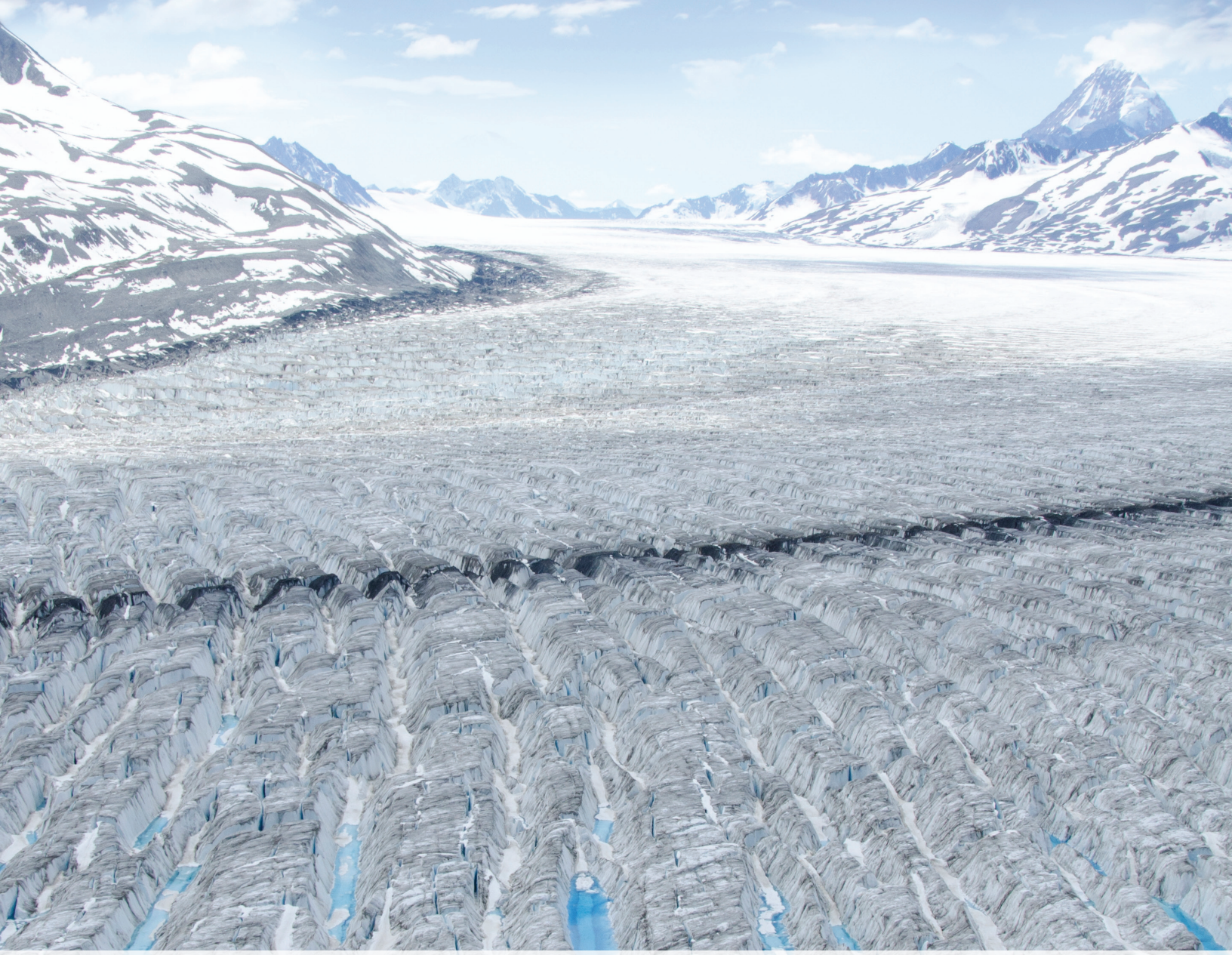

Compendium of Yukon Climate Change Science

2016 Supplement

Northern Climate ExChange
YUKON RESEARCH CENTRE · Yukon College

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

TAKING ACTION ON CLIMATE CHANGE

Yukon Government

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Foreword

The Compendium is intended to provide an overview of recent climate change work involving Yukon. This document is intended to supplement the 2003-2013 version of the Compendium with climate change work that has taken place during 2015 and 2016. 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
- Wolf Creek Research Basin database
- Kluane Lake Research Station Bibliography
- NCE Library
- Northern Research Institute Fellowship Grants list
- Journal database searches
- Forest Management in a Changing Climate: Compendium of Information Sources
- Government of Canada and Government of Yukon websites
- AANDC Present and Past Climate Change Adaptation Projects list
- Internet searches
- Internal knowledge

The Compendium is not an exhaustive list of climate change-related work in Yukon over the 2015-2016 period. A greater emphasis was placed on information that is available online. That being said, the Northern Climate ExChange would appreciate being informed of any relevant information that should be included, or if there are any errors in the Compendium.

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

Entries can be searched by various keywords listed in the index, and all entries have been classified according to the area the research took place within the Yukon or abroad. The keyword 'traditional knowledge' was used when the research integrated knowledge from First Nations communities, and the keyword 'local knowledge' was used when information was integrated from a multicultural community or broad area.

This supplementary 2015-2016 edition of the Compendium expands upon the previous edition (2003-2013). I would like to thank Alison Perrin, John Streicker, and Bronwyn Benkert for their assistance.

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September 2016

Table of Contents

1. Changing Climate

1.1. Climate Change Effects and Modelling

Evidence for a wavier jet stream in response to rapid Arctic warming

Research Location: Global Arctic

Publication Type: Journal Article

Publication Date: 2015

Abstract: New metrics and evidence are presented that support a linkage between rapid Arctic warming, relative to Northern hemisphere mid-latitudes, and more frequent high-amplitude (wavy) jet-stream configurations that favor persistent weather patterns. We find robust relationships among seasonal and regional patterns of weaker poleward thickness gradients, weaker zonal upper-level winds, and a more meridional flow direction. These results suggest that as the Arctic continues to warm faster than elsewhere in response to rising greenhouse-gas concentrations, the frequency of extreme weather events caused by persistent jet-stream patterns will increase.

Local Relevance: A warming Arctic is promoting amplified jet-stream trajectories, which favors persistent weather patterns and a higher likelihood of extreme weather events. With increasing warming of the Arctic due to greenhouse gas emissions the jet stream will grow increasingly wavy in character, which will increase the extreme weather events throughout the world.

Keywords: jet stream, Arctic amplification, extreme weather, global Arctic

Available Online: http://iopscience.iop.org/article/10.1088/1748-9326/10/1/014005

Citation: Francis, J.A. and Vavrus, S.J., 2015. Evidence for a wavier jet stream in response to rapid Arctic warming. Environmental Research Letters, vol. 10, no. 1, doi:10.1088/1748-9326/10/1/014005.

Interim Progress Report for the Integrated Ecosystem Model for Alaska and Northwest Canada. Fairbanks, AK: Scenarios Network for Alaska and Arctic Planning

Research Location: Alaska and Yukon

Publication Type: Report

Publication Date: 2015

Executive Summary Excerpt: The Integrated Ecosystem Model (IEM) for Alaska and Northwest Canada is generating a broad variety of datasets to help users understand and manage landscape change. The geographic domain of the IEM (Figure 2) is based on ecological rather than political boundaries, so its products will be a valuable resource for entities focusing on landscape issues that do not necessarily stop at the Alaska-Canada border.

This report describes the progress of the IEM project from January 1, 2013 through August 31, 2014, and specifically reports on new data products developed during this time period. Categories of data products include climate, land cover, soil properties (including permafrost), fire disturbance, treeline and vegetation dynamics, plant productivity, and carbon storage. The IEM group is also developing a thermokarst disturbance model and models that use IEM outputs to estimate how landscape and ecological change will affect natural resources.

The executive summary begins with a description of accomplishments during the report period. It concludes with a description of interactions between the IEM project and other research efforts in Alaska and Northwest Canada and an outlook for the final two years of the project

Local Relevance: The Integrated Ecosystem Model (IEM) for Alaska and Northwest Canada will try to project how climate change will drive changes in arctic and boreal landscapes. The IEM uses three ecosystem models that link changing climate scenarios to different ecological and physical processes. Maps and other products generated by the IEM can be used for regional assessments, scenario development and climate adaptation planning. Climate change is expected to affect many aspects of our environment (i.e., permafrost dynamics, hydrology, fire disturbance and vegetation succession) creating processes that influence one another; the IEM aims to simulate those interactions.

Keywords: ecosystem modelling, climate projections, precipitation change, vegetation change, permafrost change, IEM, TEM, ALFRESCO, GIPL

Available Online: https://csc.alaska.edu/resource/interim-progress-report-IEM

Citation: McGuire, A.D., 2015. Interim Progress Report for the Integrated Ecosystem Model for Alaska and Northwest Canada. Fairbanks, AK: Scenarios Network for Alaska and Arctic Planning, https://csc.alaska.edu/resource/interim-progress-report-IEM [accessed May, 2016].

Toward daily climate scenarios for Canadian Arctic coastal zones with more realistic temperature-precipitation interdependence

Research Location: Coastal Area, Yukon

Publication Type: Journal Article

Publication Date: 2015

Abstract: The interdependence between climatic variables should be taken into account when developing climate scenarios. For example, temperature-precipitation interdependence in the Arctic is strong and impacts on other physical characteristics, such as the extent and duration of snow cover. However, this interdependence is often misrepresented in climate simulations. Here we use two two-dimensional (2-D) methods for statistically adjusting climate model simulations to develop plausible local daily temperature (T_{mean}) and precipitation (Pr) scenarios. The first 2-D method is based on empirical quantile mapping (2Dqm) and the second on parametric copula models (2Dcopula). Both methods are improved here by forcing the preservation of the modeled long-term warming trend and by using moving windows to obtain an adjustment specific to each day of the year. These methods were applied to a representative ensemble of 13 global climate model simulations at 26 Canadian Arctic

coastal sites and tested using an innovative cross-validation approach. Intervariable dependence was evaluated using correlation coefficients and empirical copula density plots. Results show that these 2-D methods, especially 2Dqm, adjust individual distributions of climatic time series as adequately as one common one-dimensional method (1Dqm) does. Furthermore, although 2Dqm outperforms the other methods in reproducing the observed temperature-precipitation interdependence over the calibration period, both 2Dqm and 2Dcopula perform similarly over the validation periods. For cases where temperature-precipitation interdependence is important (e.g., characterizing extreme events and the extent and duration of snow cover), both 2-D methods are good options for producing plausible local climate scenarios in Canadian Arctic coastal zones.

Local Relevance: Two-dimensional models based on temperature-precipitation interdependence were used to model local climate scenarios in the Canadian Arctic. Over the calibration period the 2Dqm model performed the best, while 2Dqm and 2Dcopula models preformed similarly in validation periods. The authors suggest future work could include other climate variables such as wind, radiation and humidity. Overall, this work and future work will help provide techniques to cope with uncertainty in observed data and to better characterize extreme weather events.

Keywords: climate scenario, Arctic, intervariable dependence, statistical adjustment, quantile mapping, copula, 2-D methods

Available Online: http://onlinelibrary.wiley.com/doi/10.1002/2015JD023890/full

Citation: Gennaretti, F., Sangelantoni, L. and Grenier, P., 2015. Toward daily climate scenarios for Canadian Arctic coastal zones with more realistic temperature-precipitation interdependence. Journal of Geophysical Research, Atmospheres, vol. 120, issue 23, p. 11,862-11,877, doi:10.1002/2015JD023890.

1.2. Climate Change Adaptation

Implementation Framework for Climate Change Adaptation Planning at a Watershed Scale

Research Location: Canada-Wide

Publication Type: Report

Publication Date: 2015

Excerpt: This *Implementation Framework for Climate Change Adaptation Planning at a Watershed Scale* (Framework) was developed by the Water Monitoring and Climate Change Project Team of the Canadian Council of Ministers of the Environment (CCME) Water Management Committee (WMC). The Framework provides watershed managers with a structured process to identify and reduce climate vulnerability and risk, and build resiliency within the watershed. The Framework presents a methodology through which a group of individuals can come together to assess and manage vulnerabilities and risks stemming from climate change at a watershed level. It is informed by existing international and domestic climate change adaptation frameworks that appear in published literature and a jurisdictional survey of climate change adaptation practitioners from across Canada. The Framework lists seven key steps, each with a series of tasks and outcomes. Inherent to the process is the

intention of adaptive management. The method of managing adaptively is appropriate for this context in dealing with uncertainty in climate change as well as the importance of tracking, monitoring and evaluating adaptive measures designed to reduce climate risk.

Local Relevance: This framework goes through seven steps in order to initiate adaptive planning at a watershed level. The Framework encompasses aspects of both top-down and bottom-up planning, with the majority of the steps common to both types of planning. The steps include building a team, collecting information, assessing the problems, forming solutions, and implementation and monitoring. Overall, the steps follow an adaptive management framework applied to the watershed management scale. This Framework can help governments, watershed agencies and organizations understand the impacts of climate change, assess watershed vulnerabilities and risks, and adaptively manage the natural assets in order to sustain ecosystem resiliency

Keywords: watershed management, adaptive management, Canada-wide

Available Online: http://www.ccme.ca/en/resources/cci.html

Citation: Canadian Council of Ministers of the Environment, 2015. Implementation framework for climate change adaptation planning at a watershed scale. Canadian Council of Ministers of the Environment, Winnipeg, MB, 56 p.

Scenario planning during rapid ecological change: lessons and perspectives from workshops with southwest Yukon wildlife managers

Research Location: Southwest Yukon

Publication Type: Journal Article

Publication Date: 2015

Abstract: Scenario planning has been increasingly advocated as a strategic planning tool for enabling natural resource managers to make decisions in the face of uncertainty and rapid change. However, few examples exist that discuss the technique's application in that field. We used a scenario planning approach to develop wildlife management goals and evaluated participants' perceptions of scenario planning as a goal development tool. Study participants emphasized the context-specificity of management goals, and that "no-regrets" management strategies might not be constructive. We found that scenario planning can help resource managers identify needs that have been overlooked but may become important in the future. Scenarios can likely be used to develop management goals for other resources within the same system. Scenario planning provides a way to apply traditional ecological knowledge and local knowledge in a planning process in a respectful manner. Further process-oriented findings may be helpful to practitioners or researchers considering this approach: workshops should to be temporally close together for participants to retain context during the process, and ensuring continuity of workshop participants is important. Study participants judged scenario planning to be an effective tool to stimulate group-thought on longer time scales, facilitate adaptive learning, and enhance institutional linkages. Ultimately such outcomes can help groups comprising diverse participants to develop shared mental models of the future and identify pathways to achieve them.

Local Relevance: Scenario planning was described by participants as enabling broad thinking and making sharing perspectives easier. Scenario planning was also seen to help resource managers identify potential future needs. Scenario planning was seen as to help apply traditional ecological knowledge and local knowledge to a planning process in a respectful way. Overall the use of scenario planning can help identify system drivers and future-oriented goals that allow for proactive, rather than reactive, management.

Keywords: Champagne & Aishihik First Nations, climate change, participatory research, qualitative, scenario planning, social-ecological system (SES), wildlife management, southwest Yukon

Available Online: http://www.ecologyandsociety.org/vol20/iss1/art61/

Citation: Beach, D. and Clark, D., 2015. Scenario planning during rapid ecological change: lessons and perspectives from workshops with southwest Yukon wildlife managers. Ecology and Society, vol. 20, no. 1, art. 61, 33 p.

1.3. Climate Change Mitigation

Production of magnesium-rich solutions by acid leaching of chrysotile: A precursor to field-scale deployment of microbially enabled carbonate mineral precipitation

Research Location: Clinton Creek Asbestos Mine, Yukon

Publication Type: Journal Article

Publication Date: 2015

Abstract: Carbonate minerals are one of the primary carbon sinks under investigation for sequestering anthropogenic carbon dioxide (CO_2). Ultramafic rock has the potential to act as a magnesium source for carbonate precipitation reactions utilizing atmospheric CO_2. This study characterizes the release of magnesium from chrysotile tailings from the Clinton Creek Asbestos Mine (Yukon, Canada) by means of a 42-day leaching experiment using sulfuric acid. Low acid concentrations (targeting 8.33% and 16.67% dissolution of chrysotile) resulted in stoichiometric, dissolution. Moderate (33.33% and 66.67% dissolution) and high (100% dissolution) acid concentrations resulted in non-stoichiometric dissolution of chrysotile. Here, the concentration ratio of Mg:Si in solution was greater than expected for moderate acid concentrations and lower than expected for high acid concentrations. The moderate acid reaction system demonstrated that as much as 84% of the magnesium found in chrysotile can be released into solution via chemical weathering. However, at high acid concentrations, Mg values were in fact lower than the moderate acid reactivity, presumably resulting from adsorption of soluble magnesium to amorphous silica, a byproduct of extensive magnesium leaching from chrysotile fibers. The production of magnesium-rich solutions in this experiment demonstrates that a highly concentrated starting material for magnesium carbonate precipitation reactions can be produced from chrysotile-bearing tailings, providing ultra-mafic hosted mines with an important resource for developing technological strategies for reducing their net carbon emissions. This process represents a win-win scenario for the

management of chrysotile-bearing mine wastes, in which a hazardous material is transformed into a geologically stable mineral sink for 'carbon dioxide storage'.

Local Relevance: It was found that mine tailings from the Clinton Creek Asbestos mine could be used as a source of magnesium. The magnesium was used to as a starting material to produce a magnesium carbonate precipitate using atmospheric CO_2. A hazardous material was thus transformed into a stable mineral sink which also reduced net carbon emissions.

Keywords: chrysotile, leaching, magnesium, carbon sequestration, microbial carbonation, x-ray diffraction, industrial mitigation, Clinton Creek Asbestos Mine, Yukon

Available Online: https://www.researchgate.net/publication/281325820_Production_of_magnesium-rich_solutions_by_acid_leaching_of_chrysotile_A_precursor_to_field-scale_deployment_of_microbially_enabled_carbonate_mineral_precipitation

Citation: McCutcheon, J., Dipple, G.M., Wilson, S.A. and Southam, G., 2015. Production of magnesium-rich solutions by acid leaching of chrysotile: A precursor to field-scale deployment of microbially enabled carbonate mineral precipitation. Chemical Geology, vol. 413, p. 119-131, doi:10.1016/j.chemgeo.2015.08.023.

