profile measured on Herschel Island shows recent permafrost warming. A model of the ground temperature regime illustrates that the temperature at the top of the permafrost and at a depth of 20 m has increased since the earliest period of measurement (1899-1905). This model also indicates that the depth of the active layer has increased since 1985.

Keywords: *Beaufort Sea, ground temperature, Herschel Island, north Yukon, permafrost, permafrost modelling*

Available Online: Abstract

Citation: Burn, C.R., Zhang, Y. 2009. "Permafrost and Climate Change at Herschel Island (Qikiqtaruq), Yukon Territory, Canada." *Journal of Geophysical Research* 114: F02001, doi:10.1029/2008JF001087.

Evaluating the Major Controls on Permafrost Distribution in Ivvavik National Park based on Process-Based Modelling

Research Location: *Ivvavik National Park, Yukon*
Publication Date: *2010*
Publication Type: *Conference Proceedings*

Affiliation: *Centre for Remote Sensing, Natural Resources Canada*
Contact: *Yu Zhang, Natural Resources Canada*

Abstract: The permafrost status at some representative sites in three typical land types (as mountain tops, coastal plains, and river valleys) in Ivvavik National Park was evaluated using a process-based model. The results showed that ground conditions were the most important factor controlling the Active Layer Thickness (ALT). ALT in rocky or gravel ground was deeper (80 - 220 cm), whereas peaty or clay soil made ALT shallower (25 - 50 cm deep) in the park. Active-layer is usually deeper in mountain sites due to the rocky ground conditions. Air temperature is another significant factor affecting both ALT and permafrost thickness. ALT has become significantly deeper since the mid 1980s corresponding to the climate warming.

Local Relevance: Permafrost active layer thickness in Ivvavik National Park significantly increased from the 1980s onward in relation to increasing air temperatures. The model illustrates that air temperature, solar radiation, and peat layer all affect the thickness of the active layer. Conversely, modeled precipitation and wind speed had limited effect on the base height of the active layer. Model outputs indicate that active layer thickness is primarily controlled by the ground conditions at any particular site.

Keywords: *air temperature, Ivvavik National Park, north Yukon, permafrost, permafrost modelling*

Available Online: Full Article

Citation: Wang, X., Zhang, Y., Fraser, R., Chen, W. 2010. "Evaluating the Major Controls on Permafrost Distribution in Ivvavik National Park based on Process-Based Modelling." *In:* 63rd Canadian Geotechnical Conference & 6th Canadian Permafrost Conference, September 12-16, 2010, Calgary, Alberta, p. 1235-1241.

Initial Results from the First Year of the Permafrost Outreach Program, Yukon, Canada

Research Location: *Beaver Creek, Whitehorse, Ross River, Faro, Dawson, and Old Crow, Yukon*
Publication Date: *2009*
Publication Type: *Journal Article*

Affiliation: *Yukon Geological Survey*
Contact: *Panya S. Lipovsky, Yukon Geological Survey*

Abstract: In 2007, a permafrost outreach program was initiated in Yukon, Canada by installing long-term permafrost monitoring stations near public schools in Whitehorse, Faro, Ross River, Dawson, Old Crow and Beaver Creek. Shallow boreholes were drilled near participating schools, and data loggers were installed to measure hourly air and ground temperatures at a variety of depths. Frost tubes were also installed in fall 2008 to start monitoring seasonal freezing and thawing trends in the active layer. School students are actively engaged with field data collection and interpretation of results posted on a central website. The program also provides baseline data that can be used to characterize local permafrost conditions and detect long-term changes. A snapshot of current permafrost conditions is provided for each monitoring station, based on the first year of data collection.

Local Relevance: Boreholes were drilled in six Yukon communities to investigate the state of permafrost across the territory and to engage students. Mean annual ground temperature is warmer than -1°C at all of the sites except for Old Crow and Beaver Creek. Again with the exception of Old Crow, maximum annual permafrost temperatures at the study sites were very close to 0°C, which is characteristic of melting ice-rich permafrost. The thickness of the active layer was greatest in Ross River where there was no natural organic ground cover. Permafrost degradation as a result of surface disturbance was observed at Beaver Creek, Faro, and Ross River, where ground subsidence is evident.

Keywords: *Beaver Creek, Dawson, Faro, ground temperature, Kwanlin Dün First Nation, Old Crow, permafrost, Ross River, Ross River Dena Council, Ta'an Kwäch'än Council, Tr'ondëk Hwëch'in First Nation, Vuntut Gwitchin First Nation, Whitehorse, White River First Nation, Yukon-wide*

Available Online: Full Article

Citation: Lipovsky, P.S. and Yoshikawa, K., 2009. Initial Results from the First Year of the Permafrost Outreach Program, Yukon, Canada. *In*: Yukon Exploration and Geology 2008, L.H. Weston, L.R. Blackburn and L.L. Lewis (eds.), Yukon Geological Survey, p. 161-172.

Modelling Climate Change Effects on the Spatial Distribution of Mountain Permafrost at Three Sites in Northwest Canada

Research Location: *Wolf Creek and Ruby Range, Yukon; Haines Summit, British Columbia*
Publication Date: *2011*
Publication Type: *Journal Article*

Affiliation: *University of Ottawa*
Contact: *Philip P. Bonnaventure, University of Ottawa*

Abstract: Spatial models of present-day mountain permafrost probability were perturbed to examine potential climate change impacts. Mean annual air temperature (MAAT) changes were simulated by adjusting elevation in the models, and cloud cover changes were examined by altering the partitioning of direct beam and diffuse radiation within the calculation for potential incoming solar radiation (PISR). The effects of changes in MAAT on equilibrium permafrost distribution proved to be more important than those due to cloud cover. Under a –2 K scenario (approximating Little Ice Age conditions), permafrost expanded into an additional 22–43% of the study areas as zonal boundaries descended by 155–290 m K^{-1}. Under warming scenarios, permafrost probabilities progressively declined and zonal boundaries rose in elevation. A MAAT change of +5 K, caused two of the areas to become essentially permafrost-free. The absolute values of these predictions were affected up to ±10% when lapse rates were altered by ±1.5 K km^{-1} but patterns and trends were maintained. A higher proportion of diffuse radiation (greater cloud cover) produced increases in permafrost extent of only 2–4% while decreases in the diffuse radiation fraction had an equal but opposite effect. Notwithstanding the small change in overall extent, permafrost probabilities on steep south-facing slopes were significantly impacted by the altered partitioning. Combined temperature and PISR partitioning scenarios produced essentially additive results, but the impact of changes in the latter declined as MAAT increased. The modelling illustrated that mountain permafrost in the discontinuous zone is sensitive spatially to long-term climate change and identified those areas where changes may already be underway following recent atmospheric warming.

Local Relevance: Modelling was done with respect to permafrost extent and distribution in the Wolf Creek Basin and Ruby Range. A modeled annual air temperature increase of 5°C predicted that essentially all of the permafrost would disappear from Wolf Creek and just over 10% would be left at Ruby Range. Smaller temperature increases had little effect on permafrost in shaded or high-elevation areas. It should be noted that the model calculates equilibrium states and does not address time frame. Therefore, the stated results are relevant to the long term, and for the short term, results should be considered as only addressing the few metres of permafrost closest to the surface.

Keywords: *permafrost, permafrost modelling, Ruby Range, south Yukon, St. Elias Mountains, Wolf Creek*

Available Online: Full Article

Citation: Bonnaventure, P.P., Lewkowicz, A.G. 2011. "Modelling Climate Change Effects on the Spatial Distribution of Mountain Permafrost at Three Sites in Northwest Canada." *Climatic Change* 105: 293-312.

Disequilibrium Response of Permafrost Thaw to Climate Warming in Canada over 1850–2100

Research Location: *Canada*
Publication Date: *2008*
Publication Type: *Journal Article*

Affiliation: *Canada Centre for Remote Sensing, Natural Resources Canada*
Contact: *Yu Zhang, Natural Resources Canada*

Abstract: Climate warming would induce permafrost thaw. However, the response of permafrost to atmospheric climate change could take from a few years to millennia. In this study, we simulated the transient changes in ground thermal regimes and permafrost status in Canada over 1850–2100 at a half-degree latitude/longitude resolution using a process-based model. The results show that the ground thermal regimes were in strong disequilibrium, with much stronger warming near the surface than in deeper ground. The reduction in permafrost extent (20.5–24.0%) by the end of the 21st century was much smaller than equilibrium projections, but permafrost thaw would continue after the 21st century even if air temperature stops increasing. Permafrost thaw from the top was very significant, and the area with supra-permafrost taliks increased exponentially, especially during the 21st century. This marked permafrost thaw from the top could have significant impacts on hydrology, landscape, soil biogeochemistry, ecosystems, and infrastructure.

Local Relevance: This study utilized models to simulate changes in ground temperatures over the period 1850-2100. The model illustrated that permafrost thaw primarily occurred from the top down and that permafrost will continue to thaw even if air temperature increases are stopped. The implications of permafrost thaw from the top down include hydrological, infrastructure, and ecosystem impacts.

Keywords: *ground temperature, impacts, permafrost, permafrost modelling, Yukon-wide*

Available Online: Abstract

Citation: Zhang, Y., Chen, W., Riseborough, D.W. 2008. "Disequilibrium Response of Permafrost Thaw to Climate Warming in Canada over 1850–2100." *Geophysical Research Letters* 35: L02502, doi:10.1029/2007GL032117.

Modelling and Mapping Techniques

Potential Inclusion of Vegetation Indices in Mountain Permafrost Modeling

Research Location: *Wolf Creek, Johnson's Crossing, Sa Dena Hes mine, Faro, Keno, Dawson, and Ruby Range, Yukon; Haines Summit, British Columbia*
Publication Date: *2008*
Publication Type: *Conference Proceedings*

Affiliation: *University of Ottawa*
Contact: *Antoni G. Lewkowicz, University of Ottawa*

Excerpt: A widely-used method to model the distribution of mountain permafrost employs basal temperature of snow (BTS) measurements as an indicator of the probability of permafrost presence. Multiple regression is used to develop a spatial field of BTS values, and these values are used to predict the distribution of permafrost either through the BTS "rules-of-thumb" or through ground-truthing relationships (e.g., Lewkowicz & Ednie 2004). The best independent variables for modeling BTS values are generally elevation and potential incoming solar radiation (PISR) (e.g., Gruber & Hoelzle 2001, Lewkowicz & Ednie 2004, Ødegård et al.1999). Multiple regression of BTS against these variables generally results in r^2 values of 0.3–0.4, indicating that there are other important factors affecting BTS values and hence permafrost (Gruber & Hoelzle 2001, Lewkowicz & Ednie 2004), one of which is vegetation.

Vegetation affects the surface offset (Smith & Riseborough 2002) by influencing turbulent energy fluxes, by shading the ground surface in summer and by altering snow distribution in winter, especially in mountain catchments where significant redistribution of snow may occur (e.g., Pomeroy et al. 2006). A small number of attempts have been made to include vegetation in permafrost spatial models using vegetation indices and land cover classifications created from remotely sensed satellite images. However, there is no generally accepted method to represent vegetation for this purpose…

Local Relevance: Although vegetation is strongly related to elevation, this study indicates that vegetation cover may affect permafrost independently of its association with elevation. This effect is most obvious at the three study sites with less permafrost below shrub-covered areas than at forested areas; this may be the result of shrubs trapping blowing snow which insulates the ground from cold air temperatures. It is suggested that vegetation cover may affect permafrost on a local scale, dependent on regional climate.

Keywords: *central Yukon, Dawson, Faro, ground temperature, Johnson's Crossing, Keno, Mayo, First Nation of Na-Cho Nyäk Dun, permafrost, permafrost modelling, Ross River Dena Council, Ruby Range, Sa Dena Hes mine, south Yukon, Tr'ondëk Hwëch'in First Nation, vegetation, Wolf Creek*

Available Online: Full Article

Citation: Kremer, M., Lewkowicz, A.G., Sawada, M., Bonnaventure, P.P., 2008. Potential Inclusion of Vegetation Indices in Mountain Permafrost Modeling. *In*: Ninth International Conference on Permafrost, Extended Abstracts, D.L. Kane and K.M. Hinkel (eds.), Fairbanks, Alaska, June 29-July 3, 2008, p. 149-150.

Interchangeability of Mountain Permafrost Probability Models, Northwest Canada

Research Location: *south and central Yukon*
Publication Date: *2008*
Publication Type: *Journal Article*

Affiliation: *University of Ottawa*
Contact: *Antoni G. Lewkowicz, University of Ottawa*

Abstract: Spatial models of mountain permafrost probability based on measurements of the basal temperature of snow (BTS) and ground-truthing were developed for three study areas located >200 km apart. The interchangeability of these locally derived empirical-statistical models was examined by predicting BTS values from the equations developed at the other two sites, and using logistic regression to relate these modelled values to the local ground-truthed data. Equations for two of the areas were effectively interchangeable, producing permafrost extent predictions within 2% of each other, and permafrost probabilities within ±0.1 for more than 85% of the cells. Predictions were much less similar when their equations were applied to the third area and when its equation was applied to them. Model interchangeability appears to depend on where a site lies on a continuum from elevation controlled (infinite ratio of the standardised coefficient of elevation to that of potential incoming solar radiation in the BTS equation), to radiation dominated (ratio much less than unity of the same variables). Extensive ground-truthing is essential, helping to constrain the logistic regression and hence the overall permafrost percentage. Additional investigations are needed to relate these ratios to regional climate in order to allow the spatial interpolation of permafrost probability models across the North American Cordillera.

Local Relevance: This study investigates the ability to use a permafrost probability model equation developed for one site at another site and yield accurate results. It was determined that for two of the sites studied, their equations could be interchanged with very little error; however, using these equations for the third study site produced much larger errors. This led to the conclusion that the ability to interchange permafrost models depends on whether permafrost at that site is controlled by solar radiation or by elevation.

Keywords: *central Yukon, permafrost, permafrost modelling, south Yukon*

Available Online: Abstract

Citation: Lewkowicz, A.G., Bonnaventure, P.P. 2008. "Interchangeability of Mountain Permafrost Probability Models, Northwest Canada." *Permafrost and Periglacial Processes* 19(1): 49-62.

Potential Use of Rock Glaciers as Mountain Permafrost Indicators in Yukon Territory, Canada

Research Location: *Yukon*
Publication Date: *2008*
Publication Type: *Conference Proceedings*

Affiliation: *University of Ottawa*
Contact: *Antoni G. Lewkowicz, University of Ottawa*

Excerpt: Analysis of the distribution of active rock glaciers is widely accepted as a way to establish the lower boundary of mountain permafrost. Rock glaciers have been used in this capacity for modeling probable permafrost distribution, mainly in Europe (e.g., Imhof 1996, Lambiel & Reynard 2001, Frauenfelder 2005, Etzelmüller et al. 2007, Fukui et al. 2007, and others). All of these models have examined permafrost distribution over relatively small areas.

We are beginning a similar project in Canada's Yukon Territory. A key difference from previous research is the spatial extent over which the study is being conducted. Currently the distribution of rock glaciers and their activity status are being examined in the southern half of the territory, an area of approximately 250,000 km^2.

A second difference between this and the European research is that in North America, rock glacier distribution may represent only the lower limit of high elevation permafrost. Permafrost also occurs in lower elevation valley bottoms due to a combination of temperature inversions due to cold air drainage (Lewkowicz & Ednie, 2004), and ecological interactions associated with surface hydrology. This situation does not occur in Europe, where rock glacier distribution can be used to model the full extent of permafrost in mountainous areas.

Our broad goal is to use the distribution of rock glaciers as an independent means of testing mountain permafrost probability models. This abstract focuses on potential sources of information and current knowledge of rock glacier distribution…

Local Relevance: In previous studies, the distribution of rock glaciers has been used as an indication of the lower limit of permafrost in mountainous regions. This paper introduces a study intended to produce the first rock glacier inventory of southern Yukon. This inventory may then lead to developing a permafrost probability map or to critiquing current permafrost models for the area. However, rock glacier distribution may only represent the lower limit of high-elevation mountain permafrost, as permafrost can form in lower elevation areas in Yukon due to regional climate factors.

Keywords: *central Yukon, glaciers, Kluane Ranges, Pelly Mountains, permafrost, permafrost mapping, Selwyn Mountains, south Yukon*

Available Online: Full Article

Citation: Page, A., Lewkowicz, A., Lipovsky, P., Bond, J., 2008. Potential Use of Rock Glaciers as Mountain Permafrost Indicators in Yukon Territory, Canada. *In*: Ninth International Conference on Permafrost, Extended Abstracts, D.L. Kane and K.M. Hinkel (eds.), Fairbanks, Alaska, June 29-July 3, 2008, p. 243-244.

Surface Offsets and *N*-Factors across Altitudinal Tree Line, Wolf Creek Area, Yukon Territory, Canada

Research Location: *Wolf Creek Research Basin, Yukon*
Publication Date: *2008*
Publication Type: *Conference Proceedings*

Affiliation: *University of Ottawa*
Contact: *Emily Schultz, University of Ottawa*

Excerpt: Site-specific conditions that control ground heat flow and the surface temperature regime play an important role in determining permafrost occurrence in the discontinuous zone (Smith & Riseborough 2002). These include depth of snow, soil properties, and vegetation cover. As it is currently impractical to fully evaluate the effects of these variables on the energy balance in mountain basins, climate-permafrost relations must be simplified. One method that has recently been attempted is the TTOP model (Juliussen & Humlum 2007), which describes the relationship

between the mean annual air temperature and the temperature at the top of permafrost in terms of the surface and thermal offsets (Smith & Riseborough 2002). Key components of this model are *n*-factors, which relate air and ground climate by establishing the ratio between air and surface freezing (winter) and thawing (summer) degree-days, thus summarizing the surface energy balance on a seasonal basis. Here we examine surface offsets and freezing and thawing *n*-factor variability at a number of sites through altitudinal tree line in the southern Yukon…

Local Relevance: Air and ground surface temperatures were measured at various sites within the Wolf Creek Research Basin to determine climatic controls affecting the freezing and thawing factor components of a permafrost model. Freezing factors varied with vegetation cover and altitude, and snow depth is the most important determinant of freezing factors. Thawing factors showed less variation across the sites than freezing factors.

Keywords: *air temperature, ground temperature, permafrost, permafrost modelling, south Yukon, vegetation, Wolf Creek*

Available Online: Full Article

Citation: Schultz, E.A., Lewkowicz, A.G., 2008. Surface Offsets and *N*-Factors across Altitudinal Tree Line, Wolf Creek Area, Yukon Territory, Canada. *In*: Ninth International Conference on Permafrost, Extended Abstracts, D.L. Kane and K.M. Hinkel (eds.), Fairbanks, Alaska, June 29-July 3, 2008, p. 273-274.

Geophysical Mapping of Ground Ice in the Western Canadian Arctic

Research Location: *King Point, Yukon; Richards Island, Northwest Territories*
Publication Date: *2008*
Publication Type: *Conference Proceedings*

Affiliation: *William Lettis & Associates, Inc.*
Contact: *Wayne H. Pollard, McGill University*

Abstract: Warming in the Arctic is occurring sooner and more rapidly than was initially expected and is predicted to increase with time. The nature and distribution of ground ice is one of the most unpredictable geological variables in near-surface materials characterized by continuous permafrost. It is also the main reason permafrost is considered vulnerable to climate warming. In this study, coordinated measurements by two complementary geophysical tools—capacitive-coupled resistivity (CCR) and ground penetrating radar (GPR)—were used to map ground ice and cryostratigraphy at King Point and Richards Island in the western Canadian Arctic. Validation of geophysical interpretations was accomplished using adjacent natural exposures. The synergenistic benefits of using these two geophysical tools permitted accurate mapping of various types of ground ice including massive ice, and wedge ice, and detection of the top of the massive ice bodies.

Local Relevance: Various permafrost characteristics were mapped using capacitive-couples resistivity (CCR) and ground penetrating radar (GPR) geophysical techniques. When these two techniques are used concurrently, a more accurate estimate of permafrost depth can be obtained. In addition, using both techniques results in accurate mapping of ground ice characteristics.

Keywords: *Beaufort Sea, King Point, north Yukon, permafrost, permafrost mapping, Yukon Coastal Plain*

Available Online: Full Article

Citation: De Pascale, G.P., Pollard, W.H., 2008. Geophysical Mapping of Ground Ice in the Western Canadian Arctic. *In*: Ninth International Conference on Permafrost, Vol. 1, D.L. Kane and K.M. Hinkel (eds.), Fairbanks, Alaska, June 29-July 3, 2008, p. 337-342.

Coastal Erosion

Fifty Years of Coastal Erosion and Retrogressive Thaw Slump Activity on Herschel Island, Southern Beaufort Sea, Yukon Territory, Canada

Research Location: *Herschel Island, Yukon*
Publication Date: *2008*
Publication Type: *Journal Article*

Affiliation: *McGill University*
Contact: *Wayne H. Pollard, McGill University*

Abstract: Patterns of coastal erosion in the Arctic differ dramatically from those coasts in more temperate environments. Thick sea ice and shore-fast ice limit wave-based erosional processes to a brief open water season, however despite this, permafrost coasts containing massive ice, ice wedges and ice-bonded sediments tend to experience high rates of erosion. These high rates of erosion reflect the combined thermal–mechanical processes of thawing permafrost, melting ground ice, and wave action. Climate change in the Arctic is expected to result in increased rates of coastal erosion due to warming permafrost, increasing active layer depths and thermokarst, rising sea levels, reduction in sea ice extent and duration, and increasing storm impacts. With the most ice-rich permafrost in the Canadian Arctic, the southern Beaufort Sea coast between the Tuktoyaktuk Peninsula and the Alaskan border is subject to high rates of erosion and retrogressive thaw slump activity. Under many climate change scenarios this area is also predicted to experience the greatest warming in the Canadian Arctic. This paper presents results of a remote sensing study on the long-term patterns of coastal erosion and retrogressive thaw slump activity for Herschel Island in the northern Yukon Territory. Using orthorectified airphotos from 1952 and 1970 and an Ikonos image from 2000 corrected with control points collected by kinematic differential global positioning system and processed using softcopy photogrammetric tools, mean coastal retreat rates of 0.61 m/yr and 0.45m/yr were calculated for the periods 1952–1970 and 1970–2000, respectively. The highest coastal retreat rates are on north–west facing shorelines which correspond to the main direction of storm-related wave attack. During the period 1970–2000 coastal retreat rates for south to south–east facing shorelines displayed a distinct increase even though these are the most sheltered orientations. However, south to south–east facing shorelines correspond to the orientations where the highest densities of retrogressive thaw slumps are observed. Differences in rates of headwall retreat of retrogressive thaw slumps and coastal erosion results in the formation of larger thermokarst scars and the development of polycyclic thaw slumps on south to south–east exposures. The number and the total area of retrogressive thaw slumps increased by 125% and 160%, respectively, between 1952 and 2000. As well, the proportion of active retrogressive thaw slumps

increased dramatically. Polycyclic retrogressive thaw slumps appear to develop in a periodic fashion, related to retrogressive thaw slump stage and maximum inland extent.

Local Relevance: Results suggest that there has been a decline in coastal erosion on Herschel Island during the latter half of the 20th century, likely as a result of decreased storm activity and increased variability in the spatial distribution of storms. However, although there has been an overall decrease in coastal erosion, south-facing coastlines have experienced increasing rates of coastal erosion, a phenomenon the researchers attribute to climate warming. Warmer temperatures have destabilized the ice-rich permafrost on south-facing coasts, allowing for storm activity to do increased damage. This slumping of ice-rich permafrost has increased in frequency and is correlated with the 1.6°C increase in mean summer temperature seen in this area from 1961-1990.

Keywords: *air temperature, Beaufort Sea, coastal erosion, Herschel Island, north Yukon, permafrost*

Available Online: Full Article

Citation: Pollard, W.H., Lantuit, H. 2008. "Fifty Years of Coastal Erosion and Retrogressive Thaw Slump Activity on Herschel Island, Southern Beaufort Sea, Yukon Territory, Canada." *Geomorphology* 95: 84-102.

Modeling the Erosion of Ice-Rich Deposits along the Yukon Coastal Plain

Research Location: *Komakuk Beach, King Point, and Shingle Point, Yukon*
Publication Date: *2008*
Publication Type: *Conference Proceedings*

Affiliation: *McGill University*
Contact: *Wayne H. Pollard, McGill University*

Abstract: The Yukon Coastal Plain is an area of ice-rich deposits along the Canadian Beaufort Sea and has been identified as highly vulnerable to the effects of sea-level rise and climate warming. Erosion is a function of the composition and morphology of coastal features, as well as wave energy. This paper outlines a simple model that considers these factors. Variations in ground ice contents and onshore and nearshore morphology are examined, as is their effect on the coastal dynamics of the region. Ice volumes are variable, ranging 52% to 84% by volume. A wave climate for the region is hindcast from historical climate records with offshore significant wave heights averaging between 0.32 and 0.45 m. Modeled wave energy shows that cross-shore energy is up to four times greater than longshore. Net longshore sediment transport is westward at all sites although the magnitude varies. Potential erosion is appraised.

Local Relevance: A simple model was developed to assess the vulnerability of the Yukon Coastal Plain to erosion. This model integrates wave energy and the ice content of the ground in order to study the effects of wave energy on rates of coastal erosion. A possible rate of coastal retreat is calculated for this area.

Keywords: *Beaufort Sea, coastal erosion, erosion modelling, King Point, Komakuk Beach, north Yukon, permafrost, Single Point, Yukon Coastal Plain*

Available Online: Full Article

Citation: Couture, N.J., Hoque, M.A., Pollard, W.H., 2008. Modeling the Erosion of Ice-Rich Deposits along the Yukon Coastal Plain. *In*: Ninth International Conference on Permafrost, Vol. 1, D.L. Kane and K.M. Hinkel (eds.), Fairbanks, Alaska, June 29-July 3, 2008, p. 303-308.

Thermal and Mechanical Erosion along Ice-Rich Arctic Coasts

Research Location: *King Point, Kay Point and Sabine Point, Yukon*
Publication Date: *2008*
Publication Type: *Conference Proceedings*

Affiliation: *McGill University*
Contact: *Wayne H. Pollard, McGill University*

Abstract: Block failure and retrogressive thaw slump activity are significant modifiers of Arctic costal morphology. This study investigates these erosional processes along ice-rich bluffs of the southern Beaufort Sea coast through a series of analytical models. Block failure potential is linked with different permafrost features like ice wedges and thermo-erosional niches. Failure often occurs along the ice wedge axis when wave erosion undercuts the base of the cliff. Model results indicate that low cliff heights tend to exhibit overturning failure, whereas high cliffs display sliding failure. Headwall retreat of retrogressive thaw slumps are also analyzed using parametric model calculations that incorporate energy balance activity to model melting ground ice. Model findings for block failure and headwall retreat are supported by field observations made in 2007 and previous studies. Using the approaches discussed in this paper, long-term morphologic patterns along Arctic coasts can be estimated using the spatial and rheological nature of permafrost materials and meteorological inputs.

Local Relevance: This study investigates erosional processes along the Yukon Coastal Plain with findings relevant to predicting climate change impacts on the region. Temperature affects both of the erosional processes studied: temperature affects block failure by altering the stability of the ice-rich ground, and; higher temperatures increase the rate of retrogressive thaw slump activity, leading to greater coastal headwall retreat.

Keywords: *Beaufort Sea, coastal erosion, erosion modelling, Kay Point, King Point, permafrost, north Yukon, Sabine Point, Yukon Coastal Plain*

Available Online: Full Article

Citation: Hoque, M.A., Pollard, W.H., 2008. Thermal and Mechanical Erosion along Ice-Rich Arctic Coasts. *In*: Ninth International Conference on Permafrost, Vol. 1, D.L. Kane and K.M. Hinkel (eds.), Fairbanks, Alaska, June 29-July 3, 2008, p. 741-746.

Past and Future Forcing of Beaufort Sea Coastal Change

Research Location: *Beaufort Sea (Tuktoyaktuk and Pelly Island, NWT)*
Publication Date: *2007*
Publication Type: *Journal Article*

Affiliation: *Geological Survey of Canada*
Contact: *Gavin K. Manson, Geological Survey of Canada*

Abstract: Changes to the Beaufort Sea shoreline occur due to the impact of storms and rising relative sea level. During the open-water season (June to October), storm winds predominantly from the north-west generate waves and storm surges which are effective in eroding thawing ice-rich cliffs and causing overwash of gravel beaches. Climate change is expected to be enhanced in Arctic regions relative to the global mean and include accelerated sea-level rise, more frequent extreme storm winds, more frequent and extreme storm surge flooding, decreased sea-ice extent, more frequent and higher waves, and increased temperatures. We investigate historical records of wind speeds and directions, water levels, sea-ice extent and temperature to identify variability in past forcing and use the Canadian Global Coupled Model ensembles 1 and 2 (CGCM1 and CGCM2) climate modelling results to develop a scenario forcing future change of Beaufort Sea shorelines. This scenario and future return periods of peak storm wind speeds and water levels likely indicate increased forcing of coastal change during the next century resulting in increased rates of cliff erosion and beach migration, and more extreme flooding.

Local Relevance: The researchers analyzed wind characteristics, sea level, sea-ice extent, and air temperature for the southern Beaufort Sea in order to better understand past climate change and predict future change. There has been a significant sea-level rise since 1962, accompanied by insignificant increases in air temperature and decreases in ice extent. Although there is likely to be a decrease in storm frequency overall, severe storms are predicted to increase in frequency. Based on a 1-5 scale (where 1 is very unlikely and 5 is very likely) deceased sea-ice extent, sea-level rise, and increased temperatures are very likely, and; increased frequency of severe storms and increased wave energy are likely. More flooding and increased rates of coastal change are predicted.

Keywords: *Beaufort Sea, climate modelling, coastal erosion, erosion modelling, north Yukon, permafrost, sea ice, sea-level rise*

Available Online: Full Article

Citation: Manson, G.K., Solomon, S.M. 2007. "Past and Future Forcing of Beaufort Sea Coastal Change." *Atmosphere-Ocean* 45(2): 107-122.

Investigating the Effects of Climate Change and Sea Level Rise on the Coastal Processes of the Beaufort Sea, Yukon Territory

Research Location: *Herschel Island, Yukon*
Publication Date: *2004*
Publication Type: *Academic Dissertation*
Affiliation: *McGill University*
Contact: *Wayne H. Pollard, McGill University*

Abstract: High latitude areas have been identified in most GCMs as regions where global warming will appear earliest and be the greatest. Since much of Canada's north is underlain by permafrost, a warming of 3-5°C could cause widespread erosion and thermokarst. The Arctic coastal zone is particularly vulnerable, as it lies at the interface between terrestrial systems dominated by permafrost, and marine systems dominated by sea ice and wave action. This study aims at understanding some mechanisms of arctic coastal erosion, such as thermoerosional niches and block failure. The final goal of this research is to identify the areas of Herschel Island, Yukon Territory, which are likely to experience the greatest magnitude of change in the near future. This information is then coupled with a climate change scenario in order to predict future coastal erosion in the area.

Local Relevance: It is expected that ice-rich coasts of Herschel Island will be exposed to 25% greater erosion rates if current trends continue. Physical erosion resulting from wave action will increase in a predictable fashion based on wave energy and storm frequency. The various types of erosion that occur on Herschel Island are documented and a climate-change scenario was developed in order to run a model to predict future coastal erosion.

Keywords: *Beaufort Sea, climate modelling, coastal erosion, erosion modelling, Herschel Island, north Yukon, permafrost*

Available Online: Full Article

Citation: Turner, J. 2004. "Investigating the Effects of Climate Change and Sea Level Rise on the Coastal Processes of the Beaufort Sea, Yukon Territory." MSc diss., McGill University.

4. Forestry

Treeline

Tree Spatial Pattern within the Forest–Tundra Ecotone: A Comparison of Sites across Canada

Research Location: *Yukon; Manitoba; Labrador*
Publication Date: *2011*
Publication Type: *Journal Article*
Affiliation: *Dalhousie University*
Contact: *Karen A. Harper, Dalhousie University*

Abstract: Although many studies have focused on factors influencing treeline advance with climate change, less consideration has been given to potential changes in tree spatial pattern across the forest–tundra ecotone. We investigated trends in spatial pattern across the forest–tundra ecotone and geographical variation in the Yukon, Manitoba, and Labrador, Canada. Tree cover was measured in contiguous quadrats along transects up to 100 m long located in Forest, Ecotone, and Tundra sections across the forest–tundra transition. Spatial patterns were analyzed using new local variance to estimate patch size and wavelet analysis to determine the scale and amount of aggregation. Compared with the Forest, tree cover in the Ecotone was less aggregated at most sites, with fewer smaller patches of trees. We found evidence that shorter trees may be clumped at some sites, perhaps due to shelter from the wind, and we found little support for regular spacing that would indicate competition. With climate change, trees in the Ecotone will likely become more aggregated as patches enlarge and new patches establish. However, results were site-specific, varying with aspect and the presence of krummholz (stunted trees); therefore, strategies for adaptation of communities to climate change in Canada's subarctic forest would need to reflect these differences.

Local Relevance: The projected influence of climate change on the distribution of trees at the boundary between forest and tundra was investigated. It was found that there was limited evidence supporting competition between tree species. There was also an indication that shorter trees may grow closer together, perhaps for shelter from the wind. As the climate warms, it is expected that trees at the boundary will become more closely packed, but findings vary by region.

Keywords: *forestry, treeline, Yukon-wide*

Available Online: Abstract

Citation: Harper, K.A., Danby, R.K., De Fields, D.L., Lewis, K.P., Trant, A.J., Starzomski, B.M., Savidge, R., Hermanutz, L. 2011. Tree Spatial Pattern within the Forest–Tundra Ecotone: A Comparison of Sites across Canada. *Canadian Journal of Forest Research* 41(3): 479-489.