1.4. Historical Influence

Late-Holocene climate variability and ecosystem responses in Alaska inferred from high-resolution multiproxy sediment analyses at Grizzly Lake

Research Location: Grizzly Lake, Alaska

Publication Type: Journal Article

Publication Date: 2015

Abstract: The late-Holocene shift from *Picea glauca* (white spruce) to *Picea mariana* (black spruce) forests marked the establishment of modern boreal forests in Alaska. To understand the patterns and drivers of this vegetational change and the associated late-Holocene environmental dynamics, we analyzed radiocarbon-dated sediments from Grizzly Lake for chironomids, diatoms, pollen, macrofossils, charcoal, element composition, particle size, and magnetic properties for the period 4100-1800 cal BP. Chironomid assemblages reveal two episodes of decreased July temperature, at ca. 3300-3150 (ca -1 °C) and 2900-2550 cal BP (ca -2 °C). These episodes coincided with climate change elsewhere in the Northern Hemisphere, atmospheric reorganization, and low solar activity. Diatom-inferred lake levels dropped by ca. 5 m at 3200 cal BP, suggesting dry conditions during the period 3200-1800 cal BP. *P. glauca* declined and *P. mariana* expanded at ca. 3200 cal BP; this vegetational change was linked to diatom-inferred low lake levels and thus decreased moisture availability. Forest cover declined at 3300-3100, 2800-2500 and 2300-2100 cal BP and soil erosion as inferred from increased values of Al, K, Si, Ti, and Ca intensified, when solar irradiance was low. Plant taxa adapted to disturbance and cold climate (e.g. *Alnus viridis*, shrub *Betula*, *Epilobium*) expanded during these periods of reduced forest cover. This open vegetation type was associated with high fire activity that peaked at 2800 cal BP, when climatic

conditions were particularly cold and dry. Forest recovery lagged behind subsequent climate warming (≤+3 °C) by ca. 75 -225 years. Our multiproxy data set suggests that *P. glauca* was dominant under warm-moist climatic conditions, whereas *P. mariana* prevailed under cold-dry and warm-dry conditions. This pattern implies that climatic warming, as anticipated for this century, may promote *P. glauca* expansions, if moisture availability will be sufficiently high, while *P. mariana* may expand under dry conditions, possibly exacerbating climate impacts on the fire regime.

Local Relevance: In more warm and moist climates projected for interior Alaska and western Canada for future climate scenarios, *P. glauca* (white spruce) is expected to expand its range. If drier conditions prevail in future climates, *P. mariana* (black spruce) may expand its range. In the Grizzly Lake region, when *P. mariana* dominated the landscape, there was a high level of fire activity. The highest rate of fire incidence was found in cold-dry periods of forest collapse.

Keywords: paleoecology, vegetation, boreal, fire, erosion, climate change, 2800 event, 2.8 ka event, Alaska

Available Online: http://www.sciencedirect.com/science/article/pii/S0277379115300858

Citation: Tinner, W., Beer, R., Bigler, C., Clegg, B.F., Jones, R.T., Kaltenrieder, P., van Raden, U.J., Gilli, A. and Hu, F.S., 2015. Late-Holocene climate variability and ecosystem responses in Alaska inferred from high-resolution multiproxy sediment analyses at Grizzly Lake Quaternary Science Reviews, vol. 126, p. 41-56.

Palynological evidence for a warmer boreal climate in the Late Pliocene of the Yukon Territory, Canada

Research Location: Bonanza Creek, Yukon

Publication Type: Journal Article

Publication Date: 2015

Abstract: The Late Pliocene (3.6–2.6 Ma) was a period of significant global warmth, considered a potential analogue for future anthropogenic climate change. Newly discovered fine-grained sediments from between the gold-bearing lower and upper White Channel Gravels show the presence of a wetland or lake within Bonanza Creek, Dawson Mining District, Yukon. This environment was surrounded by a diverse Pinaceae-dominated boreal forest with significant stands of angiosperms in favourable sites. Quantitative climate reconstructions derived from pollen and spores reveal a mean annual temperature at least 6 °C warmer than today with warm summers and relatively mild winters. Finally, the new pollen assemblage is used to discuss the age of the White Channel Gravels.

Local Relevance: Approximately 3.6-2.6 million years ago (the Late Pliocene) the mean annual temperature was at least 6 °C warmer than today with warm summers and mild winters. During this time in the Bonanza Creek area, most of the land was dominated by a *Pinaceae* boreal forest structure. The study of past vegetation conditions in warmer climates can help predict future vegetation conditions in the Yukon as the climate warms.

Keywords: Late Pliocene, pollen, spores, boreal forest, warmer climate, Klondike Mining District, paleoclimatology, Bonanza Creek, Yukon, Canada

Available Online: http://dx.doi.org/10.1080/01916122.2014.940471

Citation: Pound, M.J., Lowther, R.I., Peakall, J., Chapman, R.J. and Salzmann, U., 2015. Palynological evidence for a warmer boreal climate in the Late Pliocene of the Yukon Territory, Canada. Palynology, vol. 39, issue 1, p. 91-102. doi:10.1080/01916122.2014.940471.

Reconstructing the paleohydrology of a Cretaceous Alaskan paleopolar coastal plain from stable isotopes of bivalves

Research Location: Colville River, Alaska

Publication Type: Journal Article

Publication Date: 2016

Abstract: As global mean annual temperatures continue to rise, modern Arctic climates are changing at an incredibly fast rate. To predict changing climate dynamics, a number of researchers have been focused on characterizing Arctic climate from ancient greenhouse worlds such as the Cretaceous and Eocene. Characterization of these climates requires analysis of a variety of proxy materials. Here we use bivalve shells, identified as *Nucula* aff. *Nucula percrassa* Conrad, from the Cretaceous (early Maastrichtian) Prince Creek Formation in combination with isotope data from previous lithologic and isotopic studies to characterize a cool-house Cretaceous climate bounded by greenhouse climates (mid-Cretaceous thermal maximum and Late Paleocene climate). Bivalves were analyzed by powder X-ray diffraction (PXRD), cathodoluminescence (CL), and thin section petrography to determine mineralogy and integrity of shells. PXRD analysis indicates that shells are composed of primary aragonite and not secondary calcite. Thin section and CL images reveal well preserved shell morphology including daily growth lines, and no luminescent patches or coarsening of crystal sizes to indicate diagenetic alteration/recrystallization. Aragonite carbon isotopic composition ($\delta^{13}C_{arag}$) range from + 0.45‰ to − 3.00‰ VPDB and average − 1.58‰. Aragonite oxygen isotopic composition ($\delta^{18}O_{arag}$) range from − 10.48‰ to − 15.42‰ VPDB and average − 12.83‰. Using temperatures from 4.5 °C to 12.5 °C, the salinity–$\delta^{18}O_{water}$ relationship of a modern Arctic setting from Torres et al. (2011), and the water–aragonite equation of Grossman and Ku (1986) reveal salinity ranges between 8 and 17.7 ppt. Using these salinity ranges and temperatures, *N. percrassa* precipitated shell aragonite from water that ranged between $\delta^{18}O_{water}$ = − 14.41‰ VSMOW (at 12.5 °C) and − 16.23‰ (at 4.5 °C). Shell growth was in equilibrium with water that represents a coastal, mixed water setting such as an estuary. When combined with previous studies, the mixture of fresh:marine water represents a 50%:50% to 72%:28% mixture and ranged between − 14.41‰ and − 16.23‰ during spring to summer months.

Local Relevance: This data can be compared to greenhouse and full ice-house climate data from other studies to determine ecological and environmental changes that can be expected in the Arctic as climate shifts from warm to cool-house conditions and vice versa. The authors found evidence that moderate increases in global temperatures can lead to increases in latitudinal precipitation, which may create more regionally humid and warm climates of mild summers and winters. The use of a variety of fossil

materials and minerals was found to be able to reconstruct paleohydrology and paleoecosystems of ancient terrestrial environments.

Keywords: paleontology, paleoclimatology, geochemistry, x-ray diffraction, terrestrial ecosystem, high-latitude, Alaska

Available Online: http://www.sciencedirect.com/science/article/pii/S0031018215003922

Citation: Suarez, C.A., Flaig, P.P., Ludvigson, G.A., González, L.A., Tian, R., Zhou, H., McCarthy, P.J., Van der Kolk, D.A. and Fiorillo, A.R., 2016. Reconstructing the paleohydrology of a Cretaceous Alaskan paleopolar coastal plain from stable isotopes of bivalves. Palaeogeography, Palaeoclimatology, Palaeoecology, vol. 441, Part 2, p. 339-351, doi:10.1016/j.palaeo.2015.07.025.

Synoptic scale controls on the $\delta^{18}O$ in precipitation across Beringia

Research Location: Eastern Beringia, Yukon and Alaska

Publication Type: Journal Article

Publication Date: 2015

Abstract: Oxygen isotope records of precipitation ($\delta O\text{-}^{18}_{precip}$) from Beringia are thought to reflect synoptic-scale circulation changes associated with the Aleutian Low. To delineate the spatial pattern of $\delta^{18}O_{precip}$ associated with the two dominant modes of Aleutian Low circulation, we combine modern $\delta^{18}O_{precip}$ and deuterium excess data with climate reanalysis and back trajectory modeling. Aleutian Low strength and position are revealed to systematically affect regional moisture source and $\delta^{18}O_{precip}$; whereby a strengthened Aleutian Low causes lower (higher) $\delta^{18}O_{precip}$ in western (eastern) Beringia. We compare a new 100 year-long $\delta^{18}O$ record from the Aleutian Islands with the North Pacific Index, the primary indicator of Aleutian Low strength, and find a significant positive relationship ($r = 0.43$, $P < 0.02$, $n = 28$) that tracks late twentieth century change. This study demonstrates synoptic-scale circulation controls on our isotope record and provides a coherent framework for interpreting existing and emerging paleoisotope data from the region.

Local Relevance: The Aleutian Low, a large-scale feature of mean low sea level pressure and the most dominant characteristic of North Pacific climate, influences regional temperature and precipitation patterns. The use of $\delta^{18}O_{precip}$ data over a 100 year time period from Adak in the Aleutian Islands at the heart of the Aleutian Low, allowed for a calibrated approach to interpret $\delta^{18}O_{precip}$ data within the Yukon. A framework from the pattern analyzed here can be used to interpret modern and paleoisotope records in context of regional atmospheric circulation.

Keywords: Aleutian Low, oxygen isotopes, oxygen isotope precipitation, hydrogen isotope precipitation, North Pacific, paleoisotope data, Eastern Beringia

Available Online: http://onlinelibrary.wiley.com/doi/10.1002/2015GL063983/pdf

Citation: Bailey, H.L., Kaufman, D.S., Henderson, A.C.G. and Leng, M.J., 2015. Synoptic scale controls on the O-18 in precipitation across Beringia. Geophysical Research Letters, vol. 42, issue 11, p. 4608-4616, doi:10.1002/2015GL063983.

1.5. Traditional/Indigenous Knowledge

How Permafrost Thaw May Impact Food Security of Jean Marie River First Nation, NWT

Research Location: Jean Marie River, Northwest Territories

Publication Type: Conference Paper

Publication Date: 2015

Abstract: The Jean Marie River First Nation (JMRFN) assembled a project team to exchange traditional, local and scientific knowledge to produce maps showing the vulnerability of traditional use areas near Jean Marie River to permafrost thaw. Landscape changes driven by permafrost thaw have and will have considerable impacts on country food. The vulnerability hazard map resulting from this project is tailored to the needs of the JMRFN community, is culturally oriented and, when overlain with spatial traditional land use information, brings a new, integrated perspective regarding climate change impacts on the JMRFN. This project represents a prototype for future surveys with mapping aimed at identifying and quantifying the impacts of permafrost degradation from a broader and more holistic viewpoint that combines western science and traditional and local knowledge.

Local Relevance: This project offers a prototype on how to integrate traditional, local and scientific knowledge in the identification of impacts of permafrost degradation. Several impacts for this specific community were found including: reduced access to important areas for harvesting country food, changes to terrain and their ecosystems, water quality impacts, fish impacts, and the potential negative impacts to culturally significant practices such as traditional land use, occupancy practices, Traditional Knowledge exchange, and relationships with the land.

Keywords: Traditional Knowledge, traditional food impacts, hazard mapping, Jean Marie River, NWT

Available Online:
https://www.researchgate.net/publication/282328455_How_Permafrost_Thaw_May_Impact_Food_Security_of_Jean_Marie_River_First_Nation_NWT

Citation: Calmels, F., Laurent, C., Brown, R. and Ireland, M., 2015. How Permafrost Thaw May Impact Food Security of Jean Marie River First Nation, NWT. Canadian Geotechnical Conference Paper, GEOQuébec 2015 Challenges from North to South, 8 p.

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

Research Location: Ruby, Alaska

Publication Type: Journal Article

Publication Date: 2015

Abstract: In the Arctic and Subarctic, the contribution of Indigenous knowledge to understanding environmental change has been established over the last several decades. This paper explores the role

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

Local Relevance: Indigenous knowledge (IK) was found to compliment scientific understanding of hydrologic change in three ways. Firstly, IK can provide valuable data where western scientific knowledge is missing; that is, the long-term historical data derived from IK is crucial to the understanding of impacts of climate change on river system hydrology. Second, IK helps point to new areas of inquiry not considered previously by western science; for example, observed changes in acoustic qualities of river ice breakup or sediment regimes can lead to new research questions. Thirdly, IK can provide methods of observation in long-term monitoring projects. This paper recommends additional studies throughout the Yukon River Basin; however, future studies should include a multidisciplinary approach as this study used social science methods only.

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

Available Online: http://arctic.journalhosting.ucalgary.ca/arctic/index.php/arctic/article/view/4459

Citation: Wilson, N.J., Walter, M.T. and Waterhouse, J., 2015. Indigenous Knowledge of Hydrologic Change in the Yukon River Basin: A Case Study of Ruby, Alaska. Arctic, vol. 68, no. 1, p. 93-106.

Integrating local knowledge and science: economic consequences of driftwood harvest in a changing climate

Research Location: Tanana, Alaska

Publication Type: Journal Article

Publication Date: 2015

Abstract: The integration of local knowledge and science represents an opportunity to enhance the understanding of interrelations among climate, hydrology, and socioeconomic systems while providing mutual benefits to scientists and rural communities. Insight from rural Alaskans helped to identify a social-ecological threshold used to model potential driftwood harvest from the Yukon River. Information from residents of Tanana, Alaska, was combined with scientific data to model driftwood harvest rates. Modeling results estimated that between 1980 and 2010, hydrologic factors alone were responsible for a 29% decrease in the annual wood harvest, which approximately balanced a 23% reduction in wood

demand because of a decline in number of households. The community's installation of wood-fired boilers in 2007 created a threshold increase (76%) in wood demand that is not met by driftwood harvest. Modeling analyses of numerous climatic scenarios illustrated that increases in hydrologic variability would decrease the reliability of future driftwood harvest. Economic analyses demonstrated that increased climatic variability could have serious economic consequences for subsistence users while demanding more of their time. Lost time is important because it reduces their availability for performing other subsistence activities and learning to adapt to climate-related challenges. Our research may benefit communities by providing a tool that can be used to predict the timing and duration of driftwood runs. Information gathered from discussions with local stakeholders provided critical information for model development and thus provided a better understanding of regional social-ecological dynamics. Our research also illustrates the potential for regional-scale adaptations to limit the social-ecological impacts of environmental change, while providing economic opportunities and energy independence that reduce their vulnerability to variations in climate.

Local Relevance: The timing of harvest of driftwood during the June rise of the Yukon River in Tanana correlated well with western science observations of high-flow events of the Yukon River in June. Residents of Tanana stated their harvesting of driftwood had become more variable; western science noted similar findings. Driftwood mobilization threshold is defined as a level of river discharge, that once exceeded, mobilizes driftwood until the river discharge peaks; this driftwood mobilization threshold was found to coincide to the timing of driftwood harvest. A model was developed to show when the driftwood mobilization threshold was passed; the model was developed through a combination of local knowledge and data from a U.S. Geological Survey gauging station on the Yukon River at Stevens Village, upstream of Tanana. The use of the model could help communities reduce uncertainty in environmental variability even if they do not harvest driftwood. The authors suggest that their research shows how a partnership between local stakeholders and scientists can lead to the development of tools that help people adapt to a changing climate by allowing for increased prediction in seasonal cycles.

Keywords: biomass, climate, driftwood, economics, flood, hydrology, large woody debris, local knowledge, participatory research, social-ecological model, threshold, Alaska

Available Online: http://www.ecologyandsociety.org/vol20/iss1/art25/

Citation: Jones, C.E., Kielland, K., Hinzman, L.D. and Schneider, W.S, 2015. Integrating local knowledge and science: economic consequences of driftwood harvest in a changing climate. Ecology and Society, vol. 20, no. 1, art. 25, 14 p.

2. Hydrology

2.1. General

The Arctic Freshwater System in a Changing Climate

Research Location: Circumpolar Arctic

Publication Type: Report

Publication Date: 2016

Excerpt: This report is an output of the Arctic Freshwater Synthesis project. The project is a review of the latest scientific literature on the sources, fluxes, storage and effects of changes in freshwater resources in the Arctic. It comprises six chapters, covering the atmosphere, oceans, terrestrial hydrology, ecosystems, Arctic resources and infrastructure, and modeling. It is intended to be used by the scientific community and to develop policy recommendations for local, regional and national governments.

Local Relevance: The report looks at how freshwater systems will change throughout the Arctic and how this will affect the local population. It begins with known effects on the freshwater systems in the Arctic. The report then looks at how freshwater changes will affect the following: the atmosphere, landscapes and ecosystems, coasts and near-shore environments, ocean currents and biology, ability of Arctic to provide ecosystem services, how the Arctic 'stores' carbon, and the effect of freshwater changes on the Arctic economy.

Keywords: freshwater impacts, literature reviews, circumpolar arctic

Available Online: http://www.climate-cryosphere.org/media-gallery/1583-afs-summary

Citation: CliC/AMAP/IASC, 2016. The Arctic Freshwater System in a Changing Climate. WCRP Climate and Cryosphere (CliC) Project, Arctic Monitoring and Assessment Programme (AMAP), International Arctic Science Committee (IASC), 28 p.

Arctic sea ice thickness loss determined using subsurface, aircraft, and satellite observations

Research Location: Arctic Ocean

Publication Type: Journal Article

Publication Date: 2015

Abstract: Sea ice thickness is a fundamental climate state variable that provides an integrated measure of changes in the high-latitude energy balance. However, observations of mean ice thickness have been sparse in time and space, making the construction of observation-based time series difficult. Moreover, different groups use a variety of methods and processing procedures to measure ice thickness, and each observational source likely has different and poorly characterized measurement and sampling errors.

Observational sources used in this study include upward-looking sonars mounted on submarines or moorings, electromagnetic sensors on helicopters or aircraft, and lidar or radar altimeters on airplanes or satellites. Here we use a curve-fitting approach to determine the large-scale spatial and temporal variability of the ice thickness as well as the mean differences between the observation systems, using over 3000 estimates of the ice thickness. The thickness estimates are measured over spatial scales of approximately 50 km or time scales of 1 month, and the primary time period analyzed is 2000–2012 when the modern mix of observations is available. Good agreement is found between five of the systems, within 0.15 m, while systematic differences of up to 0.5 m are found for three others compared to the five. The trend in annual mean ice thickness over the Arctic Basin is -0.58 ± 0.07 m decade^{-1} over the period 2000–2012. Applying our method to the period 1975–2012 for the central Arctic Basin where we have sufficient data (the SCICEX box), we find that the annual mean ice thickness has decreased from 3.59 m in 1975 to 1.25 m in 2012, a 65% reduction. This is nearly double the 36% decline reported by an earlier study. These results provide additional direct observational evidence of substantial sea ice losses found in model analyses.

Local Relevance: Differences in mean ice thickness from the various measuring systems are highly variable, even for measurements obtained from samples nearly identical in time and space. This study characterizes these differences for a broad range of observing systems with a single number that characterizes the difference between any two observing systems. The results of this study provide an estimate of the relative biases of the measurement systems; however, more research is required in order to understand, characterize and correct these errors before the observational ice thickness record can be homogenized.