Tree-line Dynamics: Adding Fire to Climate Change Prediction

Research Location: *Eagle Plains, Yukon*
Publication Date: *2010*
Publication Type: *Journal Article*

Affiliation: *University of Saskatchewan*
Contact: *Carissa D. Brown, University of Saskatchewan*

Excerpt: Fire is the dominant disturbance that drives ecosystem structure and function in the boreal forest of North America (Weber and Flannigan, 1997). Fire frequency varies widely across different regions of the boreal forest, but the interval between fires is generally long enough for trees to re-establish and recover to mature stands before the stand burns again (Heinselman, 1981; Payette, 1992). In the western boreal forest of North America, historic fire-return intervals have been estimated as typically 80 – 120 years between fires (Johnson, 1992). Tree establishment occurs most rapidly in the first years following fire, when the availability of viable seed and nutrients is at its highest (Johnson and Fryer, 1989; Johnstone et al., 2004). In a typical fire cycle of one to two

centuries, the individuals that germinate in the first few years following a fire are the same individuals that reach reproductive maturity and are burned in the next fire, continuing the cycle of post-fire self-replacement…

Local Relevance: As global temperatures increase, forest fires are expected to become more frequent. It is hypothesized that black spruce forests at the forest-tundra boundary may actually recede in a warming climate due to more-frequent fires. Black spruce trees take a relatively long time to mature to a reproductive state; therefore, more-frequent fires may kill the trees before they are able to produce cones. This could lead to a change from coniferous forest to either deciduous forest or to tundra which will affect the forest's role as a carbon sink.

Keywords: *black spruce, central Yukon, forest fire, forestry, treeline, north Yukon*

Available Online: Full Article

Citation: Brown, C.D. 2010. "Tree-line Dynamics: Adding Fire to Climate Change Prediction. *Arctic* 63(4): 488-492."

Evidence of Recent Treeline Dynamics in Southwest Yukon from Aerial Photographs

Research Location: *Kluane Ranges, St. Elias Mountains, Yukon*
Publication Date: *2007*
Publication Type: *Journal Article*

Affiliation: *University of Alberta*
Contact: *Ryan K. Danby, Queens University*

Abstract: Small-scale vertical aerial photographs taken in 1947 and 1948 covering 200 km^2 of the Kluane Ranges, southwest Yukon, were compared with corresponding photographs taken in 1989 for the purpose of characterizing changes in the distribution and abundance of white spruce (*Picea glauca* (Moench) Voss) at the alpine treeline. Digital photogrammetry, including orthorectification and on-screen interpretation, was supplemented by stereoscopic inspection of the original prints. Qualitative assessment of change across nine image pairs was accompanied by quantitative analysis of changes in spruce density and elevation using 1 hectare plots and 100 m wide elevational belt transects, respectively, superimposed on the orthorectified images. Significant changes were observed over the 41 years, but the degree of change varied throughout the study area. The most common changes were an increase in canopy size of individual trees and an increase in stand density resulting from the establishment of new individuals. Several instances of treeline advance were also observed. An absence of major natural disturbances or widespread land use change indicates that treeline change is attributable to climate. Results from concurrent dendroecological studies indicate that these dynamics represent only part of the total extent of change to occur during the 20th century.

Local Relevance: Photographs from 1989 were compared to photographs from 1947-1948 to determine what changes had occurred along the treeline. The researchers primarily noted greater

growth of individual trees, followed by greater tree density and upward advance. Increased tree growth commonly occurred as the only change or accompanied by increased density, while elevational advance generally occurred alongside the other two changes. The researchers believe these changes are the result of climate change and that the photographic evidence likely underestimates the extent of treeline dynamics during this time.

Keywords: *forestry, treeline, Kluane Ranges, south Yukon, St. Elias Mountains*

Available Online: Full Article

Citation: Danby, R.K., Hik, D.S. "Evidence of Recent Treeline Dynamics in Southwest Yukon from Aerial Photographs." *Arctic* 60(4): 411-420.

Variability, Contingency and Rapid Change in Recent Subarctic Alpine Tree Line Dynamics

Research Location: *Kluane Ranges, St. Elias Mountains, Yukon*
Publication Date: *2007*
Publication Type: *Journal Article*

Affiliation: *University of Alberta*
Contact: *Ryan K. Danby, Queens University*

Summary: 1 Boundaries between forest and tundra ecosystems, tree lines, are expected to advance in altitude and latitude in response to climate warming. However, varied responses to 20th century warming suggest that in addition to temperature, tree line dynamics are mediated by species-specific traits and environmental conditions at landscape and local scales. **2** We examined recent tree line dynamics at six topographically different, but climatically similar, sites in south-west Yukon, Canada. Dendroecological techniques were used to reconstruct changes in density of the dominant tree species, white spruce (*Picea glauca*), and to construct static age distributions of willow (*Salix* spp.), one of two dominant shrub genera. Data were analysed to identify periods and rates of establishment and mortality and to relate these to past climate. **3** Tree line elevation and stand density increased significantly during the early to mid 20th century. However, this change was not uniform across sites. Spruce advanced rapidly on south-facing slopes and tree line rose 65–85 m in elevation. Tree line did not advance on north-facing slopes, but stand density increased 40–65%. Differences observed between aspects were due primarily to the differential presence of permafrost. Additional variability among sites was related to slope and vegetation type. Results were less conclusive for willow, but evidence for an advance was found at two sites. **4** Increases in stand density were strongly correlated with summer temperatures. The period of rapid change coincided with a 30-year period of above average temperatures, beginning in 1920. The highest correlations were obtained using a forward average of 30–50 years, supporting the hypothesis that tree line dynamics are controlled more by conditions influencing recruitment than by establishment alone. **5** The changes observed at several sites are suggestive of a threshold response and challenge the notion that tree lines respond gradually to climate warming. Overall, the results provide further

evidence to support the idea that the pattern and timing of change is contingent on local, landscape, and regional-scale factors, as well as species' biology.

Local Relevance: This research revealed an increase in white spruce density on north-facing slopes and treeline advance on south-facing slopes, both related to warm temperatures throughout the 20th century. The difference between slopes is due to the distribution of permafrost. Summer temperatures have been increasing gradually since the 1850s, but the treeline response occurred suddenly and as a delayed response to temperature; this implies that treeline dynamics in response to climate change may occur rapidly once a threshold temperature in surpassed. There was a reduction in tree growth after 1950, likely related to a temperature decrease from 1950-1980. The study also found limited recent tree growth (1980s to present), but this could be due to sampling height restrictions or to insufficient moisture.

Keywords: *air temperature, treeline, Kluane Ranges, south Yukon, St. Elias Mountains, white spruce*

Available Online: Full Article

Citation: Danby, R.K., Hik, D.S. 2007. "Variability, Contingency and Rapid Change in Recent Subarctic Alpine Tree Line Dynamics." *Journal of Ecology* 95: 352-363.

Shrub Line Advance in Alpine Tundra of the Kluane Region: Mechanisms of Expansion and Ecosystem Impacts

Research Location: *Kluane region, Yukon*
Publication Date: *2007*
Publication Type: *Journal Article*
Affiliation: *University of Alberta*
Contact: *Isla H. Myers-Smith, University of Alberta*

Excerpt: With a warming climate, northern ecosystems will face significant ecological changes such as permafrost thaw, increased forest fire frequency, and shifting ecosystem boundaries, including the spread of tall shrubs into tundra. In northern mountain ranges such as those in the southwestern Yukon, the shrub line will likely advance up mountain slopes with climate warming (Danby and Hik, 2007). This loss of alpine tundra will decrease the success of obligate tundra species such as hoary marmot (*Marmota caligata*), collared pika (*Ochotona collaris*), and ptarmigan (*Lagopus* sp.) (Martin, 2001). Vegetation changes in northern ecosystems are also likely to affect foraging mammals and birds (Hinzman et al., 2005). For example, increases in the biomass of woody shrub species such as willow may reduce habitat for caribou (Sturm et al., 2005a) while benefiting moose (Kelsall, 1972). In addition to modifying wildlife habitat, increased shrub height and density will make traversing tundra more difficult, a problem for hikers and hunters…

Local Relevance: This study aims to clarify the relationship between climate forcing and feedbacks and vegetation changes. Preliminary results do not show a correlation between shrub cover and the amount of CO_2 released to the atmosphere; however, it's predicted a shrub canopy would result in higher temperatures under the canopy and lead to greater CO_2 release through decomposition.

Other preliminary results indicate that a shrub canopy reduces the species diversity of tundra sites. It is proposed that shrub cover may increase snow trapping which would result in warmer ground temperatures and facilitate more shrub expansion.

Keywords: *carbon, treeline, south Yukon, vegetation*

Available Online: Full Article

Citation: Myers-Smith, I. 2007. "Shrub Line Advance in Alpine Tundra of the Kluane Region: Mechanisms of Expansion and Ecosystem Impacts." *Arctic* 60(4): 447-451.

Improving the Parameterization of Snow Processes to Model the Implications of Shrub-Tundra Expansion on Soil Temperatures

Research Location: *Wolf Creek Research Basin, Yukon*
Publication Date: *2008*
Publication Type: *Conference Proceedings*

Affiliation: *Centre for Ecology and Hydrology*
Contact: *Richard L.H. Essery, University of Edinburgh*

Excerpt: Field observations, satellite remote sensing, and models suggest that the recent warming of the Arctic has caused an increase in shrub cover (Sturm et al. 2005, Jia et al. 2006, Tape et al. 2006). This change in vegetation structure is expected to significantly affect snow distributions and interactions between the land surface and the atmosphere, with consequences for the hydrology, ecology, carbon, and energy balances of the region. Shrubs capture wind-blown snow, increasing snow depths, and decreasing winter water losses through sublimation. The low thermal conductivity of snow insulates the soil, deepening the active layer and affecting the permafrost regime. Thus, snow/permafrost interactions will be at the core of feedback loops leading to further shrub expansion. For example, warmer winter soil temperatures lead to increased microbial activity and hence to greater nutrient availability, which will further stimulate shrub growth (Chapin et al. 2005, Tape et al. 2006). Carbon cycling will also be affected, although the environmental effects of greater shrub abundance are uncertain. Sturm et al. (2005) suggest that the Arctic may become a carbon sink because of increasing production of above-ground shrub biomass. On the other hand, thawing of permafrost is expected to liberate large amounts of carbon currently sequestered in frozen organic soils (Solomon et al. 2007)…

Local Relevance: The aim of this study is to investigate how the representation of snow processes in climate models affects the simulated ground temperature. Simulations of ground temperature are important for predicting northward movement of the shrub-tundra boundary. It was determined that using a model that includes more-complex snow processes is much more accurate at determining ground temperature than the original model. The original model consistently underestimates ground temperatures; however, the new model includes the insulating effects of snow cover on ground temperature and therefore predicts warmer, more-accurate ground temperatures.

Keywords: *forestry, ground temperature, soil, south Yukon, treeline, vegetation, Wolf Creek*

Available Online: Full Article

Citation: Menard, C., Essery, R., Clark, D., 2008. Improving the Parameterization of Snow Processes to Model the Implications of Shrub-Tundra Expansion on Soil Temperatures. *In*: Ninth International Conference on Permafrost, Extended Abstracts, D.L. Kane and K.M. Hinkel (eds.), Fairbanks, Alaska, June 29-July 3, 2008, p. 209-210.

The Influence of Shrubs on Soil Temperatures in Alpine Tundra

Research Location: *Ruby Range, Yukon*
Publication Date: *2008*
Publication Type: *Conference Proceedings*
Affiliation: *University of Alberta*
Contact: *Isla H. Myers-Smith, University of Alberta*

Excerpt: With a warming climate, northern ecosystems will face significant ecological changes such as permafrost thaw, increased forest fire frequency, and shifting ecosystem boundaries, including the spread of tall shrubs into tundra. In northern mountain ranges such as those in the southwestern Yukon, the shrub line will likely advance up mountain slopes with climate warming. In the last 50 years, rapid shrub expansion has been documented in arctic Alaska (Sturm et al. 2001a, Tape et al. 2006) and the Northern Yukon and NWT (Trevor Lantz, pers. com.) using repeat aerial photography. Paleoecological evidence suggests that tall shrubs last invaded tundra ecosystems in Alaska and northwestern Canada between 7,000 and 12,000 years ago, during the warm post-glacial period (Ritchie 1984). Growing season temperatures are again warming in Alaska and western Canada (Stafford et al. 2000), and concurrent with this trend, satellite imagery shows a greening of the Arctic (Stow et al. 2004). The correlation between warming and greening has been used to link climate change with shrub expansion (Sturm et al. 2001a); however, the exact mechanisms driving shrub increase are probably more complex. A combination of changes in nutrient mineralization, snow depth, microclimate, (Sturm et al. 2001b) disturbance (Trevor Lantz, pers. com.), and species interactions are most likely all contributing factors to shrub expansion patterns on the landscape…

Local Relevance: The effect of vegetation cover on ground temperature was investigated by creating study sites with different vegetation characteristics. Preliminary results indicate that in the summer, shrubs shade the ground from incoming sunlight (as compared to tundra areas without shrub cover) and result in cooler ground temperatures; however, it is predicted that in winter shrubs will trap snow and result in warmer ground temperatures. Warmer winter ground temperatures could accelerate nutrient cycling and reduce carbon storage, while cooler summer temperatures may increase carbon storage.

Keywords: *carbon, forestry, ground temperature, Ruby Range, soil, south Yukon, St. Elias Mountains, treeline, vegetation*

Available Online: Full Article

Citation: Myers-Smith, I.H., Hik, D.S., 2008. The Influence of Shrubs on Soil Temperatures in Alpine Tundra. *In*: Ninth International Conference on Permafrost, Extended Abstracts, D.L. Kane and K.M. Hinkel (eds.), Fairbanks, Alaska, June 29-July 3, 2008, p. 219-220.

Forest Growth

Growth Responses of Three Coexisting Conifer Species to Climate across Wide Geographic and Climate Ranges in Yukon and British Columbia

Research Location: *southern British Columbia to central Yukon*
Publication Date: *2010*
Publication Type: *Journal Article*
Affiliation: *University of Northern British Columbia*
Contact: *Scott Green, University of Northern British Columbia*

Abstract: This work aimed to compare radial growth–climate relationships among three coexisting coniferous tree species across a wide geographic and climate range from southern British Columbia (BC) to central Yukon, Canada. Tree-ring data were collected from 20 mature stands of white spruce (*Picea glauca*), lodgepole pine (*Pinus contorta* var. *latifolia*), and subalpine fir (*Abies lasiocarpa*). Linear relationships between annual growth variation and monthly and seasonal climate were quantified with correlation and regression analyses, and variation in climate–growth responses over a climatic gradient were quantified by regressing growth responses against local mean climatic conditions. Temperatures had more consistent and stronger correlations with growth for all three species than precipitation, but growth–climate responses varied among species and among sites. In particular, pine and fir populations showed different responses between BC and Yukon, whereas spruce showed a more consistent response across the study domain. Results indicate that (1) the response and sensitivity of trees to seasonal climate variables vary among species and sites and (2) winter temperatures prior to growth may have significant impacts on pine and fir growth at some sites. The capacity to adapt to climate change will likely vary among the study species and across climatic gradients, which will have implications for the future management of mixed-species forests in Yukon and BC.

Local Relevance: The relationship between tree growth and climate was investigated using tree rings for white spruce, pine, and subalpine fir trees. It was found that tree growth varied more strongly with temperature than with precipitation; however, the relationship between tree growth and climate varied among the tree species and the sites studied. It was also determined that pine and fir growth might be influenced by the temperature of the previous winter.

Keywords: *air temperature, central Yukon, forestry, forest growth, south Yukon, tree ring, white spruce*

Available Online: Abstract

Citation: Miyamoto, Y., Griesbauer, H.P., Green, D.S. 2010. "Growth Responses of Three Coexisting Conifer Species to Climate across Wide Geographic and Climate Ranges in Yukon and British Columbia." Forest Ecology and Management 259(3): 514-523.

Climate and Nutrient Influences on the Growth of White Spruce Trees in the Boreal Forests of the Yukon

Research Location: *Kluane region, Yukon*
Publication Date: *2008*
Publication Type: *Journal Article*
Affiliation: *University of Toronto Scarborough*
Contact: *Rudy Boonstra, University of Toronto Scarborough*

Abstract: The boreal forests of North America are undergoing major changes because of the direct effects of global warming and increased CO_2 levels. Plant production in the boreal forest is nutrient limited, and we examined how long-term fertilization affected growth of white spruce *Picea glauca* in the face of these major changes. We conducted a large-scale experiment by fertilizing two 1 km^2 stands of white spruce in the southwestern Yukon with commercial NPK fertilizer from 1987 to 1994. Tree growth was measured by the width of annual increments in 60 trees from each of 2 control and of 2 matched fertilized 1 km^2 sites for the period from 1977 to 1997 in a before, during, and after experimental design. Ring widths increased in both control and fertilized trees over this period as summer temperatures increased. Ring widths in fertilized trees increased from 9 to 48% over control trees during the years in which fertilizer was added, but immediately fell back to control levels from 1995 to 1997 at 1 site as soon as fertilization was stopped. In the long term, nitrogen in these forests may become tied up in shrubs, grasses, herbs, and fungi and not be available to the trees. There are 2 other possible explanations for this lack of sustained tree growth: first, the conversion of nitrogen into a form not readily available to spruce and, second, a spruce bark beetle outbreak that hit the southwestern Yukon during and after 1994 and affected 1 study site much more than the other.

Local Relevance: Experimental and control areas were created at two sites in the Kluane area, Flint and Grizzly, with Flint having a lower tree density. Experimental areas at both sites showed increased growth in response to fertilizer addition; however, trees in the Grizzly site responded more dramatically because they were more nutrient-deprived. After fertilization was stopped, trees in the Flint site reverted to the growth rate of the control site by the next year, whereas growth of trees in the Grizzly site only showed a slight decrease three years later. This inconsistent response could be the result of nutrient storage by other forest species in the Flint site or a spruce bark beetle infestation that affected the Flint site more than the Grizzly site. The researchers also note an increase in tree-ring width consistent with increasing summer temperatures in this area.

Keywords: *air temperature, fertilization, forestry, forest growth, south Yukon, tree ring, white spruce*

Available Online: Full Article

Citation: Boonstra, R., Desantis, L., Krebs, C.J., Hik, D.S. 2008. "Climate and Nutrient Influences on the Growth of White Spruce Trees in the Boreal Forests of the Yukon." *Climate Research* 36:123-130.

Responses of White Spruce (*Picea glauca*) to Experimental Warming at a Subarctic Alpine Treeline

Research Location: *southwest Yukon*
Publication Date: *2007*
Publication Type: *Journal Article*

Affiliation: *University of Alberta*
Contact: *Ryan K. Danby, Queens University*

Abstract: From 2001 to 2004 we experimentally warmed 40 large, naturally established, white spruce [*Picea glauca* (Moench) Voss] seedlings at alpine treeline in southwest Yukon, Canada, using passive open-top chambers (OTCs) distributed equally between opposing north and south-facing slopes. Our goal was to test the hypothesis that an increase in temperature consistent with global climate warming would elicit a positive growth response. OTCs increased growing season air temperatures by 1.8°C and annual growing degree-days by one-third. In response, warmed seedlings grew significantly taller and had higher photosynthetic rates compared with control seedlings. On the south aspect, soil temperatures averaged 1.0°C warmer and the snow-free period was nearly 1 month longer. These seedlings grew longer branches and wider annual rings than seedlings on the north aspect, but had reduced Photosystem-II efficiency and experienced higher winter needle mortality. The presence of OTCs tended to reduce winter dieback over the course of the experiment. These results indicate that climate warming will enhance vertical growth rates of young conifers, with implications for future changes to the structure and elevation of treeline contingent upon exposure-related differences. Our results suggest that the growth of seedlings on north-facing slopes is limited by low soil temperature in the presence of permafrost, while growth on south-facing slopes appears limited by winter desiccation and cold-induced photoinhibition.

Local Relevance: In order to study the impacts of warming on tree growth, 40 white spruce seedlings were surrounded by warming chambers. These seedlings displayed increased growth height and higher rates of photosynthesis than seedlings that were not warmed. Compared to trees on north-facing slopes, trees on south-facing slopes showed a greater growth response and reduced photosynthesis; researchers hypothesize that growth of south-facing trees is restricted by drying up in winter and cold air temperatures that inhibit photosynthesis. The growth of north-facing trees is likely limited by cold soil temperatures. In summary, warming temperatures will result in taller trees on both north- and south-facing slopes.

Keywords: *forestry, treeline, south Yukon, forest growth, white spruce*

Available Online: Abstract

Citation: Danby, R.K., Hik, D.S. 2007. "Responses of White Spruce (*Picea glauca*) to Experimental Warming at a Subarctic Alpine Treeline." *Global Change Biology* 13(2): 437-451.

Residual Effects of NPK Fertilization on Shrub Growth in a Yukon Boreal Forest

Research Location: *Kluane Lake, Yukon*
Publication Date: *2005*
Publication Type: *Journal Article*

Affiliation: *University of British Columbia*
Contact: *Michael C. Melnychuk, University of British Columbia*

Abstract: Residual effects of nutrient additions were sustained in shrubs 4–8 years after fertilization stopped in a northern boreal forest in Yukon, Canada. We measured the growth rate of grey willow (*Salix glauca* L.) and bog birch (*Betula glandulosa* Michx.) twigs during the growing seasons of 1998, 2001, and 2002, 4–8 years after NPK fertilization from 1987 to 1994 had ceased. We also measured the nitrogen concentration of the 1998 growth tissue. Willow twigs had significantly higher growth rates in previously fertilized shrubs than control shrubs in these 3 years, even greater than differences observed during fertilization. Willow also had higher N concentration in fertilized twigs than control twigs. Birch growth was negatively correlated with hare abundance during the snowshoe hare (*Lepus americanus*) abundance cycle. Birch growth rate was higher in fertilized twigs than control twigs in 1998 during the hare peak, but fertilized birch twigs approached control levels by 2002 following the hare decline.

Local Relevance: During the fertilization period, both shrubs showed a positive growth response. Willow showed an even stronger growth response once fertilization was stopped, illustrating that the residual effects of fertilization may be greater than the immediate effects. Birch shrubs also showed a strong residual response; however, birch growth is more subject to snowshoe hare abundance. In years with low hare populations, there was little difference in growth between experimental and control plots of birch trees; however, in years with high hare populations, experimental plots showed much higher growth rates. Researchers are uncertain whether the growth discrepancy during high hare years was simply coincidental.

Keywords: *fertilization, forestry, Kluane Lake, snowshoe hare, south Yukon*

Available Online: Full Article

Citation: Melnychuk, M.C., Krebs, C.J. 2005. "Residual Effects of NPK Fertilization on Shrub Growth in a Yukon Boreal Forest." *Canadian Journal of Botany* 83: 399-404.

Tree-Ring Analysis of Five *Picea Glauca*-Dominated Sites from the Interior Boreal Forest in the Shakwak Trench, Yukon Territory, Canada

Research Location: *Shakwak Trench, Yukon*
Publication Date: *2005*
Publication Type: *Journal Article*

Affiliation: *University of Ottawa*
Contact: *Konrad Gajewski, University of Ottawa*

Abstract: Five tree-ring chronologies were developed from low-elevation stands of white spruce (*Picea glauca* [Moench] Voss) situated in the interior boreal forest of the Shakwak Trench, Yukon Territory. The objective of this study was to investigate the climate impacts on tree growth using trees from within plots located in an interior boreal forest. The five chronologies depict similar trends in tree-ring width, suggesting a significant climatic influence on tree growth. Although the variability and sensitivity of these chronologies is lower than that of treeline sites, low-frequency ring-width variability is remarkably coherent among all the sites used in this study. The relationship between the chronologies and the regional climate data demonstrates that precipitation is more highly correlated with tree-ring width than temperature. This study demonstrates the importance of climate influences on tree growth within sites located in the interior of the boreal forest.

Local Relevance: Results obtained indicate that tree growth is consistent across the study region, illustrating the importance of large-scale climatic conditions. This study yields a correlation between tree-ring width and precipitation that is more significant than the correlation between ring width and temperature. Autumn precipitation is predictive of tree growth the following year and growth is stimulated by low temperatures during the growing season and high temperatures during the winter. In summary, this study predicts that large areas of the boreal forest will undergo similar alterations in response to climate change.

Keywords: *air temperature, forestry, precipitation, Shakwak Trench, south Yukon, forest growth, tree ring, white spruce*

Available Online: Full Article

Citation: Zalatan, R., Gajewski, K. 2005. "Tree-Ring Analysis of Five *Picea Glauca*-Dominated Sites from the Interior Boreal Forest in the Shakwak Trench, Yukon Territory, Canada." *Polar Geography* 29(1): 1-16.

Non-Equilibrium Succession Dynamics Indicate Continued Northern Migration of Lodgepole Pine

Research Location: *south and central Yukon*
Publication Date: *2003*
Publication Type: *Journal Article*

Affiliation: *University of Alaska Fairbanks*
Contact: *Jill F. Johnstone, University of Saskatchewan*

Abstract: Because species affect ecosystem functioning, understanding migration processes is a key component of predicting future ecosystem responses to climate change. This study provides evidence of range expansion under current climatic conditions of an indigenous species with strong ecosystem effects. Surveys of stands along the northern distribution limit of lodgepole pine (*Pinus contorta* var. *latifolia*) in central Yukon Territory, Canada showed consistent increases in pine dominance following fire. These patterns differed strongly from those observed at sites where pine has been present for several thousand years. Differences in species thinning rates are unlikely to account for the observed increases in pine dominance. Rates of pine regeneration at its range limits

were equivalent to those of spruce, indicating a capacity for rapid local population expansion. The study also found no evidence of strong climatic limitation of pine population growth at the northern distribution limit. We interpret these data as evidence of current pine expansion at its range limits and conclude that the northern distribution of lodgepole pine is not in equilibrium with current climate. This study has implications for our ability to predict vegetation response to climate change when populations may lag in their response to climate.

Local Relevance: This study proposes that the current northern distribution of lodgepole pine is not limited by climatic factors. Instead, pine migration is highly dependent on forest fires, with the proportion of pine trees near the northern limit increasing drastically following fire disturbance. It is concluded that the current northern limit of lodgepole pine is not in equilibrium with climatic conditions, posing difficulties predicting ecosystem changes resulting from global warming. In addition, the continued northward migration of pine into spruce forests will affect the forest's role in the carbon cycle.

Keywords: *central Yukon, forest fire, forestry, south Yukon*

Available Online: Full Article

Citation: Johnstone, J.F., Chapin, F.S. 2003. "Non-Equilibrium Succession Dynamics Indicate Continued Northern Migration of Lodgepole Pine." *Global Change Biology* 9: 1401-1409.

Effects of Water Addition on Biotic and Abiotic Components of a Dry Boreal Forest in the Yukon

Research Location: *Kluane region, Yukon*
Publication Date: *2003*
Publication Type: *Academic Dissertation*
Institution: *University of British Columbia*
Contact: *Charles J. Krebs, University of British Columbia*

Abstract: To test the response of the dry Kluane boreal forest ecosystem (Yukon, Canada) to increased rainfall as predicted from climate change scenarios I irrigated three 1.5 ha forest stands from 1995-1999, to double baseline summer rainfall levels. I tested if various biotic and abiotic components of this ecosystem would react to the reduction of the summer water deficit relative to three control stands. I predicted that in response to irrigation: 1) growth (or biomass) in some species of plants would increase. 2) red-backed voles would in turn increase in numbers with greater plant-food availability because they are food-limited herbivores. 3) mushroom biomass would increase. 4) decomposition would increase, and hence 5) net nitrogen (ammonium, NH_4^+) mineralization by soil microbes (i.e. nitrogen availability for plant nutrition) would also increase, further improving plant growth (1).

Over the five years of irrigation, none of the selected species of plants nor the voles reacted to irrigation. Mushroom biomass increased 2.5-fold on irrigated stands. Litter decomposition increased log-linearly with the enhanced actual evapotranspiration (AET) following irrigation. Soil microbes

immobilized NH_4^+ (rendering it unavailable to plants) as AET increased, while net NH_4^+ mineralization remained unchanged…

Local Relevance: None of the plant species studied experienced increased growth as a result of five years of irrigation, but mushroom biomass increased 2.5 times. The plants did not respond to irrigation because it did not result in greater nitrogen availability for plants due to soil microbe activity. This lack of increased plant growth is accompanied by increased decomposition, indicating that increased rainfall as a result of climate change may convert the boreal forest to a carbon source. However, this process may revert as changing forest conditions result in more nitrogen available to plants in the long-term.

Keywords: *carbon, forestry, irrigation, microbes, mushrooms, nitrogen, south Yukon*

Available Online: Full Article

Citation: Carrier, P. 2003. "Effects of Water Addition on Biotic and Abiotic Components of a Dry Boreal Forest in the Yukon." PhD diss., University of British Columbia.

Disturbance

A Sensitive Slope: Estimating Landscape Patterns of Forest Resilience in a Changing Climate

Research Location: *Fox Lake, Yukon*
Publication Date: *2010*
Publication Type: *Journal Article*

Affiliation: *University of Saskatchewan*
Contact: *Jill F. Johnstone, University of Saskatchewan*

Abstract: Changes in Earth's environment are expected to stimulate changes in the composition and structure of ecosystems, but it is still unclear how the dynamics of these responses will play out over time. In long-lived forest systems, communities of established individuals may be resistant to respond to directional climate change, but may be highly sensitive to climate effects during the early life stages that follow disturbance. This study combined analyses of pre-fire and post-fire tree composition, environmental data, and tree ring analyses to examine landscape patterns of forest recovery after fire in the south-central Yukon, Canada, a climatically dry region of boreal forest where there is evidence of increasing drought stress. Pre-fire stand composition and age structures indicated that successional trajectories dominated by white spruce (*Picea glauca*) with little aspen (*Populus tremuloides*) comprised most of the study area during the last fire cycle. Although spruce seedling recruitment after the fire was highest at sites near unburned seed sources and where surface organic layers were shallow, spruce seedling densities were often insufficient to regenerate the pre-fire spruce forests. In particular, sites in the warmer topographic locations of the valley lowland and south-facing slopes typically had few spruce seedlings and instead were dominated by aspen. The opposite pattern was observed on north-facing slopes. Age reconstructions of pre-and post-fire stands indicate that future canopy composition is driven by initial post-fire recruitment and thus observed landscape differences in seedling recruitment are likely to be maintained through the

next 100–200 years of succession. Observed results support the hypothesis that sites experiencing greater environmental stress show the lowest resilience to disturbance, or greatest compositional changes. Analyses of tree-ring responses to climate variables across the same landscape indicate that patterns of tree growth prior to a disturbance may be a useful predictor of landscape variations in forest resilience, allowing managers to better anticipate where future changes in forest composition are likely to occur.

Local Relevance: Pre-fire, the forest of the Fox Lake valley was mainly composed of white spruce trees; however, after the 1998 fire, trembling aspen began to dominate the study area. This is different than after previous fires in which white spruce continued to be the main species. The researchers hypothesize that the warmer climate is inhibiting white spruce regeneration after disturbance. This implies a possible transition from a boreal forest dominated by coniferous trees (spruce) to a forest of deciduous trees (aspen) which would have profound ecological impacts. This study also illustrates a possible relationship between tree ring signals and the resilience of a forest community to environmental disturbance; drought-stressed areas showed the greatest species redistribution from spruce to aspen following forest fire disturbance.

Keywords: *aspen, central Yukon, drought, forest fire, forestry, Fox Lake, south Yukon, tree ring, white spruce*

Available Online: Full Article

Citation: Johnstone, J.F., McIntire, E.J.B., Pedersen, E.J., King, G., Pisaric, M.J.F. 2010. "A Sensitive Slope: Estimating Landscape Patterns of Forest Resilience in a Changing Climate." *Ecosphere* 1(6): 14, doi:10.1890/ES10-00102.1.

Impacts of Drought on Forest Growth and Regeneration following Fire in Southwestern Yukon, Canada

Research Location: *southwest Yukon*
Publication Date: *2005*
Publication Type: *Journal Article*

Affiliation: *Canadian Forest Service, Natural Resources Canada*
Contact: *Ted Hogg, Natural Resources Canada*

Abstract: The valleys of southwestern Yukon have a continental climate with average annual precipitation of <300 mm. In 1958, fires burned large areas of mature mixedwood forests dominated by white spruce (*Picea glauca* (Moench) Voss) in the valleys near Whitehorse. Since then, the burned areas have shown poor regeneration of spruce, but have been colonized by scattered clones of trembling aspen (*Populus tremuloides* Michx.) interspersed by grassland. The objective of the study was to examine the influence of climatic variation on forest growth and regeneration in the 1958 burn and the adjacent unburned forests. Tree-ring analysis was conducted on 50 aspen and 54 white spruce in 12 mature stands where these species were codominant, and on 147 regenerating aspen in the 1958 Takhini burn. The mature stands were uneven-aged and the patterns of growth variation for the aspen and spruce between 1944 and 2000 were similar. Growth of both species was most

strongly related to variation in precipitation. The regenerating aspen had a wide age-class distribution (1959–2000) and their growth was also positively related to precipitation. The results indicate that these forests have been slow to regenerate after fire, and are vulnerable if the climate becomes drier under future global change.

Local Relevance: Of the factors studied, precipitation had the greatest impact on the growth of mature spruce and aspen, where greater precipitation promotes growth. In addition, researchers observed that forest growth after fire was much slower than they would have expected. Therefore, it is predicted that if the climate becomes warmer and drier, there will be a reduction in forest cover in the southwest Yukon due to both temperature-induced drought stress and poor growth following forest fires.

Keywords: *aspen, drought, forest fire, forestry, precipitation, south Yukon, forest growth, white spruce*

Available Online: Full Article

Citation: Hogg, E.H., Wein, R.W. 2005. "Impacts of Drought on Forest Growth and Regeneration following Fire in Southwestern Yukon, Canada." *Canadian Journal of Forest Research* 35: 2141-2150.

Large Forest Fires in Canada and the Relationship to Global Sea Surface Temperatures

Research Location: *Canada*
Publication Date: *2006*
Publication Type: *Journal Article*

Affiliation: *Climate Research Division, Environment Canada*
Contact: *Walter R. Skinner, Environment Canada*

Abstract: Relationships between variations in peak Canadian forest fire season (JJA) severity and previous winter (DJF) global sea surface temperature (SST) variations are examined for the period 1953 to 1999. Coupled modes of variability between the seasonal severity rating (SSR) index and the previous winter global SSTs are analyzed using singular value decomposition (SVD) analysis. The robustness of the relationship is established by the Monte Carlo technique. The importance of the leading three SVD modes, accounting for approximately 90% of the squared covariance, to Canadian summer forest fire severity is identified. The first mode relates strongly to the global long-term trend, especially evident in the warming of the Southern Hemisphere oceans, and shows significant positive correlation in the forested regions of northwestern, western and central Canada, while southern B.C., the extreme northwest coastal regions of B.C. and Yukon, and the Great Lakes region are identified as having significant negative correlation. The second mode relates to the multidecadal variation of Atlantic SST (AMO) and shows highly significant negative correlation extending from the western NWT and Canadian Prairie Provinces across northern Ontario and Quebec. The third mode is related to Pacific Ocean processes and the interrelationship between El Niño–Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO) and shows strong positive correlation in western Canada and negative correlation in the lower Great Lakes region of

southern Ontario and southern Quebec. A 6-month lag relationship between Canadian forest fire variability and large-scale SSTs may provide the basis for developing long-range forecasting schemes for fire severity in Canada.

Local Relevance: This study investigates the relationship between forest fire severity and the sea-surface temperature of the previous winter. A higher rate of warming of the Southern Hemisphere oceans is positively correlated with fire severity in most of northwestern Canada and is negatively correlated with fire severity in the northwest coastal regions. Fire severity in northwest Canada is related to the Pacific Decadal Oscillation (PDO) and El Niño–Southern Oscillation (ENSO). The positive phase of PDO and the warm phase of ENSO lead to greater fire severity in northwest Canada. This research may be the foundation for using sea-surface temperatures to predict forest fire severity.

Keywords: *El Niño/Southern Oscillation, fire prediction, forest fire, forestry, Pacific Decadal Oscillation, sea-surface temperature, Yukon-wide*

Available Online: Full Article

Citation: Skinner, W.R., Shabbar, A., Flannigan, M.D., Logan, K. 2006. "Large Forest Fires in Canada and the Relationship to Global Sea Surface Temperatures." *Journal of Geophysical Research* 111: D14106, doi:10.1029/2005JD006738.

Potential Alteration by Climate Change of the Forest-Fire Regime in the Boreal Forest of Central Yukon Territory

Research Location: *Dawson and Mayo, Yukon*
Publication Date: *2005*
Publication Type: *Journal Article*

Affiliation: *Carleton University*
Contact: *Chris R. Burn, Carleton University*

Abstract: Statistical relations were obtained to describe the association between forest fires and climate for the Dawson and Mayo fire management districts, central Yukon Territory. Annual fire incidence, area burned, and seasonal fire severity rating were compared with summer observations of mean temperature, total precipitation, mean relative humidity, and mean wind speed. The relations were obtained by multiple regression and combined with regional scenarios of future climate from general circulation models. The strongest statistical associations for fire occurrence and area burned were with temperature and precipitation at Dawson. Depending on the scenario, the statistics suggest that the average annual fire occurrence and area burned may as much as double by 2069, but there may still be years with few fires. The maximum number of fires may increase by two-thirds over present levels, and the maximum area burned per summer may increase to more than three times the present value. Without incorporating changes in climate variability into the scenarios, the year-to-year variability in number of fires is not projected to increase, but the range in area burned per summer may rise by about 15%.

Local Relevance: Overall, the most important variable in predicting fire severity in the Mayo and Dawson region is moisture. In addition, lightening-ignited fires and area burned are strongly correlated with temperature, and fire occurrence is negatively correlated with precipitation. 7 General Circulation Models were analysed for central Yukon: all simulated warmer summer temperatures; 4 of 7 predicted decreased moisture availability, and; most called for an increase in precipitation. Using these scenarios, model results predict more forest fires and an increase in area burned as climate change continues. The highest predictions call for 60% more fires per year by 2010-2039 and a 20% increase in area burned by 2040-2069.

Keywords: *central Yukon, climate modelling, Dawson, fire prediction, First Nation of Na-Cho Nyäk Dun, forest fire, forestry, hazards, Mayo, precipitation, Tr'ondëk Hwëch'in First Nation*

Available Online: Full Article

Citation: McCoy, V.M., Burn, C.R. 2005. "Potential Alteration by Climate Change of the Forest-Fire Regime in the Boreal Forest of Central Yukon Territory." *Arctic* 58(3): 276-285.

Risk Assessment of the Threat of Mountain Pine Beetle to Canada's Boreal and Eastern Pine Forests

Research Location: *Canada*
Publication Date: *2008*
Publication Type: *Government Publication*

Affiliation: *Canadian Forest Service, Natural Resources Canada*
Contact: *Vince Nealis, Natural Resources Canada*

Excerpt: The mountain pine beetle (*Dendroctonus ponderosae* Hopkins) is the most destructive insect pest of mature pine forests in western North America (Safranyik and Carroll 2006). Periodic eruptions of populations cause widespread mortality, especially to lodgepole pine (*Pinus contorta* Dougl. ex Loud. var. *latifolia* Engelm.) The recent outbreak in British Columbia began in the late 1990s. By 2006, nearly 10 million ha of pine forests had some level of tree mortality and an estimated 582 million m^3 of timber had been lost.

In the past few years, new infestations have appeared further north and east in British Columbia and Alberta, outside the historical recorded range of the mountain pine beetle. These new infestations are thought to be the result of migration of beetles from outbreaks west of the continental divide into areas east of the divide where there are suitable hosts for attack. Survival of broods has been favoured by a series of mild winters. This combination of available hosts and favourable weather has been observed in the past in the southern Canadian prairies. The current situation is novel, however, in that these new, more northerly areas of attack are not the isolated pine stands of southern Alberta but part of a relatively contiguous pine forest which extends across the boreal zone. Consequently, there is the potential for a native, western insect pest to become invasive outside its historic geographic range within Canada and attack pine species to which it has not been exposed previously. This leads to the question, "Is the mountain pine beetle a threat to the boreal

and eastern pines forests of Canada?" If so, management response objectives and strategies must be considered…

Local Relevance: Predictions of future distribution and effects of the mountain pine beetle were accumulated from expert sources at two workshops in 2007. It is expected that changing climatic conditions will allow the mountain pine beetle in British Columbia to expand its range northward towards Yukon in the near future.

Keywords: *climate modelling, forestry, mountain pine beetle, south Yukon*

Available Online: Full Report

Citation: Canada. Natural Resources Canada. *Risk Assessment of the Threat of Mountain Pine Beetle to Canada's Boreal and Eastern Pine Forests*. Pacific Forestry Centre, Victoria, British Columbia: 2008.

Spruce Beetle and the Forests of the Southwest Yukon

Research Location: *southwest Yukon*
Publication Date: *2006*
Publication Type: *Government Publication*
Affiliation: *Canadian Forest Service, Natural Resources Canada*
Contact: *Brad Hawkes, Natural Resources Canada*

Abstract: Beginning in about 1990, populations of spruce beetle, *Dendroctonus rufipennis* Kirby (Coleoptera: Scolytidae), reached epidemic levels and began killing drought-stressed white spruce, *Picea glauca* within Kluane National Park and Reserve in the southwest Yukon. By 1994, when the infestation was first discovered, the beetle had already killed spruce over an area of 32 000 ha and had moved from the Alsek River drainage within the park into public forest lands and First Nations settlement lands within the Shakwak Trench north of Haines Junction. In 2000, while the infestation continued to expand, a decision was made to establish a network of plots within infested stands to assess and document the changes that were occurring to the treed overstory and understory, as well as to the associated flora. Also, in response to the greatly increased fire hazard posed by the beetle-killed trees, tree crown and surface fuels were analyzed and a relative fire hazard rating system was developed. From 2000 to 2003, 27 plots were established in the Alsek River drainage within Kluane National Park, the Shakwak Trench from Congdon Creek in the north to Klukshu Village in the south and east within the Dezadeash River Valley as far as Canyon. A supplementary root disease assessment was completed within selected plots in 2003. As of the date of this report, spruce beetles are still killing trees over large areas, with an accumulated area of infestation in excess of 350 000 ha, and trees are still dying within some of the plots. This establishment report summarizes the findings from the first round of assessments and will serve as a baseline against which later assessments will be compared. To realize the full intent of the project, the second round will be completed some years after the collapse of the beetle infestation when the trees have begun shedding their fine fuels. This will allow the stands to begin adjusting to the loss or partial loss of the white spruce overstory, and increased light penetration to the forest floor will have begun to stimulate a response in the treed understory and the surface vegetation.

Local Relevance: Climate warming in the southwest Yukon has led to an outbreak of the spruce bark beetle and many resultant changes to the forest system. Initially, trees killed by the beetle just lose their needles; it is not until the branches are shed that the consequences of increased light penetration to the forest floor will be realized. More light reaching the ground will likely cause changes to lower-level vegetation and may affect future species composition of the forest. Dead trees from the beetle epidemic have resulted in a greater fire risk due to an increase in fuel availability.

Keywords: *forest fire, Shakwak Trench, south Yukon, spruce bark beetle*

Available Online: Full Report

Citation: Canada. Natural Resources Canada. *Spruce Beetle and the Forests of the Southwest Yukon*. Pacific Forestry Centre, Victoria, British Columbia: 2006.

Spruce Beetle Outbreaks on the Kenai Peninsula, Alaska, and Kluane National Park and Reserve, Yukon Territory: Relationship to Summer Temperatures and Regional Differences in Disturbance Regimes

Research Location: *Kluane National Park and Reserve, Yukon; Kenai Peninsula, Alaska*
Publication Date: *2006*
Publication Type: *Journal Article*

Affiliation: *Kenai National Wildlife Refuge, U.S. Fish and Wildlife Service*
Contact: *Edward E. Berg, U.S. Fish and Wildlife Service*

Abstract: When spruce beetles (*Dendroctonus rufipennis*) thin a forest canopy, surviving trees grow more rapidly for decades until the canopy closes and growth is suppressed through competition. We used measurements of tree rings to detect such growth releases and reconstruct the history of spruce beetle outbreaks at 23 mature spruce (*Picea* spp.) forests on and near the Kenai Peninsula, Alaska and four mature white spruce (*Picea glauca*) forests in Kluane National Park and Reserve, Yukon Territory. On the Kenai Peninsula, all stands showed evidence of 1–5 thinning events with thinning occurring across several stands during the 1810s, 1850s, 1870–1880s, 1910s, and 1970–1980s, which we interpreted as regional spruce beetle outbreaks. However, in the Kluane region we only found evidence of substantial thinning in one stand from 1934 to 1942 and thinning was only detected across stands during this same time period. Over the last 250 years, spruce beetle outbreaks therefore occurred commonly among spruce forests on the Kenai Peninsula, at a mean return interval of 52 years, and rarely among spruce forests in the Kluane region where cold winter temperatures and fire appear to more strongly regulate spruce beetle population size. The massive 1990s outbreaks witnessed in both regions appeared to be related to extremely high summer temperatures. Recent outbreaks on the Kenai Peninsula (1971–1996) were positively associated with the 5-year backwards running average of summer temperature. We suggest that warm temperature influences spruce beetle population size through a combination of increased overwinter survival, a doubling of the maturation rate from 2 years to 1 year, and regional drought-induced stress of

mature host trees. However, this relationship decoupled after 1996, presumably because spruce beetles had killed most of the susceptible mature spruce in the region. Thus sufficient numbers of mature spruce are needed in order for warm summer temperatures to trigger outbreaks on a regional scale. Following the sequential and large outbreaks of the 1850s, 1870–1880s, and 1910s, spruce beetle outbreaks did not occur widely again until the 1970s. This suggests that it may take decades before spruce forests on the Kenai Peninsula mature following the 1990s outbreak and again become susceptible to another large spruce beetle outbreak. However, if the recent warming trend continues, endemic levels of spruce beetles will likely be high enough to perennially thin the forests as soon as the trees reach susceptible size.

Local Relevance: Tree-ring measurements showed evidence of the known 1940s spruce bark beetle outbreak and indicated that all four Kluane stands had experienced forest fires. Beetle outbreaks have occurred and been sustained due to periods of warmer summers—above-average temperatures beginning in 1989 in the Kluane region are associated with the 1990s outbreak and warm 1930s temperatures are related to the 1934 outbreak. Warm summers allow for greater beetle reproduction and cause trees to suffer drought stress; however, in Kluane it's suspected that drought stress is the more-important factor. Spruce bark beetle infestations have been restricted in Kluane as compared to the Kenai Peninsula because Kluane experiences colder winters and more forest fires.

Keywords: *air temperature, drought, forestry, spruce bark beetle, south Yukon, white spruce*

Available Online: Full Article

Citation: Berg, E.E., Henry, J.D., Fastie, C.L., De Volder, A.D., Matsuoka, S.M. 2006. "Spruce Beetle Outbreaks on the Kenai Peninsula, Alaska, and Kluane National Park and Reserve, Yukon Territory: Relationship to Summer Temperatures and Regional Differences in Disturbance Regimes." *Forest Ecology and Management* 227: 219-232.

Soil Microbial Communities Resistant to Changes in Plant Functional Group Composition

Research Location: *Kluane, Yukon*
Publication Date: *2011*
Publication Type Topic: *Journal Article*

Affiliation: *University of British Columbia*
Contact: *Jennie R. McLaren, University of Texas at Arlington*

Abstract: The soil community is an often ignored part of research which links plant biodiversity and ecosystem functioning despite their influence on numerous functions such as decomposition and nutrient cycling. Few consistent patterns have been detected that link plant and soil community composition. We used a removal experiment in a northern Canadian grassland to examine the effects of plant functional group identity on soil microbial community structure and function. Plant functional groups (graminoids, legumes and forbs) were removed independently from plots for five growing seasons (2003–2007) and in the fifth year effects on the soil microbial community were examined using substrate-induced respiration (SIR – a measure of metabolic diversity) and phospholipid fatty acid analysis (PLFA – a measure of microbial community composition). Removal treatments were also crossed with both a fertilizer treatment and a fungicide treatment to determine

if effects of functional group identity on the soil community were context dependent. Plant functional group identity had almost no effect on the soil microbial community as measured by either SIR or PLFA. Likewise, soil properties including total carbon, pH, moisture and nutrients showed a limited response to plant removals in the fifth year after removals. We found a direct effect of fertilizer on the soil community, with fertilized plots having decreased metabolic diversity, with a decreased ability to metabolize amino acids and a phenolic acid, but there was no direct soil microbial response to fungicide. We show that in this northern Canadian grassland the soil microbial community is relatively insensitive to changes in plant functional group composition, and suggest that in northern ecosystems, where plant material is only slowly incorporated into the soil, five growing seasons may be insufficient to detect the impact of a changing plant community on the soil microbes.

Local Relevance: After five years of removing individual plant groups from experimental sites, there was very little effect on both soil microbial composition and soil properties. However, researchers suggest that this lack of response may be due to slow uptake of plant material by soil organisms in northern ecosystems, thereby indicating a slow response of soil properties to altered plant species. Addition of fertilizer did have an effect on the soil community, resulting in decreased metabolic diversity.

Keywords: *carbon, fertilization, microbes, soil, south Yukon, vegetation*

Available Online: Abstract

Citation: Marshall, C.B., McLaren, J.R., Turkington, R. 2011. "Soil Microbial Communities Resistant to Changes in Plant Functional Group Composition." *Soil Biology and Biochemistry* 43(1): 78-85.

Forest Management

Climate Change and Canada's Forests—From Impacts to Adaptation

Research Location: *Canada*
Publication Date: *2009*
Publication Type: *Government Publication*

Affiliation: *Canadian Forest Service, Natural Resources Canada*
Contact: *Tim Williamson, Natural Resources Canada*

Abstract: Climate change is already affecting Canada's forests. Current visible effects include changes in the frequency and severity of disturbances (such as fires, drought, severe storms, and damaging insect and disease attacks): other less visible changes such as change in the timing of spring bud burst are also underway. One of the consequences of future climate change will be further increases in the frequency and severity of extreme weather events and disturbances. Changes in productivity, species composition, and age-class distribution are also expected. Moisture and temperature are key factors affecting productivity. Productivity is likely to decrease in areas that are now or will become drier; productivity is expected to increase (at least in the near term) in northern areas that are currently limited by cold temperatures. An important consideration, however, is that

genotypes tend to be finely adapted to local climates and potential productivity gains may not be realized if forest managers don't match genotypes to suitable climates. A higher percentage of the forests will be in younger age classes, and the frequency of early succession species and species adapted to disturbance will increase. Climatically suitable habitats for most species will move northward and will increase in elevation but the actual movement of species will lag behind the rate of movement of climatic niches. Climate change has implications for both current and future timber supply. The net impact of climate change on timber supply will vary from location to location. The recent mountain pine beetle event shows that climate-related factors can have dramatic effects on timber supply in a relatively short time period. Climate change will impact harvest operations. A significant portion of the harvest in Canada occurs in the winter when the ground is frozen. Harvesting on frozen ground allows for access to wetlands, reduces soil disturbance, and decreases costs of delivered wood. The magnitudes of change in climate that will be faced by Canada's forests and forest management sector and the consequent scale of expected impacts have no historical analogue. Canada's forest sector will need to adapt and it will need to do so without the benefit of prior experience. Forest managers can expect the unexpected and they can expect that change will be ongoing and unrelenting. Some general recommendations for beginning to address climate change in Canada's forest sector include enhancing the capacity to undertake integrated assessment of vulnerabilities to climate change at various scales; increasing resources to monitor the impacts of climate change; increasing resources for impacts and adaptation science; reviewing forest policies, forest planning, forest management approaches, and institutions to assess our ability to achieve social objectives under climate change; embedding principles of risk management and adaptive management into forest management; and maintaining or improving the capacity for communicating, networking, and information sharing with the Canadian public and within the forest sector.

Local Relevance: Climate change is likely to cause ecosystem disruption that will affect traditional ways of life: northward movement of the boundary between forest and tundra may alter the migration routes of woodland caribou and encroach upon their habitat, and; a greater number of forest fires may directly harm woodland caribou. Increased forest-fires as a result of climate change are likely to result in a younger forest and reduce the carbon-storage capacity of the northern boreal forest. 2004 was a record forest fire season for Yukon, resulting from the highest summer temperature on record, below-average rain, and a higher frequency of lightning strikes. The northward movement of the tree line is expected to lag behind climatic changes due to the slow process of species recruitment; however, eventually trees will expand into tundra areas and tundra will take over forest areas that suffer forest fire. It is also possible that permafrost thaw may convert boreal forests into treed wetlands over longer time periods.

Keywords: *adaptation, forest management, forestry, impacts, Yukon-wide*

Available Online: Full Report

Citation: Williamson, T.B.; Colombo, S.J.; Duinker, P.N.; Gray, P.A.; Hennessey, R.J.; Houle, D.; Johnston, M.H.; Ogden, A.E.; Spittlehouse, D.L. 2009. Climate change and Canada's forests: from impacts to adaptation. Sustain. For. Manag. Netw. and Nat. Resour. Can., Can. For. Serv., North. For. Cent., Edmonton, AB. 104 p.

Adapting to Climate Change in the Southwest Yukon: Locally Identified Research and Monitoring Needs to Support Decision Making on Sustainable Forest Management

Research Location: *Champagne and Aishihik Traditional Territory, Yukon*
Publication Date: *2009*
Publication Type: *Journal Article*

Affiliation: *University of British Columbia; Energy, Mines and Resources Yukon*
Contact: *Aynslie E. Ogden, University of British Columbia/Government of Yukon*

Abstract: In a community-directed forest management context, research is needed that will help both the managers of forest resources and the community residents who set forest management directions to consider climate change in their decision making. Specific research needed in light of climate change to support implementation of the forest management plan for the Champagne and Aishihik Traditional Territory, southwest Yukon, was identified through 1) sessions with local forest practitioners and 2) a community climate change workshop. Local residents highlighted the importance of formalizing a monitoring network based on local knowledge as part of a broader adaptive management framework. They also wanted an important role in any discussion on adapting existing forest management plans, practices, and policies to incorporate climate change considerations. Forest practitioners expressed a need for research to identify forest management tactics that would enable them to achieve community-directed forest management objectives in light of climate change. Addressing these research needs will have benefits beyond just adapting forest management to climate change. Climate change is providing the impetus and a forum for discussing a broader issue: the need for a more comprehensive research and monitoring program to support the sustainable management of forest resources.

Local Relevance: This paper analyses the results of a community workshop and a study involving forest practitioners, both aimed at determining research and monitoring needs for the forests of the Champagne and Aishihik Traditional Territory. The 2006 workshop was attended by more than 130 people (100 of whom were local residents) and many noted changes in weather (warmer temperatures, less snow), fish and wildlife, and altered forest species and ecosystems. Workshop participants expressed a desire for local people to be involved in monitoring of forests and wildlife. The 2007 study involved 30 forest practitioners that expressed the need for increased research and monitoring to identify promising forest management practices. The researchers believe that ongoing collaboration between local residents, governments, and academics will act to enhance the community's adaptive capacity.

Keywords: *adaptation, Champagne and Aishihik First Nations, forest management, forestry, Haines Junction, local knowledge, research needs, south Yukon, Yukon First Nations*

Available Online: Full Article

Citation: Ogden, A.E., Innes, J.L. 2009. Adapting to Climate Change in the Southwest Yukon: Locally Identified Research and Monitoring Needs to Support Decision Making on Sustainable Forest Management. *Arctic* 62(2): 159-174.

Climate Change Adaptation and Regional Forest Planning in Southern Yukon, Canada

Research Location: *Champagne and Aishihik Traditional Territory and Teslin Tlingit Traditional Territory, Yukon*
Publication Date: *2008*
Publication Type: *Journal Article*

Affiliation: *University of British Columbia; Energy, Mines and Resources Yukon*
Contact: *Aynslie E. Ogden, University of British Columbia/Government of Yukon*

Abstract: Recent interest in sustainable forest management planning in the Yukon has coincided with growing public awareness of climate change, providing an opportunity to explore how forestry plans are incorporating climate change. In this paper, the Strategic Forest Management Plans for the Champagne and Aishihik First Nations Traditional Territory (CATT) and the Teslin Tlingit Traditional Territory (TTTT) are examined for evidence of adaptation to climate change. For each plan, management policies and practices that are also recognized as ways to adapt to climate change are identified to provide information on the incremental costs and benefits of additional adaptation efforts. A typology for classifying sustainable forest management plans according to how they address climate change is proposed and applied to the CATT and TTTT plans. This typology, which may be useful to any future retrospective assessments on how successful these or other sustainable forest management plans have been in addressing and managing the risks posed by climate change, consists of a matrix that categorizes plans into one of four types; (1) proactive-direct, (2) proactive-indirect, (3) reactive-direct, and (4) reactive-indirect. Neither of the plans available for the southern Yukon explicitly identifies climate change vulnerabilities and actions that will be taken to reduce those vulnerabilities and manage risks. However, both plans have incorporated some examples of 'best management practices' for sustainable forest management that are also consistent with appropriate climate adaptation responses. Even in a jurisdiction facing rapid ecological changes driven by climate change, where there is a relatively high level of awareness of climate change and its implications, forestry planning processes have yet to grapple directly with the risks that climate change may pose to the ability of forest managers to achieve the stated goals and objectives of sustainable forest management plans.

Local Relevance: This paper reviews the Strategic Forest Management Plans for the Champagne and Aishihik and Teslin Tlingit Traditional Territories in order to assess whether they address climate change vulnerabilities. It was determined that neither Plan directly addresses the risks that climate change poses to forest management or adaptation strategies that could be implemented to deal with such vulnerabilities. Nonetheless, some of the management strategies that were identified as most-promising are those that also make sense from a climate change adaptation perspective.

Keywords: *adaptation, Champagne and Aishihik First Nations, forest management, forestry, south Yukon, Teslin Tlingit First Nation, Yukon First Nations*

Available Online: Abstract

Citation: Ogden, A.E., Innes, J.L. 2008. "Climate Change Adaptation and Regional Forest Planning in southern Yukon, Canada." *Mitigation and Adaptation Strategies for Global Change* 13: 833-861.

Perspectives of Forest Practitioners on Climate Change Adaptation in the Yukon and Northwest Territories of Canada

Research Location: *Yukon and Northwest Territories*
Publication Date: *2007*
Publication Type: *Journal Article*

Affiliation: *University of British Columbia*
Contact: *Aynslie E. Ogden, University of British Columbia/Government of Yukon*

Abstract: Forestry practitioners in the Yukon and Northwest Territories of Canada were asked to complete a questionnaire examining the likely impacts of climate change on forest sector sustainability and adaptation options to climate change. Practitioners were asked to self-assess their knowledge on various aspects of climate change and ranked their level of knowledge as generally only poor to fair, despite past educational efforts in this area. Changes in the intensity, severity or magnitude of forest insect outbreaks, changes in extreme weather events, and changes in the intensity, severity or magnitude of forest fires were the three impacts most frequently identified as having had an impact on sustainability. More than half of the respondents indicated that commodity prices, availability of timber, trade policies, environmental regulations, and the ability to secure needed capital as presently having more of a negative impact on sustainability than climate change. The assessment of 65 potential adaptation options was structured according to the criteria of the Montréal Process. The majority of respondents considered the goals of adaptation to be synonymous with the criteria of sustainable forest management, indicating the Montréal Process criteria provide a suitable framework for assessing adaptation options in the forest sector. The intensity, severity and magnitude of forest insect outbreaks under future climate conditions, forest growth and productivity, precipitation, climate variability and the intensity, severity and magnitude of forest fires were ranked as the most important areas where further information would be of assistance to decision-making.

Local Relevance: This paper highlights the results of a questionnaire completed by forest practitioners in Yukon and Northwest Territories, of which most of the respondents represented Yukon. The respondents generally assessed their knowledge of climate change and related factors as poor to fair. Most of the practitioners state that non-climatic factors (such as prices and policies) currently have a greater impact on forest sustainability than climate change; however, they believe that good forest management practices are also the way to adapt to climate change. Forest fires, insect outbreaks, and extreme weather events were most often noted as having had an adverse effect on sustainability.

Keywords: *adaptation, forest management, forestry, impacts, local knowledge, Yukon-wide*

Available Online: Full Article

Citation: Ogden, A.E., Innes, J.L. 2007. "Perspectives of Forest Practitioners on Climate Change Adaptation in the Yukon and Northwest Territories of Canada." *The Forestry Chronicle* 83(4): 557-569.

Incorporating Climate Change Adaptation Considerations into Forest Management Planning in the Boreal Forest

Research Location: *boreal forest*
Publication Date: *2007*
Publication Type: *Journal Article*

Affiliation: *University of British Columbia*
Contact: *Aynslie E. Ogden, University of British Columbia/Government of Yukon*

Abstract: Climate change will pose increasing challenges to forest managers working to achieve sustainable forest management in the boreal forest. To date, discussions around when, where and how to consider adaptation in forest management plans for the boreal forest have been limited. As a starting point, specific objectives for climate change adaptation need to be articulated, which we consider to be synonymous with the criteria for conservation and sustainable management of boreal forests as defined by the Montréal Process. Secondly, because forest management plans are hierarchal — there are higher level strategic plans and lower level operational plans — it is important to distinguish at which planning level adaptation options are most appropriately considered. The purpose of this paper is to put forward a range of alternative adaptation options that forest managers working in the boreal zone could consider during the development of strategic and operational forest management plans in order to achieve sustainability as defined by the Montréal Process.

Local Relevance: This paper presents adaptation options for attaining sustainable forest management in the boreal forest. Precise goals for climate change adaptation need to be specified and the level of planning at which adaptation is to be considered also needs to be determined. The researchers believe that climate change adaptations are the same actions needed for sustainable forest management and conservation.

Keywords: *adaptation, forest management, forestry, Yukon-wide*

Available Online: Abstract

Citation: Ogden, A.E., Innes, J. "Incorporating Climate Change Adaptation Considerations into Forest Management Planning in the Boreal Forest." *International Forestry Review* 9(3): 713-733.

Forest Management in a Changing Climate: Building the Environmental Information Base for Southwest Yukon (Overview Report)

Research Location: *Champagne and Aishihik Traditional Territory*
Publication Date: *2006*

Affiliation: *University of British Columbia*
Contact: *Aynslie E. Ogden, University of British Columbia/Government of Yukon*

Publication Type: *Project Report*

Excerpt: The goal of this project is to develop knowledge and identify actions that forest managers can consider to help make forests—and the communities and people who rely on them—less likely to be negatively affected by the impacts of climate change. The information provided by this project will help the people who will make decisions about forest management by giving them high quality information to base their decisions on. It is particularly important that managers have reliable information because the forests they are managing are important to people and their communities, and people use the forests every day for recreation, subsistence and for wood for various purposes.

Local Relevance: The majority of this overview report is dedicated to highlighting the key findings of the five background reports produced for this project. The first backgrounder, "Climate, Climate Variability and Climate Change," delves into past, present, and future climates of the southwest Yukon. The second backgrounder, "The Changing Physical Environment," identifies current and possible future changes to the physical environment. The third backgrounder, "Climate Change and Major Forest Disturbance," discusses the spruce bark beetle and forest fires, and how these factors affect forest management. This is followed by "Climate Change and Ecosystem Dynamics" which highlights possible changes to both plant and animal species in the boreal forest. The last backgrounder, "Climate Change and Social/Cultural Values," aims to determine factors that will help decrease vulnerability to future climatic changes. This report also discusses forest management in the Champagne and Aishihik Traditional Territory.

Keywords: *Champagne and Aishihik First Nations, forest management, forestry, impacts, local knowledge, south Yukon*

Available Online: Forest Management in a Changing Climate (Overview Report)

Forest Management in a Changing Climate Project Website

Citation: NCE. 2006. *Forest Management in a Changing Climate: Building the Environmental Information Base for Southwest Yukon*. Northern Climate ExChange: Whitehorse, Yukon.

5. Glaciology

Glacier Systems

Sustained Rapid Shrinkage of Yukon Glaciers since the 1957–1958 International Geophysical Year

Research Location: *St. Elias and Mackenzie Mountains, Yukon*
Publication Date: *2010*
Publication Type: *Journal Article*
Affiliation: *University of Alberta*
Contact: *Nicholas E. Barrand, British Antarctic Survey*

Abstract: Glaciers in the Yukon, NW Canada, lost 22% of their surface area during the 50 years following the 1957–58 International Geophysical Year, coincident with increases in average winter and summer air temperatures and decreases in winter precipitation. Scaling these results to ice volume change, we obtain a total mass loss of 406 ±177 Gt, which accounts for 1.13 ± 0.49 mm of global sea-level rise. Yukon glaciers thinned by 0.78 ± 0.34 m yr^{-1} water equivalent, a regional thinning rate exceeded only by mountain glaciers in Patagonia and Alaska. Our scaling analysis suggests the remaining glaciers have the capacity to contribute a further 5.04 mm to global sea-level rise.

Local Relevance: It was determined that Yukon glaciers experienced a surface area decrease of 22% during the fifty-year period from 1956-1958 to 2006-2008. This period of melting was accompanied by increasing summer and winter temperatures, as well as decreasing winter precipitation. Less snow and warmer summers mean that glaciers accumulate less in winter and melt more in summer. This is aggravated by warmer winter temperatures which can cause winter melt and also results in a greater proportion of winter precipitation falling as rain. The estimated contribution of this glacial melt to sea-level rise was calculated, as was the proposed future contribution should the glaciers melt entirely.

Keywords: *air temperature, glaciology, precipitation, Mackenzie Mountains, sea-level rise, south Yukon, St. Elias Mountains*

Available Online: Full Article

Citation: Barrand, N.E., Sharp, M.J. 2010. "Sustained Rapid Shrinkage of Yukon Glaciers since the 1957–1958 International Geophysical Year." *Geophysical Research Letters* 37(7): L07501, doi:10.1029/2009GL042030.

Airborne and Spaceborne DEM- and Laser Altimetry-derived Surface Elevation and Volume Changes of the Bering Glacier System, Alaska, USA, and Yukon, Canada, 1972-2006

Research Location: *Bering Glacier system, Alaska and Yukon*
Publication Date: *2009*
Publication Type: *Journal Article*

Affiliation: *University of Alaska Fairbanks*
Contact: *Reginald R. Muskett, University of Alaska Fairbanks*

Abstract: Using airborne and spaceborne high-resolution digital elevation models and laser altimetry, we present estimates of interannual and multi-decadal surface elevation changes on the Bering Glacier system, Alaska, USA, and Yukon, Canada, from 1972 to 2006. We find: (1) the rate of lowering during 1972-95 was 0.9±0.1 m a^{-1}; (2) this rate accelerated to 3.0±0.7 m a^{-1}during 1995-2000; and (3) during 2000-03 the lowering rate was 1.5±0.4 m a^{-1}. From 1972 to 2003, 70% of the area of the system experienced a volume loss of 191±17 km^3, which was an area-average surface

elevation lowering of 1.7±0.2 m a^{-1}. From November 2004 to November 2006, surface elevations across Bering Glacier, from McIntosh Peak on the south to Waxell Ridge on the north, rose as much as 53 m. Up-glacier on Bagley Ice Valley about 10 km east of Juniper Island nunatak, surface elevations lowered as much as 28 m from October 2003 to October 2006. NASA Terra/MODIS observations from May to September 2006 indicated muddy outburst floods from the Bering terminus into Vitus Lake. This suggests basal-englacial hydrologic storage changes were a contributing factor in the surface elevation changes in the fall of 2006.