Keywords: sea ice loss, sea ice loss detection - lidar, sea ice loss detection - altimeters, sea ice loss detection - sonar

Available Online: http://www.the-cryosphere.net/9/269/2015/tc-9-269-2015.html

Citation: Lindsay, R. and Schweiger, A., 2015. Arctic sea ice thickness loss determined using subsurface, aircraft, and satellite observations. Cryosphere, vol. 9, issue 1, p. 269-283, doi:10.5194/tc-9-269-2015.

2.2. Paleohydrology

Integration of paleolimnological and contemporary hydroecological analyses to decipher effects of multiple stressors on water-rich northern landscapes

Research Location: Old Crow Flats, Wapusk National Park, and Slave River Delta

Publication Type: PhD Thesis

Publication Date: 2015

Abstract: Northern freshwater ecosystems provide important habitat and resources which support abundant wildlife and waterfowl populations and the traditional lifestyle of many First Nation communities. However, concerns have been mounting regarding the effects of multiple stressors, including climate change and other human-related activities in these regions. In order to

understand the consequences of stressors, information on both present and past conditions is needed. This thesis addresses knowledge gaps by using a combination of contemporary and paleolimnological methods to characterize lake and pond responses to different stressors in three northern landscapes. A paleolimnological record in combination with aerial images was used to investigate causes of lake-level changes at a lake in the Old Crow Flats (OCF). Contemporary measurements were used to identify how hydrological and limnological conditions of coastal ponds in Wapusk National Park (WNP) differ seasonally and with disturbance from Lesser Snow Geese (LSG). Paleolimnological studies were also used in this landscape to determine how hydroecological conditions have changed during the past few centuries in response to climate warming and LSG population expansion. At a lake in the Slave River Delta (SRD), paleolimnological studies of hydrology and contaminant deposition were used to establish baseline concentrations and assess if temporal changes have occurred in response to northern industrial development. Together, these studies provide a detailed record of environmental changes in response to stressors at three large northern freshwater landscapes...

Local Relevance: This thesis used an integration of paleolimnological and contemporary hydroecological analyses to decipher the effects of multiple stressors on water-rich northern landscapes. The methods used in this study can help to address research needs and concerns of local communities and agencies by characterizing the pre-disturbance conditions and evaluating the effects of different stressors. The baselines characterized here can provide effective tools for ongoing monitoring of freshwater ecosystems.

Keywords: paleolimnology, Lesser Snow Geese, northern industrial development, Old Crow Flats, carbon, Wapusk National Park, Slave River Delta, thermokarst lakes, metals, Giant Mine

Available Online: https://uwspace.uwaterloo.ca/handle/10012/9672

Citation: MacDonald, L.T., 2015. Integration of paleolimnological and contemporary hydroecological analyses to decipher effects of multiple stressors on water-rich northern landscapes. PhD thesis, University of Waterloo, Waterloo, ON, 225 p.

Multiple water isotope proxy reconstruction of extremely low last glacial temperatures in Eastern Beringia (Western Arctic)

Research Location: Klondike Goldfields, Yukon

Publication Type: Journal Article

Publication Date: 2016

Abstract: Precipitation isotopes are commonly used for paleothermometry in high latitude regions. Here we present multiple water isotope proxies from the same sedimentary context – perennially frozen loess deposits in the Klondike Goldfields in central Yukon, Canada, representing parts of Marine Isotope Stages (MIS) 4, 3 and 2 – allowing us to uniquely corroborate fractionations and temperature conversions during these Late Pleistocene cold stages. We include new and existing proxy data from: relict wedge ice, a direct archive for snowmelt; relict pore ice, an archive for bulk soil water integrating

year-round precipitation; and hydrated volcanic glass shards and fossil plant waxes, which are also thought to integrate year-round precipitation but are subject to large fractionations. In some cases, our temperature estimates based on existing proxy data are much cooler than previously estimated due to our use of source water corrections for the glacial ocean, new transfer functions calibrated specifically for northern North America ($\delta D_{precip} = 3.1‰ \cdot °C^{-1} \times T - 155‰$; and $\delta^{18}O_{precip} = 0.41‰ \cdot °C^{-1} \times T - 20.2‰$), and novel insights on the apparent net fractionation correction for Eastern Beringian steppe-tundra plant waxes ($\varepsilon_{wax/precip} = -59 \pm 10‰$). The snowmelt origin of wedge ice ensures a relatively constrained winter-spring seasonality of contributing precipitation, as supported by the consistency between water isotope measurements from Late Holocene wedge ice and modern winter-spring precipitation. Wedge ice dating to the transitional MIS 3/2 is isotopically depleted relative to modern spring-winter precipitation by an amount that indicates a temperature depression of ~14 ± 5 °C below modern. The soil water origin of pore ice, and other proxies integrating year-round precipitation from soil water, allows for a more variable precipitation seasonality. The isotopic composition of modern pore ice is consistent with mean annual precipitation. However, the isotopic composition of pore ice during MIS 3/2 converges on wedge ice values, signalling an increase in the ratio of cold-to-warm-season precipitation integrated by pore ice during glacial times, possibly due to drier summers as supported by the fossil record and climate model simulations. In the study region, water isotope proxies integrating year-round precipitation may overestimate annual temperature differences between today and recent cold stages due to transient precipitation seasonality, as detected here, and thus are best interpreted as upper bound estimates. Based on these proxies, we estimate that annual temperatures during MIS 4, 3/2 and 2 were depressed below the modern climate to a maximum of ~18 °C, 16 °C and 21 °C ± 4–5 °C, respectively. Our study highlights the value of multiple water isotope proxies towards understanding changes in precipitation seasonality and developing robust reconstructions of past climate, and may be particularly important for studies of the major climate transformations over glacial-interglacial timescales.

Local Relevance: Three paleotemperature estimates for three different Late Pleistocene time slices based on available water isotope proxy data were created. Temperature-precipitation isotope transfer functions were also calibrated for Eastern Beringia and northern North America. The results provide the first evidence for dry summers during Late Pleistocene cold stages. The authors believe that ice wedges provide a relatively consistent sample of cold-season precipitation, which minimizes complications of shifting precipitation seasonality.

Keywords: Eastern Beringia, precipitation isotopes, temperature reconstruction, relict ice, hydrated volcanic glass shards, fossil plant waxes, water isotopes, Klondike goldfields

Available Online: http://www.sciencedirect.com/science/article/pii/S0277379116300385

Citation: Porter, T.J., Froese, D.G., Feakins, S.J., Bindeman, I.N., Mahony, M.E., Pautler, B.G., Reichart, G., Sanborn, P.T., Simpson, M.J. and Weijers, J. W., 2016. Multiple water isotope proxy reconstruction of extremely low last glacial temperatures in Eastern Beringia (Western Arctic). Quaternary Science Reviews, vol. 137, p. 113-125, doi:10.1016/j.quascirev.2016.02.006.

The vulnerability of Arctic shelf sediments to climate change

Research Location: Circumpolar Arctic

Publication Type: Journal Article

Publication Date: 2015

Abstract: The sediments of the pan-Arctic shelves contribute an important component to the Arctic Ocean ecosystem by providing a habitat for biota (benthos), a repository for organic and inorganic non-conservative substances entering or produced within the ocean, a reactor and source of transformed substances back to the water column, and a mechanism of burial. Sediments interact with ice, ocean, and the surrounding land over a wide range of space and time scales. We discuss the vulnerability of shelf sediment to changes in (*i*) organic carbon sources, (*ii*) pathways of sediment and organic carbon supply, and (*iii*) physical and biogeochemical alteration (diagenesis). Sedimentary environments of the shelves and basins are likely to exhibit a wide variance in their response to global change because of their wide variation in sediment sources, processes, and metabolic conditions. In particular, the Chukchi and Barents shelves are dominated by inflowing waters from oceans to the south, whereas the interior shelves are more closely tied to terrigenous sources due to river inflow and coastal erosion.

Local Relevance: Several shelves in the Arctic are investigated in order to document the potential changes they may face with climate change. The shelves of interest are: Barents, Kara, Laptev, East Siberian, Chukchi, Beaufort, and Sum. The Beaufort Sea shelf was found to have the least Coastal erosion, and has 132Mt/year of sedimentation added to it. Potential areas of shelf change are also investigated and include the following: changes in supply and composition of terrestrial sediment and organic carbon, changes in source and composition of marine organic carbon, physical processes and sediment stability, and benthic and pelagic biological change. To help further our knowledge of how Arctic shelves will change with climate change, several areas of investigation are suggested and include: records in slope and basin sediments, shelf organic carbon supply, repeat shallow-water surveys, biogeographic distributions, and organic carbon flux using redox proxy markers.

Keywords: Arctic Ocean, shelves, sediment, climate change, coastal shelf degradation, sediment load, Circumpolar Arctic

Available Online: http://www.nrcresearchpress.com/doi/10.1139/er-2015-0040#.V5vWePkrJhE

Citation: Macdonald, R.W., Kuzyk, Z.A. and Johannessen, S.C., 2015. The vulnerability of Arctic shelf sediments to climate change. Environmental Reviews, vol. 4, p. 461-479, doi:10.1139/Er-2015-0040.

2.3. Yukon River Basin

Historical trends and extremes in boreal Alaska river basins

Research Location: Yukon River Basin, Yukon and Alaska

Publication Type: Journal Article

Publication Date: 2015

Abstract: Climate change will shift the frequency, intensity, duration and persistence of extreme hydroclimate events and have particularly disastrous consequences in vulnerable systems such as the warm permafrost-dominated Interior region of boreal Alaska. This work focuses on recent research results from nonparametric trends and nonstationary generalized extreme value (GEV) analyses at eight Interior Alaskan river basins for the past 50/60 years (1954/64-2013). Trends analysis of maximum and minimum streamflow indicates a strong (>+50%) and statistically significant increase in 11-day flow events during the late fall/winter and during the snowmelt period (late April/mid-May), followed by a significant decrease in the 11-day flow events during the post-snowmelt period (late May and into the summer). The April-May-June seasonal trends show significant decreases in maximum streamflow for snowmelt dominated systems (<-50%) and glacially influenced basins (-24% to -33%). Annual maximum streamflow trends indicate that most systems are experiencing declines, while minimum flow trends are largely increasing. Nonstationary GEV analysis identifies time-dependent changes in the distribution of spring extremes for snowmelt dominated and glacially dominated systems. Temperature in spring influences the glacial and high elevation snowmelt systems and winter precipitation drives changes in the snowmelt dominated basins. The Pacific Decadal Oscillation was associated with changes occurring in snowmelt dominated systems, and the Arctic Oscillation was linked to one lake dominated basin, with half of the basins exhibiting no change in response to climate variability. The work indicates that broad scale studies examining trend and direction of change should employ multiple methods across various scales and consider regime dependent shifts to identify and understand changes in extreme streamflow within boreal forested watersheds of Alaska.

Local Relevance: Many water systems in the interior Alaska Boreal are experiencing increased winter baseflow. The minimum flow results may be changing as well but changes are more strong and significant in maximum streamflow trends. Any changes in maximum streamflow responses were clearly linked to changes in climate, such as air temperature or precipitation increases or decreases. The measurements from the Yukon River Basin (near the Yukon/Alaska border) did not find direct responses to climate variability or climate change. The lack of changes in the Yukon River Basin are due to the mixed nival, glacial, and pluvial regimes that affect streamflow, which leads to a complicated system that may experience multiple effects and can result in opposing changes in the system. The authors believe that to provide a more detailed identification of the processes affecting streamflow, more fine-scale research is required such as precipitation studies and permafrost degradation studies.

Keywords: extreme events, generalized extreme value analysis, boreal, Alaska, Yukon River Basin, streamflow trends, GEV

Available Online: http://www.sciencedirect.com/science/article/pii/S0022169415003248

Citation: Bennett, K.E., Cannon, A.J. and Hinzman, L., 2015. Historical trends and extremes in boreal Alaska river basins. Journal of Hydrology, vol. 527, p. 590-607, doi:10.1016/j.jhydrol.2015.04.065.

Yukon River Water Isotope Data: Interpretation of Canadian Indigenous Observation Network Results

Research Location: Yukon River Basin, Yukon, Alaska, and British Columbia

Publication Type: Report

Publication Date: 2015

Introduction: This project examines a robust set of water isotope data collected within the Yukon River watershed. The data was collected by the Yukon River Intertribal Watershed Council (YRITWC)'s Indigenous Observation Network (ION) of community-based monitors over the past several years, at sampling nodes along the Yukon River. Here, the YRITWC has partnered with the Northern Climate ExChange (NCE; part of the Yukon Research Centre at Yukon College) to work towards interpretation of the isotope data collected from Canadian stations.

Local Relevance: Several sites were analyzed for their isotopic sources which could determine if they were more heavily influenced by summer precipitation or annual precipitation. One group of samples was influenced by annual precipitation and another by summer precipitation. The two groups did not seem split by geography but instead by sample year. The sample sites include: Atlin Lake above and below Atlin, Teslin Lake and Teslin River, Bennett Lake, Tagish River, Yukon River, White River, and Stewart River. Several recommendations for future isotope work are given and include the following: more processing of samples to establish hydrological trends; integration of new sample results into current time series plots in this report; expansion of sampling activities; creating more efficient sampling locations; example results in context of Yukon River Inter-tribal Water Council parameters; comparing results from Yukon River to Stewart River; and to compare sample trends to climate trends once more data is available.

Keywords: isotope data, YRITWC, indigenous observation network, Yukon River Basin

Available Online:
https://www.yukoncollege.yk.ca/research/abstracts/yukon_river_water_isotope_data_interpretation_of_canadian_indigenous_observ

Citation: Northern Climate ExChange, 2015. Yukon River Water Isotope Data: Interpretation of Canadian Indigenous Observation Network Results. Yukon Research Centre, Yukon College, 36 p.

2.4. Northern Lakes and Ponds

Changes in lake area in response to thermokarst processes and climate in Old Crow Flats, Yukon

Research Location: Old Crow Flats, Yukon

Publication Type: Journal Article

Publication Date: 2015

Abstract: Growing evidence indicates that lake-dominated ecosystems at high latitudes are undergoing significant hydrological changes. Research examining these changes is complicated because both thermokarst and climatic processes likely influence lake dynamics. To examine the relative impacts of these processes in permafrost landscapes, we investigated the dynamics of lake area and number in Old Crow Flats (OCF), Yukon using historical air photos and satellite imagery. Between 1951 and 2007, OCF experienced a decline of ~6000 ha in total lake area but gained 232 lakes. Close to half (49%) of the difference in lake area was driven by the rapid and persistent drainage of 38 large lakes. These catastrophic drainages were associated with new or enlarged outlet channels, resulted in the formation of numerous residual ponds, and were likely driven by thermokarst processes. Our analysis shows that catastrophic lake drainages have become more than 5 times more frequent in recent decades. These changes are likely related to the impacts of increased temperature and precipitation on thermokarst processes. Fifty-nine of the 170 intensively studied lakes showed either large bidirectional fluctuations or gradual cumulative declines. These changes affected a much smaller portion of OCF and were likely driven by interactions between increased precipitation and temperature and individual catchment characteristics. To anticipate landscape-scale changes in these systems, and assess their impact on hydrology, wildlife habitat, and carbon storage, field research is required to better characterize the mechanisms responsible for changes.

Local Relevance: The authors of this study have demonstrated that thermokarst and climatic processes drive different responses in lake systems impacted by increasing temperature and precipitation. Catastrophic drainage in Old Crow Flats accounted for a decline in lake area of nearly half between 1951 and 2007 and suggests that thermokarst processes are a key driver of the changes occurring in this landscape. The authors also suggest that permanent reductions in lake area will have significant implications for local wildlife, vegetation dynamics and carbon storage. Following lake drainage, changes in vegetation provide high-quality habitat for moose. Additionally, in Arctic environments, lake drainage in typically followed by permafrost aggradation and peatland development which may increase regional soil carbon storage.

Keywords: Old Crow Flats, thermokarst lakes, permafrost, aerial photos, satellite imagery, precipitation change, temperature change

Available Online:
https://www.researchgate.net/publication/272196969_Changes_in_lake_area_in_response_to_thermokarst_processes_and_climate_in_Old_Crow_Flats_Yukon

Citation: Lantz, T.C. and Turner, K.W., 2015. Changes in lake area in response to thermokarst processes and climate in Old Crow Flats, Yukon. Journal of Geophysical Research: Biogeosciences, vol. 120, issue 3, p. 513-524. doi:10.1002/2014JG002744.

The evolution of a thermokarst-lake landscape: Late Quaternary permafrost degradation and stabilization in interior Alaska

Research Location: Yukon Flats, Alaska

Publication Type: Journal Article

Publication Date: 2016

Abstract: Thermokarst processes characterize a variety of ice-rich permafrost terrains and often lead to lake formation. The long-term evolution of thermokarst landscapes and the stability and longevity of lakes depend upon climate, vegetation and ground conditions, including the volume of excess ground ice and its distribution. The current lake status of thermokarst-lake landscapes and their future trajectories under climate warming are better understood in the light of their long-term development. We studied the lake-rich southern marginal upland of the Yukon Flats (northern interior Alaska) using dated lake-sediment cores, observations of river-cut exposures, and remotely-sensed data. The region features thick (up to 40 m) Quaternary deposits (mainly loess) that contain massive ground ice. Two of three studied lakes formed ~11,000–12,000 cal yr BP through inferred thermokarst processes, and fire may have played a role in initiating thermokarst development. From ~9000 cal yr BP, all lakes exhibited steady sedimentation, and pollen stratigraphies are consistent with regional patterns. The current lake expansion rates are low (0 to <7 cm yr^{-1} shoreline retreat) compared with other regions (~30 cm yr^{-1} or more). This thermokarst lake-rich region does not show evidence of extensive landscape lowering by lake drainage, nor of multiple lake generations within a basin. However, LiDAR images reveal linear "corrugations" (>5 m amplitude), deep thermo-erosional gullies, and features resembling lake drainage channels, suggesting that highly dynamic surface processes have previously shaped the landscape. Evidently, widespread early Holocene permafrost degradation and thermokarst lake initiation were followed by lake longevity and landscape stabilization, the latter possibly related to establishment of dense forest cover. Partial or complete drainage of three lakes in 2013 reveals that there is some contemporary landscape dynamism. Holocene landscape evolution in the study area differs from that described from other thermokarst-affected regions; regional responses to future environmental change may be equally individualistic.

Local Relevance: In the early Holocene, widespread permafrost degradation and thermokarst lake initiation were followed by lake longevity and landscape stabilization, the latter possibly related to the establishment of dense forest cover. The Yukon Flats in northern interior Alaska was found to have evolved differently in the Holocene than other thermokarst-affected regions which may suggest to region-specific responses to future environmental change.

Keywords: Alaska, Holocene, LiDAR, non-linear processes, permafrost degradation, thermokarst lakes, Yukon Flats

Available Online: http://www.sciencedirect.com/science/article/pii/S0037073816000270

Citation: Edwards, M., Grosse, G., Jones, B.M. and McDowell, P., 2016. The evolution of a thermokarst-lake landscape: Late Quaternary permafrost degradation and stabilization in interior Alaska. Sedimentary Geology, vol. 340, p. 3-14. doi:10.1016/j.sedgeo.2016.01.018.