Local Relevance: Models and laser measurements were used to estimate surface elevation changes of the Bering Glacier system from 1972 to 2006. These estimates showed a lowering rate during the period 1995-2000 that was greater than the period from 1972-1995, and a lowering rate during 2000-2003 that was greater than the rate during 1972-1995 but less than the 1995-2000 rate. From 1972 to 2003, the glacier system experienced a volume loss correlated to the surface elevation lowering.

Keywords: *glaciology, Gulf of Alaska, mass balance, south Yukon*

Available Online: Abstract

Citation: Muskett, R.R., Lingle, C.S., Sauber, J.M., Post, A.S., Tangborn, W.V., Rabus, B.T., Echelmeyer, K.A. 2009. "Airborne and Spaceborne DEM- and Laser Altimetry-derived Surface Elevation and Volume Changes of the Bering Glacier System, Alaska, USA, and Yukon, Canada, 1972-2006." *Journal of Glaciology* 55(190): 316-326.

Recent Glacier Mass Changes in the Gulf of Alaska Region from GRACE Mascon Solutions

Research Location: *Gulf of Alaska, Yukon and Alaska*
Publication Date: *2008*
Publication Type: *Journal Article*

Affiliation: *Planetary Geodynamics Laboratory, NASA Goddard Space Flight Centre*
Contact: *Scott B. Luthcke, NASA Goddard Space Flight Centre*

Abstract: The mass changes of the Gulf of Alaska (GoA) glaciers are computed from the Gravity Recovery and Climate Experiment (GRACE) inter-satellite range-rate data for the period April 2003–September 2007. Through the application of unique processing techniques and a surface mass concentration (mascon) parameterization, the mass variations in the GoA glacier regions have been estimated at high temporal (10 day) and spatial (2x2 arc-degrees) resolution. The mascon solutions are directly estimated from a reduction of the GRACE K-band inter-satellite range-rate data and, unlike previous GRACE solutions for the GoA glaciers, do not exhibit contamination by leakage from mass change occurring outside the region of interest. The mascon solutions reveal considerable temporal and spatial variation within the GoA glacier region, with the largest negative mass balances observed in the St Elias Mountains including the Yakutat and Glacier Bay regions. The most rapid losses occurred during the 2004 melt season due to record temperatures in Alaska during that year. The total mass balance of the GoA glacier region was –84 ± 5 Gt a^{-1} contributing 0.23 ± 0.01 mm a^{-1} to global sea-level rise from April 2003 through March 2007. Highlighting the large seasonal and

interannual variability of the GoA glaciers, the rate determined over the period April 2003–March 2006 is –102 ± 5 Gt a^{-1}, which includes the anomalously high temperatures of 2004 and does not include the large 2007 winter balance-year snowfall. The mascon solutions agree well with regional patterns of glacier mass loss determined from aircraft altimetry and in situ measurements.

Local Relevance: Of all mountain glacier systems, the Gulf of Alaska glaciers are contributing the most to global sea-level rise. The St. Elias range experienced one of the most-negative mass balances of the Gulf of Alaska glaciers over the period 2003-2007. An abnormally warm year occurred in 2004, and of the regions studied, the St. Elias region displayed the greatest summer mass loss during this time. In 2006-2007 however, the rate of mass loss decreased for the St. Elias Mountains, likely to do to above-average snowfall. The mass-loss values determined for the St. Elias range are shown to be accurate by comparison with previous studies that utilized different measurement techniques. Evidence suggests that the mass balance of the St. Elias glaciers is controlled by direct and indirect climatic factors.

Keywords: *glaciology, Gulf of Alaska, mass balance, sea-level rise, south Yukon, St. Elias Mountains*

Available Online: Full Article

Citation: Luthcke, S.B., Arendt, A.A., Rowlands, D.D., McCarthy, J.J., Larsen, C.F. 2008. "Recent Glacier Mass Changes in the Gulf of Alaska Region from GRACE Mascon Solutions." *Journal of Glaciology* 54: 767-777.

Volume Changes of Alaska Glaciers: Contributions to Rising Sea Level and Links to Changing Climate

Research Location: *southwest Yukon; Alaska; northwest British Columbia*
Publication Date: *2006*
Publication Type: *Academic Dissertation*

Affiliation: *University of Alaska Fairbanks*
Contact: *Anthony A. Arendt, University of Alaska Fairbanks*

Abstract: We have used airborne altimetry to measure surface elevations along the central flowline of 86 glaciers in Alaska, Yukon Territory and northwestern British Columbia (northwestern North America). Comparison of these elevations with contours on maps derived from1950s to 1970s aerial photography yields elevation and volume changes over a 30 to 45 year period. Approximately one-third of glaciers have been re-profiled 3 to 5 years after the earlier profile, providing a measure of short-timescale elevation and volume changes for comparison with the earlier period. We have used these measurements to estimate the total contribution of glaciers in northwestern North America to rising sea level, and to quantify the magnitude of climate changes in these regions. We found that glaciers in northwestern North America have contributed to about 10% of the rate of global sea level rise during the last half-century and that the rate of mass loss has approximately doubled during the past decade. During this time, summer and winter air temperatures at low elevation climate stations increased by 0.2±0.1 and 0.4±0.2 °C $(decade)^{-1}$ respectively. There was also a weak trend of increasing precipitation and an overall lengthening of the summer melt season. We modeled regional changes

in glacier mass balance with climate station data and were able to reproduce altimetry measurements to within reported errors. We conclude that summer temperature increases have been the main driver of the increased rates of glacier mass loss, but winter warming might also be affecting the glaciers through enhanced melt at low elevations and a change in precipitation from snow to rain, especially in maritime regions. Uncertainties in our calculations are large, owing to the inaccuracies of the maps used to provide baseline elevations, the sparsity of accurate climate data, and the complex and dynamic nature of glaciers in these regions. Tidewater, surging, and lake-terminating glaciers have dynamical cycles that are not linked in a simple way to climate variability. We found that regional volume losses can depend on one or several large and dynamic glaciers. These glaciers should be treated separately when extrapolating altimetry data to an entire region.

Local Relevance: Mass balance predicted for the St. Elias glaciers using data from weather stations was less-negative than the actual observed mass balance over the study period. Negative mass balances were observed throughout the areas studied, presumably due to warmer summer temperatures. However, warmer winter temperatures may be causing accelerated mass loss in coastal regions such as the St. Elias Mountains via glacier melt occurring in winter and winter precipitation falling as rain rather than as snow. In addition, glacier mass changes are consistent with Pacific Decadal Oscillation and Arctic Oscillation phase changes.

Keywords: *air temperature, Arctic Oscillation, glaciology, mass balance, Pacific Decadal Oscillation, sea-level rise, south Yukon, St. Elias Mountains*

Available Online: Full Article

Citation: Arendt, A.A. 2006. "Volume Changes of Alaska Glaciers: Contributions to Rising Sea Level and Links to Changing Climate." PhD diss., University of Alaska Fairbanks.

Individual Glaciers

Present Dynamics and Future Prognosis of a Slowly Surging Glacier

Research Location: *Donjek Range, St. Elias Mountains, Yukon*
Publication Date: *2011*
Publication Type: *Journal Article*

Affiliation: *Simon Fraser University*
Contact: *Gwenn E. Flowers, Simon Fraser University*

Abstract: Glacier surges are a well-known example of an internal dynamic oscillation whose occurrence is not a direct response to the external climate forcing, but whose character (i.e. period, amplitude, mechanism) may depend on the glacier's environmental or climate setting. We examine the dynamics of a small (~5 km^2) valley glacier in Yukon, Canada, where two previous surges have been photographically documented and an unusually slow surge is currently underway. To characterize the dynamics of the present surge, and to speculate on the future of this glacier, we employ a higher-order flowband model of ice dynamics with a regularized Coulomb-friction sliding law in both diagnostic and prognostic simulations. Diagnostic (force balance) calculations capture

the measured ice-surface velocity profile only when non-zero basal water pressures are prescribed over the central region of the glacier, coincident with where evidence of the surge has been identified. This leads to sliding accounting for 50–100% of the total surface motion in this region. Prognostic simulations, where the glacier geometry evolves in response to a prescribed surface mass balance, reveal a significant role played by a bedrock ridge beneath the current equilibrium line of the glacier. Ice thickening occurs above the ridge in our simulations, until the net mass balance reaches sufficiently negative values. We suggest that the bedrock ridge may contribute to the propensity for surges in this glacier by promoting the development of the reservoir area during quiescence, and may permit surges to occur under more negative balance conditions than would otherwise be possible. Collectively, these results corroborate our interpretation of the current glacier flow regime as indicative of a slow surge that has been ongoing for some time, and support a relationship between surge incidence or character and the net mass balance. Our results also highlight the importance of glacier bed topography in controlling ice dynamics, as observed in many other glacier systems.

Local Relevance: The future of this slowly surging glacier was modelled for negative mass balance situations—in other words, situations in which the glacier is melting faster than it is being accumulated. The values used in this study for the glacier's mass balance were based on values found in previous studies for glaciers in the same region. All of these scenarios produced glacial retreat and thinning. These model runs were simplified versions of natural processes and in this case are expected to underestimate glacial retreat and thinning. The researchers hypothesize that a less-negative mass balance than present must be sustained in order for future surges to occur.

Keywords: *Donjek Range, glacier modelling, glaciology, mass balance, south Yukon, St. Elias Mountains*

Available Online: Full Article

Citation: Flowers, G.E., Roux, N., Pimentel, S., Schoof, C.G. 2009. "Present Dynamics and Future Prognosis of a Slowly Surging Glacier." *The Cryosphere* 5: 299-313.

Dynamics of a Small Surge-Type Glacier using One-Dimensional Geophysical Inversion

Research Location: *Donjek Range, St. Elias Mountains, Yukon*
Publication Date: *2009*
Publication Type: *Journal Article*

Affiliation: *Simon Fraser University*
Contact: *Gwenn E. Flowers, Simon Fraser University*

Abstract: We investigate the dynamics of a small surge-type valley glacier as part of a study to characterize glacier response to climate in the Donjek Range, southwest Yukon, Canada. Pole displacements were measured using kinematic GPS techniques during three consecutive summer field seasons. Measured surface velocities range from $<10 ma^{-1}$ over the lower 1500m of the 5 km long glacier to a maximum of $\sim 25–35 ma^{-1}$ over the upper 3500 m. Basal velocities along an

approximate flowline are reconstructed from the measured surface velocities using inverse methods. Control tests are used to validate the inversion scheme, and sensitivity tests are performed to evaluate the influence of the flow-law coefficient, shape factor and longitudinal averaging length. Inversion of the real data shows that basal motion accounts for 50–100% of the total surface motion along the flowline. Based on these results, and several other lines of evidence, we suggest this glacier may be undergoing a slow surge.

Local Relevance: The researchers hypothesize that this glacier is undergoing a slow surge—in other words, a surge inconsistent with the previous surge history of this glacier. It is possible that this surge is part of the glacier's natural surge cycle, but also likely that this slow surge may be the result of insufficient mass accumulation to support a regular surge. Based on the recent mass balance of this glacier, continuation of this slow surge will result in glacier thinning.

Keywords: *Donjek Range, glaciology, mass balance, south Yukon, St. Elias Mountains*

Available Online: Full Report

Citation: De Paoli, L., Flowers, G.E. 2009. "Dynamics of a Small Surge-Type Glacier using One-Dimensional Geophysical Inversion. "*Journal of Glaciology* 55(194): 1101-1112.

Spatial and Temporal Transferability of a Distributed Energy-Balance Glacier Melt Model

Research Location: *Donjek Range, St. Elias Mountains, Yukon*
Publication Date: *2011*
Publication Type: *Journal Article*

Affiliation: *Simon Fraser University*
Contact: *Gwenn E. Flowers, Simon Fraser University*

Abstract: Modeling melt from glaciers is crucial to assessing regional hydrology and eustatic sea level rise. The transferability of such models in space and time has been widely assumed but rarely tested. To investigate melt model transferability, a distributed energy-balance melt model (DEBM) is applied to two small glaciers of opposing aspects that are 10 km apart in the Donjek Range of the St. Elias Mountains, Yukon Territory, Canada. An analysis is conducted in four stages to assess the transferability of the DEBM in space and time: 1) locally derived model parameter values and meteorological forcing variables are used to assess model skill; 2) model parameter values are transferred between glacier sites and between years of study; 3) measured meteorological forcing variables are transferred between glaciers using locally derived parameter values; 4) both model parameter values and measured meteorological forcing variables are transferred from one glacier site to the other, treating the second glacier site as an extension of the first. The model parameters are transferable in time to within a <10% uncertainty in the calculated surface ablation over most or all of a melt season. Transferring model parameters or meteorological forcing variables in space creates large errors in modeled ablation. If select quantities (ice albedo, initial snow depth, and

summer snowfall) are retained at their locally measured values, model transferability can be improved to achieve ≤15% uncertainty in the calculated surface ablation.

Local Relevance: This study addresses whether the common practice of calibrating a glacial-melt climate model for one glacier and then extrapolating it to other glaciers in the same general area is actually accurate. Using two nearby glaciers in the Donjek Range, the transfer of model parameters (such as the reflectivity of the snow) between glaciers was relatively accurate but the transfer of meteorological values (such as the amount of snowfall) yielded large inaccuracies. Transferring both model parameters and meteorological values was also inaccurate. However, the researchers recommend that this error can be greatly improved by using glacier-specific values for ice albedo, initial snow depth, and summer snowfall.

Keywords: *Donjek Range, glacier modelling, glaciology, south Yukon, St. Elias Mountains*

Available Online: Full Article

Citation: MacDougall, A.H., Flowers, G.E. 2011. "Spatial and Temporal Transferability of a Distributed Energy-Balance Glacier Melt Model." *Journal of Climate* 24: 1480-1498.

Glacier Subsurface Heat-Flux Characterizations for Energy-Balance Modelling in the Donjek Range, Southwest Yukon, Canada

Research Location: *Donjek Range, St. Elias Mountains, Yukon*
Publication Date: *2011*
Publication Type: *Journal Article*

Affiliation: *Simon Fraser University*
Contact: *Gwenn E. Flowers, Simon Fraser University*

Abstract: We apply a point-scale energy-balance model to a small polythermal glacier in the St Elias Mountains of Canada in order to investigate the applicability and limitations of different treatments of the glacier surface temperature and subsurface heat flux. These treatments range in complexity from a multilayer subsurface model that simulates snowpack evolution, to the assumption of a constant glacier surface temperature equal to 0°C. The most sophisticated model includes dry densification of the snowpack, penetration of shortwave radiation into the subsurface, internal melting, refreezing of percolating meltwater and generation of slush layers. Measurements of subsurface temperature and surface lowering are used for model validation, and highlight the importance of including subsurface penetration of shortwave radiation in the model. Using an iterative scheme to solve for the subsurface heat flux as the residual of the energy-balance equation results in an overestimation of total ablation by18%, while the multilayer subsurface model underestimates ablation by 6%. By comparison, the 0°C surface assumption leads to an overestimation of ablation of 29% in this study where the mean annual air temperature is about –8°C.

Local Relevance: This study investigates whether glacier surface temperature and sub-surface heat flux patterns need to be included in glacier energy-balance modelling. Different errors resulting from various assumptions when applying the models are presented. It is essential to have accurate energy-balance models in order to fully understand the relationship between glaciers and climate and to enable accurate future calculations.

Keywords: *Donjek Range, glacier modelling, glaciology, south Yukon, St. Elias Mountains*

Available Online: Preview

Citation: Wheler, B.A., Flowers, G.E. 2011. "Glacier Subsurface Heat-Flux Characterizations for Energy-Balance Modelling in the Donjek Range, Southwest Yukon, Canada." *Journal of Glaciology* 57(201): 121-133.

Glacier Melt Modelling in the Donjek Range, St. Elias Mountains, Yukon Territory

Research Location: *Donjek Range, St. Elias Mountains, Yukon*
Publication Date: *2009*
Publication Type: *Academic Dissertation*

Affiliation: *Simon Fraser University*
Contact: *Gwenn E. Flowers, Simon Fraser University*

Abstract: Toward addressing the challenges associated with regional glacier melt modelling, I investigate the physical mechanisms of glacier melt using energy balance models, then test empirical temperature-index melt models for regional applications. First, five energy balance models are applied to two glaciers in the Donjek Range, St. Elias Mountains in order to quantify the differences between various treatments of the glacier surface temperature and subsurface heat flux. A model that assumes a constant 0 °C surface temperature consistently overestimates cumulative melt by 9-13%, but a simple model that computes surface temperature changes from the residual of the energy balance equation yields significant improvement. Second, I evaluate the transferability of spatially-distributed temperature-index melt models through the application of calibrated model parameters to periods and locations that differ from those used for calibration. Results show that the calibrated model parameters can be transferred between the study glaciers with minimal reductions in skill.

Local Relevance: This thesis investigates how considerations of surface temperature and sub-surface heat flux affect glacier melt models, as well as how accurately these models can be transferred through time and space. It is concluded that it is important to include the sub-surface heat flux and surface temperature in the models for the two study glaciers, and that simplifying these factors may increase melt-modelling uncertainty during the spring and fall. Melt was drastically overestimated for one of the study glaciers when the model did not include fluctuations in surface temperature. It was found that model parameters could be transferred between glaciers during the same time period, but the model performs poorly when transferred in time for the same glacier. Mass balances for the two glaciers were estimated to be negative, but there are uncertainties in this estimation associated with modelling winter accumulation.

Keywords: *Donjek Range, glacier modelling, glaciology, mass balance, south Yukon, St. Elias Mountains*

Available Online: Full Article

Citation: Wheler, B.A. 2009. "Glacier Melt Modelling in the Donjek Range, St. Elias Mountains, Yukon Territory." MSc diss., Simon Fraser University.

6. Fish and Wildlife

Implications of Climate Change for Northern Canada: Freshwater, Marine, and Terrestrial Ecosystems

Research Location: *Yukon; Northwest Territories; Nunavut*
Publication Date: *2009*
Publication Type: *Journal Article*
Affiliation: *University of Victoria; Environment Canada*
Contact: *Terry D. Prowse, University of Victoria/Environment Canada*

Abstract: Climate variability and change is projected to have significant effects on the physical, chemical, and biological components of northern Canadian marine, terrestrial, and freshwater systems. As the climate continues to change, there will be consequences for biodiversity shifts and for the ranges and distribution of many species with resulting effects on availability, accessibility, and quality of resources upon which human populations rely. This will have implications for the protection and management of wildlife, fish, and fisheries resources; protected areas; and forests. The northward migration of species and the disruption and competition from invading species are already occurring and will continue to affect marine, terrestrial, and freshwater communities. Shifting environmental conditions will likely introduce new animal-transmitted diseases and redistribute some existing diseases, affecting key economic resources and some human populations. Stress on populations of iconic wildlife species, such as the polar bear, ringed seals, and whales, will continue as a result of changes in critical sea-ice habitat interactions. Where these stresses affect economically and culturally important species, they will have significant effects on people and regional economies. Further integrated, field-based monitoring and research programs, and the development of predictive models are required to allow for more detailed and comprehensive projections of change to be made, and to inform the development and implementation of appropriate adaptation, wildlife, and habitat conservation and protection strategies.

Local Relevance: Climate change will affect species distribution and biodiversity and is expected to facilitate the expansion of new animal-transmitted diseases as well as alter the distribution of existing diseases. As the extent and distribution of sea ice continues to change, increased stress on polar bear and seal populations (as well as other marine animals) can be expected. All of these effects will have profound physical and cultural implications for people who live in the North. The authors call for more-detailed monitoring and modelling to guide the formation of adaptation strategies.

Keywords: *impacts, wildlife, Yukon-wide*

Available Online: Abstract

Citation: Prowse, T.D., Furgal, C., Wrona, F.J., Reist, J.D. 2009. "Implications of Climate Change for Northern Canada: Freshwater, Marine, and Terrestrial Ecosystems." *Ambio* 38(5): 282-289.

Community-Based Fish and Wildlife Work Plan for the Na-Cho Nyäk Dun Traditional Territory 2008-2013

Research Location: *Na-Cho Nyäk Dun Traditional Territory (NNDTT)*
Publication Date: *2008*
Publication Type: *Government Publication*
Affiliation: *Environment Yukon*
Contact: *Director, Fish and Wildlife Branch, Environment Yukon*

Excerpt: This plan represents a cooperative approach to fish and wildlife management involving the First Nation of Na-Cho Nyäk Dun (NND), the Mayo District Renewable Resources Council (MDRRC), and Environment Yukon (YG); hereafter referred to as the planning participants. The intent of this plan is to document concerns and potential solutions voiced about fish and wildlife management in the NND traditional territory (NNDTT), and not to legally bind any of the involved planning participants to specific actions or solutions described herein. This community-based fish and wildlife plan is intended to be implemented over a five-year period (2008–2013) and attempts to coordinate the efforts of the planning participants to address local fish and wildlife concerns.

The 2008–2013 Community-Based Fish and Wildlife Work Plan for the NNDTT is the fourth community-based fish and wildlife plan for the traditional territory. The plan follows the "1993–1996 Integrated Big Game Management Plan for the Mayo Region," the "1997 Integrated Wildlife Management Plan for the Nacho Nyäk Dun Traditional Territory" and the "2002–2007 Community-Based Fish and Wildlife Management Plan for the Nacho Nyäk Dun Traditional Territory."…

Local Relevance: There is concern regarding the possible effects of climate change on trout habitat in smaller lakes—obtaining data from previous studies is proposed. Habitat changes such as lakes drying up and altered moose movements have been observed, and it is noted that habitat changes can be promoted by climate change or forest fires. It is also noted that moose are affected by snow depth and whether there is ice-crusting on top of the snow. The report calls for continued monitoring of plant and animal species (with a greater focus on sheep) to identify the potential impacts of climate change on these populations.

Keywords: *central Yukon, First Nation of Na-Cho Nyäk Dun, fish, impacts, local knowledge, Mayo, moose, sheep, trout, wildlife, Yukon First Nations*

Available Online: Full Report

Citation: Na-Cho Nyäk Dun Fish and Wildlife Planning Team. 2008. *Community based fish and wildlife management plan for the Na-Cho Nyäk Dun Traditional Territory*. Environment Yukon, Whitehorse, Yukon. 45 pages.

Fish

Water Temperature Data Collection Program

Research Location: *Ta'an Kwäch'än Council Traditional Territory*
Publication Date: *2010*
Publication Type: *Government Publication*
Affiliation: *Ta'an Kwäch'än Council (TKC)*
Contact: *TKC Lands, Resources and Heritage Department*

Excerpt: The Ta'an Kwäch'än Council has received funding from Indian and Northern Affairs Climate Change Impacts and Adaptation Program to carry out a Water Temperature Collection Program within our Traditional Territory. The Program will start in the summer of 2010. We wrote this report to inform our citizens of the projects that we will be conducting. We had two other reports prepared. The first is the "Guidebook for the use of Data Loggers to measure Water Temperatures in the Southwest Yukon". This will help our staff when they carry out the field work. The second is the "Ta'an Kwäch'än Council Water Temperature Data Collection Program: a geographical, administrative and temporal context." This explains our Program to others who share the land and waters of our Traditional Territory and others beyond them. The reports can be found on the TKC website at: www.taan.ca …

Local Relevance: The Water Temperature Data Collection Program is composed of three main projects; information collected from the program can be used to calibrate hydrological models for the southwest Yukon. The first project aims to determine the effect of Lake Laberge on the temperature of the Yukon River at the lake outlet. It is suspected that the Yukon River is colder downstream of Lake Laberge which is helpful to salmon migrating upstream and may become even more important as the climate warms. The second project investigates the effects of climate-related events such as forest fires and landslides on the temperature of important streams. The third project aims to measure the temperatures of groundwater discharge zones.

Keywords: *fish, hydrology, Lake Laberge, salmon, south Yukon, Ta'an Kwäch'än Council, water temperature, Yukon First Nations, Yukon River*

Available Online: Water Temperature Data Collection Program

Monitoring Fresh Water Thermal Regimes—A Technical Context

Guidebook for Use of Data Loggers to Measure Water Temperature in the South West Yukon

Citation: Ta'an Kwäch'än Council. Dept. of Lands, Resources and Heritage. *Water Temperature Data Collection Program*. TKC: 2010.

The Biotic and Abiotic Interactions Influencing Organochlorine Contaminants in Temporal Trends (1992-2003) of Three Yukon Lakes: Focus on Lake Laberge

Research Location: *Lake Laberge, Kusawa Lake, and Quiet Lake, Yukon*
Publication Date: *2006*
Publication Type: *Academic Dissertation*

Affiliation: *University of Manitoba*
Contact: *Gary A. Stern, University of Manitoba/Fisheries and Oceans Canada*

Abstract: Periodic monitoring of contaminant levels in fish from the Yukon Territory indicated that oganochlorine (OC) contaminants had rapidly declined since the early 1990s. This study examined OC concentrations, including chlordane (ΣCHL), ΣDDT, hexachlorocyclohexane (ΣHCH), toxaphene (ΣCHB), ΣPCB and chlorinated benzenes (ΣCBz) in sentinel fish (species of consistent annual observation and collection) from two Yukon lakes (Kusawa, Quiet), and from the aquatic food web of a focus lake (Lake Laberge) across several temporal points between 1993 and 2003. OC analysis and phytoplankton counts from dated sediment cores as well as climate data were also collected. Population, morphological (length, weight, age), biochemical (lipid content, $\partial^{13}C$, $\partial^{15}N$) and OC contaminant data for fish and invertebrates (zooplankton, snails, clams) were reviewed to elucidate the primary causes for these OC declines…

Local Relevance: Oganochlorine contaminants decreased over 1992-2003 in the three Yukon lakes studied. Organochlorine contaminant levels are most-strongly determined by the length of the food chain or food web dynamics. This decreasing trend may be partly due to lower precipitation and increases in lake primary production as a result of warmer temperatures during the 1990s which both act to reduce contaminant levels at the bottom of the food chain. Another possible factor is increased fish populations, diluting contaminants as they move up the food chain. At the same time, increased rain and glacial melt can contribute more organichlorine contaminants to the lake system. It is believed that increased primary production is the main cause of the decreasing trend.

Keywords: *chlorine, contaminants, fish, Kusawa Lake, Lake Laberge, precipitation, primary production, south Yukon, Quiet Lake*

Available Online: Full Article

Citation: Ryan, M.J. 2006. "The Biotic and Abiotic Interactions Influencing Organochlorine Contaminants in Temporal Trends (1992-2003) of Three Yukon Lakes: Focus on Lake Laberge." PhD diss., University of Manitoba.

Projected Impacts of Climate Warming on Production of Lake Trout (*Salvelinus namaycush*) in Southern Yukon Lakes

Research Location: *southern Yukon*
Publication Date: *2006*
Publication Type: *Journal Article*

Affiliation: *University of Calgary*
Contact: *Jody L. Mackenzie-Grieve, Fisheries and Oceans Canada*

Abstract: We used existing models to predict changes in lake surface temperature and thermocline depth, in combination with a newly developed model to describe lake thermal profiles, to determine how thermal properties of a series of lakes located predominantly in the southern Yukon could change under three realistic climate-warming scenarios. We then used existing models to determine how relative changes in potential harvest of lake trout (*Salvelinus namaycush*) in southern Yukon lakes could change as availability of optimal thermal habitat was altered under the three warming scenarios. With warming, an overall decrease in availability of optimal thermal habitat and in lake trout potential harvest is predicted in southern Yukon lakes, although considerable lake-specific variation in direction and magnitude of change exists. For southern Yukon lakes overall, 2, 4, and 6 °C increases in mean annual air temperature lead to 12%, 35%, and 40% decreases in thermal habitat volume, respectively, and 8%, 19%, and 23% reductions in potential harvest, respectively.

Local Relevance: Data were used from 33 southern Yukon lakes to model the impacts of climate change on lake trout. Previous studies have indicated that lake trout prefer 8-12°C water; as the climate warms the availability of water of this temperature in lakes may change. Although there were variations as to whether the quantity of water with the specific temperature range in a specific lake increased or decreased, overall warming scenarios correspond with decreased habitat for lake trout. This corresponds to a decrease in potential lake trout harvest from southern Yukon lakes. It is predicted that in the long-term, preferred lake trout habitat will shift northward to colder lakes.

Keywords: *fish, hydrological modelling, south Yukon, trout, water temperature*

Available Online: Full Article

Citation: Mackenzie-Grieve, J.L., Post, J.R. 2006. "Projected Impacts of Climate Warming on Production of Lake Trout (*Salvelinus namaycush*) in Southern Yukon Lakes." *Canadian Journal of Fisheries and Aquatic Sciences* 63: 788-797.

A Review of the Occurrence of Pacific Salmon (*Oncorhynchus* spp.) in the Canadian Western Arctic

Research Location: *western Canadian Arctic*
Publication Date: *2006*
Publication Type: *Journal Article*

Affiliation: *Fisheries and Oceans Canada*
Contact: *Sam Stephenson, Fisheries and Oceans Canada*

Abstract: This manuscript summarizes all known captures of Pacific salmon (*Oncorhynchus* spp.) in the Canadian western Arctic up to the end of 2003. Historic information on Pacific salmon distribution in the Canadian western Arctic is limited, and some older identifications are suspect. It is difficult to determine whether salmon numbers are actually increasing, or whether a recently established program to gather information on Pacific salmon abundance has only made them appear more abundant than historically. However, there is no evidence of newly established populations and overall not enough information to state definitively that salmon are increasing in frequency in the Canadian western Arctic as a direct result of climate change.

Local Relevance: This paper investigates the known captures of Pacific salmon in the Canadian Arctic up to 2003, with the intention of determining whether populations of non-native salmon species have been increasing in northern waters. In Yukon, there have been reported captures of salmon thought to be chum, sockeye, and chinook. It concluded that Pacific salmon in the Arctic show an increasing trend; however, it is uncertain whether this trend is due to actual population increases or to better monitoring programs. It is determined that there have been no new populations of Pacific salmon in the Arctic and that there is no concrete evidence that climate change is resulting in higher number of Pacific salmon in the Arctic.

Keywords: *fish, salmon, Yukon-wide*

Available Online: Full Article

Citation: Stephenson, S.A. 2006. "A Review of the Occurrence of Pacific Salmon (*Oncorhynchus* spp.) in the Canadian Western Arctic." *Arctic* 59(1): 37-46.

Effect of *Ichthyophonus* on Survival and Reproduction in Yukon River Chinook Salmon

Research Location: *Yukon River; Tanana River; Chena River; Salcha River*
Publication Date: *2004*
Publication Type: *Project Report*

Affiliation: *University of Washington*
Contact: *Richard M. Kocan, University of Washington*

Abstract: Between 1999 and 2002 a total of 2,475 Yukon River Chinook salmon were examined for the presence of *Ichthyophonus* and its associated pathogenic effects. Overall infection prevalence in the Yukon River peaked at river mile l,230 at ~40% and on the Tanana River it peaked at ~30% at rm 900. Significantly more females than males were infected at all sites and all years in the Yukon River, while in the Tanana River there was no difference between male and female infection prevalence was apparent. Clinical disease in infected fish increased from ~5% at the mouth of the Yukon River to 35% at rm 731 on the Yukon River, and to 22% at rm 900 on the Tanana River. When fish approached the upper reaches of the Yukon River at river mile 1,745 (Whitehorse, Y.T.) and the spawning areas of the Chena and Salcha Rivers, infection prevalence dropped significantly to <15%. Clinical disease dropped to ~12% at rm 1,745 on the Yukon River and < 10% on the Chena and Salcha Rivers (rm 970 -1,015). Position of fish within the run did not affect infection or disease prevalence, but a higher percent of fish at the end of the run exhibited disseminated disease (multiple infected organs). This was verified by muscle biopsies taken at the U.S.-Canada border (rm 1,220). Increasing river temperature from mid June through mid July occurred during the second half of the run and appeared to be correlated with increased disease prevalence in migrating fish. *Ichthyophonus* was detected in chinook salmon in the Kuskokwim and Taku Rivers during limited surveys. The source of infection could not be determined, but no *Ichthyophonus*-infected herring could be found north of the Aleutians, while all populations of herring sampled south of the Aleutians were infected at

relatively high levels. The discovery of infected burbot demonstrated the presence of *Ichthyophonus* in a freshwater Yukon River species. It is not know if this infection is endemic or acquired through ingestion of infected salmon tissues. A limited survey of pike, grayling, sheefish and juvenile salmon revealed no infected individuals, however we found 6% of chum salmon to be infected without signs of clinical disease.

Local Relevance: From 1999 to 2002, Yukon River chinook salmon were studied for signs of the pathogen *Ichthyophonus.* There was a greater proportion of diseased fish during the second half of the run correlated with increasing water temperatures from the middle of June to mid-July. The greatest number of fish with multiple infected organs was observed during the years with highest water temperature (1999 and 2001) and the lowest number was observed during 2002, the year with the lowest water temperature. Evidence suggests that the pathogen is better able to spread and infect salmon in higher water temperatures (above 15°C).

Keywords: *Chena River, fish, pathogens, Salcha River, salmon, Tanana River, water temperature, Yukon River, Yukon River Basin*

Available Online: Full Article

Citation: Kocan, R., and Hershberger, P. 2004. "Effect of *Ichthyophonus* on Survival and Reproduction in Yukon River Chinook Salmon." University of Washington, Project # URE-13-01 & 02.

Effects of Climate Change on Mercury Concentrations in Arctic Char (*Salvelinus Alpinus*) in the High Arctic

Research Location: *the Arctic, including Herbert Lake, Yukon*
Publication Date: *2008*
Publication Type: *Academic Dissertation*

Affiliation: *University of Guelph*
Contact: *Nikolaus Gantner, University of Victoria*

Abstract: This thesis is an investigation of linkages of climate change and mercury concentrations in landlocked Arctic char and underlying food webs in Canadian Arctic lakes. Although the neurotoxin mercury is globally present in all environments, temporal and spatial trends in aquatic biota are often inconsistent, or do not exist for remote environments. Knowledge gaps include the influence of abiotic factors, possibly climate, and food web parameters on mercury accumulation in top predators. Furthermore, anthropogenic and natural mercury present in the environment are not well differentiated. To address these research needs, we collected landlocked Arctic char from 27 systems and food web organism from 18 lakes, and recorded abiotic lake characteristics expected to influence mercury cycling. Total mercury (THg) and monomethylmercury (MeHg) concentrations, and stable isotopes of carbon ($\partial^{13}C$), nitrogen ($\partial^{15}N$), and mercury ($\partial^{x}Hg$) were determined. Relationships among these measures and with environmental characteristics were investigated…

Local Relevance: Data was collected from many arctic lakes to study the transport of mercury through arctic food webs and to see if mercury concentrations had changed over time. One of the study lakes (Herbert Lake) was located in Yukon; this lake had higher mercury levels than most of the other lakes in the study. It was determined that changes in air and water temperature are unlikely to have a direct impact on mercury concentrations in arctic food webs; however, mercury may enter lake systems as permafrost thaws and increased precipitation could deposit greater amounts of mercury into lakes.

Keywords: *contaminants, fish, Herbert Lake, mercury, north Yukon*

Available Online: Full Article

Citation: Gantner, N. 2008. "Effects of Climate Change on Mercury Concentrations in Arctic Char (*Salvelinus Alpinus*) in the High Arctic." PhD diss., University of Guelph.

Mammals

Bioenergetic Prediction of Climate Change Impacts on Northern Mammals

Research Location: *Canada*
Publication Date: *2004*
Publication Type: *Journal Article*

Affiliation: *McGill University*
Contact: *Murray M. Humphries, McGill University*

Abstract: Climate change will likely alter the distribution and abundance of northern mammals through a combination of direct, abiotic effects (*e.g.*, changes in temperature and precipitation) and indirect, biotic effects (*e.g.*, changes in the abundance of resources, competitors, and predators). Bioenergetic approaches are ideally suited to predicting the impacts of climate change because individual energy budgets integrate biotic and abiotic influences, and translate individual function into population and community outcomes. In this review, we illustrate how bioenergetics can be used to predict the regional biodiversity, species range limits, and community trophic organization of mammals under future climate scenarios. Although reliable prediction of climate change impacts for particular species requires better data and theory on the physiological ecology of northern mammals, two robust hypotheses emerge from the bioenergetic approaches presented here. First, the impacts of climate change in northern regions will be shaped by the appearance of new species at least as much as by the disappearance of current species. Second, seasonally inactive mammal species (*e.g.*, hibernators), which are largely absent from the Canadian arctic at present, should undergo substantial increases in abundance and distribution in response to climate change, probably at the expense of continuously active mammals already present in the arctic.

Local Relevance: The diversity of mammal species is predicted to increase with climate change as a result of increases in ecosystem productivity, and the diversity increases are expected to be greatest further north. The distribution and relationships between herbivores and carnivores will shift as primary productivity increases. Mammals that are seasonally active are expected to increase in abundance and expand their range northward as summers become longer and winters shorter. This

will likely be accompanied by a decrease in abundance and distribution of continuously active species.

Keywords: *caribou, polar bear, primary production, snowshoe hare, wildlife, Yukon-wide*

Available Online: Full Article

Citation: Humphries, M.M., Umbanhowar, J., McCann, K.S. 2004. "Bioenergetic Prediction of Climate Change Impacts on Northern Mammals." *Integrative and Comparative Biology* 44: 152-162.

''Emerging'' Parasitic Infections in Arctic Ungulates

Research Location: *Yukon; Northwest Territories; Nunavut*
Publication Date: *2004*
Publication Type: *Journal Article*

Affiliation: *Western College of Veterinary Medicine*
Contact: *Susan J. Kutz, University of Calgary*

Abstract: Important drivers for emergence of infectious disease in wildlife include changes in the environment, shrinking habitats or concentration of wildlife, and movement of people, animals, pathogens, or vectors. In this paper we present three case-studies of emerging parasitic infections and diseases in ungulates in the Canadian north. First we discuss climate warming as an important driver for the emergence of disease associated with *Umingmakstrongylus pallikuukensis*, a nematode lungworm of muskoxen. Then we examine how *Protostrongylus stilesi*, the sheep lungworm, emerged (or re-emerged) in muskoxen after re-introduction of this host into its historical range made it sympatric with Dall's sheep. Finally, we consider *Teladorsagia boreoarcticus*, a newly described and common abomasal nematode of muskoxen that is emerging as a disease-causing parasite and may be an important regulator for muskox populations on Banks Island, Northwest Territories. These and other arctic host-parasite systems are exquisitely tuned and constrained by a harsh and highly seasonal environment. The dynamics of these systems will be impacted by climate change and other ecological disruptions. Baseline knowledge of parasite biodiversity and parasite and host ecology, together with predictive models and long-term monitoring programs, are essential for anticipating and detecting altered patterns of host range, geographic distribution, and the emergence of parasitic infections and diseases.

Local Relevance: A muskoxen parasite thriving in the region between the Mackenzie and Coppermine rivers in Northwest Territories is thought to be emerging as a result of higher parasite development rates in warmer temperatures. It is suspected that this parasite will continue to thrive in muskoxen populations that migrate west and south, possibly across the Mackenzie River. However, another muskoxen parasite recently seen in Yukon is thought to have emerged as result of species interactions, not climate change. It is expected that climate change will allow parasites and their host species to migrate northward and habitat reduction will increase chances of parasite transmission within and among species.

Keywords: *muskoxen, north Yukon, parasites, wildlife*

Available Online: Full Article

Citation: Kutz, S.J., Hoberg, E.P., Nagy, J., Polley, L., Elkin, B. 2004. "'Emerging' Parasitic Infections in Arctic Ungulates." *Integrative and Comparative Biology* 44: 109-118.

Climate Change Threatens Polar Bear Populations: A Stochastic Demographic Analysis

Research Location: *Beaufort Sea*
Publication Date: *2010*
Publication Type: *Journal Article*

Affiliation: *University of Alaska Fairbanks*
Contact: *Christine M. Hunter, University of Alaska Fairbanks*

Abstract: The polar bear (*Ursus maritimus*) depends on sea ice for feeding, breeding, and movement. Significant reductions in Arctic sea ice are forecast to continue because of climate warming. We evaluated the impacts of climate change on polar bears in the southern Beaufort Sea by means of a demographic analysis, combining deterministic, stochastic, environment-dependent matrix population models with forecasts of future sea ice conditions from IPCC general circulation models (GCMs). The matrix population models classified individuals by age and breeding status; mothers and dependent cubs were treated as units. Parameter estimates were obtained from a capture–recapture study conducted from 2001 to 2006. Candidate statistical models allowed vital rates to vary with time and as functions of a sea ice covariate. Model averaging was used to produce the vital rate estimates, and a parametric bootstrap procedure was used to quantify model selection and parameter estimation uncertainty. Deterministic models projected population growth in years with more extensive ice coverage (2001–2003) and population decline in years with less ice coverage (2004–2005). LTRE (life table response experiment) analysis showed that the reduction in λ in years with low sea ice was due primarily to reduced adult female survival, and secondarily to reduced breeding. A stochastic model with two environmental states, good and poor sea ice conditions, projected a declining stochastic growth rate, log λ_s, as the frequency of poor ice years increased. The observed frequency of poor ice years since 1979 would imply log $\lambda_s \approx -0.01$, which agrees with available (albeit crude) observations of population size. The stochastic model was linked to a set of 10 GCMs compiled by the IPCC; the models were chosen for their ability to reproduce historical observations of sea ice and were forced with ''business as usual'' (A1B) greenhouse gas emissions. The resulting stochastic population projections showed drastic declines in the polar bear population by the end of the 21st century. These projections were instrumental in the decision to list the polar bear as a threatened species under the U.S. Endangered Species Act.

Local Relevance: A population model was developed to predict the future consequences of climate change on polar bears living in the southern Beaufort Sea area. From 2001-2003 to 2004-2005, the length of the ice-free season in this area increased by about 50%. The model output yielded an 80-94% chance that this polar bear population would become extinct by 2100 as a result of declining sea ice extent and thickness. Polar bears require sea ice to hunt prey and provide travel routes; decreased sea ice results in nutritional deficits, starvation, and increased risk of injury.

Keywords: *Beaufort Sea, climate modelling, north Yukon, polar bear, population dynamics, sea ice, wildlife*

Available Online: Full Article

Citation: Hunter, C.M., Caswell, H., Runge, M.C., Regehr, E.V., Amstrup, S.C., Stirling, I. 2010. "Climate Change Threatens Polar Bear Populations: A Stochastic Demographic Analysis." *Ecology* 91(10): 2883-2897.

The Role of Phenotypic Plasticity in Responses of Hunted Thinhorn Sheep Ram Horn Growth to Changing Climate Conditions

Research Location: *Southern Lakes, Pelly Mountains, Ruby Range, and Ogilvie/Mackenzie Mountains, Yukon*
Publication Date: *2010*
Publication Type: *Journal Article*

Affiliation: *University of Helsinki*
Contact: *John Loehr, University of Helsinki*

Abstract: When phenotypic change occurs over time in wildlife populations, it can be difficult to determine to what degree it is because of genetic effects or phenotypic plasticity. Here, we assess phenotypic changes over time in horn length and volume of thinhorn sheep (*Ovis dalli*) rams from Yukon Territory, Canada. We considered 42 years of horn growth from over 50,000 growth measurements in over 8000 individuals. We found that weather explained a large proportion of the annual fluctuation in horn growth, being particularly sensitive to spring weather. Only 2.5% of variance in horn length growth could be explained by an individual effect, and thus any genetic changes over the time period could only have had a small effect on phenotypes. Our findings allow insight into the capacity for horn morphology to react to selection pressures and demonstrate the overall importance of climate in determining growth.

Local Relevance: This study investigated changes in the length and volume of the horns of thinhorn sheep over 42 years in order to determine whether the observed changes were a result of phenotypic plasticity or genetic effects. Altered horn growth was determined to be mainly due to phenotypic plasticity and was particularly affected by spring weather.

Keywords: *evolution, Mackenzie Mountains, Pelly Mountains, phenotypic plasticity, Ruby Range, sheep, south Yukon, wildlife*

Available Online: Abstract

Citation: Loehr, J., Carey, J., O'Hara, R.B., Hik, D.S. 2010. "The role of Phenotypic Plasticity in Responses of Hunted Thinhorn Sheep Ram Horn Growth to Changing Climate Conditions." *Journal of Evolutionary Biology* 23(4): 783-790.

Rationale for Implementing Conservation Measures to Protect the Porcupine Caribou Herd

Research Location: *range of the Porcupine Caribou herd*
Publication Date: *2009*
Publication Type: *Government Publication*

Affiliation: *Environment Yukon*
Contact: *Environment Yukon*

Excerpt: This paper articulates Yukon Government's scientific rationale for implementing interim conservation measures for the Porcupine Caribou Herd (PCH) and is aimed at a broad audience with a diverse and varied background. This information has been used in public meetings and for government-to-government consultation.

The Yukon Governments decision to propose interim conservation measures was based on our obligations under the land claims agreements to ensure conservation, optimum long term productivity of the herd, sustainability of the herd, and a sustainable harvest. Yukon Government's concern for conservation is shared by all First Nations and Inuvialuit who use the herd for subsistence, as well as the co-management bodies who have a mandate for the management of the herd, communities within the Canadian range of the herd, and the general Yukon public. These collective concerns and our obligation under the land claims agreements, and our obligation to the Yukon public, provided the direction for government to propose these interim measures…

Local Relevance: Part of the recent Porcupine caribou population decline may be related to warmer spring temperatures that cause freeze-thaw events during spring migration, resulting in poor conditions for migrating and feeding. It is also possible that the vast burning of the Eagle Plains area which destroyed essential lichen habitat was related to climate change. Overall, it is expected that climate change will be detrimental to the Porcupine caribou herd. As part of a model that predicted the herd population to decrease to 50,000 caribou by 2020 under previous harvest levels, a value of 19% mortality was assigned to the combined effects of climate change and development.

Keywords: *caribou, north Yukon, wildlife*

Available Online: Full Report

Citation: Yukon. Dept. of Environment. "Rationale for Implementing Conservation Measures to Protect the Porcupine Caribou Herd." Environment Yukon: 2009.

Contaminants in Arctic Moose and Caribou – 2006—Technical Report

Research Location: *ranges of the Porcupine, Qamanirjuaq, and Dolphin and Union caribou herds*
Publication Date: *2008*
Publication Type: *Technical Report*

Affiliation: *Gamberg Consulting*
Contact: *Mary Gamberg, Gamberg Consulting*

Executive Summary: Moose and caribou provide an important food resource for Northerners across the Arctic, and have been designated in the NCP blueprint as key species for monitoring contaminants in the terrestrial Arctic ecosystem.

Tissue samples were collected from the Bluenose, Dolphin and Union, Porcupine and Qamanirjuaq caribou herds and from the Deh Cho moose in 2006/7. Samples were also collected from the Bathurst caribou as an adjunct to the program. The moose results have not been interpreted pending receiving the sample collection information. Results from the analysis of the Bathurst and Bluenose caribou herds have been received and analyzed and are currently being interpreted in conjunction with NWT biologists. Results from the Porcupine, Qamanirjuaq and Dolphin and Union herds are presented in this report…

Local Relevance: Arsenic and lead concentrations in the Porcupine caribou herd declined, potentially due to reduced emissions of these contaminants to the atmosphere in North America and Europe. Mercury and selenium concentrations increased, possibly due to higher emissions into the atmosphere or to climate warming altering mercury composition and deposition in arctic environments. The second option is likely, as atmospheric measurements indicate steady mercury levels following a recent decline in atmospheric mercury concentration. The level of toxic substances found in the Porcupine caribou herd was not considered dangerously high.

Keywords: *caribou, contaminants, north Yukon, wildlife*

Available Online: Full Report

Citation: Gamberg, M. 2008. "Contaminants in Artic Moose and Caribou – 2006." Gamberg Conuslting, Technical Report, 21 p.

Recent Infestation of Forest Stands by Spruce Beetles does not Predict Habitat Use by little brown bats (*Myotis lucifugus*) in Southwestern Yukon, Canada

Research Location: *southwest Yukon*
Publication Date: *2011*
Publication Type: *Journal Article*

Affiliation: *University of Calgary*
Contact: *Robert M.R. Barclay, University of Calgary*

Abstract: Insect outbreaks affect forest structure which may have significant effects on the habitat of other animals. Forest-dwelling insectivorous bats are likely affected by associated changes in the abundance of roost trees and insect prey, altered foraging and flying efficiency, and predation risk. We examined the short-term effects (3-13 years post-infestation) of an outbreak of spruce beetles (*Dendroctonus rufipennis*) on the habitat use of little brown bats (*Myotis lucifugus*) in the boreal forest of the southwestern Yukon, Canada. We measured bat activity, using Anabat II bat detectors, in 90 forested stands that had experienced from 0 to 90% tree mortality due to spruce beetles. We used generalized linear models to assess whether bat activity varied with tree mortality, season, tree density, canopy closure, or distance to the nearest lake or town. Bat activity did not vary significantly with tree mortality, season, or canopy closure, but decreased with increasing tree density. Bat activity

was significantly greater in areas close to both the nearest lake and nearest town, and was low in areas that were far from either. Our results indicate that in the short-term, habitat use by little brown bats was not related to the severity of spruce beetle infestation, but suggest that in the long-term, bats may be positively affected by decreased tree density as beetle-killed trees fall down.

Local Relevance: It was determined that spruce bark beetle infestations do not affect bat activity in the short term; however, the researchers hypothesize that bats will positively benefit from beetle outbreaks in the long term. This is because trees die and fall down as a result of beetle infestations, and bat activity was found to increase with decreasing tree density.

Keywords: *bats, south Yukon, spruce bark beetle, wildlife*

Available online: Abstract

Citation: Randall, L.A., Barclay, R.M., Reid, M.L., and Jung, T.S. 2011. "Recent Infestation of Forest Stands by Spruce Beetles does not Predict Habitat Use by little brown bats (*Myotis lucifugus*) in Southwestern Yukon, Canada." *Forest Ecology and Management* 261(11): 1950-1956.

Problems and Pitfalls in Relating Climate Variability to Population Dynamics

Research Location: *Kluane Lake, Yukon*
Publication Date: *2006*
Publication Type: *Journal Article*

Affiliation: *University of British Columbia*
Contact: *Charles J. Krebs, University of British Columbia*

Abstract: We discuss 3 methodological issues involved in climate-population dynamics research. Precise alternative hypotheses are the first requirement, and correlational studies are the weakest way to test the multiple working hypotheses required. Large-scale effects are difficult to investigate because of heterogeneity in environmental variables, and long-term predictions require more patience to test adequately. Multifactorial hypotheses are required for the investigation of climatic effects but these are too often vague and qualitative. Complex computer models can almost never be empirically validated and their predictions should be carefully examined. We illustrate these problems with 3 case studies: snowshoe hares in Canada, desert rodents in Arizona, and red kangaroos in Australia. Correlations abound but mechanistic understanding is limited because of long causal chains and indirect effects.

Local Relevance: The reproductive effort of snowshoe hares in the southwest Yukon is correlated with the sunspot number of two years prior. If this correlation is meaningful, it could be because sunspot numbers are also related to snow depth, which affects food availability and predation by lynx. Food availability affects nutritional status which would affect reproduction. On the other hand, increased predation would increase stress levels, affecting nutritional status or directly affecting the number of young per female hare. This case study illustrates that climate has indirect effects on population dynamics, and that this effect can occur via multiple pathways.

Keywords: *population dynamics, snowshoe hare, wildlife, south Yukon*

Available Online: Full Article

Citation: Krebs, C.J., Berteaux, D. 2006. "Problems and Pitfalls in Relating Climate Variability to Population Dynamics." *Climate Research* 32: 143-149.

Do Changes in Berry Crops Drive Population Fluctuations in Small Rodents in the Southwestern Yukon?

Research Location: *Kluane Lake, Yukon*
Publication Date: *2010*
Publication Type: *Journal Article*
Affiliation: *University of British Columbia*
Contact: *Charles J. Krebs, University of British Columbia*

Abstract: Small mammals in boreal forest ecosystems fluctuate dramatically in abundance and 1 possible mechanism to explain these changes is the bottom-up hypothesis of variation in food supplies. Here we ask if variation in berry crops produced by 6 major species of dwarf shrubs and herbs, epigeous mushroom crops, and white spruce seeds allow us to predict changes in the abundance of the red-backed vole (*Myodes [= Clethrionomys] rutilus*), the deer mouse (*Peromyscus maniculatus*), and field voles (*Microtus oeconomus* and *M. pennsylvanicus* combined) over 13 years (1997–2009) in the Kluane Lake region of the southwestern Yukon, Canada. *M. rutilus* is the dominant rodent in these forests, comprising 64% of the catch. Overwinter survival is a key demographic variable in all these rodents, and the winter food supply—principally berries produced the previous summer—may be 1 key to overwinter survival. We predicted that berry, mushroom, and tree seed crops in year t would produce changes in rodent density in year t + 1. We could explain statistically 78–98% of the variation in May and August abundance of all 3 rodent species with indices of berry crops and mushrooms in the previous summer. For *M. rutilus* the critical predictor was berry crops of *Empetrum nigrum*. For *P. maniculatus*, the critical species were *Arctostaphylos uva-ursi*, *A. rubra*, and mushrooms. Spruce seed crops were not significantly correlated with rodent densities or changes in density. A large fraction of the variation in rodent numbers in this ecosystem is explained by a simple bottom-up model of population limitation.

Local Relevance: Most of the variation in summer population density of the three rodent species studied could be explained by the berry and mushroom crop production of the previous summer, supporting the hypothesis that food supply directly affects overwinter survival. The three species studied were the red-backed vole, the deer mouse, and field voles. The researchers suggest that berry production may be an indicator of overall plant production in this ecosystem. In addition, population variation could not be explained by white spruce seed production for any of the species.

Keywords: *berries, mice, mushrooms, population dynamics, south Yukon, voles, wildlife*

Available Online: Full Article

Citation: Krebs, C.J., Cowcill, K., Boonstra, R., Kenney, A.J. 2010. "Do Changes in Berry Crops Drive Population Fluctuations in Small Rodents in the Southwestern Yukon?" *Journal of Mammalogy* 91(2): 500-509.

Keeping Pace with Fast Climate Change: Can Arctic Life Count on Evolution?

Research Location: *Kluane Lake, Yukon*
Publication Date: *2004*
Publication Type: *Journal Article*
Affiliation: *Université du Québec à Rimouski*
Contact: *Dominique Berteaux, Université du Québec à Rimouski*

Abstract: Adaptations to the cold and to short growing seasons characterize arctic life, but climate in the Arctic is warming at an unprecedented rate. Will plant and animal populations of the Arctic be able to cope with these drastic changes in environmental conditions? Here we explore the potential contribution of evolution by natural selection to the current response of populations to climate change. We focus on the spring phenology of populations because it is highly responsive to climate change and easy to document across a wide range of species. We show that evolution can be fast and can occur at the time scale of a few decades. We present an example of reproductive phenological change associated with climate change (North American red squirrels in the Yukon), where a detailed analysis of quantitative genetic parameters demonstrates contemporary evolution. We answer a series of frequently asked questions that should help biologists less familiar with evolutionary theory and quantitative genetic methods to think about the role of evolution in current responses of ecological systems to climate change. Our conclusion is that evolution by natural selection is a pertinent force to consider even at the time scale of contemporary climate changes. However, all species may not be equal in their capacity to benefit from contemporary evolution.

Local Relevance: A population of red squirrels near Kluane Lake has shifted its birthing date earlier by about 18 days over the past 10 years in response to climate change. It was determined that while 62% of this shift was due to a direct response to changing climatic conditions, 13% of the shift was the result of evolutionary changes in species genetics. Evolution has occurred because squirrels that breed earlier in the year are more likely to have offspring that survive. As a result of responding directly to altered conditions and microevolution, this population has managed to keep pace with climate change in the Kluane region. Researchers caution that other species may not be able to evolve as quickly as the red squirrel.

Keywords: *evolution, phenology, phenotypic plasticity, population dynamics, south Yukon, squirrels, wildlife*

Available Online: Full Article

Citation: Berteaux, D., Réale, D., McAdam, A.G., Boutin, S. 2004. "Keeping Pace with Fast Climate Change: Can Arctic Life Count on Evolution?" *Integrative and Comparative Biology* 44: 140-151.

Influence of Food Hoarding Behavior on the over-Winter Survival of Pikas in Strongly Seasonal Environments

Research Location: *Ruby Range, Yukon*
Publication Date: *2009*
Publication Type: *Journal Article*
Affiliation: *University of Alberta*
Contact: *Shawn F. Morrison, University of Alberta*

Abstract: Food hoarding is a behavioral adaptation of some herbivores to manage food availability through time and space. In strongly seasonal environments, where summer growing seasons are short relative to winter, an earlier start to hoarding should increase the amount of vegetation stored for winter and improve subsequent survival. We examined hoarding behavior ('haying') and its impact on survival for a small alpine lagomorph, the collared pika (*Ochotona collaris*) in Yukon, Canada. We used a combination of video surveillance, haypile measurements, and survival data from marked individuals of known age and sex. Annual haypile initiation was strongly influenced by age and year. Adult pikas began haying an average of 16 days earlier in 2004 relative to 2005, whereas young of the year (juveniles) did not vary in the timing of haypile initiation. The mean haying rate per hour increased monthly from 3.7 ± 0.7 trips in June to 6.6 ± 0.8 trips in August. Simulation analysis estimated the median haypile mass (dry weight) by mid-September to be 5.5 kg. At least 75% of simulated haypiles had a minimum of 90 days (3 months) of food reserves, and 50% of simulated haypiles had a minimum of 177 days (5.9 months) of food reserves by mid-September, supporting the hypothesis that haypiles serve as the primary source of food during winter. Survival was greatest for pikas in 2005 when they began haying prior to 31 July, but the benefits of earlier accumulation of vegetation on survival also varied between years. The implications of earlier spring snowmelt are discussed with respect to pika foraging and overwinter survival.

Local Relevance: This study investigated whether different patterns of pika food hoarding have an influence on overwinter survival. This study supports the hypothesis that food hoarding provides the main food source during the winter for pikas. Earlier summer foraging was beneficial for pikas, but the extent of this benefit varied between years. In addition, this paper discusses how pika food hoarding and overwinter survival are affected by earlier spring snowmelt.

Keywords: *pikas, population dynamics, Ruby Range, south Yukon, wildlife*

Available Online: Abstract

Citation: Morrison, S.F., Pelchat, G., Donahue, A., Hik, D.S. 2009. "Influence of Food Hoarding Behavior on the over-Winter Survival of Pikas in Strongly Seasonal Environments." *Oecologia* 159(1): 107-116.

Demographic Analysis of a Declining Pika *Ochotona collaris* Population: Linking Survival to Broad-Scale Climate Patterns via Spring Snowmelt Patterns

Research Location: *Ruby Range, Yukon*
Publication Date: *2007*
Publication Type: *Journal Article*
Affiliation: *University of Alberta*
Contact: *Shawn F. Morrison, University of Alberta*

Summary: 1. Demographic analysis is essential in order to determine which factors, such as survival, fertility and other life-history characteristics, have the greatest influence on a population's rate of growth (λ). **2.** We used life-table response experiments (LTREs) to assess the relative importance of survival and fertility rates for an alpine lagomorph, the collared pika *Ochotona collaris*, using 12 years (1995–2006) of census data. The LTRE analysis was repeated for each of three subpopulations within the main study site that were defined by aspect (east, west and south). **3.** Across the entire study site, the survival and fertility of adults contributed 35·6 and 43·5%, respectively, to the variance observed in the projected population growth rate, V(λ), whereas juvenile survival contributed 20·9%. Adult survival and fertility contributed approximately equal amounts for each subpopulation when considered separately, although their rank order varied spatially. **4.** Adult survival across the entire site was positively correlated to the Pacific Decadal Oscillation (PDO) with a time lag of 1 year, and was uncorrelated to adult density. The PDO was negatively correlated to the timing of spring snowmelt at our site, implicating the importance of earlier spring conditions and plant phenology on the subsequent winter survival of adults and therefore, population growth. **5.** When subpopulations were analysed separately, survivals and fertilities were variously correlated to lagged PDO and adult densities, but the patterns varied spatially. Therefore, the mechanisms underlying V(λ) can vary substantially over relatively short distances.

Local Relevance: Researchers observed a recent decline in pika populations at the study site. This decline is attributed to altered winter and spring snow conditions correlated with the Pacific Decadal Oscillation. Earlier snowmelt is beneficial for pikas, resulting in better nutritional status during the breeding season and allowing for a longer period of harvesting for winter food stocks. Winter rain events are detrimental, increasing mortality due to exposure or to ice forming on top of the snow. With climate change, snowmelt has been occurring earlier and winter freeze-thaw events are expected to increase in frequency.

Keywords: *Pacific Decadal Oscillation, pikas, population dynamics, Ruby Range, south Yukon, wildlife*

Available Online: Full Article

Citation: Morrison, S.F., Hik, D.S. 2007. "Demographic Analysis of a Declining Pika *Ochotona collaris* Population: Linking Survival to Broad-Scale Climate Patterns via Spring Snowmelt Patterns." *Journal of Animal Ecology* 76: 899-907.

Interannual Variation in Timing of Parturition and Growth of Collared Pikas (*Ochotona collaris*) in the Southwest Yukon

Research Location: *Ruby Range, St. Elias Mountains, Yukon*
Publication Date: *2004*
Publication Type: *Journal Article*
Affiliation: *University of Alberta*
Contact: *David S. Hik, University of Alberta*

Abstract: The length of the snow-free season has a significant influence on reproduction and growth in northern alpine environments, and these life history traits may provide sensitive indicators of the responses of organisms to climate change. We examined growth rates and timing of parturition of collared pikas (*Ochotona collaris*) from 1995–2002 in the Ruby Range, Yukon Territory, Canada. Growth rates were best described using a Gompertz model, in which the asymptotic mass, determined from the average male and female weights, was 157 g, the growth rate constant (K) was 0.0557, and the age at inflection (I) was 18.12 days, for a birth weight of 10 g. The maximum growth rate for North American pikas (*O. collaris* and *O. princeps*) increased with latitude, with maximum growth rates being approximately one-third greater in northern populations where the snow-free season is less than three months long. The mean parturition date varied significantly among years from 3 June to 3 July, and delayed parturition was correlated with indices of high snow accumulation and, to a lesser extent, late spring snowmelt. However, parturition date did not significantly affect the subsequent over-winter survival of juveniles in this population, suggesting that pikas are able to adjust to seasonal uncertainty associated with highly variable spring conditions.

Local Relevance: The average breeding date of a population of pikas was shown to fluctuate based on climatic conditions, with breeding date being postponed as a result of increased snow cover and delayed snowmelt. Pikas may be able to use environmental cues to adjust breeding date in order for birthing to occur alongside vegetation growth. There was no evidence that breeding date affects pika survival, but it may affect early survival before young pikas emerge from the nest. Based on this evidence, pikas show an ability to adjust to changing climate conditions.

Keywords: *phenology, phenotypic plasticity, pikas, population dynamics, Ruby Range, south Yukon, wildlife*

Available Online: Full Article

Citation: Franken, R.J., Hik, D.S. 2004. "Interannual Variation in Timing of Parturition and Growth of Collared Pikas (*Ochotona collaris*) in the Southwest Yukon." *Integrative and Comparative Biology* 44: 186-193.

Population Limitation of the Northern Red-Backed Vole in the Boreal Forests of Northern Canada

Research Location: *Shakwak Trench, Yukon*
Publication Date: *2006*
Publication Type: *Journal Article*
Affiliation: *University of Toronto Scarborough*
Contact: *Rudy Boonstra, University of Toronto Scarborough*

Summary: 1. Across the vast boreal forests of North America, no population cycles in *Clethrionomys* species occur. In Eurasia, by contrast, some *Clethrionomys* populations of the same species undergo regular 3–5-year cycles. We examined the effects of nutrients, food, competitors, predators and climate on population limitation in the northern red-backed vole (*Clethrionomys rutilus* Pallas) in the south-western Yukon to determine why this difference occurs. **2.** From 1986 to 1996 we added food, reduced large mammal predators and excluded snowshoe hares (*Lepus americanus* Erxleben) from large plots and found that none of these manipulations affected red-backed vole abundance. Adding nutrients as nitrogen, phosphorus and potassium (NPK) fertilizer had a slight negative effect, probably acting through a reduction in dwarf shrub productivity caused by competition from grasses. **3.** We monitored weasel populations directly through trapping and indirectly through snow tracking. Predation by these vole specialists was irrelevant as a limiting factor most of the time because voles in this area do not reach the densities needed to sustain weasel populations. Other boreal forest mammal and bird predators did not focus on red-backed voles. However, when red-backed vole populations increased in the forest and *Microtus* voles also increased in the meadows, weasel populations increased and may have temporarily depressed red-backed voles in winter. **4.** We monitored one major potential food, white spruce seeds, but seed fall was not related to population changes in red-backed voles, even after mast years. **5.** We assessed the impact of weather variables, and the average depth of the snow pack during winter (October–March) was correlated directly with vole demography, having both direct effects in that year and delayed effects in the following year. **6.** Our long-term trapping data (1973–96) indicate that *Clethrionomys* populations fluctuated, with peaks following hare peaks by 2–3 years. **7.** We propose that the key variable limiting these vole populations is overwinter survival, and this is a function of overwinter food from berries produced during the previous summer by dwarf shrubs. These shrubs may be stimulated by abundant moisture from winter snows or by periodic fertilization from large quantities of pellets produced at snowshoe hare peaks.

Local Relevance: Manipulation of various aspects of the boreal forest ecosystem determined that red-backed vole population density is not significantly affected by predation or availability of white spruce seeds. Addition of NPK fertilizer slightly reduced vole populations, likely an indirect effect of increased grass growth limiting the productivity of berry-producing shrubs. It is hypothesized that overwinter survival is the key determinant of vole population density, and that overwinter survival depends on berry production by dwarf shrubs. Berry production is in turn promoted by deeper winter snow cover and fertilization by snowshoe hare feces.

Keywords: *berries, fertilization, population dynamics, south Yukon, voles, wildlife*

Available Online: Full Article

Citation: Boonstra, R., Krebs, C.J. 2006. "Population Limitation of the Northern Red-Backed Vole in the Boreal Forests of Northern Canada." *Journal of Animal Ecology* 75: 1269-1284.

Birds

Variable Reproductive Effort for Two Ptarmigan Species in Response to Spring Weather in a Northern Alpine Ecosystem

Research Location: *Pika Creek Valley, Ruby Range, Yukon*
Publication Date: *2010*
Publication Type: *Journal Article*
Affiliation: *University of British Columbia*
Contact: *Kathy M. Martin, University of British Columbia*

Abstract: Predicting how animal populations respond to climate change requires knowledge of how species traits influence the response of individuals to variation in annual weather. Over a four-year study with two warm and two cold years, we examined how sympatric rock ptarmigan *Lagopus muta* and white-tailed ptarmigan *L. leucura* in the southern Yukon Territory respond to spring weather in terms of breeding phenology and the allocation of reproductive effort. The onset of breeding was approximately synchronous; for each one-degree rise in spring temperature, mean breeding dates of rock and white-tailed ptarmigan advanced by about 2.7 and 4 days respectively. Although onset of breeding was similar, the two species differed in their reproductive effort. As breeding was delayed, average first clutch sizes of rock ptarmigan declined from 9.4 to 5.8 eggs over the breeding period, while those of white-tailed ptarmigan only declined from an average of 7.8 to 6.8. Rock ptarmigan were also less likely to re-nest if their first clutch was lost to predators and as a consequence they had shorter breeding seasons. White-tailed ptarmigan produced about 25% more offspring annually than rock ptarmigan and contributed more young through re-nesting. While white-tailed ptarmigan had higher annual reproductive output, adult rock ptarmigan had a 20–25% higher annual survival rate, which may indicate a reproduction–survival trade-off for the two species. These results show that even within the same location, closely related species can differ in how they allocate effort as environmental conditions fluctuate.