Disappearing Arctic tundra ponds: Fine-scale analysis of surface hydrology in drained thaw lake basins over a 65 year period (1948-2013)

Research Location: Barrow Peninsula, Alaska

Publication Type: Journal Article

Publication Date: 2015

Abstract: Long-term fine-scale dynamics of surface hydrology in Arctic tundra ponds (less than 1 ha) are largely unknown; however, these small water bodies may contribute substantially to carbon fluxes, energy balance, and biodiversity in the Arctic system. Change in pond area and abundance across the upper Barrow Peninsula, Alaska, was assessed by comparing historic aerial imagery (1948) and modern submeter resolution satellite imagery (2002, 2008, and 2010). This was complemented by photogrammetric analysis of low-altitude kite-borne imagery in combination with field observations (2010-2013) of pond water and thaw depth transects in seven ponds of the International Biological Program historic research site. Over 2800 ponds in 22 drained thaw lake basins (DTLB) with different geological ages were analyzed. We observed a net decrease of 30.3% in area and 17.1% in number of ponds over the 62 year period. The inclusion of field observations of pond areas in 1972 from a historic research site confirms the linear downward trend in area. Pond area and number were dependent on the age of DTLB; however, changes through time were independent of DTLB age, with potential long-term implications for the hypothesized geomorphologic landscape succession of the thaw lake cycle. These losses were coincident with increases in air temperature, active layer, and density and cover of aquatic emergent plants in ponds. Increased evaporation due to warmer and longer summers, permafrost degradation, and transpiration from encroaching aquatic emergent macrophytes are likely the factors contributing to the decline in surface area and number of ponds.

Local Relevance: In the Barrow Peninsula of Alaska 2800 ponds in 22 drained thaw lake basins were analyzed. Ponds are excellent indicators of climate change due to their hydrological isolation, small water volumes, and large surface area-to-depth ratios. Additionally, hydrology in the Arctic landscape, particularly surface water area, is a fundamental aspect governing ecosystem structure, function and energy balance. The understanding of changes in surface hydrology in response to a changing climate is critical since global climate models suggest that the hydrological cycle will intensify with the increase in Arctic temperatures.

Keywords: aerial imagery, satellite imagery, permafrost thaw, transpiration, increasing evaporation, Alaska, Barrow Peninsula

Available Online: http://onlinelibrary.wiley.com/doi/10.1002/2014JG002778/abstract

Citation: Andresen, C. and Lougheed, V., 2015. Disappearing Arctic tundra ponds: Fine-scale analysis of surface hydrology in drained thaw lake basins over a 65 year period (1948-2013). Journal of Geophysical Research-Biogeosciences, vol. 120, issue 3, p. 466-479.

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

Research Location: Yukon Flats, Alaska

Publication Type: Journal Article

Publication Date: 2015

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

Local Relevance: Net loss of lake surface area in Arctic and Subarctic regions can lead to changes in water chemistry. The mechanisms of reduced lake area are: increased imbalance of evaporation relative to inflow, and accelerated permafrost degradation that enhances sublacustrine drainage and leaches previously frozen solutes into lakes. In shrinking lakes the concentrations of analyzed nutrients increased. Therefore, climatic-driven changes in precipitation, evaporation rate, and permafrost stability have the potential to strongly influence water levels in Arctic and Subarctic landscapes.

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

Available Online:
https://www.researchgate.net/publication/266621086_Pronounced_chemical_response_of_Subarctic_lakes_to_climate-driven_losses_in_surface_area_Global_Change_Biol

Citation: Lewis, T.L., Lindberg, M.S., Schmutz, J. A., Heglund, P.J., Rover, J., Koch, J.C. and Bertram, M.R., 2015. Pronounced chemical response of Subarctic lakes to climate-driven losses in surface area. Global Change Biology, vol. 21, issue 3, p. 1140-1152. doi:10.1111/gcb.12759

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

Research Location: Old Crow Flats, Yukon

Publication Type: Journal Article

Publication Date: 2015

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

Local Relevance: The Old Crow Flats region is dominated by shallow lakes (mainly thermokarst) which are undergoing pronounced hydrological changes consistent with a rapidly warming Arctic. Due to their small water volume, they are highly responsive to meteorological changes and rely primarily on inputs of snowmelt and intense rainfall to maintain positive water balances. This study uses landscape-scale, integrated hydrological and limnological assessments in order to improve our ability to anticipate responses of shallow subarctic lakes to ongoing and future climate variations.

Keywords: watershed research, limnology, water carbon content, water chemistry, climatic changes, soil erosion, subarctic, Old Crow Flats

Available Online: https://www.researchgate.net/publication/277564445_Source-water_inputs_and_catchment_characteristics_regulate_limnological_conditions_of_shallow_Arctic_lakes_Old_Crow_Flats_Yukon_Canada

Citation: Balasubramaniam, A.M., Hall, R.I., Wolfe, B.B., Sweetman, J.N. and Wang, X., 2015. Source water inputs and catchment characteristics regulate limnological conditions of shallow subarctic lakes (Old Crow Flats, Yukon, Canada). Canadian Journal of Fisheries and Aquatic Sciences, vol. 72, issue 7, p. 1058-1072.

3. Permafrost

3.1. Permafrost CO_2 Release

Ancient low-molecular-weight organic acids in permafrost fuel rapid carbon dioxide production upon thaw

Research Location: Fox Permafrost Tunnel, Alaska

Publication Type: Journal Article

Publication Date: 2015

Abstract: Northern permafrost soils store a vast reservoir of carbon, nearly twice that of the present atmosphere. Current and projected climate warming threatens widespread thaw of these frozen, organic carbon (OC)-rich soils. Upon thaw, mobilized permafrost OC in dissolved and particulate forms can enter streams and rivers, which are important processors of OC and conduits for carbon dioxide (CO_2) to the atmosphere. Here, we demonstrate that ancient dissolved organic carbon (DOC) leached from 35,800 y B.P. permafrost soils is rapidly mineralized to CO_2. During 200-h experiments in a novel high-temporal-resolution bioreactor, DOC concentration decreased by an average of 53%, fueling a more than sevenfold increase in dissolved inorganic carbon (DIC) concentration. Eighty-seven percent of the DOC loss to microbial uptake was derived from the low-molecular-weight (LMW) organic acids acetate and butyrate. To our knowledge, our study is the first to directly quantify high CO_2 production rates from permafrost-derived LMW DOC mineralization. The observed DOC loss rates are among the highest reported for permafrost carbon and demonstrate the potential importance of LMW DOC in driving the rapid metabolism of Pleistocene-age permafrost carbon upon thaw and the outgassing of CO_2 to the atmosphere by soils and nearby inland waters.

Local Relevance: Permafrost was collected from Yedoma permafrost soils in an extension of the Fox Permafrost Tunnel, Alaska. This study is the first to directly link rapid microbial consumption of ancient permafrost-derived dissolved organic carbon (DOC) to CO_2 production using a novel bioreactor. The results showed that substantial biodegradation of permafrost DCO occurs immediately after thaw and prior to downstream transport. The authors estimate that, by 2100, between 5 and 10 Tg of DOC will be released from Yedoma soils annually given the most recent estimates of projected thaw which represents 19-26% of annual DOC loads exported by Arctic rivers.

Keywords: permafrost, dissolved organic carbon, carbon dioxide, organic acids, Pleistocene, Fox Permafrost Tunnel, Alaska

Available Online: http://www.pnas.org/content/112/45/13946.abstract

Citation: Drake, T.W., Wickland, K.P., Spencer, R.G.M., McKnight, D.M. and Striegl, R.G., 2015. Ancient low-molecular-weight organic acids in permafrost fuel rapid carbon dioxide production upon thaw. Proceedings of The National Academy of Sciences of The United States of America (PNAS), vol. 112, issue 45, p. 13946-13951.

Recovery of arctic tundra from thermal erosion disturbance is constrained by nutrient accumulation: a modeling analysis

Research Location: Alaskan Tundra

Publication Type: Journal Article

Publication Date: 2015

Abstract: We calibrated the Multiple Element Limitation (MEL) model to Alaskan arctic tundra to simulate recovery of thermal erosion features (TEFs) caused by permafrost thaw and mass wasting. TEFs could significantly alter regional carbon (C) and nutrient budgets because permafrost soils contain large stocks of soil organic matter (SOM) and TEFs are expected to become more frequent as the climate warms. We simulated recovery following TEF stabilization and did not address initial, short-term losses of C and nutrients during TEF formation. To capture the variability among and within TEFs, we modeled a range of post-stabilization conditions by varying the initial size of SOM stocks and nutrient supply rates.

Simulations indicate that nitrogen (N) losses after the TEF stabilizes are small, but phosphorus (P) losses continue. Vegetation biomass recovered 90% of its undisturbed C, N, and P stocks in 100 years using nutrients mineralized from SOM. Because of low litter inputs but continued decomposition, younger SOM continued to be lost for 10 years after the TEF began to recover, but recovered to about 84% of its undisturbed amount in 100 years. The older recalcitrant SOM in mineral soil continued to be lost throughout the 100-year simulation.

Simulations suggest that biomass recovery depended on the amount of SOM remaining after disturbance. Recovery was initially limited by the photosynthetic capacity of vegetation, but became co-limited by N and P once a plant canopy developed. Biomass and SOM recovery was enhanced by increasing nutrient supplies, but the magnitude, source, and controls on these supplies are poorly understood. Faster mineralization of nutrients from SOM (e.g., by warming) enhanced vegetation recovery but delayed recovery of SOM. Taken together, these results suggest that although vegetation and surface SOM on TEFs recovered quickly (25 and 100 years, respectively), the recovery of deep, mineral soil SOM took centuries and represented a major ecosystem C loss.

Local Relevance: Simulations within this paper show that thermal erosional events should result in a net release of C from the tundra to the atmosphere. The frequency of thermal erosion events and how that frequency may change with a warming climate were not known. Yet, surface soils and vegetation entering streams or lakes are quickly respired, therefore contributing more to atmospheric C.

Keywords: Alaska, arctic, biogeochemistry, disturbance, ecosystem model, global climate change, nutrient cycles, permafrost, thermokarst, tundra

Available Online: http://onlinelibrary.wiley.com/doi/10.1890/14-1323.1/abstract

Citation: Pearce, A.R., Rastetter, E.B., Kwiatkowski, B.L., Bowden, W.B., Mack, M.C. and Jiang, Y., 2015. Recovery of arctic tundra from thermal erosion disturbance is constrained by nutrient accumulation: a modeling analysis. Ecological Applications, vol. 25, issue 5, p. 1271-1289.

3.2. Paleoenvironmental Permafrost

Holocene ice-wedge polygon development in northern Yukon permafrost peatlands (Canada)

Research Location: Herschel Island, Yukon

Publication Type: Journal Article

Publication Date: 2016

Abstract: Ice-wedge polygon (IWP) peatlands in the Arctic and Subarctic are extremely vulnerable to climatic and environmental change. We present the results of a multidisciplinary paleoenvironmental study on IWPs in the northern Yukon, Canada. High-resolution laboratory analyses were carried out on a permafrost core and the overlying seasonally thawed (active) layer, from an IWP located in a drained lake basin on Herschel Island. In relation to 14 Accelerator Mass Spectrometry (AMS) radiocarbon dates spanning the last 5000 years, we report sedimentary data including grain size distribution and biogeochemical parameters (organic carbon, nitrogen, C/N ratio, $\delta^{13}C$), stable water isotopes ($\delta^{18}O$, δD), as well as fossil pollen, plant macrofossil and diatom assemblages. Three sediment units (SUs) correspond to the main stages of deposition (1) in a thermokarst lake (SU1: 4950 to 3950 cal yrs BP), (2) during transition from lacustrine to palustrine conditions after lake drainage (SU2: 3950 to 3120 cal yrs BP), and (3) in palustrine conditions of the IWP field that developed after drainage (SU3: 3120 cal yrs BP to 2012 CE). The lacustrine phase (pre 3950 cal yrs BP) is characterized by planktonic-benthic and pioneer diatom species indicating circumneutral waters, and very few plant macrofossils. The pollen record has captured a regional signal of relatively stable vegetation composition and climate for the lacustrine stage of the record until 3950 cal yrs BP. Palustrine conditions with benthic and acidophilic diatom species characterize the peaty shallow-water environments of the low-centered IWP. The transition from lacustrine to palustrine conditions was accompanied by acidification and rapid revegetation of the lake bottom within about 100 years. Since the palustrine phase we consider the pollen record as a local vegetation proxy dominated by the plant communities growing in the IWP. Ice-wedge cracking in water-saturated sediments started immediately after lake drainage at about 3950 cal yrs BP and led to the formation of an IWP mire. Permafrost aggradation through downward closed-system freezing of the lake talik is indicated by the stable water isotope record. The originally submerged IWP center underwent gradual drying during the past 2000 years. This study highlights the sensitivity of permafrost landscapes to climate and environmental change throughout the Holocene.

Local Relevance: Approximately 3950 cal yrs BP a thermokarst lake on Hershel Island drained. Post drainage was the development of ice-wedge polygon peatlands which persist to this day. The drainage is believed to not be directly related to climate variations but due to gully incisions which tapped the lake. Since 3120 cal yrs BP organic carbon was rapidly incorporated into aggrading permafrost under wet, acidic and low-oxygen conditions, which makes arctic peatlands extensive carbon reservoirs. Overall the fossil pollen has recorded a very local vegetation signal since lake drainage, which does not allow inference about regional climate variations; yet, local vegetation succession and diversity patterns can be inferred, especially in combination with the study of plant macrofossils.

Keywords: permafrost peatlands, Arctic, thermokarst, talik, ice-wedge polygon, pollen, diatoms, plant macrofossils, stable water isotopes, deuterium excess

Available Online: http://www.sciencedirect.com/science/article/pii/S0277379116300403

Citation: Fritz, M., Wolter, J., Rudaya, N., Palagushkina, O., Nazarova, L., Obu, J., Rethemeyer, J., Lantuit, H. and Wetterich, S., 2016. Holocene ice-wedge polygon development in northern Yukon permafrost peatlands (Canada). Quaternary Science Reviews, p. 1-19, doi:10.1016/j.quascirev.2016.02.008.

Incidence of Late Pleistocene-Holocene climate on the concurrent landscape and permafrost development of the Beaver Creek region, southwestern Yukon, Canada

Research Location: Beaver Creek, Yukon

Publication Type: Conference Publication

Publication Date: 2015

Abstract: The Beaver Region is located in southwestern Yukon and was not glaciated during the last glacial advance (Late Wisconsinian, 26-11.7Ky BP). The site lies on Middle Wisconsinian to Holocene deposits covering a disintegration moraine; prior cryostratigraphic investigations have shown the presence of ice-rich cryofacies and syngenetic ice wedges down to 10 m below the surface. The objective of this paper is to propose a conceptual model linking the permafrost cryostratigraphy to the post-glacial climate history. 29 boreholes have been analysed in relation to the topography, ecology and pedology. Five cryostratigraphic units have been defined, characterized and related to specific development stages. As results, the contemporary landscape can be defined in two contrasted zones; mesic convex, and humid concave areas. This differentiated geomorphology affects the modern landscape evolution from a geothermal, hydrologic, ecologic, pedogenic and cryogenic perspective.

Local Relevance: The geomorphology of hills and depressions inherited from the Mirror Creek disintegration moraine affects geosystem evolution today. This study examines the cryostratigraphy of a disintegration moraine in order to propose a model of concurrent landscape and permafrost development in relation to past climatic events during the Late Pleistocene-Holocene period and provides a framework for conceptualizing long-term terrain dynamics and permafrost history.

Keywords: Cenozoic, glacial geology, Holocene, paleoclimatology, paleogeography, paleohydrology, Quaternary, upper Pleistocene

Available Online: http://geocryolab.ca/ice/en/incidence-of-late-pleistocene-holocene-climate-on-the-concurrent-landscape-and-permafrost-development-of-the-beaver-creek-region-southwestern-yukon-canada/

Citation: Sliger, M., Fortier, D., deGrandpré, I. and Lapointe-Elmrabti, L., 2015. Incidence of late Pleistocene-Holocene climate on the concurrent landscape and permafrost development of the Beaver Creek region, southwestern Yukon, Canada. Conference Paper, GeoQuebec 2015 – 7th Canadian Permafrost Conference and 68th Canadian Geotechnical Conference, QC, 9 p.

3.3. Modelling and Mapping Techniques

Distribution of near-surface permafrost in Alaska: Estimates of present and future conditions

Research Location: Alaska

Publication Type: Journal Article

Publication Date: 2015

Abstract: High-latitude regions are experiencing rapid and extensive changes in ecosystem composition and function as the result of increases in average air temperature. Increasing air temperatures have led to widespread thawing and degradation of permafrost which in turn has affected ecosystems, socioeconomics, and the carbon cycle of high latitudes. Here we overcome complex interactions among surface and subsurface conditions to map near-surface permafrost through decision and regression tree approaches that statistically and spatially extend field observations using remotely sensed imagery, climatic data, and thematic maps of a wide range of surface and subsurface biophysical characteristics. The data fusion approach generated medium-resolution (30-m pixels) maps of near-surface (within 1 m) permafrost, active-layer thickness, and associated uncertainty estimates throughout mainland Alaska. Our calibrated models (overall test accuracy of ~85%) were used to quantify changes in permafrost distribution under varying future climate scenarios assuming no other changes in biophysical factors. Models indicate that near-surface permafrost underlies 38% of mainland Alaska and that near-surface permafrost will disappear on 16 to 24% of the landscape by the end of the 21st Century. Simulations suggest that near-surface permafrost degradation is more probable in central regions of Alaska than more northerly regions. Taken together, these results have obvious implications for potential remobilization of frozen soil carbon pools under warmer temperatures. Additionally, warmer and drier conditions may increase fire activity and severity, which may exacerbate rates of permafrost thaw and carbon remobilization relative to climate alone. The mapping of permafrost distribution across Alaska is important for land-use planning, environmental assessments, and a wide-array of geophysical studies.
Local Relevance: Permafrost distribution was mapped in Alaska through the use of decision and regression tree approaches that statistically and spatially extended field observations using remotely sensed imagery, climatic data, and thematic maps of a wide range of surface and subsurface biophysical characteristics. Medium resolution (30-m pixel) maps of near-surface (within 1m) permafrost, active-layer thickness, and uncertainty estimates were generated for mainland Alaska. Calibrated models had a 85% test accuracy and were used to quantify changes in permafrost distribution under varying future climate scenarios. Models indicated permafrost covered 38% of Alaska and a 16 – 24% decrease in permafrost by the end of the 21st century. The model used assumed static surface conditions and did not take into account possible dynamic changes in fire regimes, hydrology, vegetation, soils, and feedbacks associated with permafrost responses to climate warming.