Local Relevance: This study investigated the response of two closely-related ptarmigan species (rock and white-tailed) to spring weather conditions. For both species, warmer spring temperatures corresponded with earlier breeding. Compared to rock-ptarmigan, white-tailed ptarmigan produced more young with warmer spring temperatures but had lower rates of adult survival.

Keywords: *phenology, population dynamics, ptarmigan, south Yukon, wildlife*

Available Online: Abstract

Citation: Wilson, S., Martin, K. 2010. "Variable Reproductive Effort for two Ptarmigan Species in Response to Spring Weather in a Northern Alpine Ecosystem." *Journal of Avian Biology* 41(3): 319-326.

Influence of Environmental Variation on Habitat Selection, Life History Strategies and Population Dynamics of Sympatric Ptarmigan in the Southern Yukon Territory

Research Location: *Pika Creek Valley, Ruby Range, Yukon*
Publication Date: *2008*
Publication Type: *Academic Dissertation*
Affiliation: *University of British Columbia*
Contact: *Kathy M. Martin, University of British Columbia*

Abstract: Climatic variation is an important driver of avian life history and population dynamics. Climate change models predict increased variability for many regions and to predict the effects on species, we need to examine how their life history characteristics influence their response to climate. I studied how environmental conditions influenced the ecology of white-tailed (*Lagopus leucura*) and rock ptarmigan (*L. mutus*) in tundra habitats of the southern Yukon Territory. Although sympatric in the study area, breeding territories were generally segregated, with white-tailed ptarmigan selecting steep, rocky slopes at higher elevations and rock ptarmigan preferring lower elevation sedge meadows. For both species, cold spring temperatures delayed the onset of breeding, resulting in smaller clutch sizes and fewer hatched young per female. However, delayed breeding led to a stronger reduction in these rates for rock ptarmigan, suggesting a lower resilience to extend reproductive effort in colder years. White-tailed ptarmigan were also more likely to re-nest following failure and had higher daily nest survival, both of which contributed to greater annual productivity compared to rock ptarmigan.

Annual adult survival showed the opposite pattern to productivity as rock ptarmigan survival was about 24% higher than white-tailed ptarmigan. This finding suggested a reproduction-survival trade-off exists for the two species, which may be driven by differing susceptibility to environmental factors in the region. Life history theory predicts that if the likelihood of future breeding opportunities is low, individuals should increase current reproductive effort, which may explain why white-tailed ptarmigan have longer breeding seasons and higher reproductive effort under unfavourable climatic conditions. Population models showed that growth rates (λ) were approximately stable for rock ptarmigan (λ=1.01), but declining for white-tailed ptarmigan (λ=0.96). Simulations showed that warmer spring temperatures over the next few decades would elevate λ by ~0.05 for both species, but the extent of increase in λ may be reduced with more variable spring conditions. Population growth will also depend on how changing winter conditions influence survival for each species. Model simulations suggest that if juvenile and adult survival are positively correlated, rock ptarmigan would be more resilient to severe years that simultaneously depress reproduction and survival.

Local Relevance: In years of late snowmelt, the ptarmigan started breeding later, but there was no movement to a different habitat. During warmer years, both species (rock and white-tailed) experienced more successful reproduction. The author hypothesizes that the most drastic impact of climate change on the ptarmigan populations studied will be the reduction in habitat of rock and white-tailed ptarmigan as trees and shrubs expand to higher elevations. In summary, the short-term effects of climate change on ptarmigan may be beneficial as a result of increased reproductive success, but in the long-term, loss of habitat could have adverse effects.

Keywords: *phenology, population dynamics, ptarmigan, Ruby Range, south Yukon, St. Elias Mountains, wildlife*

Available Online: Full Article

Citation: Wilson, S.D. 2008. "Influence of Environmental Variation on Habitat Selection, Life History Strategies and Population Dynamics of Sympatric Ptarmigan in the Southern Yukon Territory." PhD diss., University of British Columbia.

Spiders

Determinants of Ground-Dwelling Spider Assemblages at a Regional Scale in the Yukon Territory, Canada

Research Location: *Yukon*
Publication Date: *2010*
Publication Type: *Journal Article*
Affiliation: *McGill University*
Contact: *Christopher M. Buddle, McGill University*

Abstract: Arctic fauna is undergoing significant alteration in response to global climate change, yet we know little regarding the factors that determine species assemblages at northern latitudes. We used a latitudinal transect to assess environmental determinants of ground-dwelling spider assemblages across the boreal forest-tundra transition at a regional scale. Using multivariate techniques, we tested 3 complementary hypotheses regarding the factors that best explain patterns of assemblage structure. We predicted that spider assemblages would respond most strongly to vegetation composition and structure and that climate and spatial variables would explain less of the variation in the data. We sampled ground dwelling spiders using pitfall traps placed at 36 sites along the latitudinal transect. We constructed 3 separate matrices of spatial, climate, and vegetation variables, with each matrix representing a hypothesis. We used redundancy analysis with variation partitioning to determine which matrix of environmental variables best explained patterns in a matrix of spider abundances. We then used a separate redundancy analysis to determine which environmental variables best explained the variation in measures of species richness and activity density. We collected a total of 2890 individual spiders representing 103 species, 58 genera, and 13 families. Our analysis supports the hypothesis that vegetation composition and its related structure best explain patterns in northern spider assemblages at a regional scale.

Local Relevance: In order to predict the effects of climate change on northern fauna, one must understand the various controls on assemblage distribution. This study determined that spider assemblages in Yukon are best explained by vegetation composition and structure.

Keywords: *spiders, vegetation, Yukon-wide*

Available Online: Abstract

Citation: Bowden, J.J., Buddle, C.M. 2010. "Determinants of Ground-Dwelling Spider Assemblages at a Regional Scale in the Yukon Territory, Canada." *Ecoscience* 17(3): 287-297.

Spider Assemblages across Elevational and Latitudinal Gradients in the Yukon Territory, Canada

Research Location: *Yukon*
Publication Date: *2010*
Publication Type: *Journal Article*

Affiliation: *McGill University*
Contact: *Christopher M. Buddle, McGill University*

Abstract: Arthropod assemblages in the Arctic are set for substantial changes in response to climate change, yet we know little about the ecological structure of many groups in the North. We tested the effects of elevation and latitude on northern spider assemblages by sampling along nine mountains across three latitudes in the Yukon Territory, Canada. Spiders were collected in 216 pitfall traps placed at four elevations along each of the nine mountains, representing 36 sites sampled across three latitudes (i.e., distinct mountain ranges). We collected 1954 individuals representing 89 species, 57 genera, and 12 families of spiders. Using nested ANOVAs, we found significant main effects of latitude, elevation, and an interaction of the two factors on species richness and abundance. Using MRPP and NMS ordination, we also found significant effects of latitude and mountain on species composition, but within each of the three latitudes, only elevation produced significant effects. Our study suggests that changes along spatial gradients associated with changes in habitat can have significant effects on the structure of spider assemblages, but responses vary among mountain ranges. We show that within a given mountain range, individual mountains may be used as spatial replicates for studies about northern arthropod assemblages.

Local Relevance: This study investigated the effects of latitude and elevation on spider assemblages in Yukon to assist predictions of climate change impacts on northern arthropods. Species richness and abundance could be described by latitude, elevation, or a combination of the two. When considering specific latitudes, elevation was the only factor to have a significant effect on species composition. This study illustrates that the structure of spider assemblages can be significantly impacted by different habitats.

Keywords: *spiders, vegetation, Yukon-wide*

Available Online: Abstract

Citation: Bowden, J.J., Buddle, C.M. 2010. "Spider Assemblages across Elevational and Latitudinal Gradients in the Yukon Territory, Canada." *Arctic* 63(3): 261-272.

7. Hazards

Climate Change and Natural Hazards in Northern Canada: Integrating Indigenous Perspectives with Government Policy

Research Location: *northern Canada*
Publication Date: *2005*
Publication Type: *Journal Article*
Affiliation: *John Newton Associates*
Contact: *Aynslie E. Ogden, University of British Columbia/Government of Yukon*

Abstract: A study of the relationship between natural hazards and climate change in the international context provides the background for a discussion of the expected changes. In the context of this global discussion, this paper reviews the current perspectives of those natural hazards that are likely to be influenced by climate change, using northern Canada as a regional case study. The northern implications of the United Nations Framework Convention on Climate Change are examined, including the status of climate change action by the northern territorial governments, the evolving role of indigenous people, and the responsibility for climate change impacts. The difficulties surrounding natural hazards research in remote locations, and the approaches of indigenous people to natural hazards are then presented. The paper concludes with a suggested policy approach for climate change and natural hazards in northern Canada, underscoring the need for more comprehensive adaptive strategies to complement the current tendency to focus on the mitigation of greenhouse gases produced in this region.

Local Relevance: Natural hazards and their and relationship to climate change in northern Canada were investigated, as well as the best ways to address these hazards. This paper presents indigenous perspectives of hazard adaptation and issues associated with conducting hazards research in the north. Finally, a policy recommendation for dealing with natural hazards is presented. In order to address climate change in the north, the researchers suggest integrating more adaptive measures instead of solely focusing on mitigation.

Keywords: *adaptation, hazards, policy, Yukon-wide*

Available Online: Abstract

Citation: Newton, J., Paci, C.D.J., Ogden, A. 2005. "Climate Change and Natural Hazards in Northern Canada: Integrating Indigenous Perspectives with Government Policy." *Mitigation and Adaptation Strategies for Global Change* 10: 541-571.

Flooding

Community Flood Planning: An Assessment of Hazard and Response in the Dawson City Region, Yukon, Canada

Research Location: *Dawson, Yukon*
Publication Date: *2010*
Publication Type: *Academic Dissertation*
Affiliation: *McGill University*
Contact: *Erica Beasley, City of Whitehorse*

Abstract: The Dawson City region has a long history of flooding that extends beyond its establishment during the Klondike Gold Rush. Dawson has evolved into a modern settlement with infrastructure that is vulnerable to inundation. After a devastating flood in 1979, a dyke was built to protect the townsite which has helped to ameliorate the flood-threat; however, residual risks exist and development that has occurred on the Klondike River floodplain has placed newer subdivisions in peril. In this report, the structural and policy approaches implemented in the region are assessed. Information on hazards associated with climate change are synthesised and GIS is used as a tool for flood-simulation. Research findings point to deficiencies in local hazard information and the inefficiencies in land use that contribute to the encroachment of vulnerable lands. Recommendations are made for risk-minimisation, which hinge on strategic residential growth and the redistribution of essential services.

Local Relevance: In the Dawson area, there has been a trend of earlier spring river break-up dates since 1896, and it is predicted that warmer winter temperatures and greater seasonal temperature variability will manifest in more ice-jam floods. In 2002/2003 for example, abnormally-warm December temperatures caused some of the ice on the Klondike River to break up and resulted in flooding of low-lying areas. This thesis includes an assessment of possible flood scenarios and which locations in Dawson would be flooded in each case. It is recommended that there be limited in-filling of the Dawson town site and the Klondike Valley area because these locations are at a high flood risk.

Keywords: *central Yukon, Dawson, flooding, hazards, Klondike River, Tr'ondëk Hwëch'in First Nation, Yukon River*

Available Online: Full Article

Citation: Beasley, E. 2010. "Community Flood Planning: An Assessment of Hazard and Response in the Dawson City Region, Yukon, Canada." MA diss., McGill University.

Landsliding Following Forest Fire on Permafrost Slopes, Klondike Area, Yukon, Canada

Research Location: *Steele Creek, Klondike Goldfields, Yukon*
Publication Date: *2008*
Publication Type: *Conference Proceedings*
Affiliation: *University of Ottawa*
Contact: *Antoni G. Lewkowicz, University of Ottawa*

Excerpt: In the boreal forest, fire is often followed by widespread active layer detachment sliding (McRoberts & Morgenstern 1974a, 1974b, Lewkowicz & Harris 2005a, 2005b). Forest fire, with a recurrence interval of 25–300 years, kills adult trees, destroys much of the insulating mossy organic layer, and blackens the ground surface (Dyrness et al. 1986).Seasonal thaw depths (active layer thickness) generally increase in the years following forest fire (Yoshikawa et al. 2003), although this can vary according to the slope aspect and state of vegetation (Swanson 1996, Lewkowicz & Harris 2005b). When the heat reaches the permafrost, it may thaw the ice-rich transient layer, which lies just below the average maximum depth of thaw (Shur et al. 2005). Water released by this process may raise soil porewater pressures sufficiently to destabilize slopes and cause active layer detachment sliding (McRoberts & Morgenstern 1974a). Active layer detachment failures occur when all or a portion of the active layer separates from the permafrost beneath and moves as a semi-competent, unsaturated mass downhill over the lubricated slip surface of the thaw plane. Failures occur within the active layer or the transient layer and are triggered by high porewater pressures over frozen ground (Lewkowicz & Harris 2005b). The depth of the initial failure plane is limited by the position of the permafrost table (Harris & Lewkowicz 2000)…

Local Relevance: Many forest fires occurred in the Klondike region in 2004 and were followed by landslide activity at Steele Creek. These detachments occurred because the forest fires weakened the tree root system and caused accelerated permafrost thaw. It is likely that with a warming climate accompanied by permafrost thaw and more frequent and intense forest fires, Yukon will experience more landslides.

Keywords: *central Yukon, forest fire, hazards, landslide, permafrost, Steele Creek*

Available Online: Full Article

Citation: Coates, J., Lewkowicz, A.G., 2008. Landsliding Following Forest Fire on Permafrost Slopes, Klondike Area, Yukon, Canada. *In*: Ninth International Conference on Permafrost, Extended Abstracts, D.L. Kane and K.M. Hinkel (eds.), Fairbanks, Alaska, June 29-July 3, 2008, p. 49-50.

The Role of Permafrost in the 2002 Ten Mile Creek Debris Torrent, Yukon, Canada

Research Location: *Ten Mile Creek, Yukon*
Publication Date: *2008*
Publication Type: *Conference Proceedings*
Affiliation: *Yukon Geological Survey*
Contact: *Panya S. Lipovsky, Yukon Geological Survey*

Excerpt: In June 2002, a catastrophic debris torrent initiated from a moderate north-facing slope in the headwaters of Ten Mile Creek, in central Yukon, Canada. Field evidence indicates that permafrost was a major contributing factor that caused an initial landslide which then triggered the debris torrent. The mechanism of failure in the initial landslide appears to be unique in comparison to other permafrost-related landslides (i.e., retrogressive thaw failures and active layer detachments) documented in the region (Lipovsky et al. 2006, Lipovsky & Huscroft 2007, Lyle 2006)…

Local Relevance: This study aims to determine the cause of the landslide and debris torrent at Ten Mile Creek in 2002. It is hypothesized that the frozen ground below the landslide source trapped groundwater flow, allowing for pressure to build up underground. The pressure continued to increase until the permafrost and unfrozen ground above this pressure source ruptured. At this point, the stored groundwater drained rapidly, causing the debris torrent. The researchers suggest that permafrost warming associated with climatic warming in this region since 1930 may have weakened the permafrost layer, allowing for the rupture to occur more easily.

Keywords: *central Yukon, hazards, landslide, permafrost, Ten Mile Creek*

Available Online: Full Article

Citation: Lipovsky, P., Huscroft, C., Lewkowicz, A., Etzelmüller, B., 2008. The Role of Permafrost in the 2002 Ten Mile Creek Debris Torrent, Yukon, Canada. *In*: Ninth International Conference on Permafrost, Extended Abstracts, D.L. Kane and K.M. Hinkel (eds.), Fairbanks, Alaska, June 29-July 3, 2008, p. 189-190.

The July 2007 Rock and Ice Avalanches at Mount Steele, St. Elias Mountains, Yukon, Canada

Research Location: *Mount Steele, St. Elias Mountains, Yukon*
Publication Date: *2008*
Publication Type: *Journal Article*
Affiliation: *Yukon Geological Survey*
Contact: *Panya S. Lipovsky, Yukon Geological Survey*

Abstract: A large rock and ice avalanche occurred on the north face of Mount Steele, southwest Yukon Territory, Canada, on July 24, 2007. In the days and weeks preceding the landslide, several smaller avalanches initiated from the same slope. The ice and rock debris traveled a maximum horizontal distance 5.76 km with a maximum vertical descent of 2,160 m, leaving a deposit 3.66 km^2 in area on Steele Glacier. The seismic magnitude estimated from long-period surface waves (M_s) is 5.2. Modeling of the waveforms suggests an estimated duration of approximately 100 s and

an average velocity of between 35 and 65 m/s. This landslide is one of 18 large rock avalanches known to have occurred since 1899 on slopes adjacent to glaciers in western Canada. We describe the setting, reconstruct the event chronology and present a preliminary characterization of the Mount Steele ice and rock avalanches based on field reconnaissance, analysis of seismic records and an airborne LiDAR survey. We also present the results of a successful dynamic simulation for the July 24 event.

Local Relevance: This paper described the events surrounding the 2007 Mount Steele avalanche. The landslide is one of few to have occurred on mountain slopes adjacent to glaciers since the beginning of the 20th century. The significance of this event, both regionally and globally, is addressed.

Keywords: *hazards, Mt. Steele, landslide, south Yukon, St. Elias Mountains*

Available Online: Abstract

Citation: Lipovsky, P.S., Evans, S.G., Clague, J.J., Hopkinson, C., Couture, R., Bobrowsky, P., Ekström, G., Demuth, M.N., Delaney, K.B., Roberts, N.J., Clarke, G., Schaeffer, A. 2008. "The July 2007 Rock and Ice Avalanches at Mount Steele, St. Elias Mountains, Yukon, Canada." *Landslides* 5: 445-455.

A Reconnaissance Inventory of Permafrost-Related Landslides in the Pelly River Watershed, Central Yukon

Research Location: *Pelly River Basin, Yukon*
Publication Date: *2007*
Publication Type: *Journal Article*

Affiliation: *Yukon Geological Survey*
Contact: *Panya S. Lipovsky, Yukon Geological Survey*

Abstract: A reconnaissance inventory of permafrost-related landslides in the Pelly River watershed was conducted in 2006, largely in response to local community concerns regarding the potential impacts of climate change on slope stability and possible effects on water quality. Using aerial photograph analysis, satellite imagery, and visual inspection from a fixed-wing aircraft, over 100 permafrost-related slides were located near the Pelly and MacMillan rivers and various tributaries. Basic geomorphic characteristics were determined for many of the failures based on analysis of remote sensing data, and reviews of existing literature and surficial geology maps. Most of the landslides identified were small active-layer detachments and retrogressive thaw failures. Several large failures also illustrate important characteristics associated with permafrost-related landslides, including their source-area setting, triggers, high mobility, the longevity of their activity and their ability to impact very large areas. The nature and distribution of the identified failures highlights a number of implications for land-use in central Yukon and emphasizes the need for enhanced methods of permafrost detection and regional mapping in the Territory.

Local Relevance: Researchers located over 100 permafrost-related landslides in the study area; most of the slides were initiated over 15 years ago but many of them have remained active. Results indicate that forest fires and river erosion seem to be the two processes that most often directly affect permafrost stability in the region. It is believed that climate change has both initiated and sustained landslides in this region via many factors that directly influence permafrost such as river flow levels, forest fires, and snow depth.

Keywords: *hazards, landslide, Pelly River Valley, permafrost, south-central Yukon*

Available Online: Full Article

Citation: Lipovsky, P. and Huscroft, C., 2007. A Reconnaissance Inventory of Permafrost-Related Landslides in the Pelly River Watershed, Central Yukon. *In:* Yukon Exploration and Geology 2006, D.S. Emond, L.L. Lewis and L.H. Weston (eds.), Yukon Geological Survey, p. 181-195.

Active-Layer Detachments Following the Summer 2004 Forest Fires near Dawson City, Yukon

Research Location: *Mickey Creek, Steele Creek, and Fifty Mile Creek, Yukon*
Publication Date: *2006*
Publication Type: *Journal Article*
Affiliation: *Yukon Geological Survey*
Contact: *Panya S. Lipovsky, Yukon Geological Survey*

Abstract: Numerous active-layer detachments occurred in watersheds surrounding Dawson City following forest fires that burned the area during the summer of 2004. The distribution of these shallow landslides was mapped in the Mickey Creek, Steele Creek and Fifty Mile Creek watersheds. Selected slope failures were surveyed in detail to describe their geometry and geomorphological settings in order to investigate the mechanisms of failure, and to assess the effects of the forest fires on local permafrost conditions. The failures generally initiated on moderate convex slopes at shallow depths (< 65 cm) in silty colluvium; frost tables were close to 1 m in depth. Most active-layer detachments were on the order of 5-20 m wide and 10-100 m long and occurred on slopes with a variety of aspects; however, the detachments occurred only where permafrost was present. In some cases, they developed on gentle slopes (as low as 10°) and traveled several hundred metres, depositing sediment directly into creeks, or across access trails. Their cumulative effects may significantly impact sediment transport within the watersheds. Potential concerns for fish habitat and implications for placer mining water quality regulations have consequently been raised.

Local Relevance: Close to 150 active-layer detachments were located after the 2004 forest fires near Dawson. Detachments occurred on moderate to steep slopes where permafrost was present. This paper highlights the impacts of forest fires on permafrost stability, such as increasing absorbed solar radiation, reducing heat transfer to the atmosphere, and increasing heat transfer to deeper ground. As well as forest fire, it is suspected that the many heavy precipitation events in the Steele Creek

catchment in 2005 contributed to ground instability. Possible implications for Chinook salmon are presented, including increased sedimentation and nutrient availability.

Keywords: *central Yukon, Fifty Mile Creek, fish, forest fire, hazards, landslide, Mickey Creek, permafrost, salmon, Steele Creek*

Available Online: Full Article

Citation: Lipovsky, P.S., Coates, J., Lewkowicz, A.G. and Trochim, E., 2006. Active-Layer Detachments Following the Summer 2004 Forest Fires near Dawson City, Yukon. *In:* Yukon Exploration and Geology 2005, D.S. Emond, G.D. Bradshaw, L.L. Lewis and L.H. Weston (eds.), Yukon Geological Survey, p. 175-194.

Landslide Processes in Discontinuous Permafrost, Little Salmon Lake (NTS 105L/1 and 2), South-Central Yukon

Research Location: *Little Salmon Lake, Yukon*
Publication Date: *2005*
Publication Type: *Journal Article*

Affiliation: *Queen's University*
Contact: *Jean Hutchinson, Queen's University*

Abstract: With increasing development in areas of discontinuous permafrost, greater emphasis is being placed on slope hazard assessment. The current research project was initiated in response to the occurrence of a large flow-type slide, the Magundy River landslide, with the aim of identifying and characterizing slope hazards in the Little Salmon Lake area of the central Yukon. Terrain evaluation studies identified over 35 areas of past and present landslide activity in the project area. Field work was completed in the summer of 2004 to obtain ground truth for the terrain evaluation and to further characterize the most prominent and active landslides. This paper provides an overview of the research project and summarizes observations on four distinct landslide processes found in the Little Salmon Lake area: debris flow, rock slumping, bimodal flow and multiple retrogressive slumping.

Local Relevance: This paper describes four separate landslides near Little Salmon Lake. One of the landslides is inactive, and is likely initiated by heavy rainfall or rapid snowmelt. Of the three active landslides, one may be affected by the thawing of ground ice while the other two are related to permafrost decay. Researchers state it is likely that triggering events for these landslides are the result of climate change and that climate change must always be considered when addressing issues of slope stability.

Keywords: *hazards, landslide, Little Salmon Lake, south-central Yukon*

Available Online: Full Article

Citation: Lyle, R.R., Hutchinson, D.J. and Preston, Y., 2005. Landslide Processes in Discontinuous Permafrost, Little Salmon Lake (NTS 105L/1 and 2), South-Central Yukon. *In*: Yukon Exploration and Geology 2004, D.S. Emond, L.L. Lewis and G.D. Bradshaw (eds.), Yukon Geological Survey, p. 193-204.

Permafrost and Landslide Activity: Case Studies from Southwestern Yukon Territory

Research Location: *Alaska Highway corridor, southwest Yukon*
Publication Date: *2004*
Publication Type: *Journal Article*

Affiliation: *Yukon Geological Survey*
Contact: *Crystal A. Huscroft, Thompson Rivers University*

Abstract: Five case studies of recent landslides in southwestern Yukon Territory illustrate the role of permafrost in landslide processes of the region. In the Marshall Creek basin, permafrost degradation after recent forest fires caused numerous debris flows near the valley bottom. Similarly, on Haeckel Hill, fire-related deepening of the active layer has facilitated active layer detachment slides on upper hillside slopes. In the Kluane Range, the interface between frozen and unfrozen ground appears to control the depth of movement for active layer detachment slides and debris flows along Silver Creek. The failure mechanism on Mount Sumanik is controlled by a frozen substrate, which contributes to a reduction in drainage and elevated pore-water pressure. Lastly, thawing of segregated ice has caused a thaw slump of fine-grained sediment in lacustrine terraces along Takhini River.

Local Relevance: Five permafrost-related landslides in the southwest Yukon provide precedents for future landslides that may result from climate change. The landslides in Marshall Creek Basin and on Haeckel Hill were the result of fire disturbance that increased the depth of the active layer; therefore, more forest fires as a result of climate change will lead to more of this type of ground failure. In addition, predicted increases in air temperature and snow depth would also increase active layer depth. The Silver Creek and Mount Sumanik landslides were the result of heavy rainfall, indicating that more heavy rainfall events associated with climate change may lead to this type of landslide. Increasing precipitation may also lead to river migration, causing ground slumping like that observed in the Takhini Valley.

Keywords: *Haeckel Hill, hazards, Kluane Ranges, landslide, Marshall Creek, Mt. Sumanik, Silver Creek, south Yukon, Takhini River Valley*

Available Online: Full Article

Citation: Huscroft, C.A., Lipovsky, P. and Bond, J.D., 2004. Permafrost and Landslide Activity: Case Studies from Southwestern Yukon Territory. *In*: Yukon Exploration and Geology 2003, D.S. Emond and L.L. Lewis (eds.), Yukon Geological Survey, p. 107-119.

A Regional Characterization of Landslides in the Alaska Highway Corridor, Yukon

Research Location: *Alaska Highway corridor, Yukon*
Publication Date: *2004*
Publication Type: *Government Publication*

Affiliation: *Yukon Geological Survey*
Contact: *Crystal A. Huscroft, Thompson Rivers University*

Executive Summary: The following report describes the settings, causes and geological controls of landslides in the Alaska Highway corridor. Although diverse geologic, geomorphic and climatic environments exist in the region, most landslides are related to the presence of shallow bedrock or permafrost, unconsolidated sediment on steep slopes, weak bedrock, groundwater hydrology, river erosion or the degradation of ice-rich permafrost.

Where geologic controls provide appropriate settings, intense rainfall, rapid snow melt and seismic events play important roles in triggering failures. Rainstorms that reach thresholds of combined intensity and duration have triggered abundant shallow landslides within the corridor. Debris flows have historically posed the highest risk to low-lying regions and are capable of damaging settlements and transportation routes.

The Shakwak Valley has the highest concentration of landslides within the corridor due to the abundance of steep slopes, high relief and widespread discontinuous permafrost. In Wellesley Depression, shallow permafrost and its subsidence has an important influence on slope instabilities. Landslides in the Yukon Plateau primarily relate to the presence of silt- and ice-rich tills on steep valley sides as well as the incision of fine-grained lacustrine terraces in valley bottoms. Debris flows after intense rainfall events are the most common form of landslide in the Kaska Mountains. Finally, in Liard Lowland, failures associated with glacial meltwater and modern stream incision are the most common landslide events…

Local Relevance: This publication highlights the most common types of landslides observed in various areas within the Alaska Highway corridor and factors controlling landslide activity in each area. If climate change results in more summer precipitation, a deeper snowpack, or rapid spring thaw, more landslides will occur. Gullies in parts of the White Mountain area and Kluane Lake are vulnerable to landslides caused by heavy rainfall. Deeping of the active layer of permafrost may have two effects: in ice-rich ground, such as the Kluane Ranges, it may lead to greater detachment-failure landslides; in ice-poor ground it may reduce landslides caused by water pressure buildup. A greater number of forest fires will definitely result in more landslides and glacier retreat is expected to promote landslides, especially in parts of the Kluane Ranges.

Keywords: *hazards, Kaska Mountains, Kluane Ranges, landslide, Shakwak Trench, south Yukon*

Available Online: Full Article

Citation: Huscroft, C.A., Lipovsky, P.S. and Bond, J.D., 2004. A regional characterization of landslides in the Alaska Highway corridor, Yukon. Yukon Geological Survey, Open File 2004-18, 65 p., report and CD-ROM.

Climate Change and Mining in Canada

Research Location: *Canada*
Publication Date: *2011*
Publication Type: *Journal Article*

Affiliation: *University of Guelph*
Contact: *Tristan D. Pearce, University of Guelph*

Abstract: Climate is an important component of the operating environment for the Canadian mining sector. However, in recent years mines across Canada have been affected by significant climatic hazards, several which are regarded to be symptomatic of climate change. For the mining sector, climate change is a pressing environmental threat and a significant business risk. The extent to which the mining sector is able to mitigate its own impact and adapt to climate change will affect its long-term success and prosperity, and have profound economic consequences for host communities. This paper draws upon case studies conducted with mining operations in Canada involving in-depth interviews with mining professionals and analysis of secondary sources to characterize the vulnerability of the Canadian mining industry to climate change. Five key findings are discussed: i) mines in the case studies are affected by climate events that are indicative of climate change, with examples of negative impacts over the past decade; ii) most mine infrastructure has been designed assuming that the climate is not changing; iii) most industry stakeholders interviewed view climate change as a minor concern; iv) limited adaption planning for future climate change is underway; v) significant vulnerabilities exist in the post-operational phase of mines. This paper argues for greater collaboration among mining companies, regulators, scientists and other industry stakeholders to develop practical adaptation strategies that can be integrated into existing and new mine operations, including in the post-operational phase.

Local Relevance: The Minto mine released untreated water into the Yukon River (with more waste discharge than license standards) in both 2008 and 2009 because it was not prepared to deal with increased precipitation. Planning for future torrential rain events has been limited, as the mine requested permission to release untreated water again for 2009 and 2010. Permafrost thaw caused the tailing dumps of the abandoned Clinton Creek asbestos mine to fail, blocking the flow of Wolverine Creek and destroying aquatic life. Future implications of climate change on the mining industry are expected to be high for mines that are located in permafrost areas due to infrastructure damage.

Keywords: *central Yukon, Clinton Creek mine, economic development, industry, infrastructure, mining, Minto mine, south-central Yukon*

Available Online: Abstract

Citation: Pearce, T.D., Ford, J.D., Prno, J., Duerden, F., Pittman, J., Beaumier, M., Berrang-Ford, L., Smit, B. 2011. "Climate Change and Mining in Canada." *Mitigation and Adaptation Strategies for Global Change* 16: 347-368.

Climate Change and Canadian Mining: Opportunities for Adaptation

Research Location: *Canada*
Publication Date: *2009*
Publication Type: *Project Publication*
Affiliation: *Arctic North Consulting*
Contact: *Tristan D. Pearce, University of Guelph*

Excerpt: The scientific evidence that the climate is changing is now beyond doubt and a link to human emissions is well established (IPCC, 2007c, b). Acknowledging this fact, research has broadened from focusing solely on the causes and nature of change to its implications for human activity. For individual sectors, and regional and national economies, identifying and characterising impacts and vulnerabilities is of tremendous value because changing environmental conditions have major implications for economic viability and social and cultural well-being. It is increasingly recognised that by identifying and anticipating potential vulnerabilities stakeholders, practitioners and regulators can take pro-active approaches to reducing future uncertainties. Our understanding of the implications of climate change for major industrial activities in Canada, however, remains limited (Health Canada, 2008, Lemmen et al., 2008)…

Local Relevance: Permafrost melt is likely to threaten transport and building infrastructures and may increase environmental damage from waste-retention water bodies. Increased precipitation may affect the stability of decommissioned mine sites and cause erosion and wash-outs of access roads between mine sites and main roads, as was the case of 400 metres of the Minto Mine access road in 2008. Changes in river hydrology may impact the Minto Mine which utilizes ferries and winter roads to access the Klondike Highway. There are also potential benefits resulting from climate change, such as easier mineral access in placer mining as permafrost melts.

Keywords: *adaptation, central Yukon, economic development, industry, infrastructure, mining, Minto mine, south-central Yukon*

Available Online: Full Report

Citation: ArcticNorth Consulting. 2009. *Climate Change and Mining in Canada: Opportunities for Adaptation*. Report prepared for: the David Suzuki Foundation.

Implications of Climate Change for Economic Development in Northern Canada: Energy, Resource, and Transportation Sectors

Research Location: *Yukon; Northwest Territories; Nunavut*
Publication Date: *2009*
Publication Type: *Journal Article*
Affiliation: *University of Victoria; Environment Canada*
Contact: *Terry D. Prowse, University of Victoria/Environment Canada*

Abstract: Northern Canada is projected to experience major changes to its climate, which will have major implications for northern economic development. Some of these, such as mining and oil and

gas development, have experienced rapid expansion in recent years and are likely to expand further, partly as the result of indirect effects of changing climate. This article reviews how a changing climate will affect several economic sectors including the hydroelectric, oil and gas, and mining industries as well as infrastructure and transportation, both marine and freshwater. Of particular importance to all sectors are projected changes in the cryosphere, which will create both problems and opportunities. Potential adaptation strategies that could be used to minimize the negative impacts created by a climate change are also reviewed.

Local Relevance: Hydroelectric power generation is likely to be impacted by a loss of natural storage capacity resulting from reduced winter snow buildup and by reduced glacier melt contributions to streamflow. Thawing permafrost increases the likelihood that contaminants will be leached from waste retention facilities in the mining and oil and gas sectors. On a time scale of years, permafrost degradation from ground disturbance will be more pronounced than degradation from climate change; however, the opposite is true when we consider periods of decades. This can be seen from infrastructure damage in Dawson as a result of permafrost thaw. Communities and facilities located near major waterways may benefit from a longer transport window, as the ice-free season increases.

Keywords: *economic development, energy, hydroelectricity, impacts, Yukon-wide*

Available Online: Full Article

Citation: Prowse, T.D., Furgal, C., Chouinard, R., Melling, H., Milburn, D., Smith S.L. 2009. "Implications of Climate Change for Economic Development in Northern Canada: Energy, Resource, and Transportation Sectors." *Ambio* 38(5): 272-281.

True North: Adapting Infrastructure to Climate Change in Northern Canada

Research Location: *Yukon; Northwest Territories; Nunavut*
Publication Date: *2009*
Publication Type: *Government Publication*
Affiliation: *National Round Table on the Environment and the Economy*
Contact: *National Round Table on the Environment and the Economy*

Executive Summary: Climate change is a reality, and the global frontline runs directly through Canada's North. Warming temperatures, changing precipitation and land ice conditions, melting glaciers and sea ice, earlier springs, increasingly volatile weather, and shifts in the distribution of animals and plants are all occurring. The impacts of climate change touch all regions of Canada, presenting environmental, social, and economic risks, and some potential opportunities. However, Canada's North is particularly affected, with warming taking place at faster rates than throughout Canada as a whole, and more quickly than projected by climate models, even under the most pessimistic scenarios.

Adapting to the impacts of climate change, not just limiting the magnitude of future change through global mitigation of greenhouse gas emissions, is essential for northern communities to be secure in the decades ahead. The impacts of climate change pose risks to a range of economic sectors and systems that northerners value. Chief among them is the region's infrastructure, including its roads, buildings, communications towers, energy systems, and waste disposal sites for

communities, and large-scale facilities and waste-containment sites that support the territories' energy and mining operations. The risk to infrastructure systems will only intensify as the climate continues to warm…

Local Relevance: This report addresses climate change impacts and adaptations in Canada's north, including the vulnerability of infrastructure and the role of governments in adaptation. Climate change trends and projections are highlighted and recommendations for future actions and strategies are expressed. In Yukon, airport infrastructure could be affected by thawing permafrost, as well as increased temperature and precipitation which increase air moisture levels. Changes to river-ice breakup can damage infrastructure, as was the case in 2009 near Dawson and Faro. Silting and decreased flows in the Porcupine River have affected transportation in Old Crow. Communications infrastructure may be at risk because fibre optic cables traverse highways adjacent to rivers at risk of flooding.

Keywords: *adaptation, economic development, infrastructure, policy, Yukon-wide*

Available Online: Full Report

Citation: Canada. National Round Table on the Environment and the Economy. (2009). True North: Adapting Infrastructure to Climate Change in Northern Canada. Ottawa: NRTEE

Geophysical and Borehole Investigations of Permafrost Conditions Associated with Compromised Infrastructure in Dawson and Ross River, Yukon

Research Location: *Dawson and Ross River, Yukon*
Publication Date: *2011*
Publication Type: *Journal Article*
Affiliation: *Yukon Geological Survey*
Contact: *Sarah Laxton, Yukon Geological Survey*

Abstract: The effects of permafrost degradation in Yukon have serious negative implications for the structural integrity of vertical infrastructure. This is especially pertinent for critical buildings such as hospitals, schools, etc., in small communities that are situated on top of warm, ice-rich permafrost. Projections of mean annual air temperature over the next few decades, based on regional climatic models, indicate that air temperature will rise, hastening the thaw of permafrost. The combination of rising of air temperatures and buildings situated on warm permafrost has prompted this investigation into the vulnerability of Yukon Government vertical infrastructure. The application of DC resistivity and ground penetrating radar in conjunction with borehole drilling indicates that in Dawson there is warm ice-rich permafrost beneath the Palace Grand Theatre; the Old Territorial Administration building is underlain by primarily unfrozen sediment; and permafrost under the St. Andrew's Church is characterized by high variability. A deep active layer was observed at Ross River School and geophysical surveys indicate that warm water drainage from the roof is contributing to the thaw of the underlying permafrost.

Local Relevance: A survey was conducted to investigate the state of permafrost at various sites in both Dawson and Ross River. In Dawson, the Palace Grand Theatre is at risk for damage due to permafrost degradation because it is underlain by ice-rich permafrost that is at a temperature just below freezing. Increasing depth of the active layer may cause damage to certain areas of St. Andrew's Church, while the Old Territorial Administration Building is not at risk. In Ross River, the Ross River School may be at risk for damage because it is situated on top of permafrost with a deep active layer. The drainage of warm water from the roof into the ground will accelerate permafrost degradation below the school.

Keywords: *central Yukon, Dawson, infrastructure, permafrost, Ross River, Ross River Dena Council, south-central Yukon, Tr'ondëk Hwëch'in First Nation*

Available Online: Full Article

Citation: Laxton, S. and Coates, J., 2011. Geophysical and Borehole Investigations of Permafrost Conditions Associated with Compromised Infrastructure in Dawson and Ross River, Yukon. *In*: Yukon Exploration and Geology 2010, K.E. MacFarlane, L.H. Weston and C. Relf (eds.), Yukon Geological Survey, p. 135-148.

Impact of Groundwater Flow on Permafrost Degradation: Implications for Transportation Infrastructures

Research Location: *Beaver Creek, Yukon*
Publication Date: *2010*
Publication Type: *Conference Proceedings*
Affiliation: *Université de Montréal; Université Laval*
Contact: *Isabelle de Grandpré, University of Montreal*

Abstract: The Alaska Highway is the main terrestrial link between Alaska and the contiguous USA. Since its rehabilitation in the past decades the road has subsided in response to the degradation of the underlying ice-rich permafrost. At the study site near Beaver Creek (Yukon) the embankment material now intersects the natural groundwater table. It is suggested that water flow under the road proceeds along preferential flow paths essentially located within thawed embankment material. Measurements of water temperature indicate that the water is progressively loosing heat as it flows under the road. We propose that this energy transfer to the surrounding ground contributes to the degradation of the underlying permafrost through various processes of convective and conductive heat transfer.

Local Relevance: The embankment of the Alaska Highway near Beaver Creek is now intersecting the water table and groundwater flow paths because the underlying natural ground has subsided as a result of permafrost decay. During the summers of 2008 and 2009, the road subsided at a rate of 30 cm per summer. The flow of groundwater beneath the highway causes permafrost degradation as heat from the water is transferred to the surrounding permafrost.

Keywords: *Alaska Highway, Beaver Creek, groundwater table, infrastructure, permafrost, south-central Yukon, White River First Nation*

Available Online: Full Article

Citation: de Grandpré, I., Fortier, D., Stephani, E. 2010. "Impact of Groundwater Flow on Permafrost Degradation: Implications for Transportation Infrastructures." *In:* 63rd Canadian Geotechnical Conference & 6th Canadian Permafrost Conference, September 12-16, 2010, Calgary, Alberta, p. 534-540.

Experimentation of Mitigation Techniques to Reduce the Effects of Permafrost Degradation on Transportation Infrastructures at Beaver Creek Experimental Road Site (Alaska Highway, Yukon)

Research Location: *Beaver Creek, Yukon*
Publication Date: *2010*
Publication Date: *Conference Proceedings*
Affiliation: *Université Laval*
Contact: *Guy Doré, Université Laval*

Abstract: In order to better understand permafrost degradation on transport infrastructures, 12 experimental sections have been constructed on the Alaskan Highway near Beaver Creek. These sections experiment one or several combined methods of thermal stabilization such as convection air embankment, heat drains, grass-covered embankment, reflecting surfaces and snow clearing on embankment slopes. To rigorously monitor the temperature evolution for the next years and to determine the efficiency of theses text sections, thermistor cables have been installed into the shoulder and at the center of the embankment.

Local Relevance: Various experimental techniques to reduce permafrost degradation at the Alaska Highway near Beaver Creek have been implemented. Preliminary results suggest that snow removal and air convection systems successfully protect permafrost. Snow removal allows cold air to penetrate the ground during winter and air convection systems transport cold air to the ground in winter and warm air away from the ground in summer. In addition, permafrost degradation was greater at experimental sites with more road excavation.

Keywords: *Alaska Highway, Beaver Creek, infrastructure, permafrost, south-central Yukon, White River First Nation*

Available Online: Full Article

Citation: Lepage, J.M., Doré, G. 2010. "Experimentation of Mitigation Techniques to Reduce the Effects of Permafrost Degradation on Transportation Infrastructures at Beaver Creek Experimental Road Site (Alaska Highway, Yukon)." In: 63rd Canadian Geotechnical Conference & 6th Canadian Permafrost Conference, September 12-16, 2010, Calgary, Alberta, p. 526-533.

Preservation of the Alaska Highway

Research Location: *Beaver Creek, Yukon*
Publication Date: *2008*
Publication Type: *Conference Proceedings*
Affiliation: *Université Laval*
Contact: *Eva Stephani, University of Alaska Fairbanks*

Excerpt: Road construction in permafrost areas affects the thermal regime of frozen soils via removal of the vegetation, compaction of the soil, road cut, and use of black asphalt pavement, for instance. The thermal degradation of the permafrost causes the ground ice to melt and results in permafrost thaw settlement, as well as subsidence and cracking of pavement. In many northern areas, roads are now showing signs of instability as a result of permafrost degradation, which could be partly due to recent climate warming. According to the IPCC projection of climate warming, this situation will undoubtedly be exacerbated in the future (IPCC 2007).

The Alaska Highway is an essential and widely used communication link between Alaska, Canada, and the southern United States. The highway has a poor driving surface, and some sections of the embankments have experienced substantial settlement. Severe pavement subsidence, longitudinal cracking, and potholes could eventually threaten the structural integrity of the infrastructure. Sections of the Alaska Highway built on ice-rich permafrost might eventually require relocation or replacement with a different design, and sections built on permafrost with a lower volume of ice will require at least rehabilitation. Alternative designs and mitigation measures should be adopted in order to reduce maintenance costs. The Yukon Government has decided to implement a test section at Beaver Creek, Yukon Territory, Canada (62°20′N, 140°50′W). Engineering mitigation measures will be tested to control the degradation of the permafrost. Six techniques will be implemented at the Beaver Creek experimental road site: (1) Air convection embankment (ACE); (2) heat drain; (3) air duct cooling system; (4) thermo-reflective snow shed; (5) grass-covered embankment; and (6) light-colored aggregate bituminous surface treatments (BST)…

Local Relevance: As the active layer of the natural permafrost ground below the road increases in depth, it causes subsidence of the overlying embankment. The drainage of water from thawed ground below the embankment is limited and the upper part of the permafrost under the road is vulnerable to thaw. The researchers call for a detailed characterization of the permafrost at this site in order to understand how susceptible the permafrost is to climate warming and to determine the best methods to control permafrost decay.

Keywords: *Alaska Highway, Beaver Creek, infrastructure, permafrost, south-central Yukon, White River First Nation*

Available Online: Full Article

Citation: Stephani, E., Fortier, D., Shur, Y., Doré, G., Stanley, B., 2008. Preservation of the Alaska Highway. *In*: Ninth International Conference on Permafrost, Extended Abstracts, D.L. Kane and K.M. Hinkel (eds.), Fairbanks, Alaska, June 29-July 3, 2008, p. 299-300.

8. Food Security

Traditional Food Attributes Must be Included in Studies of Food Security in the Canadian Arctic

Research Location: *Canadian Arctic*
Publication Date: *2007*
Publication Type: *Journal Article*

Affiliation: *McGill University*
Contact: *Harriet V. Kuhnlein, McGill University*

Abstract: Objectives. The objective was to explore some typically understudied characteristics of food security in Arctic Canada: observed changes to traditional food systems, perceived advantages and health benefits of traditional food and traditional food preferences. **Study Design.** Data analysis used a cross-sectional survey of Yukon First Nations, Dene/Métis and Inuit women in 44 Arctic communities. **Methods.** Open-ended responses to 4 questions were used to qualitatively investigate roles traditional foods play in Arctic food security. Chi-square tests were applied to responses to ascertain differences by age and region. A fifth question explored agreement with cultural responses to harvesting and using traditional food. **Results.** Traditional food was regarded as natural and fresh, tasty, healthy and nutritious, inexpensive, and socially and culturally beneficial. Between 10% and 38% of participants noticed recent changes in the quality or health of traditional food species, with physical changes and decreasing availability being reported most often. Caribou, moose and seal were among the foods considered particularly healthy and held special values in these populations. The opinion that all traditional food was healthy was also popular. More than 85% of participants agreed with most cultural attributes of traditional food. **Conclusions.** This study confirms that traditional food remains important to Arctic indigenous women and that food security in the Arctic is contingent upon access to these foods.

Local Relevance: A survey involving women in 44 arctic communities, including Yukon First Nations communities, was conducted to delve into the role of traditional foods in arctic food security. Participants highlighted many physical, health, and cultural benefits of traditional foods. 38.2% of the participants noted recent changes in traditional food sources; the most common being physical changes to animals and fish, reduced animal and fish populations, and increasing difficulty accessing populations. In summary, this study shows that traditional foods are extremely important to indigenous women; therefore, availability of traditional foods is critical to food security.

Keywords: *caribou, fish, food security, traditional knowledge, wildlife, Yukon First Nations, Yukon-wide*

Available Online: Full Article

Citation: Lambden, J., Receveur, O., Kuhnlein, H.V. 2007. "Traditional Food Attributes Must be Included in Studies of Food Security in the Canadian Arctic." *International Journal of Circumpolar Health* 66(4): 308-319.

Local Observations of Climate Change and Impacts on Traditional Food Security in Two Northern Aboriginal Communities

Research Location: *Beaver Creek, Yukon; Fort Providence, Northwest Territories*
Publication Date: *2006*
Publication Type: *Journal Article*

Institution: *McGill University*
Contact: *Laurie H.M. Chan, University of Northern British Columbia*

Abstract: Objectives. Our primary objective was to record participant observations of changes in the local environment, harvesting situations and traditional food species and to explore what impact these may have on traditional food. **Study design.** A participatory study with 2 northern Aboriginal communities in Canada. **Methods.** Focus groups were conducted in both communities. Both specific and open-ended questions were asked, to gather information about the traditional food harvest and a qualitative analysis was conducted. **Results.** Members from both communities are witnessing variable changes in climate that are affecting their traditional food harvest. New species and changes in migration of species being observed by community members have the potential to affect the consumption of traditional food. Similarly, changes in water levels in and around harvesting areas are affecting access to harvest areas, which in turn affects the traditional food harvest. **Conclusions.** Community members have been required to change their harvest mechanisms to adapt to changes in climate and ensure an adequate supply of traditional food. A strong commitment to programs that will ensure the protection of traditional food systems is necessary.

Local Relevance: The participants of the White River First Nation at Beaver Creek have noticed changes in species distribution and migratory patterns: deer, lynx, and cougars have been seen around the community; different plants have been identified; birds are migrating north earlier in the spring and migrating south later in the fall, and; there has been a large decrease in the population of the local caribou herd. Community members have noticed less precipitation accompanied by drier conditions and lower berry crop yields. The observed trend of less snow in the winter may lead to increased caribou predation by coyotes. Thunder storms are occurring in unusual months and there has been much less ice on water bodies around Beaver Creek. Predicting the weather has become more difficult, storms are endangering travelers, and warmer temperatures are making it more difficult to safely dry meat.

Keywords: *Beaver Creek, caribou, food security, impacts, south-central Yukon, traditional knowledge, White River First Nation, wildlife, Yukon First Nations*

Available Online: Full Article

Citation: Guyot, M., Dickson, C., Paci, C., Furgal, C., Chan, H.M. 2006. "Local Observations of Climate Change and Impacts on Traditional Food Security in Two Northern Aboriginal Communities." *International Journal of Circumpolar Health* 65(5): 403-415.

Adaptation and Sustainability in a Small Arctic Community: Results of an Agent-Based Simulation Mode

Research Location: *Old Crow, Yukon*
Publication Date: *2004*
Publication Type: *Journal Article*
Affiliation: *University of Alaska Anchorage*
Contact: *Matthew D. Berman, University of Alaska Anchorage*

Abstract: Climate warming and resource development could alter key Arctic ecosystem functions that support fish and wildlife resources harvested by local indigenous communities. A different set of global forces—government policies and tourism markets—increasingly directs local cash economies that communities use to support subsistence activities. Agent-based computational models (ABMs) contribute to an integrated assessment of community sustainability by simulating how people interact with each other and adapt to changing economic and environmental conditions. Relying on research and local knowledge to provide rules and parameters for individual and collective decision making, our ABM generates hypothetical social histories as adaptations to scenario-driven changes in environmental and economic conditions. The model generates projections for wage employment, cash income, subsistence harvests, and demographic change over four decades based on a set of user-defined scenarios for climate change, subsistence resources, development, and government spending. Model outcomes assess how scenarios associated with economic and climate change might affect the local economy, resource harvests, and the well-being of residents for the Western Arctic Canadian community of Old Crow, Yukon. The economic and demographic outcomes suggest implications for less quantifiable social and cultural changes. The model can serve as a discussion tool for a fuller exploration of community sustainability and adaptation issues.

Local Relevance: Researchers use a simulation model parameterized by scientific research and local knowledge to predict the social responses to changing environmental and economic conditions in Old Crow. Model results address caribou harvest, income, and employment among other variables. Decreases in caribou harvest are predicted; however, gear sharing, harvest sharing, and community hunts can mitigate some of the detrimental effects of reduced harvest on the local economy. It is noted that the independence resulting from the Vuntut Gwitchin land-claim agreement may increase Old Crow's adaptive capacity.

Keywords: *caribou, food security, local knowledge, social modelling, north Yukon, Old Crow, Vuntut Gwitchin First Nation, Yukon First Nations*

Available Online: Full Article

Citation: Berman, M., Nicolson, C., Kofinas, G., Tetlichi, J. 2004. "Adaptation and Sustainability in a Small Arctic Community: Results of an Agent-Based Simulation Mode." *Arctic* 57(4): 401-414.

Where the Wild Things Are: Seasonal Variation in Caribou Distribution in Relation to Climate Change

Research Location: *ranges of the Porcupine and Bathurst caribou herds*
Publication Date: *2005*
Publication Type: *Journal Article*

Affiliation: *Canadian Wildlife Service, Environment Canada*
Contact: *Canadian Wildlife Service (Yukon)*

Abstract: In this study, we develop a method to analyse the relationships between seasonal caribou distribution and climate, to estimate how climatic conditions affect interactions between humans and caribou, and ultimately to predict patterns of distribution relative to climate change. Satellite locations for the Porcupine (*Rangifer tarandus granti*) and Bathurst (*R. t. groenlandicus*) caribou herds were analysed for eight ecologically-defined seasons. For each season, two levels of a key environmental factor influencing caribou distribution were identified, as well as the best climate data available to indicate the factor's annual state. Satellite locations were grouped according to the relevant combination of season and environmental factor. Caribou distributions were compared for opposing environmental factors; this comparison was undertaken relative to hunting access for the Porcupine Herd and relative to exposure to mining activity for the Bathurst Herd. Expected climate trends suggest an overall increase in access to Porcupine caribou for Aklavik (NWT) hunters during the winter and rut seasons, for Venetie (Alaska) hunters during midsummer and fall migration and for Arctic Village (Alaska) during midsummer. Arctic Village may experience reduced availability with early snowfalls in the fall, but we expect there to be little directional shift in the spring migration patterns. For the Bathurst Herd, we expect that fewer caribou would be exposed to the mines during the winter, while more caribou would be exposed to the combined Ekati and Diavik mining zone in the early summer and to the Lupin-Jericho mining zone during the fall migration. If changes in climate cause an increased presence of caribou in the mining sites, monitoring and mitigation measures may need to be intensified.

Local Relevance: For the community of Old Crow, snowmelt and snowfall timing significantly alter the ability of hunters to access caribou in some locations during both spring migration and calving and fall migration and rut season, respectively. In addition, insects significantly affect accessibility in one location. The impacts of different climate conditions varied across the communities studied, with no factor benefiting all. It is predicted that the Porcupine Caribou range will experience deeper snow cover, increased insect harassment, and delayed snowfall. Researchers expect little change in spring migration patterns but caution that ideal times for hunting may change with climate change.

Keywords: *caribou, food security, north Yukon, Old Crow, Vuntut Gwitchin First Nation, wildlife, Yukon First Nations*

Available Online: Full Article

Citation: McNeil, P., Russell, D.E., Griffith, B., Gunn, A., Kofinas, G.P. 2005. "Where the Wild Things Are: Seasonal Variation in Caribou Distribution in Relation to Climate Change." *Rangifer*, Special Issue,16: 51-63.

Hunting for Models: Grounded and Rational Choice Approaches to Analyzing Climate Effects on Subsistence Hunting in an Arctic Community

Research Location: *Old Crow, Yukon*
Publication Date: *2004*
Publication Type: *Journal Article*
Affiliation: *University of Alaska Anchorage*
Contact: *Matthew D. Berman, University of Alaska Anchorage*

Abstract: Climate change and uncertain economies challenge small Native communities of the North American Arctic, with their reliance on local fish and wildlife resources. Methodological boundaries of single-discipline analyses limit the contribution of academic research to the real-world questions facing Arctic residents. Oversimplified assumptions and lack of data hamper mainstream economic approaches based on rational choice, while more grounded approaches suffer from inability to generalize. We attempt to integrate these two approaches to project the effects of climate change on subsistence hunting in a Canadian Arctic community. In our collaboration, we find that rational choice modeling suggests specific questions that help direct the grounded research. Grounded methods provide general relationships and hypotheses as well as data for economic modeling. Using local knowledge (LK) obtained from grounded methods, we estimate a discrete-choice travel-cost model of subsistence hunting, projecting that climate warming may cost a typical household the equivalent of a half day of lost time during a hunting season. Besides providing data needed to make rational choice applications realistic, grounded methods reveal qualitative information essential for understanding relationships. We conclude that integration and synthesis of these disparate analytical approaches provides insights that neither method alone could have produced.

Local Relevance: Researchers used local knowledge and socially-based models to predict the impacts of climate change on caribou subsistence hunting in Old Crow. Early winters with little snowfall reduce accessibility to hunting grounds and warmer summers increase meat spoilage. Modelling predicts that during years of later winter freeze-up (a consequence of climate change), less than 10% of Old Crow residents will hunt and the average household that does hunt will lose half a day's worth of time per season.

Keywords: *caribou, food security, north Yukon, Old Crow, social modelling, local knowledge, Vuntut Gwitchin First Nation, wildlife, Yukon First Nations*

Available Online: Full Article

Citation: Berman, M., Kofinas, G. 2004. "Hunting for Models: Grounded and Rational Choice Approaches to Analyzing Climate Effects on Subsistence Hunting in an Arctic Community." *Ecological Economics* 49: 31-46.

9. Pollutants

Assessing the Long-range Transport of PAH to a sub-Arctic Site using Positive Matrix Factorization and Potential Source Contribution Function

Research Location: *Little Fox Lake, Yukon*
Publication Date: *2010*
Publication Type: *Scientific Journal*
Affiliation: *McMaster University*
Contact: *Brian McCarry, McMaster University*

Abstract: Gas-phase and particle-phase atmospheric samples collected in a sparsely populated sub-Arctic environment in the Yukon Territory, Canada were analyzed for a wide range of organic pollutants including polycyclic aromatic hydrocarbons (PAH). Receptor modeling using positive matrix factorization (PMF) was applied to a PAH data set from samples collected between August 2007 and December 2008 to afford four factors. These factors were designated as fossil fuel combustion emissions, particle-phase wood combustion emissions, gas-phase wood combustion emissions, and unburned petroleum/petrogenic emissions. The multiple linear regression-derived average contributions of these factors to the total PAH concentrations were 14% for fossil fuel combustion, 6% for particle-phase wood combustion emissions, 46% for gas-phase wood combustion emissions and 34% for petrogenic emissions. When the total PAH concentrations (defined as the sum of twenty-two PAH) and the PMF-modeled PAH concentrations set were compared, the correlation was excellent (R^2 = 0.97). Ten-day back trajectories starting at four different heights were used in a potential source contribution function analysis (PSCF) to assess the potential source regions of these PAH factors. Mapping the computed PSCF values for the four PMF factors revealed different source regions in the northern hemisphere for each PMF factor. Atmospheric transport of PAH occurred from both relatively short and long distances with both continental (North American) and trans-oceanic (Asian) sources contributing significantly to the total PAH. This study provides evidence of the transport of fossil fuel and wood combustion emissions from Asia, continental North America and northern Europe to sub-Arctic Canada (and by extension to the Canadian Arctic) primarily during cooler (fall-winter) months. This study demonstrates for the first time that the combined PMF-PSCF methodology can be used to identify geographically-disperse PAH source contributors on a hemispherical scale.

Local Relevance: This study investigates the transport of air pollutants to the arctic based on data collected from Yukon. The sources of these pollutants were identified as fossil fuel combustion, wood combustion, and unburned petroleum emissions. These pollutants were transported primarily during fall and winter from Asia, continental North America, and northern Europe.

Keywords: *atmospheric transport, Little Fox Lake, pollutants, south Yukon*

Available Online: Abstract

Citation: Sofowote, U.M., Hung, H., Rastogi, A.K., Westgate, J.N., Deluca, P.F., Su, Y., McCarry, B.E. 2010. "Assessing the Long-range Transport of PAH to a sub-Arctic Site using Positive Matrix Factorization and Potential Source Contribution Function." *Atmospheric Environment* 45(4): 967-976.

The Gas/Particle Partitioning of Polycyclic Aromatic Hydrocarbons Collected at a Sub-Arctic Site in Canada

Research Location: *Little Fox Lake, Yukon*
Publication Date: *2010*
Publication Type: *Journal Article*

Affiliation: *McMaster University*
Contact: *Brian McCarry, McMaster University*

Abstract: Polycyclic aromatic hydrocarbons (PAH) were measured in air samples at a remote air monitoring site established in the Yukon Territory, Canada as part of a global project (International Polar Year; IPY) to study the potential for atmospheric long-range transport of anthropogenic pollutants to the Arctic. Gas- and particle-phase PAH were collected in polyurethane foam plugs and on glass fibre filters respectively from August 2007 to October 2009. PAH concentrations were found to be highest in the winter months and lowest in summer. The gas/particle partitioning coefficients of 3–5 ringed PAH were computed and seasonal averages were compared. In the summer time, lower molecular mass PAH exhibited relatively higher partitioning into the particle-phase. This particle-phase partitioning led to the shallowest slopes being recorded during summer for the log–log correlation plots between the PAH partition coefficients and their sub-cooled vapour pressures. Air mass back trajectories suggest that local impacts may be more important during the summer time which is marked by increased camping activities at camping sites in the proximity of the sampling station. In conclusion, both summer and wintertime variations in PAH concentrations and gas/particle partitioning are considered to be source- and phototransformation-dependent rather than dependent on temperature-driven shifts in equilibrium partitioning.

Local Relevance: Levels of anthropogenic particulates were measured at a site near Little Fox Lake as part of the IPY-INCAPTA project investigating the transport of pollutants to the arctic. The particulate levels were highest during the winter, mainly as a result of long-range transport from other parts of the world. However, the researchers hypothesize that an observed increase in particular pollutants during the winter may be a consequence of increased residential heating during the winter in the north. It is also hypothesized that local sources of anthropogenic particulates from camping activities out-weight long-range sources during the summer months.

Keywords: *atmospheric transport, pollutants, south Yukon*

Available Online: Full Article

Citation: Sofowote, U.M., Hung, H., Rastogi, A.K., Westgate, J.N., Su, Y., Severko, E., D'Sa, I., Roach, P., Fellin, P., McCarry, B.E. 2010. "The Gas/Particle Partitioning of Polycyclic Aromatic Hydrocarbons Collected at a Sub-Arctic Site in Canada." *Atmospheric Environment* 44(38): 4919-4926.

Ice Core Record of Rising Lead Pollution in the North Pacific Atmosphere

Research Location: *Mount Logan, Yukon*
Publication Date: *2010*
Publication Type: *Journal Article*
Affiliation: *University of Maine*
Contact: *Erich C. Osterberg, Dartmouth College*

Abstract: A high-resolution, 8000 year-long ice core record from the Mt. Logan summit plateau (5300 m asl) reveals the initiation of trans-Pacific lead (Pb) pollution by ca. 1730, and a >10-fold increase in Pb concentration (1981–1998 mean = 68.9 ng/l) above natural background (5.6 ng/l) attributed to rising anthropogenic Pb emissions from Asia. The largest rise in North Pacific Pb pollution from 1970–1998 (end of record) is contemporaneous with a decrease in Eurasian and North American Pb pollution as documented in ice core records from Greenland, Devon Island, and the European Alps. The distinct Pb pollution history in the North Pacific is interpreted to result from the later industrialization and less stringent abatement measures in Asia compared to North America and Eurasia. The Mt. Logan record shows evidence for both a rising Pb emissions signal from Asia and a trans-Pacific transport efficiency signal related to the strength of the Aleutian Low.

Local Relevance: An ice core record from the St. Elias Mountains shows an increase in lead amounts after 1970, the opposite of what was observed at north Atlantic and Arctic sites. This is because Asia is the primary source of lead transport to the north Pacific; the increase in lead levels reflects the pattern of increased industrialization in Asia. Lead is also a byproduct of fossil fuel combustion and metal smelting, activities that are expanding in Asia. The researchers hypothesize that stringent emissions controls will be required in Asia to reduce lead transport to the north Pacific.

Keywords: *atmospheric transport, Mt. Logan, pollutants, south Yukon, St. Elias Mountains*

Available Online: Downloadable PDF

Citation: Osterberg, E., Mayewski, P., Kreutz, K., Fisher, D., Handley, M., Sneed, S., Zdanowicz, C., Zheng, J., Demuth, M., Waskiewicz, M., Bourgeois, J. 2008. "Ice Core Record of Rising Lead Pollution in the North Pacific Atmosphere." *Geophysical Research Letters* 35(5): 1-4.

Temporal and Spatial Variabilities of Atmospheric Polychlorinated Biphenyls (PCBs), Organochlorine (OC) Pesticides and Polycyclic Aromatic Hydrocarbons (PAHs) in the Canadian Arctic: Results from a Decade of Monitoring

Research Location: *Tagish and Little Fox Lake, Yukon; Alert and Kinngait, Nunavut; Dunai Island and Amderma, Russia*
Publication Date: *2005*
Publication Type: *Journal Article*
Affiliation: *Meteorological Service of Canada*
Contact: *Haley H. Hung, Environment Canada*

Abstract: The Northern Contaminants Program (NCP) baseline monitoring project was established in 1992 to monitor for persistent organic pollutants (POPs) in Arctic air. Under this project, weekly samples of air were collected at four Canadian and two Russian arctic sites, namely Alert, Nunavut; Tagish, Yukon; Little Fox Lake, Yukon; Kinngait, Nunavut; Dunai Island, Russia and Amderma, Russia. Selected POPs, including polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs) and organochlorine (OC) pesticides, were analyzed in both the gas and particulate phases.

This paper summarizes results obtained from this project in the past 5 years. Temporal trends were developed for atmospheric PCBs and OCs observed at Alert using a digital filtration (DF) technique. It was found that trends developed with 5 years of data (1993–1997) did not differ significantly from those determined with 7 years of data (1993–1999). This implies that with the DF technique, long-term trends can still be developed with less than 10 years of data. An acceleration in decline of OC and PCB air concentrations was noted in 1999 for some compounds, although the reason is unknown. Monitoring efforts must continue to assess the effect of this decline on the long-term trends of POPs in the Canadian Arctic.

Occasional high *trans*-/*cis*-chlordane ratios and heptachlor air concentrations measured at Alert between 1995 and 1997 suggests sporadic fresh usage of chlordane-based pesticides. However, significant decreasing trends of chlordanes along with their chemical signatures has provided evidence that emission of old soil residues is replacing new usage as an important source to the atmosphere. Measurements of OC air concentrations conducted at Kinngait in 1994–1995 and 2000–2001 indicated faster OC removal at this location than at Alert. This may be attributed to the proximity of Kinngait to temperate regions where both biotic and abiotic degradation rates are faster.

The PAH concentrations observed at Alert mimic those at mid-latitudes and are consistent with long-range transport to the Arctic, particularly for the lighter PAHs. A decline in particulate PAH was observed, similar to atmospheric sulphate aerosol and can be attributed to the collapse of industrial activity in the former Soviet Union between 1991 and 1995.

Spatial comparisons of OC seasonality at Alert, Tagish, Dunai and Kinngait show elevated air concentrations of some compounds in spring. However, elevated spring concentrations were observed for different compounds at different sites. Potential causes are discussed. Further investigation in the atmospheric flow pattern in spring which is responsible for the transport of POPs into the Arctic is required. OC and PCB air concentrations at Alert were found to be influenced by two climate variation patterns, the North Atlantic Oscillation (NAO) and the Pacific North American (PNA) pattern. Planetary atmospheric patterns must be taken into account in the global prediction and modelling of POPs in the future.

Local Relevance: As part of the Northern Contaminants Program, persistent organic pollutant (POP) monitoring stations were set up in northern Canada and Russia. At the Tagish site, there was evidence for increased POP concentrations in spring—potential reasons for this are highlighted in the paper. POP concentrations were affected by atmospheric oscillations which must considered when making future predictions about POPs.