Keywords: Alaska, data mining, pedometrics, near-surface permafrost, machine learning, remote sensing

Available Online: http://www.sciencedirect.com/science/article/pii/S0034425715300778

Citation: Pastick, N.J., Jorgenson, M.T., Wylie, B.K., Nield, S.J., Johnson, K.D. and Finley, A.O., 2015. Distribution of near-surface permafrost in Alaska: Estimates of present and future conditions. Remote Sensing of Environment, vol. 168, p. 301-315, doi: 10.1016/j.rse.2015.07.019

Assessment of a land cover driven TTOP model for mountain and lowland permafrost using field data, southern Yukon and northern British Columbia, Canada

Research Location: Southern Yukon and Northern British Columbia

Publication Type: Conference Paper

Publication Date: 2015

Abstract: Air, ground surface and top of permafrost temperatures (TTOP) were measured at 55 sites in three areas of Yukon and northern British Columbia in order to explore relationships between climate-permafrost transfer functions and environmental variables and to assess and validate the TTOP model. The strongest factors controlling climate permafrost transfer functions are elevation and land cover, though slope, aspect, topographic position and surficial geology were also investigated. In 1000 iterations of the model using randomly-generated equally possible scenarios, 64% of the TTOP model predictions were within ±1°C of measured values, a result that is 6% better than applying a uniform 3°C total offset to the mean annual air temperature. A sensitivity analysis confirmed that the TTOP model is most sensitive to changes in the freezing n-factor, thermal conductivity ratio of the ground, and summer air temperatures.

Local Relevance: Current permafrost monitoring has noted warming permafrost during the last 20-30 years; zones of discontinuous permafrost have seen thawing. The impacts of warming or thawing permafrost include: changes in the magnitude and frequency of geohazards such as rockfalls, active layer detachments and retrogressive thaw slumps; infrastructure challenges caused by thaw settlement and deepening active layers; and positive feedback to the global climate system due to greenhouse gases released from thawing organic materials. In the validation of top of permafrost temperature (TTOP) modelling it was found 64% of model predictions were within ±1°C of measured values Improvements to the model may be made with higher resolution elevation and surficial geology datasets.

Keywords: active layer, top of the permafrost temperatures, thermal conductivity, freezing n-factor, southern Yukon, northern British Columbia

Available Online:
https://www.researchgate.net/publication/282649555_Assessment_of_a_land_cover_driven_TTOP_model_for_mountain_and_lowland_permafrost_using_field_data_southern_Yukon_and_northern_British_Columbia_Canada

Citation: Bevington, A. and Lewkowicz, A.G., 2015. Assessment of a land cover driven TTOP model for mountain and lowland permafrost using field data, southern Yukon and northern British Columbia, Canada. Conference Paper, GeoQuebec 2015 – 7th Canadian Permafrost Conference and 68th Canadian Geotechnical Conference, QC, 10 p.

3.4. Permafrost Characterization

Characterizing permafrost valley fills along the Alaska Highway, southwest Yukon

Research Location: Beaver Creek, Alaska Highway, Yukon

Publication Type: Conference Paper

Publication Date: 2015

Abstract: In the Beaver Creek area of southwest Yukon, the Alaska Highway traverses both glaciated and non-glaciated terrain from the Last Glacial Maximum. In this area permafrost characteristics are strongly influenced by regional glacial history including the distribution of relict Pleistocene permafrost. Here we characterize the distribution and history of permafrost in a valley fill along the Alaska Highway between Beaver Creek and the Alaska border using a multidisciplinary approach. Our surveys include Electrical Resistivity Tomography (ERT), permafrost drilling, cryostratigraphy, and geochemical analyses to define the boundaries and characteristics of the valley fill. Using ERT data we mapped the widespread distribution of ice-rich organic silts of Holocene age that unconformably overlie relict syngenetic permafrost from the Late Pleistocene within the valley fill. Radiocarbon dating and stable isotope analyses of δ18O and δD, combined with detailed cryostratigraphy, confirm the presence of relict syngenetic ground ice from the Late Pleistocene (>57,000 14C years BP), indicating the considerable antiquity of ice-rich permafrost at this southerly locality.

Local Relevance: Detailed borehole and ERT data were able to provide maps of distribution of ice-rich Holocene and Late Pleistocene permafrost. It was found that Late Pleistocene permafrost was uncomformably overlain by ice-rich Holocene material. Overall, the results show potential for long-term preservation of permafrost at remarkably warm sites such as the Alaska Highway corridor. Also, any effective highway maintenance of the Alaska Highway requires an understanding of the permafrost distribution in the highway corridor. Use of borehole data and electrical resistivity tomography were shown to be effective local-scale permafrost mapping tools.

Keywords: Pleistocene, valley fill, electrical resistivity tomography, permafrost drilling, cryostratigraphy, geochemical analyses, Holocene, Beaver creek, Alaska highway

Available Online:
https://www.researchgate.net/publication/282328615_Characterizing_permafrost_valley_fills_along_the_Alaska_Highway_southwest_Yukon

Citation: Pumple, J., Froese, D. and Calmels, F., 2015. Characterizing permafrost valley fills along the Alaska Highway, southwest Yukon. Conference Paper, GeoQuebec 2015 – 7th Canadian Permafrost Conference and 68th Canadian Geotechnical Conference, QC, 8 p.

Distribution and growth of thaw slumps in the Richardson Mountains – Peel Plateau region, northwestern Canada

Research Location: Peel Plateau, Yukon

Publication Type: Journal Article

Publication Date: 2015

Abstract: Retrogressive thaw slumps are one of the most active geomorphic features in permafrost terrain. This study investigated the distribution and growth of thaw slumps in the Richardson Mountains and Peel Plateau region, northwestern Canada, using Tasseled Cap (TC) trend analysis of a Landsat image stack. Based on the TC linear trend image, more than 212 thaw slumps were identified in the study area, of which 189 have been active since at least 1985. The surface area of the slumps ranges from 0.4 to 52 ha, with 10 slumps exceeding 20 ha. The thaw slumps in the region are all situated within the maximum westward extent of the Laurentide Ice Sheet. Based on relations between frequency distribution of slumps and that of terrain factors in the landscape, the slumps are more likely to occur on the ice-rich hummocky rolling moraines at elevations of 300-350 m and 450-500 m and along east-facing slopes (slope aspects of 15° to 180°) with gradients of 8° to 12°. Pixel-level trend analysis of the TC greenness transformation in the Landsat stack allowed calculating headwall retreat rates for 19 thaw slumps. The 20-year average retreat rates (1990-2010 period) for 19 slumps ranged from 7.2 to 26.7 m yr^{-1}, with the largest slumps having higher retreat rates. At the regional scale, the 20-yr headwall retreat rates are mainly related to slope aspect, with south- and west-facing slopes exhibiting higher retreat rates, and large slumps appear to be generating feedbacks that allow them to maintain growth rates well above those of smaller slumps. Overall, the findings presented in this study allow highlighting of key sensitive landscapes and ecosystems that may be impacted by the presence and growth of thaw slumps in one of the most rapidly warming region in the Arctic.

Local Relevance: The distribution and growth of thaw slumps in the Richardson Mountains and Peel Plateau region were investigated using Tasseled Cap trend analysis of a Landsat image stock. This study highlights those sensitive landscapes and terrestrial and freshwater ecosystems that may be impacted by the presence and growth of thaw slumps in one of the most rapidly warming regions in the Arctic.

Keywords: thaw slumps, thermokarst, permafrost, tasseled cap transformations, Peel Plateau, size frequency, northwestern Canada, Yukon

Available Online:
https://www.researchgate.net/publication/272390451_Distribution_and_growth_of_thaw_slumps_in_the_Richardson_Mountains-Peel_Plateau_region_northwestern_Canada

Citation: Lacelle, D., Brooker, A., Fraser, R.H. and Kokelj, S.V., 2015. Distribution and growth of thaw slumps in the Richardson Mountains-Peel Plateau region, northwestern Canada. Geomorphology, vol. 235, p. 40-51. doi:10.1016/j.geomorph.2015.01.024.

Impact of land cover disturbance on permafrost landscapes: Case Studies from Yukon communities

Research Location: Dawson, Burwash Landing and Whitehorse; Yukon

Publication Type: Conference Paper

Publication Date: 2015

Abstract: Using examples from three case studies in Yukon communities, we investigate the role of anthropogenic disturbance on permafrost landscapes. Landscape modifications investigated include alternations to surface vegetation for fire protection adjacent to communities, and land clearing to support economic activities like surface mining and agriculture. In most cases, the removal of protective vegetative cover resulted in permafrost degradation, leading to the development of near-surface taliks over decadal-scale time periods. Conversely, light alteration to vegetative cover (e.g., stand thinning for fire protection) does not appear to have altered permafrost presence or distribution. Results have implications for community-scale land use planning in the context of a changing climate.

Local Relevance: In Burwash Landing, a FireSmart zone where light alteration to vegetative cover (e.g., stand thinning for fire protection) does not appear to have altered permafrost presence or distribution. In an adjacent firebreak, vegetation removal had a greater impact on the ground thermal regime, leading to a deepening of the active layer and the development of a supra-permafrost talik up to 8 m deep with potential warming of underlying permafrost. The authors suggest additional studies which determine the threshold at which vegetation removal triggers permafrost degradation.

In Dawson City where site clearing for placer mining lead to the removal of the top layers of soil and vegetation, the active layer thickened and supra-permafrost taliks developed. The ice-rich permafrost degraded at an average rate of 0.5 to 1 m per year over the past ~10 years. Conversely, in adjacent forested zones the active layer is limited to ~50 cm. In nearby agricultural fields that have been used over the past four decades, the near-surface permafrost has degraded. The degradation has lead to the creation of linear water channels around ice wedge polygons, and thermokarst ponds and lakes.

Keywords: case studies, anthropogenic disturbance, fire protection, land clearing, taliks, land use planning

Available Online:
https://www.researchgate.net/publication/282156327_Impact_of_land_cover_disturbance_on_permafrost_landscapes_Case_studies_from_Yukon_communities

Citation: Grandmont, K., Roy, L.-P., de Grandpré, I., Fortier, D., Benkert, B. and Lewkowicz, A., 2015. Impact of land cover disturbance on permafrost landscapes; case studies from Yukon communities. Conference Paper, GeoQuebec 2015 – 7th Canadian Permafrost Conference and 68th Canadian Geotechnical Conference, QC, 8 p.

Increased precipitation drives mega slump development and destabilization of ice-rich permafrost terrain, northwestern Canada

Research Location: Peel Plateau, Yukon

Publication Type: Journal Article

Publication Date: 2015

Abstract: It is anticipated that an increase in rainfall will have significant impacts on the geomorphology of permafrost landscapes. Field observations, remote sensing and historical climate data were used to investigate the drivers, processes and feedbacks that perpetuate the growth of large retrogressive thaw slumps. These "mega slumps" (5-40 ha) are now common in formerly glaciated, fluvially incised, ice-cored terrain of the Peel Plateau, NW Canada. Individual thaw slumps can persist for decades and their enlargement due to ground ice thaw can displace up to 10^6 m^3 of materials from slopes to valley bottoms reconfiguring slope morphology and drainage networks. Analysis of Landsat images (1985-2011) indicate that the number and size of active slumps and debris tongue deposits has increased significantly with the recent intensification of rainfall. The analyses of high resolution climatic and photographic time-series for summers 2010 and 2012 shows strong linkages amongst temperature, precipitation and the downslope sediment flux from active slumps. Ground ice thaw supplies meltwater and sediments to the slump scar zone and drives diurnal pulses of surficial flow. Coherence in the timing of down valley debris tongue deposition and fine-scaled observations of sediment flux indicate that heavy rainfall stimulates major mass flow events. Evacuation of sediments from the slump scar zone can help to maintain a headwall of exposed ground ice, perpetuating slump growth and leading to larger disturbances. The development of debris tongue deposits divert streams and increase thermoerosion to initiate adjacent slumps. We conclude that higher rainfall can intensify thaw slump activity and rapidly alter the slope-sediment cascade in regions of ice-cored glaciogenic deposits.

Local Relevance: Within the Peel Plateau, major increases in the number and size of active slump surfaces and debris tongues since the mid-1980s have coincided with significant increases in the magnitude and intensity of rainfall. Air temperature and precipitation was found to influence the moisture regime of slump soils, driving downslope sediment transport from the slump scar zone, and resulting in debris tongue enlargement. In 2010, strong relationships between air temperature and flow events were observed when frequent rain maintained slopes in saturated conditions. Overall, it was found that more precipitation can lead to rapid destabilization of ice-rich, fluvially incised, moraine-dominated landscapes. The destabilization of these regions can lead to increased sediment loads in rivers and coastal zones throughout the North, and have enduring consequences on slope and fluvial geomorphology and downstream ecosystems.

Keywords: climate change, ground ice, landscape change, mass wasting, permafrost, rainfall intensity, thaw slump, thermokarst

Available Online: http://www.sciencedirect.com/science/article/pii/S0921818115000545

Citation: Kokelj, S.V., Tunnicliffe, J., Lacelle, D., Lantz, T.C., Chin, K.S. and Fraser, R., 2015. Increased precipitation drives mega slump development and destabilization of ice-rich permafrost terrain, northwestern Canada. Global and Planetary Change, vol. 129, p. 56-68, doi:10.1016/j.gloplacha.2015.02.008.

Sensitivity of airborne geophysical data to sublacustrine and near-surface permafrost thaw

Research Location: Yukon Flats, Alaska

Publication Type: Journal Article

Publication Date: 2015

Abstract: A coupled hydrogeophysical forward and inverse modeling approach is developed to illustrate the ability of frequency-domain airborne electromagnetic (AEM) data to characterize subsurface physical properties associated with sublacustrine permafrost thaw during lake-talik formation. Numerical modeling scenarios are evaluated that consider non-isothermal hydrologic responses to variable forcing from different lake depths and for different hydrologic gradients. A novel physical property relationship connects the dynamic distribution of electrical resistivity to ice saturation and temperature outputs from the SUTRA groundwater simulator with freeze-thaw physics. The influence of lithology on electrical resistivity is controlled by a surface conduction term in the physical property relationship. Resistivity models, which reflect changes in subsurface conditions, are used as inputs to simulate AEM data in order to explore the sensitivity of geophysical observations to permafrost thaw. Simulations of sublacustrine talik formation over a 1000-year period are modeled after conditions found in the Yukon Flats, Alaska. Synthetic AEM data are analyzed with a Bayesian Markov chain Monte Carlo algorithm that quantifies geophysical parameter uncertainty and resolution. Major lithological and permafrost features are well resolved by AEM data in the examples considered. The subtle geometry of partial ice saturation beneath lakes during talik formation cannot be resolved using AEM data, but the gross characteristics of sub-lake resistivity models reflect bulk changes in ice content and can identify the presence of a talik. A final synthetic example compares AEM and ground-based electromagnetic responses for their ability to resolve shallow permafrost and thaw features in the upper 1-2 m below ground outside the lake margin.

Local Relevance: Airborne electromagnetic (AEM) surveys are a means for remotely detecting subsurface electrical resistivity associated with the co-evolution of permafrost and hydrologic systems. The authors have shown that large-scale geologic and permafrost structures can be accurately estimated with AEM methodologies. Sublacustrine thaw can also be identified, but the specific geometry of partial ice saturation beneath lakes is poorly resolved by AEM. The authors suggest AEM data may be most useful in characterizing subsurface properties as opposed to monitoring changes in permafrost.

Keywords: active layer, airborne methods, electromagnetic methods, geophysical methods, glacial geology, ground water, hydrology, periglacial features, permafrost, resistivity, taliks

Available Online: http://www.the-cryosphere.net/9/781/2015/

Citation: Minsley, B.J., Wellman, T.P., Walvoord, M.A. and Revil, A., 2015. Sensitivity of airborne geophysical data to sublacustrine and near-surface permafrost thaw. Cryosphere, vol. 9, issue 2, p. 781-794, doi:10.5191/tc-9-781-2015.

'Warm' Tundra: Atmospheric and Near-Surface Ground Temperature Inversions Across an Alpine Treeline in Continuous Permafrost, Western Arctic, Canada

Research Location: Peel Plateau, Yukon

Publication Type: Journal Article

Publication Date: 2015

Abstract: Permafrost conditions were examined between 2010 and 2014 at four sites across an alpine treeline on Peel Plateau, Northwest Territories, Canada. Ground and air temperature sensors were installed in forest and tundra between 30 and 500 m asl. Annual mean air temperatures increased and the number of freezing degree days declined with elevation, due to persistent winter air temperature inversions. The annual mean temperature at the permafrost surface (T_{ps}) in mineral soils increased with elevation from about -2.5 °C in lowland forest to about -1.5 °C in dwarf shrub tundra. The increase in T_{ps} coincided with higher air temperatures and earlier snow accumulation at tundra sites. The higher T_{ps} in alpine tundra compared to lowland forest in Peel Plain contrasts with the northward decrease in T_{ps} across latitudinal treeline elsewhere in the western Arctic. An increase in T_{ps} with elevation may be common in Arctic mountain environments due to the prevalence of atmospheric temperature inversions in winter. In such contexts, although vegetation characteristics are governed by summer climate, permafrost conditions are critically influenced by the winter regime. The tundra permafrost on Peel Plateau is considerably warmer and, hence, more sensitive to disturbance than perennially frozen ground north of treeline in other parts of the western Arctic.

Local Relevance: Permafrost temperatures on the tundra of the Peel Plateau were warm most likely due to higher air temperatures in winter due to atmospheric temperature inversions, relatively deep snow in the tundra and rapid snow accumulation in some areas due to wind redistribution. The study is important to infrastructure development as the presence of tundra in continuous permafrost zones does not necessarily imply cold (< -5.0 °C) permafrost conditions. Also, due to high permafrost temperatures on the Peel Plateau and their correlation with snow depth, an increase in snow cover with climate change could lead to permafrost degradation in the Peel Plateau tundra area. Finally, along the embankment of the Dempster Highway, increased snow depth due to increased shrub cover could lead to degradation of permafrost.

Keywords: permafrost, thermal regime, treeline, atmospheric inversions, Peel Plateau, Dempster Highway, Yukon

Available Online: http://onlinelibrary.wiley.com/doi/10.1002/ppp.1838/abstract

Citation: O'Neill, H.B., Burn, C.R., Kokelj, S.V. and Lantz, T.C., 2015. 'Warm' Tundra: Atmospheric and Near-Surface Ground Temperature Inversions Across an Alpine Treeline in Continuous Permafrost, Western Arctic, Canada. Permafrost and Periglacial Processes, vol. 26, issue 2, p. 103-118, doi: 10.1002/ppp.1838.

3.5. Permafrost and Infrastructure

Geophysical imaging of permafrost conditions along the northern Yukon Alaska Highway

Research Location: Alaska Highway km 1811-1898, Yukon

Publication Type: Conference Paper

Publication Date: 2015

Abstract: Three sections of the northern Yukon Alaska Highway have been identified for testing the usefulness of geophysical surveys for understanding permafrost degradation and assisting with highway management. Results from capacitive resistivity and ground-penetrating radar surveys are analyzed and interpreted along with surficial maps, geotechnical borehole records, and surface observations of highway roughness and distress. Observed damage appears to be associated with a variety of ground ice conditions. The geophysical results help elucidate the terrain conditions and support the conclusion that multiple subsurface processes contribute to highway degradation. Several geophysical signatures are interpreted as indicative of terrain conditions involving ice-rich ground, frozen ground, thaw-susceptible sediments and shallow groundwater.