Keywords: *atmospheric transport, Carcross/Tagish First Nation, Little Fox Lake, pollutants, south Yukon, Tagish*

Available Online: Abstract

Citation: Hung, H., Blanchard, P., Halsall, C.J., Bidleman, T.F., Stern, G.A., Fellin, P., Muir, D.C.G., Barrie, L.A., Jantunen, L.M., Helm, P.A., Ma, J., Konoplev, A. 2005. "Temporal and Spatial Variabilities of Atmospheric Polychlorinated Biphenyls (PCBs), Organochlorine (OC) Pesticides and Polycyclic Aromatic Hydrocarbons (PAHs) in the Canadian Arctic: Results from a Decade of Monitoring." *Science of the Total Environment* 342(1-3): 119-144.

10. General

Regional Assessment of GCM-Simulated Current Climate over Northern Canada

Research Location: *Yukon; Northwest Territories; Nunavut; Quebec/Labrador*
Publication Date: *2006*
Publication Type: *Journal Article*
Affiliation: *Aquatic Ecosystem Impacts Research Division, Environment Canada*
Contact: *Barrie R. Bonsal, Environment Canada*

Abstract: Several international Global Climate Models (GCMs) are evaluated on their ability to simulate the mean values and spatial variability of current (1961–90) temperature and precipitation over four regions across Canada's North. A number of observed climate data sets for Arctic Canada are also assessed. Results reveal a close correspondence, particularly for temperature, among the four observed climate data sets assessed. However, the various GCM simulations of this observed climate show considerable inter-regional and seasonal variability, with temperature more accurately simulated than precipitation. Temperature findings indicate that the British HadCM3, German ECHAM4, and Japanese CCSR-98 models best replicate annual and seasonal values over all sub-regions. The Canadian CGCM2 and U.S. NCAR-PCM models have intermediate accuracy, and the Australian CSIRO-Mk2b and U.S. GFDL-R30 models are least representative. Temperature simulations from the various GCMs collectively display a similar degree of accuracy over all sub-regions, with no clear evidence of superiority in any given area. Precipitation, conversely, is accurately simulated by the majority of models only over northern Quebec/Labrador. All GCMs substantially overestimate annual and seasonal precipitation amounts in the western and central Canadian Arctic.

Local Relevance: For Yukon, most of the GCMs accurately model temperatures over 1961-1990 as well as spatial differences in temperature across the region. Spring was the most-accurately modelled season with respect to temperature. All of the GCMs overestimate precipitation in Yukon, ranging from 187mm to more than 364mm greater than the observed precipitation; however, one model (HadCM3) accurately modelled winter precipitation. The models also poorly portray the spatial variation in precipitation over Yukon, likely because Yukon has a wide range of topographical features. This paper highlights the best GCMs for modelling temperature and precipitation over individual regions and the Canadian north as a whole.

Keywords: *air temperature, climate modelling, hydrology, precipitation, Yukon-wide*

Available Online: Full Article

Citation: Bonsal, B.R., Prowse, T.D. 2006. "Regional Assessment of GCM-Simulated Current Climate over Northern Canada." *Arctic* 59(2): 115-128.

Climate Change Risk Assessment and Vuntut Gwitchin Final Agreement Analysis

Research Location: *Old Crow, Yukon*
Publication Date: *2009*
Publication Type: *Project Report*
Affiliation: *Arctic Athabaskan Council*
Contact: *Council of Yukon First Nations*

Executive Summary: Climate change is having an unequivocal impact on the Arctic environment (IPCC 2007). The citizens of the Vuntut Gwitchin First Nation and others who live in Old Crow, Yukon, north of the Arctic Circle, are experiencing climate-induced impacts such as changes in temperature, water, flora, fauna, and permafrost. These impacts, observed through both local and scientific methods, have implications for people's way of life culture, health, socio-economic structure and environment.

The Old Crow Climate Change Risk Assessment and Final Agreement Analysis project was conducted from November 2006 to July 2008 to address the community's concerns about a changing climate. This pilot project, initiated by the Arctic Athabaskan Council (AAC), outlined three objectives: 1) conduct a legal analysis of the Vuntut Gwitchin First Nation Final Agreement to determine the presence of language that can be used to support climate change initiatives. The analysis determined that there is legal backing in the Final Agreement to support climate change initiatives through the Fish and Wildlife chapter as well as the Land Use Planning chapter. 2) conduct an assessment of Umbrella Final Agreement-mandated organizations and climate change. The response to climate change by these organizations has been most accurately determined as inactive, with some notable exceptions. Recommendations were developed to address climate change concerns. 3) conduct the initial stages of a climate change risk assessment and adaptation project for a single Yukon First Nation. Through this portion of the project, the Old Crow community identified 14 indicators of climate change and the impacts and risks associated with changes to these indicators. Where possible, management actions were identified.

This Old Crow Climate Change Risk Assessment and Final Agreement project should be followed up with a risk management and adaptation plan that begins by addressing the risks identified in this report…

Local Relevance: Two areas within the Vuntut Gwitchin First Nation Final Agreement, the Land Use Planning and Fish and Wildlife sections, contain language that could provide backing for action on climate change; however, there is no wording that requires a direct response to climate change in any portion of the Final Agreement. It was also determined that organizations belonging to the Umbrella Final Agreement have been deficient in their response to climate change. Members from the community of Old Crow identified 14 possible indicators of climate change and the importance of each indicator. These include wildlife, climatic variables, vegetation, and landscape features and are described in detail.

Keywords: *north Yukon, Old Crow, policy, Umbrella Final Agreement, Vuntut Gwitchin First Nation, Yukon First Nations*

May be Available upon Request

Citation: AAC. 2009. *Climate Change Risk Assessment and Final Agreement Analysis*. Arctic Athabaskan Council: Whitehorse, Yukon.

Yukon Government Initiatives

Pan-Territorial Adaptation Strategy: Moving Forward on Climate Change Adaptation in Canada's North

Research Location: *Yukon; Northwest Territories; Nunavut*
Publication Date: *2011*
Publication Type: *Government Publication*
Affiliation: *Government of Yukon; Government of the Northwest Territories; Government of Nunavut*
Contact: *Premier's Office, Government of Yukon*

Executive Summary: Climate change impacts vary widely in nature and magnitude across Canada's North. The Governments of Nunavut, the Northwest Territories and Yukon agreed in 2009 to work together on climate change, with a focus on practical adaptation measures.

The *Pan-Territorial Adaptation Strategy: Moving Forward on Climate Change Adaptation in Canada's North* identifies six approaches for supporting current and future climate change actions: 1) Source funding 2) Collaborate with other governments 3) Support communities 4) Integrate adaptation 5) Share knowledge and understanding 6) Develop and share tools, technology and innovation.

Adaptation requires governments to manage risks and ensure that Northern infrastructure, ecosystems and cultures are resilient to future changes. The territorial governments commit to work closely with partners at all levels—local, national, international—as well as with Aboriginal governments and organizations by sharing climate change adaptation knowledge and developing collaborative activities.

Local Relevance: This publication was the result of an event at the 2009 Northern Premiers' Forum in which the governments of the northern territories agreed to work together to better understand climate change impacts and propose suitable adaptation measures. Six strategies for adaptation are outlined which include: establishing secure, effective funding for organizations addressing climate change adaptation; building partnerships between the governments of the three territories, including aboriginal governments; supporting communities' adaptation efforts; integrating adaptation strategies into government planning; disseminating climate change information to the public, and; expanding monitoring and data collection efforts.

Keywords: *adaptation, pan-territorial, policy, Yukon-wide*

Available Online: Full Report

Citation: Yukon, Northwest Territories, Nunavut. Premier's Office. "Pan-Territorial Adaptation Strategy: Moving Forward on Climate Change Adaptation in Canada's North." In *A Northern Vision: A Stronger North and a Better Canada*. Whitehorse: 2011.

Paths to a Renewable North: A Pan-Territorial Renewable Energy Inventory

Research Location: *Yukon; Northwest Territories; Nunavut*
Publication Date: *2011*
Publication Type: *Government Publication*
Affiliation: *Government of Yukon; Government of the Northwest Territories; Government of Nunavut*
Contact: *Premier's Office, Government of Yukon*

Excerpt: Providing energy to meet the needs of Northern households, communities, and industry in Canada's three territories is difficult, but critically important. Currently, imported fossil fuels provide a large percentage of the heat and power used in Nunavut, Northwest Territories and Yukon. Dependence on imported fossil fuels puts us at an economic disadvantage; the three territories are vulnerable to high costs, price volatility and supply disruptions. The burning of these fuels also emits greenhouse gases that contribute to the changing climate that is affecting the North.

At the 2009 Northern Premiers' Forum, the three territorial Premiers committed to developing an inventory of current and future renewable energy resources. This inventory describes the current state of renewable energy use in the territories, outlines actions being taken and describes policies under development to increase renewable energy use in the North. Finally, the inventory highlights the geographic and policy contexts faced by each territory that shape our distinct opportunities and challenges in the development of renewable energy…

Local Relevance: This report outlines various renewable energy resources and strategies, and their feasibility for each of the territories. Yukon has undeveloped hydroelectric potential that could be developed—but there are significant associated financial, social and economic costs. Integrating solar power into existing electrical grids is being investigated via projects such as solar heat and electricity at Yukon College. With proper harvesting techniques, biomass can be a useful renewable energy source and a bioenergy strategy is being developed for Yukon. Studies have shown that Yukon has substantial geothermal potential.

Keywords: *adaptation, energy, hydroelectricity, infrastructure, pan-territorial, policy, renewable energy, Yukon-wide*

Available Online: Full Report

Citation: Yukon, Northwest Territories, Nunavut. Premier's Office. "Paths to a Renewable North: A Pan-Territorial Renewable Energy Inventory." In *A Northern Vision: A Stronger North and a Better Canada*. Whitehorse: 2011.

Yukon Government Climate Change Action Plan

Research Location: *Yukon*
Publication Date: *2009*
Publication Type: *Government Publication*
Affiliation: *Environment Yukon*
Contact: *Climate Change Secretariat*

Excerpt: The Climate Change Action Plan sets out how the Yukon government is responding to climate change. It shows us actions now underway as well as what new or enhanced actions would help advance our priorities. It identifies priority actions which are to be undertaken now and actions which should be undertaken in the future.

This action plan is the result of input received from more than 100 individuals and organizations through written submissions, workshops and meetings. The plan, providing clear direction and action, advances the goals of the Climate Change Strategy.

Implementation of the Action Plan will involve all departments and agencies of the Yukon government. We will also work with partners to meet the challenges and opportunities of climate change in Yukon—other governments, non-government organizations, industry, and the academic community…

Local Relevance: The Climate Change Action Plan describes Yukon government proposed actions and actions currently underway with respect to climate change. These actions are based upon four broad goals: 1) to better understand climate change; 2) enhance Yukon's adaptive capacity; 3) mitigation of greenhouse gas emissions and; 4) provide leadership in addressing climate change. For each goal, multiple detailed actions are laid out for both near-term and future responses.

Keywords: *adaptation, mitigation, policy, Yukon-wide*

Available Online: Full Report

Citation: Yukon. Dept. of Environment. *Climate Change Action Plan.* Whitehorse: 2009.

A Snapshot: Yukon Government Actions on Climate Change during 2006 & 2007

Research Location: *Yukon*
Publication Date: *2008*
Publication Type: *Government Publication*
Affiliation: *Environment Yukon*
Contact: *Climate Change Secretariat*

Excerpt: This report provides a list of programs and initiatives that were taken by the Yukon Government during 2006 and 2007. In some cases actions were 'one-time' initiatives and in others they are ongoing. In all cases, action outcomes were and continue to be complementary to the goals of the *Yukon Government Climate Change Strategy* and the *Yukon Government Climate Change Action Plan*. Collectively, the actions identified in this report and the new initiatives presented in the Action Plan provide a comprehensive overview of the Yukon Government response and approach to adaptation and mitigation of climate change related effects.

Local Relevance: This report highlights actions undertaken by various Yukon government departments addressing climate change. For each action, the responsible department and whether the action is completed or ongoing are stated. Each action fits under the four broad goals of the Yukon Government Climate Change Action Plan: 1) broaden understanding; 2) improve adaptive capacity; 3) mitigate and; 4) provide leadership.

Keywords: *adaptation, mitigation, policy, Yukon-wide*

Available Online: Full Report

Citation: Yukon. Dept. of Environment. *A Snapshot: Yukon Government Actions on Climate Change during 2006 & 2007.* Whitehorse: 2008.

Energy Strategy for Yukon

Research Location: *Yukon*
Publication Date: *2008*
Publication Type: *Government Publication*
Affiliation: *Energy, Mines and Resources Yukon*
Contact: *Energy Solutions Center*

Excerpt: The *Energy Strategy for Yukon* identifies energy priorities for the Yukon government. It proposes a vision for the energy sector and principles to guide Yukon government decisions. Goals, strategies and actions for efficiency and conservation, renewable energy, electricity, oil and gas and energy choices are identified. The Strategy will provide direction for developing, managing and using energy over the next ten years.

This Strategy focuses on the Yukon government's roles and responsibilities for developing and managing energy resources. The Yukon government's energy policies and programs will also play a role in guiding other government, industry, business and individual decisions about energy. The Strategy is intended to complement and be coordinated with the government's Climate Change Strategy and Action Plan…

Local Relevance: This publication outlines Yukon's current and future energy use as well as areas in which energy development will be implemented. Goals outlined include: improve both energy efficiency and renewable energy supply by 20% in 2020; produce more electricity from renewable sources, and; identify potential energy sources. Energy efficiency will result in reduced greenhouse gas emissions and will be accomplished by strategies such as supporting local agriculture and providing programs to highlight energy efficiency options. Yukon has significant renewable energy potential including hydro, wood, wind, solar, and geothermal sources. Energy possibilities are detailed in the Strategy.

Keywords: *energy, hydroelectricity, industry, infrastructure, mitigation, policy, renewable energy, Yukon-wide*

Available Online: Full Report

Citation: Yukon. Dept. of Energy, Mines and Resources. *Energy Strategy for Yukon*. Whitehorse: 2009.

Government of Yukon Climate Change Strategy

Research Location: *Yukon*
Publication Date: *2006*
Publication Type: *Government Publication*
Affiliation: *Environment Yukon*
Contact: *Climate Change Secretariat*

Excerpt: Climate change is a global issue, presenting challenges all over the world. Most climate scientists have concluded that global temperatures are rising and that warming in the past 50 years has been accelerated by human activities that release greenhouse gases into the atmosphere.

In Yukon, and across the circumpolar north, the effects of climate change are becoming more apparent and better understood. Yukon is experiencing impacts such as thawing permafrost, increased glacial melting, rising sea levels on the north coast, beetle infestations across southern spruce forests and more extreme weather events. These climate change impacts are threatening the structural integrity of buildings, highway infrastructure, are impacting traditional ways of life, damaging heritage sites and increasing the risks, costs and impacts of forest fires…

Local Relevance: Four main goals for dealing with climate change and accompanying strategies to achieve said goals are outlined. The four goals are: improve understanding of climate change in Yukon; act to mitigate greenhouse gas emissions; improve Yukon's adaptive capacity, and; be a leader for northern climate change research and action. This publication illustrates Yukon vulnerabilities to climate change and also areas in which Yukon can benefit. The scientific basis of climate change is explained and climate change impacts in Yukon are presented.

Keywords: *adaptation, impacts, mitigation, policy, Yukon-wide*

Available Online: Full Report

Citation: Yukon. Dept. of Environment. *Climate Change Strategy*. Whitehorse: 2006.

Environment

Yukon State of the Environment Interim Report—Environmental Indicators from 2007

Research Location: *Yukon*
Publication Date: *2010*
Publication Type: *Government Publication*
Affiliation: *Environment Yukon*
Contact: *Jesse Devost, Government of Yukon*

Excerpt: Interim state of the environment reporting is a requirement of Yukon's Environment Act. The interim report's purpose is to provide an early warning and analysis of potential problems for the

environment, to allow the public to monitor progress toward the achievement of the objectives of the Environment Act and to provide baseline information for environmental planning, assessment and regulation. The focus of this interim report is to provide an update on climate change, air, water, land and nature…

Local Relevance: This report highlights climate change implications and indicators for Yukon, as well as air and water quality reports and the status of Yukon land and nature. With respect to climate change, the transportation sector comprises the largest proportion of Yukon GHG emissions. Another significant GHG source is Yukon electricity production—diesel generators are used to supplement hydroelectric power when it cannot meet energy demands. Indicators of climate change in Yukon include warmer temperatures, increased winter precipitation, and more frequent and intense storms.

Keywords: *environment, greenhouse gases, impacts, Yukon-wide*

Available Online: Full Report

Citation: Yukon. Dept. of Environment. *Yukon State of the Environment Interim Report—Environmental Indicators from 2007*. Whitehorse: 2010.

Yukon State of the Environment Report 2008

Research Location: *Yukon*
Publication Date: *2009*
Publication Type: *Government Publication*
Affiliation: *Environment Yukon*
Contact: *Heather Milligan, Government of Yukon*

Excerpt: This report tracks indicators in several areas including climate change, air, water, land, and fish and wildlife. Indicators are key measurements used to monitor, describe and interpret change. Indicators cannot provide all of the information on a particular topic, but they give key information that shows how aspects of the environment are doing. The indicators featured here are based on key criteria including data availability, data reliability, usefulness and ease of understanding. Indicators are used to evaluate and demonstrate whether environmental changes are positive or negative…

Local Relevance: This report highlights climate change trends and impacts in Yukon as well as actions that the government has supported to address climate change. A breakdown of GHG emission sources for Yukon is provided; for example, the majority of Yukon's GHG emissions come from the transportation sector—mainly from heavy-duty diesel vehicles. Climate change initiatives highlighted include the Good Energy program and development of Super GreenHome building practices. Trends include warming temperatures and increased winter precipitation, with winter temperatures and precipitation increasing further north.

Keywords: *air temperature, environment, greenhouse gases, impacts, mitigation, precipitation, Yukon-wide*

Available Online: Full Report

Citation: Yukon. Dept. of Environment. *State of the Environment Report 2008*. Whitehorse: 2009.

Climatic Determinants of Berry Crops in the Boreal Forest of the Southwestern Yukon

Research Location: *Kluane Lake, Yukon*
Publication Date: *2009*
Publication Type: *Journal Article*
Affiliation: *University of British Columbia*
Contact: *Charles J. Krebs, University of British Columbia*

Abstract: Berry crops in the southwestern Yukon were quantified from 1997 to 2008 at 10 locations along 210 km of the Alaska and Haines highways. We tested the hypothesis that the size of berry crops could be predicted from spring and summer temperature and rainfall of years t, t–1 (1 year prior), and t–2 (2 years prior). Six common species were studied in the boreal forest of the Kluane region: *Arctostaphylos rubra* (Rehd. & Wils.) Fern., *Arctostaphylos uva-ursi* (L.) Spreng. s.l., *Empetrum nigrum* L., *Vaccinium vitis-idaea* L., *Geocaulon lividum* (Richards) Fern, and *Shepherdia canadensis* (L.) Nutt.. For the first five species we counted berries on fixed 40 cm x 40 cm quadrats to obtain an index of berry production for the Kluane region for each of the 12 years, and for *S. canadensis* we counted berries on two tagged branches of 10 bushes at each location. Stepwise multiple regressions were utilized to predict the size of berry crops for each species. For all species, predictive equations could explain statistically 80%–96% of the variation in berry crops. Different weather variables characterized each plant species, and there was no common weather regression that could explain the variation in berry crops in all species. Rainfall and temperature from years t–1 and t–2 were typically the significant predictors. There was no indication of a periodicity in berry production, and 43%–60% of the quadrats counted had large berry crops at one year intervals, while other quadrats never had a high crop during the study interval.

Local Relevance: This study investigated whether berry crops of six plant species in the boreal forest could be predicted from climatic variables. It was determined that the significant predictors were the rainfall and temperature regimes of the previous two years. Weather conditions could explain most of the yearly variation (80-96%) in berry crops for each species; however, none of the species responded in the same way to the same climatic variable. Also, mean or total yearly values could not predict berry crops; monthly values were required for accurate prediction.

Keywords: *berries, Kluane Lake, south Yukon*

Available Online: Full Article

Citation: Krebs, C.J., Boonstra, R., Cowcill, K., Kenney, A.J. 2009. "Climatic Determinants of Berry Crops in the Boreal Forest of the Southwestern Yukon." *Botany* 87: 401-408.

Mushroom Crops in Relation to Weather in the Southwestern Yukon

Research Location: *Kluane Lake, Yukon*
Publication Date: *2008*
Publication Type: *Journal Article*
Affiliation: *University of British Columbia*
Contact: *Charles J. Krebs, University of British Columbia*

Abstract: Epigeous mushroom production in the boreal forest ecosystem varies dramatically from year to year. We tested the hypothesis that the aboveground production of epigeous mushrooms in the Kluane region, Yukon, could be predicted by summer rainfall. There is a single crop in this part of the boreal zone with maximum production during the first 2 weeks of August. We measured standing crops from 1993 to 2007 at 13 areas along 210 km of the Alaska Highway and Haines Road in the southwestern Yukon. Aboveground mushroom crops averaged 24 kg/ha wet weight but varied from 0.0 to 117 kg/ha over the 15 years of study, with a coefficient of variation among years of 143%. Epigeous mushroom production could be predicted from June rainfall of the current year and May rainfall of the year previous with $R^2 = 0.85$. Part of the lack of a perfect fit to rainfall was due to the constraint that years of high mushroom crops could not be followed by another high year, no matter what the rainfall pattern. We were not able to identify the species of mushrooms in this study but we confirm from natural history observations that mushrooms are a critical food for several of the small mammal species in the Yukon boreal forest.

Local Relevance: It was determined that June rainfall of the current year and May rainfall of the previous year are both good predictors of mushroom crop production in southwest Yukon, whereas temperature showed no correlation. It is hypothesized that May rainfall of the previous year affects plant energy storage which in turn affects crop production the following year. Previous research has found that increased water availability promotes mushroom crop production; however, current and past research has found that a year of high production could not be followed by another productive year, regardless of rainfall.

Keywords: *Kluane Lake, mushrooms, south Yukon*

Available Online: Full Article

Citation: Krebs, C.J., Carrier, P., Boutin, S., Boonstra, R., Hofer, E. 2008. "Mushroom crops in relation to weather in the southwestern Yukon." *Botany* 86: 1497-1502.

State of the Park Report—Kluane National Park and Reserve of Canada

Research Location: *Kluane National Park and Reserve*
Publication Date: *2008*
Publication Type: *Government Publication*
Affiliation: *Kluane National Park and Reserve of Canada*
Contact: *Kluane National Park and Reserve of Canada*

Executive Summary: Kluane National Park and Reserve of Canada (KNP&R), located in southwest Yukon, is an immense region (21,980 km^2) of high mountains, icefields, glaciers and impressive wildlife. Wilderness to some, homeland to others, the park was established in 1976 and is part of an international World Heritage Site. KNP&R is within the traditional territory of the Champagne and Aishihik First Nations (CAFN) and the Kluane First Nation (KFN); recently these Southern Tutchone people's strong ties to the park's lands have been recognized and encouraged. Parks Canada requires each national park to prepare

Parks Canada requires each national park to prepare a five-year state of the park report before launching a management planning process. This is the first such report for KNP&R. The report provides an analysis and assessment of five aspects of the park: ecological integrity; cultural resources; public appreciation and understanding; visitor experience; and cooperative management…

Local Relevance: From 1945 onward, climatic records indicate increased average temperature and precipitation, accompanied by decreased rain in summer; elders say winters are not as cold as they used to be. Icefields and glaciers have been melting rapidly in response to climate warming; elders are worried about the future of water systems in the area. Elders hear fewer birds and are worried about effects of the spruce beetle; beetle-killed trees increase the risk of ground fires, impede wildlife movement, and do not take up water from the soil. The arctic ground squirrel population has declined, possibly due to altered precipitation; however, mice and vole populations have increased, possible due to greater berry production as the forest canopy is opened by the spruce beetle. Kokanee salmon populations have decreased since 2002, perhaps due to water temperatures that are too high for optimal reproduction.

Keywords: *air temperature, Champagne and Aishihik First Nations, environment, fish, impacts, Kluane First Nation, Kluane National Park and Reserve, precipitation, salmon, south Yukon, spruce bark beetle, traditional knowledge, wildlife, Yukon First Nations*

Available Online: Full Report

Citation: Henry, D., Landry, A., Elliot, T., Gorecki, L., Gates, M., and Chow, C., 2008. *State of the Park Report—Kluane National Park and Reserve of Canada.* Parks Canada, 72 p.

Herschel Island *Qikiqtaruk* Territorial Park Management Plan

Research Location: *Herschel Island*
Publication Date: *2006*
Publication Type: *Government Publication*
Affiliation: *Environment Yukon*
Contact: *Wildlife Management Advisory Council (North Slope)*

Excerpt: Herschel Island - Qikiqtaruk Territorial Park, approximately 5 kilometres off the north coast of the Yukon, was established in 1987 as a result of the Inuvialuit Final Agreement. Its main purposes are the conservation of wildlife and habitat, protection of the heritage resources and allowing for traditional use. The island is part of the Yukon North Slope and is subject to a number of agreements

concerning management of resources. Continued co-operation with the Inuvialuit, various levels of government and other agencies is very important.

This 116 square kilometre, low-lying, treeless island and its surrounding waters support healthy wildlife populations and large numbers of migratory birds. People have used the area for hunting, shelter and as a meeting place for many centuries. Whalers were the first Europeans to use the island, starting in the 1890s. Significant historic and prehistoric sites remain…

Local Relevance: Climate change and the resulting effects on natural systems have been labeled as "major stressors" occurring at "accelerated" rates in Qikiqtaruk Territorial Park. Temperatures have risen, accompanied by increased winds, more summer storms, elevated water levels, and changes to ice. Associated with climate change are changes to natural processes, including altered vegetation, more erosion, and more frequent landslides. It is noted that the park could assist in monitoring climate change by staffing the weather station in the park. Many of the goals outlined in the report address monitoring the changing climate.

Keywords: *air temperature, Beaufort Sea, environment, hazards, Herschel Island, Herschel Island Territorial Park, impacts, north Yukon*

Available Online: Full Report

Citation: Yukon. Dept. of Environment. *Herschel Island-Qikiqtaruk Territorial Park Management Plan*. Whitehorse: 2006.

Youth and Education

Educating for a Changing Climate: The State of Climate Change Education in the Yukon

Research Location: *Yukon*
Publication Date: *2009*
Publication Type: *Project Report*
Affiliation: *Northern Climate ExChange*
Contact: *Lacia Kinnear, Northern Climate ExChange*

Excerpt: With the severity and immediacy of climate change and the unpredictable challenges it brings, the need to inform the next generation, and empower them to mitigate and adapt to climate change, is crucial. This is particularly true in the Yukon, where the effects of climate change will be severe.

This Report looks at the status of climate change teaching, learning and education in the Yukon. Many avenues for learning and teaching have been explored, whether through formal or informal education outside of the home, including elementary and secondary schools, NGO environmental education programs, and online resources…

Local Relevance: Yukon Department of Education has implemented and supported many environmental stewardship programs in Yukon schools; however, few of these programs require or promote ongoing participation. A detailed analysis of the British Columbia Department of Education

curriculum identifies elementary and secondary school courses and grade levels in which climate change and related factors are included in the Prescribed Learning Outcomes. Numerous environment-related programs and organizations aimed at Yukon teachers and students are outlined. It is concluded that there are many excellent resources for integrating climate change into Yukon schools and curricula— the most valuable of these resources are those that describe how the initiative relates to the Prescribed Learning Outcomes for that grade.

Keywords: *education, Yukon-wide, youth*

Available upon Request

Citation: Clohosey, S. 2009. "Educating for a Changing Climate: The State of Climate Change Education in the Yukon." Report prepared for: the Northern Climate ExChange.

Yukon Youth Outside (the Box) Final Report

Research Location: *Marsh Lake, Yukon*
Publication Date: *2008*
Publication Type: *Workshop Report*
Affiliation: *Government of Yukon*
Contact: *Climate Change Secretariat*

Excerpt: On August 29, 2007, 24 Yukoners between the ages of 16 and 27 packed up their gear and made their way out to Sprucewind Camp at Marsh Lake. On the shores of the flooding lake and surrounded by beetle killed trees, the youth were tasked with the question: What would Youth do, in place of the Yukon Government, if asked to solve Climate Change?

Over the course of the three day camp the group moved through a series of teambuilding, problem solving, reflective, and group discussion based activities. Quickly and almost cohesively, the participants graduated from feelings of fear, overwhelming helplessness, and pessimism, to separating fact from fiction, determining how they could be most effective, and finding hope in action. Day One was a sharing of feelings and basic knowledge. Day Two was an overwhelming determination of the complexity involved in tackling Climate Change. Day Three began with mild panic at the lack of time available to find a solution and ended with passion focused on an accomplishable outcome…

Local Relevance: Youth forum participants came up with a "PETERS" plan as a way to address climate change in Yukon—namely, Planning, Education, Transportation, Energy, Responsibility, and Supply Locally. The participants recommended: a high-density city with centralized housing and curbside collection of compost and recyclables; education to enhance knowledge; energy efficiency in transportation; government incentives and programs to motivate green practices, and; supporting local resources.

Keywords: *adaptation, mitigation, policy, Yukon-wide, youth*

Available Online: Full Report

Citation: Thiessen, J. 2008. "Yukon Youth Outside (the Box) Final Report." Report prepared for: Government of Yukon.

Research Needs

Research Needs Survey: Yukon Community Survey Results

Research Location: *Yukon*
Publication Date: *2004*
Publication Type: *Project Publication*
Affiliation: *Northern Climate ExChange*
Contact: *Lacia Kinnear, Northern Climate ExChange*

Excerpt: The Yukon Community Survey is a component of the C-CIARN North Research Needs Survey, an initiative of the North Region of the Canadian Climate Impacts and Adaptation Research Network (CCIARN North). The larger initiative involves an online survey that solicited information from a broad geographical base, community-based surveys in each of the three northern territories, a literature review of existing expressions of research needs, and a number of other approaches such as topic-focused online workshops. The purpose of the project is to help develop a broad sense of the research needed to understand and adapt to climate change impacts in Canada's North.

The Online Survey and the community-based surveys are based on the Northern Climate ExChange Gap Analysis Project, which reviewed the current state of knowledge regarding climate change in 16 natural and human systems in the North. For purposes of assessment, each system was subdivided into a number of aspects. For each aspect, the Gap Analysis Project assessed the state of baseline knowledge (both knowledge of the system before climate change and knowledge about the fundamental mechanisms operating in the system) and the state of knowledge about several different impacts (temperature change, precipitation change, other and indirect impacts) of climate change. Recognizing that a knowledge gap is not necessarily an important knowledge need, C-CIARN North then undertook the next step – to ask where, in light of the current state of knowledge, it is most important to focus research time and resources in the near future…

Local Relevance: In the Yukon Community Survey portion of the Research Needs Survey project, participants were asked two questions about 16 different human and natural systems: 1) "If researchers and community people were to study the impacts of climate change on the system, what specific topics would you like them to study?" and; 2) "Why are these research topics important?" This report presents the responses in an organized list based on the which of the 16 systems was addressed (boreal forest, fresh water, transportation, energy, tourism, infrastructure, community health, hunting and trapping, mining, tundra, waste management, agriculture, fisheries, forestry, coast, and marine).

Keywords: *impacts, research needs, Yukon-wide*

Available Online: Yukon Community Survey Results

Research Needs Survey Project Website

Citation: Eamer, C. 2004. *Research Needs Survey: Yukon Community Survey Results*. C-CIARN North, Northern Climate ExChange: Whitehorse, Yukon.

Research Needs Survey: Online Survey Results

Research Location: *Canada and United States*
Publication Date: *2004*
Publication Type: *Project Publication*

Affiliation: *Northern Climate ExChange*
Contact: *Lacia Kinnear, Northern Climate ExChange*

Excerpt: The C-CIARN North Online Research Needs Survey was administered through the C-CIARN North website in the first part of 2003, closing in early October. The purpose of the survey is to help develop a broad sense of the research needs related to climate change impacts and adaptation in Canada's North. The Online Survey is part of a larger C-CIARN North initiative that involves community-based surveys in each of the three northern territories, a literature review of existing expressions of research needs, and a number of other methods such as topic-focused online workshops.

The Online Survey is based closely on the Northern Climate ExChange Gap Analysis Project, which reviewed the state of knowledge regarding climate change in the North according to 16 natural and human systems. For purposes of assessment, each system was subdivided into a number of aspects. For each aspect, the Gap Analysis Project assessed the state of baseline knowledge (both knowledge of the system before climate change and knowledge about the fundamental mechanisms operating in the system) and the state of knowledge about several different impacts (temperature change, precipitation change, other and indirect impacts) of climate change. Recognizing that a knowledge gap is not necessarily an important knowledge need, C-CIARN North then undertook the next step – to ask where, in light of the current state of knowledge, it is most important to focus research time and resources in the near future.

The survey is complex and was aimed primarily at researchers, managers, and policy makers. Respondents were given a brief indication of the state of knowledge in the various aspects of the systems and asked to rate the importance of improving that state of knowledge. They were also asked to rate the importance of learning more about sample impacts and to suggest other potential impacts that require research. Respondents were not asked to fill out the whole survey, but only those systems that interested them or that they felt competent to discuss…

Local Relevance: An online survey was distributed to various researchers and decision-makers across Canada (and the United States to a minor extent) asking participants to state whether further research is needed regarding baseline knowledge of or impacts on 16 different human and natural systems. Of the respondents, 35% were Yukon residents. Detailed responses for each of the 16 systems (boreal forest, fresh water, transportation, energy, tourism, infrastructure, community health, hunting & trapping, mining, tundra, waste management, agriculture, fisheries, forestry, coast, and marine) are outlined.

Keywords: *impacts, research needs, Yukon-wide*

Available Online: Online Survey Results

Research Needs Survey Website

Citation: Eamer, C. 2004. *Research Needs Survey: Online Survey Results*. C-CIARN North, Northern Climate ExChange: Whitehorse, Yukon.

II. APPENDICES

Appendix A: Index

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