Local Relevance: Causes of highway damage were investigated using capacitive resistivity and ground-penetrating radar surveys, surficial maps, geotechnical borehole records, and surface observations of highway roughness and distress. The observed damage appears to be associated with a variety of ground ice conditions, hydrology and surficial geology. The highway damage was associated with poor international roughness indexes, but poor international roughness indexes were not necessarily accompanied by observed damage. The geophysical signatures indicative of terrain conditions involved ice-rich ground, frozen ground, thaw-susceptible sediments and shallow groundwater. However, no unique resistivity signature is indicative of thaw susceptibility. Overall, the analysis in this study is preliminary and requires additional work such as: advanced processing of capacitive resistivity data, investigation of any statistically significant correlation between observed damage, international roughness indexes and geophysical signature, consideration of temporal context of the borehole data base records and thermal evolution of the ground, or investigation of the data in the context of climatic trends.

Keywords: capacitive resistivity, ground-penetrating radar, surficial maps, geotechnical borehole records, highway surface observation

Available Online: http://www.na.srk.com/files/file/CStevens_YukonAlaskaHighway_2015.pdf

Citation: Oldenborger, G.A., LeBlanc, A.-M., Stevens, C.W., Chartrand, J. and Loranger, B., 2015. Conference Paper, GeoQuebec 2015 – 7th Canadian Permafrost Conference and 68th Canadian Geotechnical Conference, QC, 8 p..

Monitoring permafrost conditions along the Dempster Highway

Research Location: Dempster Highway, Yukon

Publication Type: Conference Paper

Publication Date: 2015

Abstract: The Dempster Highway, which connects the western Arctic to the national highway network, is built almost entirely on permafrost. Four long-term permafrost monitoring sites were established on the highway in 2013-14 to determine baseline thermal conditions and to follow changes in ground temperatures driven by climate change. The sites are at km 124 and 421 in Yukon and km 8.5 and 51.5 in NWT. Boreholes, up to 10 m in depth, were drilled at each site in the highway centerline, at the embankment toe, and in undisturbed ground. Data have been retrieved from thermistor cables at these sites since February 2014. The embankment toe is the warmest location at each site. In undisturbed ground, annual mean temperatures range from -3.6 to -1.1 °C. The centerline is relatively cold, with annual mean temperatures ranging from -3.9 to -2.4 °C. The permafrost at km 124 is unexpectedly thin due to groundwater movement.

Local Relevance: At the centerline of the embankment of the Dempster Highway at all sites, permafrost is stable and aggrading. At the toe of the embankment of the three sites, permafrost is degraded or is degrading. At a site associated with groundwater movement, permafrost is thin and is associated with the lowest air temperature. Overall, the integrity of the embankment along the Dempster Highway appears to be related to the abundance of near-surface ground ice; yet, due to degradation of permafrost at the toe of the embankment, side slope failure is inevitable where the ground is thaw sensitive.

Keywords: permafrost monitoring, boreholes, thermistor cables, Yukon, Northwest Territories, Dempster Highway

Available Online:
https://www.researchgate.net/publication/282185963_Monitoring_permafrost_conditions_along_the_Dempster_Highway

Citation: Idrees, M., Burn, C.R., Moore, J.L. and Calmels, F., 2015. Monitoring permafrost conditions along the Dempster Highway. Conference Paper, GeoQuebec 2015 – 7th Canadian Permafrost Conference and 68th Canadian Geotechnical Conference, QC, 8 p.

Permafrost characterization of the Dempster Highway, Yukon and Northwest Territories

Research Location: Dempster Highway, Yukon and Northwest Territories

Publication Type: Conference Paper

Publication Date: 2015

Abstract: The Dempster Highway was built over permafrost to connect the western Arctic with the national highway system. Mean annual permafrost temperatures along the route are ≥ -4 °C. Most

ground ice is found in glacial deposits, and in these materials the embankment is particularly prone to thaw subsidence. Extended periods of rain have led to debris flows blocking the road and wash outs in steep terrain and near rivers. Icings may impede drainage during freshet. These hazards are of varying relative importance along the route. The principal terrain units and permafrost-related hazards are: North Klondike, icing; Blackstone Uplands, thaw subsidence; Engineer Creek/Ogilvie River, debris flows and wash outs; Eagle Plains, relatively unaffected; Richardson Mountains and Peel Plateau, thaw subsidence; Northern Plains, icing.

Local Relevance: This paper collects and summarizes ground temperature data that have been collected along the Dempster Highway from several sources. The sources of data include: the transport Canada monitoring program; Northwestel's microwave repeater stations; investigations sponsored by the NWT Cumulative Impacts Monitoring Program; and published literature. This study is a Transport Canada initiative under their Network of Expertise in Northern Transportation Infrastructure Research. The aim of this project is to assist governments to adapt roads to challenges posed by climate change. This was achieved through the establishment of baseline data collection and assessment of permafrost response to climate warming alongside transportation infrastructure in Yukon and Northwest Territories.

Keywords: infrastructure, highways, permafrost-related hazards, icing, thaw subsidence, debris flow, wash outs, Dempster Highway, Yukon, Northwest Territories

Available Online:
https://www.researchgate.net/publication/282185955_Permafrost_characterization_of_the_Dempster_Highway_Yukon_and_Northwest_Territories

Citation: Burn, C.R., Moore, J.L., O'Neill, H.B., Hayley, D.W., Trimble, J.R., Calmels, F., Orban, S.N. and Idress, M., 2015. Permafrost characterization of the Dempster Highway, Yukon and Northwest Territories. Conference Paper, GeoQuebec 2015 – 7th Canadian Permafrost Conference and 68th Canadian Geotechnical Conference, QC, 8 p.

4. Forestry

4.1. Forest Management

Adapting sustainable forest management to climate change: criteria and indicators in a changing climate

Research Location: Canada

Publication Type: Report

Publication Date: 2014

Abstract: Canada was an early adopter of the principles of sustainable forest management (SFM). One of the earliest steps was the establishment of a framework of criteria and indicators

(C&I) for defining and assessing progress toward the achievement of SFM. However, this framework was developed before the potential consequences of climate change for forests and forest management were well understood. The current C&I assume a relatively stable climate. It is now known, however, that the climate of the future will be different from past and current climate. This change poses unprecedented challenges to forest management and may reduce the effectiveness of current C&I in defining and reporting on progress toward SFM. Decisions about how the existing C&I can be updated to account for climate change seem warranted. However, incorporating climate change into the C&I framework is not straightforward. Efforts to do so will ultimately require broad discussion and consultation at multiple scales on how progress toward SFM is to be defined and measured under a changing climate. This paper considers ways in which the C&I for SFM developed by the Canadian Council of Forest Ministers might be affected by climate change and examines options for updating them to account for climate change.

Local Relevance: This report examines how the six criteria chosen for sustainable forest management within Canada will change with climate change. The six criteria examined are: biological diversity, ecosystem condition and productivity, soil and water, role in global ecological cycles, economic and social benefits, and society's responsibility. After a discussion of the effects of climate change on each criteria, options are explored for incorporating climate change considerations into the criteria and indicators given.

Keywords: climate change, sustainable forest management, criteria and indicators, climate change impacts, adaptation, adaptive capacity, prospective indicators

Available Online: http://www.ccfm.org/pdf/CriteriaIndicatorsENG_DigitalF.pdf

Citation: Williamson, T.B. and Edwards, J.E., 2014. Adapting sustainable forest management to climate change: criteria and indicators in a changing climate. Canadian Council of Forest Ministers, Ottawa, ON, 32 p.

Adapting sustainable forest management to climate change: a review of assisted tree migration and its potential role in adapting sustainable forest management to climate change

Research Location: Canada

Publication Type: Report

Publication Date: 2014

Abstract: Many options have been proposed to adapt forest management to the effects of climate change. One of these options, assisted migration of tree species, is now being explored by forest managers. Forests have historically adjusted to changes in climate on their own. Today, however, the climate is changing much more rapidly than ever before, and there is a risk that tree species may be unable to genetically adapt or migrate quickly enough. The term "assisted migration" refers to human intervention to deliberately move species to new, more favorable locations, with the goal of helping them to survive and flourish in a changing climate. Implementing assisted migration poses new and complex scientific, social, and ethical questions. This summary report provides an overview of assisted tree migration, describes many of the potential opportunities and risks associated with this strategy, and

outlines current thinking on responsible implementation of assisted migration of tree species. Informed and open discussion among all players with an interest in the future of Canada's forests will be key to exploring the assisted migration option. This report seeks to provide a balanced overview to inform the emerging dialogue on this topic.

Local Relevance: This report provides an overview of assisted migration of tree species so they may better cope with anthropogenic climate change. The topics covered in this report include but are not limited to: opportunities, risks, species vulnerability to climate change, determining risk, legislative regime, migration distance, target sites for seeds and planting, and seed sources.

Keywords: assisted migration, assisted colonization, managed relocation, range expansion, climate change, adaptation, forest.

Available Online: http://www.ccfm.org/english/coreproducts-cc.asp

Citation: Ste-Marie, C. (compiler), 2014. Adapting sustainable forest management to climate change: a review of assisted tree migration and its potential role in adapting sustainable forest management to climate change. Canadian Council of Forest Ministers, Ottawa, ON, 14 p.

Climate change and sustainable forest management in Canada: a guidebook for assessing vulnerability and mainstreaming adaptation into decision making

Research Location: Canada

Publication Type: Report

Publication Date: 2015

Excerpt: This guidebook the final report in the series provides a "how to" tool to aid forest practitioners in applying the CCFM approach to vulnerability assessment and adaptation planning for SFM. It provides step by step details about how to complete vulnerability and adaptation assessments and includes easy to follow worksheets and numerous examples from SFM adaptation assessments already underway in Canada.

Local Relevance: The following report can offer an adaptation framework for forest managers dealing with changing climates. The framework is based on six criteria which would be: biological diversity, ecosystem condition and productivity, soil and water, role in global ecological cycles, economic and social benefits, and society's responsibility. Chapters in this guide include: provide context for vulnerability assessment, current climate and forest conditions, future climate and forest impact scenarios, assess vulnerability, adaptation options, implementation and mainstreaming of adaptation, and the worksheets.

Keywords: forest management, forest change, vulnerability assessments

Available Online: https://cfs.nrcan.gc.ca/publications?id=35956

Citation: Edwards, J.E., Pearce, C., Ogden, A.E. and Williamson, T.B., 2015. Climate change and sustainable forest management in Canada: a guidebook for assessing vulnerability and mainstreaming adaptation into decision making. Canadian Council of Forest Ministers, Ottawa, ON, 160 p.

4.2. Forest Responses to Change and Effects on Climate

Comparison of eMODIS and MOD/MYD13A2 NDVI products during 2012–2014 spring green-up periods in Alaska and northwest Canada

Research Location: Yukon River Basin, Alaska and Yukon

Publication Type: Journal Article

Publication Date: 2014

Abstract: Accurate monitoring of vegetation dynamics is required to understand the inter-annual variability and long term trends in terrestrial carbon exchange in tundra and boreal ecoregions. In western North America, two Normalized Vegetation Index (NDVI) products based on spectral reflectance data from the Moderate Resolution Imaging Spectroradiometer (MODIS) are available. The MOD/MYD13A2 NDVI product is available as a 16-day composite product in a sinusoidal projection as global hdf tiles. The eMODIS Alaska NDVI product is available as a 7-day composite geotif product in a regional equal area conic projection covering Alaska and the entire Yukon River Basin. These two NDVI products were compared for the 2012–2014 late May–late June spring green-up periods in Alaska and the Yukon Territory. Relative to the MOD/MYD13A2 NDVI product, it is likely that the eMODIS NDVI product contained more cloud-contaminated NDVI values. For example, the MOD/MYD13A2 product flagged substantially fewer pixels as "good quality" in each 16-day composite period compared to the corresponding MODIS Alaska NDVI product from a 7-day composite period. During the spring green-up period, when field-based NDVI increases, the eMODIS NDVI product averaged 43 percent of pixels that declined by at least 0.05 NDVI between 2 composite periods, consistent with cloud-contamination problems, while the MOD/MYD13A2 NDVI averaged only 6 percent of pixels. Based on a cloudy Landsat-8 scene, the eMODIS compositing process selected 23 percent pixels, while the MOD/MYD13A2 compositing process selected less than 0.003 percent pixels. Based on the results, it appears that the MOD/MYD13A2 NDVI product is superior for scientific applications based on NDVI phenology in the tundra and boreal regions of northwestern North America.

Local Relevance: Two methods were compared for accuracy and applicability in scientific applications in measuring Normalized Vegetation Index (NDVI), which were eMODIS and MOD/MYD13A2. eMODIS was found to composite landscape pixels that were likely contaminated by cloud and cloud shadow as "good quality" pixels. eMODIS cloud contamination is highlighted by 43% of pixels declined by at least 0.05 NDVI over 2 periods of spring-green up, when field-based NDVI is increasing. In contrast only 6% of pixels declined in NDVI during spring-green up for MOD/MYD13A2 measurements. Due to the high rate of cloud contamination of eMODIS NDVI measurements, MOD/MYD13A2 was found to be the best for scientific applications in boreal and tundra regions of northwestern North America.

Keywords: Alaska, boreal, NDVI, MODIs, tundra NDVI, vegetation phenology, Yukon River Basin

Available Online:
https://www.researchgate.net/publication/278661112_Comparison_of_eMODIS_and_MODMYD13A2_NDVI_products_during_2012-2014_spring_green-up_periods_in_Alaska_and_northwest_Canada

Citation: Verbyla, D., 2015. Comparison of eMODIS and MOD/MYD13A2 NDVI products during 2012–2014 spring green-up periods in Alaska and northwest Canada. International Journal of Applied Earth Observation & Geoinformation, vol. 36, p. 83-86, doi:10.1016/j.jag.2014.11.009.

Sap flow responses to seasonal thaw and permafrost degradation in a subarctic boreal peatland

Research Location: Fort Simpson, NWT

Publication Type: Journal Article

Publication Date: 2015

Abstract: Many of Canada's northern boreal peatlands are situated on discontinuous permafrost. Here, permafrost provides the physical foundation on which forests persist. However, climate warming is leading to increased rates of permafrost thaw resulting in both increased active layer thickness (ALT) as well as shrinkage of the area underlain by permafrost due to lateral thaw at plateau margins. Such changes to the substrate likely impact growth and physiological processes of the trees. Despite this, little is known about the role of active layer development, and changes to it, including thaw of the underlying permafrost on tree water relations. Here, we measured sap flow in black spruce from a peatland experiencing rapid permafrost thaw and quantified drivers of changes in sap flow. Time series analyses revealed that of the environmental drivers examined, vapour pressure deficit was the strongest predictor of diurnal sap flow, while seasonal patterns were driven largely by energy inputs; however, the environmental drivers of importance did not change as a function of ground thaw conditions. To understand the implications of changing permafrost and active layer conditions, we quantified differences in sap flow between trees in interior positions of permafrost plateaus and trees on degrading plateau edges. We found >65 % reductions in sap flow in edge trees, attributable to reduced root function at waterlogged edges. Seasonal thaw processes also influenced sap flow. Paired measures of ALT indicated a negative linear relationship with sap flow that was stronger for interior trees. Greater ALT, which corresponds with deeper frost and water tables reduced sap flow by up to 60 % and is likely attributable to drying in surface soil layers where rooting occurs. Climate warming will accelerate permafrost thaw, which our data suggests will drive decreases in the productivity of black spruce-dominated subarctic forests. These findings may thus enhance our understanding of widespread reductions in productivity in boreal forests in northwestern North America.

Local Relevance: Ground thaw was shown to decrease sap flow in black spruce. The three key drivers of changes in sap flow rates were: micro-environment conditions particularly vapour pressure deficit and shortwave radiation, lateral permafrost thaw, and seasonal thaw and active layer development. As the climate warms decreases in tree productivity may be attributed to these effects.

Keywords: black spruce, permafrost degradation, active layer thickness, sap flow, Fort Simpson, evapotranspiration, ecohydrology, discontinuous permafrost, Mackenzie River Basin, Northwest Territories, tree growth and productivity, plant-soil feedbacks

Available Online:
https://www.researchgate.net/publication/273278912_Sap_flow_responses_to_seasonal_thaw_and_permafrost_degradation_in_a_subarctic_boreal_peatland

Citation: Patankar, R., Quinton, W.L., Hayashi, M. and Baltzer, J.L., 2015. Sap flow responses to seasonal thaw and permafrost degradation in a subarctic boreal peatland. Trees, vol. 29, issue 1, p. 129-142.

Spatial variations in immediate greenhouse gases and aerosol emissions and resulting radiative forcing from wildfires in interior Alaska

Research Location: Yukon River Basin, Alaska

Publication Type: Journal Article

Publication Date: 2016

Abstract: Boreal fires can cool the climate; however, this conclusion came from individual fires and may not represent the whole story. We hypothesize that the climatic impact of boreal fires depends on local landscape heterogeneity such as burn severity, prefire vegetation type, and soil properties. To test this hypothesis, spatially explicit emission of greenhouse gases (GHGs) and aerosols and their resulting radiative forcing are required as an important and necessary component towards a full assessment. In this study, we integrated remote sensing (Landsat and MODIS) and models (carbon consumption model, emission factors model, and radiative forcing model) to calculate the carbon consumption, GHGs and aerosol emissions, and their radiative forcing of 2001-2010 fires at 30 m resolution in the Yukon River Basin of Alaska. Total carbon consumption showed significant spatial variation, with a mean of 2,615 g C m^{-2} and a standard deviation of 2,589 g C m^{-2}. The carbon consumption led to different amounts of GHGs and aerosol emissions, ranging from 593.26 Tg (CO_2) to 0.16 Tg (N_2O). When converted to equivalent CO_2 based on global warming potential metric, the maximum 20 years equivalent CO_2 was black carbon (713.77 Tg), and the lowest 20 years equivalent CO_2 was organic carbon (−583.13 Tg). The resulting radiative forcing also showed significant spatial variation: CO_2, CH_4, and N_2O can cause a 20-year mean radiative forcing of 7.41 W m^{-2} with a standard deviation of 2.87 W m^{-2}. This emission forcing heterogeneity indicates that different boreal fires have different climatic impacts. When considering the spatial variation of other forcings, such as surface shortwave forcing, we may conclude that some boreal fires, especially boreal deciduous fires, can warm the climate.

Local Relevance: From analysis of Alaskan boreal fires, the radiative forces found which were: the 20- and 100-year radiative forcing of CO_2, CH_4, and N_2O could be 7.41W m^{-2} ± 2.87 W m^{-2} and 4.97 W m^{-2} ± 2.13 W m^{-2}; and the 20- and 100-year radiative forcing of CO_2, CH_4, N_2O, BC, OC, CO, NO, NO_2, NOx, and NMOC could be 9.71 W m^{-2} ± 3.40 W m^{-2} and 5.89 W m^{-2} ± 2.41 W m^{-2}. The authors also believe that high-latitude deciduous fires could potentially cause a positive fire-albedo feedback that contributes to climate warming. A conclusion which may be especially important as deciduous vegetation may increase

with climate warming. The carbon consumption of boreal forests was found to vary significantly as well, with a mean of 2,615 g C m^{-2} ± 2,589 g C m^{-2}.

Keywords: carbon sequestration, forest fire ecology, global warming, greenhouse gases, Yukon River Basin

Available Online:
https://www.researchgate.net/publication/273298347_Spatial_variations_in_immediate_greenhouse_gases_and_aerosol_emissions_and_resulting_radiative_forcing_from_wildfires_in_interior_Alaska

Citation: Huang, S., Liu, H., Dahal, D., Jin, S., Li, S. and Liu, S.-G., 2016. Spatial variations in immediate greenhouse gases and aerosol emissions and resulting radiative forcing from wildfires in interior Alaska. Theoretical and Applied Climatology, vol. 123, issue 3, p. 581-592, doi:10.1007/s00704-015-1379-0.

4.3. Forest Growth

Regeneration Dynamics of White Spruce, Trembling Aspen, and Balsam Poplar in Response to Disturbance, Climatic, and Edaphic Factors in the Cold, Dry Boreal Forests of the Southwest Yukon, Canada

Research Location: Southwest Yukon

Publication Type: Journal Article

Publication Date: 2015

Abstract: The southwestern region of the Yukon Territory of Canada has experienced an unprecedented spruce bark beetle outbreak (*Dendroctonus rufipennis*) and an increase in the frequency of forest fires that extend beyond historical trends and that have caused significant impacts on forest structure and composition. A Strategic Forest Management Plan (SFMP) for the Champagne and Aishihik Traditional Territory located in the southwest Yukon was implemented in 2004 in response to the spruce bark beetle (*D. rufipennis*) infestation and increased fire risk. The plan has recommended salvage harvesting of beetle-killed stands as a strategy to facilitate the development of a timber industry in the region and reduce the fire risk around communities. One of the objectives of the SFMP is to maintain, restore, or enhance forest regeneration, which requires an understanding of regeneration dynamics in the region. In this study, we investigated the regeneration of white spruce (*Picea glauca*), trembling aspen (*Populus tremuloides*), and balsam poplar (*Populus balsamifera*) and the relationship with climatic, disturbance, and edaphic factors within the region. Multivariate canonical correlation analysis was used to assess the weighted relationship between regeneration presence/absence and environmental factors, and negative binomial regression analysis was used to model regeneration abundance of white spruce, trembling aspen, and balsam poplar. We found that although regeneration of all three species responded positively to disturbance, the broadleaved species occupied disturbed plots at higher ratios than white spruce. Regeneration of broadleaved species was higher in open sites with exposed aspects, indicating a preference for warmer sites with higher solar radiation inputs. These findings support the hypothesis that if fire increased in the region with the warmer climate predicted by the

Intergovernmental Panel on Climate Change, then the region will probably experience an increase in broadleaved species, leading to a more heterogeneous landscape.

Local Relevance: In the southwest Yukon, historical-high spruce bark beetle outbreaks and increasing fire activity is taking place. It was found that regeneration of broadleaf species was proportionately higher in disturbed sites. It follows that if disturbances are to continue, broadleaf species may increase in abundance. In a warmer and wetter future predicted by climate warming scenarios, it may be mixed wood stands could increase, which may benefit future fire risk. A series of recommendations are offered to enhance natural regeneration which are: "apply a variable retention strategy in areas affected by spruce bark beetle to provide sheltered conditions that will promote white spruce regeneration (Goodman and Hungate, 2006) and also increase the number of mature trees to increase seedling densities; apply prescribed burning after harvesting to promote natural regeneration of both white spruce and broadleaved species through the reduction of shrub cover and exposure of mineral substrates; and apply seed tree systems along with prescribed burning to promote recruitment of balsam poplar and trembling aspen."

Keywords: forest regeneration, boreal forest, disturbances, climate variability, white spruce, trembling aspen, balsam poplar, southwest Yukon

Available Online:
http://www.ingentaconnect.com/content/saf/jof/2015/00000113/00000005/art00005

Citation: Paudel, S.K., Nitschke, C.R., Simard, S.W. and Innes, J.L., 2015. Regeneration Dynamics of White Spruce, Trembling Aspen, and Balsam Poplar in Response to Disturbance, Climatic, and Edaphic Factors in the Cold, Dry Boreal Forests of the Southwest Yukon, Canada. Journal of Forestry, vol. 113, issue 5, p. 463-474.

The role of fire in the mid-Holocene arrival and expansion of lodgepole pine (Pinus contorta var. latifolia Engelm. Ex S. Watson) in Yukon, Canada

Research Location: Southern Yukon

Publication Type: Journal Article

Publication Date: 2015

Abstract: In north-west Canada, *Pinus contorta* (lodgepole pine) has been migrating northwards and westwards for millennia. Its regeneration is currently enhanced by fire, which may act as a trigger for local population expansion. Using Holocene charcoal records from four small (<10 ha) lakes in southern Yukon, we investigated the relationship between long-term *Pinus* population dynamics and fire. Fossil stomata extracted from dated lake sediments indicate pine was present at low densities in southern Yukon forests by ~6000 cal. yr BP. At each site, the main population expansion (indicated by an increase in *Pinus* pollen from <5% to values as high as 60%) occurred 2000->4000 years after the first local appearance of *Pinus*, suggesting a long period of stasis at low densities. Population increases - based on pollen accumulation rates (PARs) - occurred at different times at the four sites. Estimated expansion periods were ~2500-800 years, and population doubling times were ~150-600 years, similar to previous estimates. Estimated fire return intervals (FRIs) fluctuated over time. At all sites, the *Pinus* expansion

began during a phase with a relatively short FRI, but only one difference between the mean FRIs before and during the *Pinus* rise was statistically distinguishable. Nor was the subsequent higher abundance of pine associated with shorter FRIs. It is unlikely that regional pine expansion is primarily linked to changes in climate or a climate-mediated fire regime, although expansion may have been triggered at individual sites during a period of high fire frequency. The long period of stasis at low population densities suggests intrinsic control of population growth; possibly *Pinus* expansion was initially constrained by lowered reproductive fitness (Allee effect) and/or interaction with local site-based factors.

Local Relevance: The study found support for a fire-assisted expansion of pine (*Pinus contorta*), yet no evidence that subsequent local pine dominance or co-dominance altered fire regimes. Support was also found that *Pinus* was most likely assisted in range expansion by a regime of frequent fires. During *Pinus contorta*'s first few millennia of expansion into the Yukon, it was most likely limited by biological constraints on reproductive success. Overall, future population growth rates of *Pinus contorta* will most likely be affected by large increases in fire frequency or by anthropogenic landscape change.

Keywords: Allee effect, fire and climate change, Holocene, forest migration, *Pinus contorta* ssp. *latifolia*, southern Yukon

Available Online: http://hol.sagepub.com/content/25/1/64.full.pdf+html

Citation: Edwards, M., Franklin-Smith, L., Clarke, C., Baker, J., Hill, S. and Gallagher, K., 2015. The role of fire in the mid-Holocene arrival and expansion of lodgepole pine (*Pinus contorta* var. *latifolia* Engelm. ex S. Watson) in Yukon, Canada. The Holocene, vol. 25, issue 1, p, 64-78.

4.4. Shrubs

Environmental Limits of Tall Shrubs in Alaska's Arctic National Parks

Research Location: Northern Alaska

Publication Type: Journal Article

Publication Date: 2015

Abstract: We sampled shrub canopy volume (height times area) and environmental factors (soil wetness, soil depth of thaw, soil pH, mean July air temperature, and typical date of spring snow loss) on 471 plots across five National Park Service units in northern Alaska. Our goal was to determine the environments where tall shrubs thrive and use this information to predict the location of future shrub expansion. The study area covers over 80,000 km^2 and has mostly tundra vegetation. Large canopy volumes were uncommon, with volumes over 0.5 m^3/m^2 present on just 8% of plots. Shrub canopy volumes were highest where mean July temperatures were above 10.5°C and on weakly acid to neutral soils (pH of 6 to 7) with deep summer thaw (>80 cm) and good drainage. On many sites, flooding helped maintain favorable soil conditions for shrub growth. Canopy volumes were highest where the typical snow loss date was near 20 May; these represent sites that are neither strongly wind-scoured in the winter nor late to melt from deep snowdrifts. Individual species varied widely in the canopy volumes they attained and their response to the environmental factors. *Betula* sp. shrubs were the most

common and quite tolerant of soil acidity, cold July temperatures, and shallow thaw depths, but they did not form high-volume canopies under these conditions. *Alnus viridis* formed the largest canopies and was tolerant of soil acidity down to about pH 5, but required more summer warmth (over 12°C) than the other species. The *Salix* species varied widely from *S. pulchra*, tolerant of wet and moderately acid soils, to *S. alaxensis*, requiring well-drained soils with near neutral pH. Nearly half of the land area in ARCN has mean July temperatures of 10.5 to 12.5°C, where 2°C of warming would bring temperatures into the range needed for all of the potential tall shrub species to form large canopies. However, limitations in the other environmental factors would probably prevent the formation of large shrub canopies on at least half of the land area with newly favorable temperatures after 2°C of warming.

Local Relevance: If summer temperatures were to raise by 2°C in the study area of the northern National Park Service units in Alaska, the area with optimal temperature range for shrubs would increase from 23% to 70%. The authors note that half the available new area will limit tall shrub growth due to soil conditions that are too wet and acidic. Alder is the most likely candidate for shrub expansion due to its tolerance to a wide range of soil conditions. Overall, the study supports an expansion of tall shrub thickets on suitable sites where soils are suitable, and persistence of current vegetation where soils are unsuitable, summer temperatures too cold or winters too windy.

Keywords: vegetation change, tundra, shrubification, *Salix* spp., *Betula* spp., *Alnus* spp., Alaska

Available Online: http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0138387

Citation: Swanson, D.K., 2015. Environmental Limits of Tall Shrubs in Alaska's Arctic National Parks. PLoS ONE, vol. 10, issue 9, doi: 10.1371/journal.pone.0138387

5. Glaciology

Surface melt dominates Alaska glacier mass balance

Research Location: Alaska

Publication Type: Journal Article

Publication Date: 2015

Abstract: Mountain glaciers comprise a small and widely distributed fraction of the world's terrestrial ice, yet their rapid losses presently drive a large percentage of the cryosphere's contribution to sea level rise. Regional mass balance assessments are challenging over large glacier populations due to remote and rugged geography, variable response of individual glaciers to climate change, and episodic calving losses from tidewater glaciers. In Alaska, we use airborne altimetry from 116 glaciers to estimate a regional mass balance of -75 ± 11 Gt yr^{-1} (1994-2013). Our glacier sample is spatially well distributed, yet pervasive variability in mass balances obscures geospatial and climatic relationships. However, for the first time, these data allow the partitioning of regional mass balance by glacier type. We find that tidewater glaciers are losing mass at substantially slower rates than other glaciers in Alaska and collectively contribute to only 6% of the regional mass loss.

Local Relevance: Interior glaciers had faster rates of land-terminating mass loss than those in coastal sub-regions. Smaller glaciers had a more negative value for land-terminating glacier mass balance as well. Many lake-terminating glaciers showed more rapid thinning near their termini in comparison to land-terminating glaciers. For interior glaciers the regional loss is nearly double the rate found from 1962-2010.

Keywords: glacier, surface melt, airborne altimetry, Alaska

Available Online:
https://www.researchgate.net/publication/279158524_Surface_melt_dominates_Alaska_glacier_mass_balance

Citation: Larsen, C.F., Burgess, E., Arendt, A.A., O'Neel, S., Johnson, A.J. and Kienholz, C., 2015. Surface melt dominates Alaska glacier mass balance. Geophysical Research Letters, vol. 42, issue 14, p. 5902-5908.

6. Fish and Wildlife

6.1. Fish

Observed trends and climate projections affecting marine ecosystems in the Canadian Arctic

Research Location: Canadian Marine Artic

Publication Type: Journal Article

Publication Date: 2015

Abstract: Past trends and future projections of key atmospheric, oceanic, sea ice, and biogeochemical variables were assessed to increase our understanding of climate change impacts on Canadian Arctic marine ecosystems. Four subbasins are evaluated: Beaufort Sea, Canadian Arctic Archipelago, Baffin Bay/Davis Strait, and Hudson Bay Complex. Limited observations, especially for ecosystem variables, compromise the trend analyses. Future projections are predominately from global models with few contributions from available marine basin scale models. The assessment indicates a significant increase in air temperature, slight increases in precipitation and snow depth, and appreciable changes in atmospheric circulation patterns. Projections suggest an increase in storm strength and size, leading to enhanced storm surges and coastal erosion, a slight increase in wave heights, increases in gustiness, and small changes in mean wind speed. An Arctic-wide decrease in the extent of multiyear ice and a spatial and temporal increase in ice-free waters in summer have been observed and are projected to continue into the future. Limited observations of ocean properties show local freshening (Beaufort Sea) and summer warming (Baffin Bay). These trends are projected to continue along with localized strengthening in stratification. Increased ocean acidification has been observed and is projected to continue throughout the Canadian Arctic, leading to severely decreased saturation states of calcium carbonate (aragonite and calcite). Qualitative analysis of biological observations indicate large regional

differences. Increased primary production and double bloom development is seen in areas of sea ice retreat where nutrient supply is sufficient, and unchanged or reduced production is seen where nutrients are low or suppressed in response to enhanced stratification. Future primary production projections show inconsistent results, with light-dependent increase or nutrient-limited decrease dominating, dependent on the model. For the next decade, natural intradecadal variability is expected to be of similar importance as longer-term trends. To improve our capacity to assess and project climate change adaptation in marine ecosystems, more consistent observations are needed, especially over marine areas and for biogeochemical variables. Higher resolution basin-scale models are also required to provide locally applicable projections relevant for Arctic communities and management units.

Local Relevance: This study reviews available data and literature in order to provide the most recent picture of how the Canadian Arctic and associated marine systems will change in the coming century. The risk factors analyzed with current evidence include: surface air temperature, precipitation, atmospheric circulation, waves, storm surge, sea ice, ocean surface temperatures and salinity, stratification (mixed layer depth), sea level, acidity, and nutrients and primary productivity. Each risk factor has a past trend listed and a future projection of how it may change over the next 50 years.

Keywords: Arctic climate change, arctic marine ecosystems, Arctic biogeochemistry, Arctic Ocean, trends and projections, literature review

Available Online:
https://www.researchgate.net/publication/273684664_Observed_Trends_and_Climate_Projections_Affecting_Marine_Ecosystems_in_the_Canadian_Arctic

Citation: Steiner, N., Azetsu-Scott, K., Hamilton, J., Hedges, K., Hu, X., Janjua, M.Y., Lavoie, D., Loder, J., Melling, H., Merzouk, A., Perrie, W., Peterson, I., Scarratt, M., Sou, T. and Tallmann, R., 2015. Observed trends and climate projections affecting marine ecosystems in the Canadian Arctic. Environmental Reviews, vol. 23, no. 2, p. 191-239, doi:10.1139/er-2014-0066.

Vertical segregation of age-0 and age-1+ polar cod (Boreogadus saida) over the annual cycle in the Canadian Beaufort Sea

Research Location: Beautfort Sea, Canada

Publication Type: Journal Article

Publication Date: 2016

Abstract: The offshore marine ecosystem of the Canadian Beaufort Sea faces the double pressure of climate change and industrialization. Polar cod (*Boreogadus saida*) is a pivotal forage species in this ecosystem, accounting for 95 % of the pelagic fish assemblage. Its vertical distribution over the annual cycle remains poorly documented. Hydroacoustic records from 2006 to 2012 were analysed to test the hypothesis that age-0 polar cod segregate vertically from larger congeners. Trawls and ichthyoplankton nets validated the acoustic signal. Fish length, weight, and biomass were estimated from new regressions of target strength and weight on standard length. Polar cod were vertically segregated by size in all months, with small age-0 juveniles in the epipelagic (<100 m) layer and larger age-1+ deeper in the water column. From December to March, the biomass of age-1+ peaked in a mesopelagic layer

between 200 and 400 m. With increasing irradiance from April to July, the mesopelagic layer deepened and extended to 600 m. Starting in July, age-0 polar cod formed an epipelagic scattering layer that persisted until November. From September onward, age-0 left the epipelagic layer to join small age-1+ in the upper mesopelagic layer. Low biomass in the mesopelagic layer from February to September likely resulted from large polar cod settling on the seafloor to avoid diving marine mammals. Longer ice-free seasons, warmer sea-surface temperatures, or an oil spill at the surface would likely impact epipelagic age-0, while mesopelagic age-1+ would be vulnerable to an eventual oil plume spreading over and above the seafloor.

Local Relevance: Extensions of the ice-free season can lead to higher sea-surface temperatures in the spring and summer, which is the growth season of age-0 epipelagic polar cod. Higher temperatures of water proven to increase growth of polar cod larvae and juveniles which can improve recruitment. Yet, longer ice-free seasons may also increase predation of epipelagic larvae and juveniles by sea birds. The results of this study support a prediction that climate-induced modification of ice and temperature regimes will impact epipelagic larval and juvenile stages of polar cod, their planktonic food, and their predators. Age-0 and age-1+ inhabiting ice cover and inner shelf Archipelago will also be impacted, the polar cod occupying mesopelagic layer offshore will be less affected. In relation to offshore exploration for oil in the Canadian Arctic, any oil spill in the summer in the Amundsen Gulf would propagate eastward over much of the Canadian and US Beaufort Sea to the west, potentially impacting age-0 polar cod over much of its distribution. The use of dispersants on oil spills would further affect age-1+ polar cod if it propogated in the 200 to 400 m interval from December to June. Dispersant affected oil would also affect mesopelagic polar cod if it propagated in the 200 to 800 m interval from August to November.

Keywords: vertical distribution**,** ontogenic migrations, acoustics, target strength, diel vertical migrations

Available Online: https://www.researchgate.net/publication/283280712_Vertical_segregation_of_age-0_and_age-1_polar_cod_Boreogadus_saida_over_the_annual_cycle_in_the_Canadian_Beaufort_Sea

Citation: Geoffroy, M., Majewski, A., LeBlanc, M., Gauthier, S., Walkusz, W., Reist, J.D. and Fortier, L., 2015. Vertical segregation of age-0 and age-1+ polar cod (*Boreogadus saida*) over the annual cycle in the Canadian Beaufort Sea. Polar Biology, vol. 39, 15 p. doi:10.1001/s00300-015-1811-z.

6.2. Mammals

Arctic ground squirrel population collapse in the boreal forests of the Southern Yukon

Research Location: Kluane Region, Yukon

Publication Type: Journal Article

Publication Date: 2015

Abstract:

Context. The arctic ground squirrel (*Urocitellus parryii*) comprised 17% of the biomass of herbivores in the Yukon boreal forest during the summer months from 1987 to 1996 and was responsible for 23% of the energy flow at the herbivore level. By 2000, ground squirrel populations in this region collapsed to nearly zero and have remained there.
Aims. We summarise the population monitoring (since 1975) and recent experimental work that has been done on this key herbivore in the Kluane area of the southern Yukon to test one mechanistic hypothesis as the possible explanation for this population collapse and subsequent lack of recovery: predation.
Methods. Ground squirrels are the preferred summer prey of bird and mammal predators when snowshoe hare (*Lepus americanus*) populations are declining. We used translocations into formerly occupied habitat and radiotelemetry to determine movements and causes of death from 2009 to 2014. We surveyed 158 sites between 2008 and 2013 to measure the disappearance of colonies in alpine and forest habitats over 25 000 km^2.
Key results. Ground squirrels from 2000 to 2013 comprised a small fraction of the herbivore biomass in the boreal forest zone, down from 17% earlier. Most forest populations (similar to 95%) are currently extinct, whereas just over half (65%) of low-elevation meadow populations are locally extinct. One hypothesis is that ground squirrels in the forest have been driven into a predator pit from which they cannot recover. They remain abundant in alpine tundra (93% occupancy rate) and around airport runways and human habitations (97% occupancy), but there is no apparent dispersal from alpine areas down into the boreal forest.
Conclusion. The predator pit hypothesis is a likely explanation for the initial collapse and sustained decline in population size from 2000 to 2013. Recent attenuation of the hare cycle and milder winter climate have allowed shrubs to expand throughout the forest, thereby reducing visibility and increasing predation risk. This conclusion will be tested in further research using reintroductions to formerly occupied sites.
Implication. If the loss of this herbivore from the boreal forest is not reversed, predator pressure on the other major herbivores of the montane forest zone is likely to change significantly.

Local Relevance: By 2000, the Arctic Ground Squirrel (AGS) populations had collapsed in southern Yukon forests. Within this study, boreal forest was found to have the lowest density of AGS with alpine environments having the highest density (2.91 *versus* 207 burrows per hectare respectively). Attempts to translocate AGSs to previously high quality habitat were unsuccessful. The hypothesized reasons for AGS collapse were increased predation which pushed the AGS populations into a predator pit. The authors hypothesize that AGS show an Allee effect where densities below ~0.5 ha^{-1} cannot be sustained

due to a lack of sufficient alarm calls to reduce predation mortality. Shrub density has also increased due to reduced browsing by snowshoe hares and milder winters, with shrub density preventing ground squirrels from seeing approaching predators.

Keywords: Allee effect, apparent competition, burrow flooding, conspecific attraction, hibernacula, dispersal, predation, predator pit, *Urovitellus parryii*

Available Online:
https://www.researchgate.net/publication/278391147_Arctic_ground_squirrel_population_collapse_in_the_boreal_forests_of_the_Southern_Yukon

Citation: Werner, J.R., Krebs, C.J., Donker, S.A., Boonstra, R. and Sheriff, M.J., 2015. Arctic ground squirrel population collapse in the boreal forests of the Southern Yukon. Wildlife Research, vol. 42, p. 176-184.

Predicted Shifts in Small Mammal Distributions and Biodiversity in the Altered Future Environment of Alaska: An Open Access Data and Machine Learning Perspective

Research Location: Alaska

Publication Type: Journal Article

Publication Date: 2015

Abstract: Climate change is acting to reallocate biomes, shift the distribution of species, and alter community assemblages in Alaska. Predictions regarding how these changes will affect the biodiversity and interspecific relationships of small mammals are necessary to pro-actively inform conservation planning. We used a set of online occurrence records and machine learning methods to create bioclimatic envelope models for 17 species of small mammals (rodents and shrews) across Alaska. Models formed the basis for sets of species-specific distribution maps for 2010 and were projected forward using the IPCC (Intergovernmental Panel on Climate Change) A2 scenario to predict distributions of the same species for 2100. We found that distributions of cold-climate, northern, and interior small mammal species experienced large decreases in area while shifting northward, upward in elevation, and inland across the state. In contrast, many southern and continental species expanded throughout Alaska, and also moved down-slope and toward the coast. Statewide community assemblages remained constant for 15 of the 17 species, but distributional shifts resulted in novel species assemblages in several regions. Overall biodiversity patterns were similar for both time frames, but followed general species distribution movement trends. Biodiversity losses occurred in the Yukon-Kuskokwim Delta and Seward Peninsula while the Beaufort Coastal Plain and western Brooks Range experienced modest gains in species richness as distributions shifted to form novel assemblages. Quantitative species distribution and biodiversity change projections should help land managers to develop adaptive strategies for conserving dispersal corridors, small mammal biodiversity, and ecosystem functionality into the future.

Local Relevance: It was found that many northern, cold-climate, and interior small mammal communities were predicted to decrease in area, shift northward, as well as shift upward in elevation. Opposite effects for northern small mammals were predicted when compared with southern and

continental species of small mammals. Biodiversity loss was predicted for southwestern Alaska, the central interior, and the eastern Brooks Range. The potential largest species gains and highest potential for novel species interactions occured in the mountain ranges of south-central Alaska, and in the western Brooks Range.

Keywords: geographical distribution of mammals, machine learning, small mammal biodiversity, small mammal distribution change, species distribution

Available Online: http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0132054

Citation: Baltensperger, A.P. and Huettmann, F., 2015. Predicted Shifts in Small Mammal Distributions and Biodiversity in the Altered Future Environment of Alaska: An Open Access Data and Machine Learning Perspective. PLoS ONE, vol. 10*,* issue 7, 21 p. doi:10.1371/journal.pone.0132054.

Migratory response of polar bears to sea ice loss: to swim or not to swim

Research Location: Beaufort Sea and Hudson Bay, Canada

Publication Type: Journal Article

Publication Date: 2016

Abstract: Migratory responses to climate change may vary across and within populations, particularly for species with large geographic ranges. An increase in the frequency of long-distance swims (>50 km) is one predicted consequence of climate change for polar bears *Ursus maritimus*. We examined GPS satellite-linked telemetry records of 58 adult females and 18 subadults from the Beaufort Sea (BS), and 59 adult females from Hudson Bay (HB), for evidence of long-distance swimming during seasonal migrations in 2007 – 2012. We identified 115 swims across both populations. Median swim duration was 3.4 d (range 1.3 – 9.3 d) and median swim distance was 92 km (range 51 – 404 km). Swims were significantly more frequent in the BS (n = 100) than HB (n = 15). In the BS, subadults swam as frequently as lone adult females, but more frequently than adult females with offspring. We modelled the likelihood of a polar bear engaging in swims using collar data from the BS. Swims were more likely for polar bears without offspring, with the distance of the pack ice edge from land, the rate at which the pack ice edge retreated, and the mean daily rate of open water gain between June – August. Coupled with an earlier study, the yearly proportions of BS adult females swimming in 2004 – 2012 were positively associated with the rate of open water gain. Results corroborate the hypothesis that long-distance swimming by polar bears is likely to occur more frequently as sea ice conditions change due to climate warming. However, results also suggest that the magnitude of the effect likely varies within and between populations

Local Relevance: How migratory animals respond to climate change may become an early warning sign of the biotic effects that may occur. Since polar bears are a solitary species, migratory behaviour is more likely to exhibit strong individual variation to changing conditions. Evidence was found that as expanses of open water increase, so do the frequency of swims for Beaufort Sea polar bears, and that swim frequency is increasing temporally in association with sea ice change. The results here show how spatial habitat heterogeneity can vary the impact of climate change on species response. The Hudson Bay

population of polar bears were found to swim less frequently than Beaufort Sea polar bears due to different sea ice dynamics.

Keywords: polar bears, migratory response, GPS collaring

Available Online: http://onlinelibrary.wiley.com/doi/10.1111/ecog.02109/abstract

Citation: Pilfold, N.W., McCall, A., Derocher, A.E., Lunn, N.J. and Richardson, E., 2016. Migratory response of polar bears to sea ice loss: to swim or not to swim. Ecography, vol. 39, p. 001-011, Doi:10.1111/ecog.02109

Multi-temporal factors influence predation for polar bears in a changing climate

Research Location: Beaufort Sea, Canada

Publication Type: Journal Article

Publication Date: 2015

Abstract: Predation is an ecological interaction influenced by abiotic and biotic factors acting on multiple temporal scales, yet multi-temporal comparisons are rare in empirical studies. For polar bears *Ursus maritimus*, the physical configuration of the habitat and conditions in which seals are hunted may change on intra- and inter-seasonal scales. Additionally, while the effects of climate change on polar bears have focused on linking reductions in sea ice to body condition and survival, the potential changes to on-ice hunting conditions have not been examined. Employing observational counts of seals killed by polar bears between early-April and late-May 1985–2011 (n = 650), we modelled the likelihood of predation events in the Beaufort Sea, Canada at multi-temporal scales. We used the top model to estimate the expected kill rate of seals in the springs of 1985–1986 and 2005–2006 and integrated the result with fasting rates derived from physiological markers in blood samples. A log-likelihood ratio test suggested a multi-temporal approach fit the seal kill data better than any single scale alone. Predation events were influenced by ringed seal *Pusa hispida* reproduction and haul-out behaviour, regional sea ice concentration and the phase of climatic indices. The expected kill rate from the top predation model and the estimated mean biomass of seal kills were significant predictors of polar bear fasting rates. Results suggest that 50% less seal biomass was killed in 2005–2006 than in 1985–1986, which correlates with a significant increase in the frequency of polar bears in a fasting state. We propose that the documented changes in polar bear fasting rates between 1985–1986 and 2005–2006 are due to a complex set of abiotic and biotic factors including underlying prey dynamics, rather than a single-scale environmental correlation.

Local Relevance: The authors believe that climate change may also be affecting the on-ice hunting conditions for polar bears. It has been found that the probability of a predation event was influenced by abiotic and biotic factors on multi-temporal scales. Results also indicated polar bear fasting rate changes were likely due to a complex set of abiotic and biotic factors including underlying prey population dynamics. The authors suggest future studies integration the population ecology of ringed seals in relation to patterns of success of polar bear predation rates in order to provide further insight into how climate change is affecting polar bears beyond basic environmental correlations.

Keywords: predation, polar bears, multi-temporal, ringed seal

Available Online: https://www.researchgate.net/publication/272377688_Multi-temporal_factors_influence_predation_for_polar_bears_in_a_changing_climate

Citation: Pilfold, N.W., Derocher, A.E., Stirling, I. and Richardson, E., 2015. Multi-temporal factors influence predation for polar bears in a changing climate. Oikos, vol. 124, issue 8, p. 1098-1107, doi:10.1111/oik.02000.

7. Hazards

7.1. Infrastructure and Development

Dawson City Landscape Hazards: Geoscience Mapping for Climate Change Adaptation Planning

Research Location: Dawson City, Yukon

Publication Type: Report

Publication Date: 2015

Introduction: A hazards map is a map that delineates or highlights areas on the land that are affected by, or are vulnerable to, a particular hazard. For example, in northern latitudes such as Yukon, thawing permafrost can be a significant climate change-related hazard. Flooding is another common hazard faced by Yukon communities, which may or may not be directly related to thawing permafrost. Hazards maps illustrate the risk associated with these and other hazards (ranked by risk severity), and are represented graphically in stoplight colours.

Hazards maps integrate complex environmental data into an easy-to-interpret, user-friendly tool for decision-making. The maps are created on a community-by-community basis and combine information about current and future landscape and climate conditions in order to rank the risk related to environmental change. As a result, they are tailored to each community's unique environment.

Local Relevance: The physiography, vegetation, contemporary climate, past climate trends, hydrology, landscape evolution, surficial materials, stratigraphy, and permafrost areas of Dawson City are explored. Potential hazards such as seismicity, mass wasting and permafrost processes are also explored. A hazard map of the Dawson City area is created based on slope angle, slope aspect, surface materials and permafrost probability; it quantifies how these factors will change as the climate warms and ranks the Dawson landscape on a hazard ranking from low to high. In the Dawson City area, 27% (211 km^2) is classified as low-risk terrain, 29% (221 km^2) is classified as moderate-risk terrain, 22% (172 km^2) is classified as moderately high-risk terrain, and 22% (172 km^2) is classified as high-risk terrain.

Keywords: hazards mapping, permafrost, surficial mapping, seismicity, climate trends, Dawson City

Available Online:
https://www.yukoncollege.yk.ca/research/project/hazard_mapping_in_yukon_communities

Citation: Benkert, B.E., Kennedy, K., Fortier, D., Lewkowicz, A., Roy, L.-P., Grandmont, K., de Grandpré, I., Laxton, S., McKenna, K. and Moote, K., 2015. Dawson City Landscape Hazards: Geoscience Mapping for Climate Change Adaptation Planning. Northern Climate ExChange, Yukon Research Centre, Yukon College, 166 p. and 2 maps.

Faro Landscape Hazards: Geoscience Mapping for Climate Change Adaptation Planning

Research Location: Faro, Yukon

Publication Type: Report

Publication Date: 2015

Introduction: A hazards map is a map that delineates or highlights areas on the land that are affected by, or are vulnerable to, a particular hazard. For example, in northern latitudes such as Yukon, thawing permafrost can be a significant climate change-related hazard. Flooding is another common hazard faced by Yukon communities, which may or may not be directly related to thawing permafrost. Hazards maps illustrate the risk associated with these and other hazards (ranked by risk severity), and are represented graphically in stoplight colours.

Hazards maps integrate complex environmental data into an easy-to-interpret, user-friendly tool for decision-making. The maps are created on a community-by-community basis and combine information about current and future landscape and climate conditions in order to rank the risk related to environmental change. As a result, they are tailored to each community's unique environment.

Local Relevance: The physiography, vegetation, contemporary climate, past climate trends, hydrology, landscape evolution, surficial materials, stratigraphy, and permafrost areas of Faro are explored. Potential hazards such as seismicity, landslide processes and permafrost processes are also explored. In the Faro area, 38.7% (36.0 km^2) is classified as low-risk terrain, 33.2% (30.9 km^2) is classified as moderate-risk terrain, and 21.4% (19.9 km^2) is classified as moderately high-risk terrain (3.8% is classified as water bodies).

Keywords: hazards mapping, permafrost, surficial mapping, seismicity, climate trends, Faro

Available Online:
https://www.yukoncollege.yk.ca/research/project/hazard_mapping_in_yukon_communities

Citation: Benkert, B.E., Fortier, D., Lipovsky, P., Lewkowicz, A., Roy, L.-P., de Grandpré, I., Grandmont, K., Turner, D., Laxton, S. and Moote, K., 2015. Faro Landscape Hazards: Geoscience Mapping for Climate Change Adaptation Planning. Northern Climate ExChange, Yukon Research Centre, Yukon College, 130 p. and 2 maps.

Ross River Landscape Hazards: Geoscience Mapping for Climate Change Adaptation Planning

Research Location: Ross River

Publication Type: Report

Publication Date: 2015

Introduction: A hazards map is a map that delineates or highlights areas on the land that are affected by, or are vulnerable to, a particular hazard. For example, in northern latitudes such as Yukon, thawing permafrost can be a significant climate change-related hazard. Flooding is another common hazard faced by Yukon communities, which may or may not be directly related to thawing permafrost. Hazards maps illustrate the risk associated with these and other hazards (ranked by risk severity), and are represented graphically in stoplight colours.

Hazards maps integrate complex environmental data into an easy-to-interpret, user-friendly tool for decision-making. The maps are created on a community-by-community basis and combine information about current and future landscape and climate conditions in order to rank the risk related to environmental change. As a result, they are tailored to each community's unique environment.

Local Relevance: The physiography, vegetation, contemporary climate, past climate trends, hydrology, landscape evolution, surficial materials, stratigraphy, and permafrost areas of Ross River are explored. Potential hazards such as seismicity, landslide processes and permafrost processes are also explored. In the Ross River area, 30.5% (6.7 km^2) is classified as low-risk terrain, 35.5% (7.8 km^2) is classified as moderate-risk terrain, and 28.2% (6.2 km^2) is classified as moderately high-risk terrain (5.9% is classified as water bodies).

Keywords: hazards mapping, permafrost, surficial mapping, seismicity, climate trends, Ross River

Available Online:
https://www.yukoncollege.yk.ca/research/project/hazard_mapping_in_yukon_communities

Citation: Benkert, B.E., Fortier, D., Lipovsky, P., Lewkowicz, A., de Grandpré, I., Grandmont, K., Turner, D., Laxton, S., Moote, K. and Roy, L.-P., 2015. Ross River Landscape Hazards: Geoscience Mapping for Climate Change Adaptation Planning. Northern Climate ExChange, Yukon Research Centre, Yukon College, 116 p. and 2 maps.

Vulnerability of the North Alaska Highway to Permafrost Thaw: A Field Guide and Data Synthesis

Research Location: Alaska Highway, Yukon

Publication Type: Report

Publication Date: 2015

Introduction: Yukon, Alaska and northern British Columbia depend heavily on road transportation to link communities and connect industrial activities to international markets. The Alaska Highway is the central

transportation corridor in Yukon. It is crucial to maintaining and expanding economic development, the quality of life of the population and international ties.

In the context of current and anticipated climate change, permafrost temperature has warmed significantly in northern territories and is expected to continue to rise (SNAP 2014). The stability of northern transportation infrastructure may be compromised by changes in permafrost, particularly in areas where the soil contains large amounts of ice. This may lead to negative impacts on economic development, including increasing the complexity and cost of road maintenance and the price of shipping goods in the North.

This report can be used to support decisions regarding road maintenance and future measures to mitigate permafrost thaw. Northern Climate ExChange (NCE) has partnered with Yukon's Highways and Public Works (HPW) to assess the vulnerability of the Alaska Highway to permafrost thaw along a 200-km section between Burwash Landing and the Yukon/Alaska border. Since its construction, this section of highway has been affected by permafrost thaw. The communities of Burwash Landing and Beaver Creek, as well as the traditional territories of White River First Nation and Kluane First Nation, are adjacent to the highway. All the people in the area depend on reliable access to transportation infrastructure to support their livelihoods.

Local Relevance: The sections of highway analyzed were from KM 1700 to 1902. The entire 200 km was divided into 13 different sections of analysis, which ranged from section level having 81.9% of it being low risk to permafrost thaw to section 10 having 91.5% of it being at a high risk to permafrost thaw. Overall, for the 200-km section between Burwash Landing and the Yukon/Alaska border, 42.7% is highly vulnerable to permafrost thaw, 38.5% has moderate vulnerability, and 18.8% has low vulnerability. In projected climate estimates the changes are expected to be more significant in the northern and southern sections of the highway. Yet, projected temperature and precipitation changes would make permafrost along the highway increasingly sporadic and isolated by 2050.

Keywords: infrastructure, permafrost, Alaska Highway

Available Online:
https://www.yukoncollege.yk.ca/research/project/vulnerability_of_the_north_alaska_highway_to_climate_change

Citation: Calmels, F., Roy, L.-P., Laurent, C., Pelletier, M., Kinnear, L., Benkert, B., Horton, B. and Pumple, J., 2015. Vulnerability of the North Alaska Highway to Permafrost Thaw: A Field Guide and Data Synthesis. Northern Climate ExChange, Yukon Research Centre, 127 p.

Community drainage system planning, design, and maintenance in northern communities

Research Location: Northern Canada

Publication Type: Report

Publication Date: 2015

Abstract:

In most northern communities, drainage system planning, design, and maintenance are often described as ad hoc processes. Community planners, engineers, and asset managers from across Canada's three territories, as well as Newfoundland and Labrador and Nunavik have emphasized that conventional drainage planning, approaches to design, and maintenance practices are inadequately defined and often poorly understood. The result is routine and chronic degradation of community infrastructure across the north. Proper drainage planning, design, and maintenance practices are essential for the protection of community infrastructure.

The effects of a changing climate bring additional challenges to the process of planning, designing, and maintaining northern drainage systems. Irregular and, in some cases, extreme events appear to set aside what might have been considered normal in the past. Many professionals agree that the changing climate has and will continue to alter northern weather conditions. Observed impacts in the north include:

• An increase in the frequency of extreme weather events resulting in greater snow accumulation, winter rain, icing, and higher winds;
• rapid spring melting;
• more sudden, intense precipitation events; and
• greater weather instability in general.

Local Relevance: The standards established in this report specify the minimum planning, design, and maintenance requirements for community drainage systems in Canada's northern communities. Its purpose is to help individuals and communities develop capacity and implement effective community drainage plans. Overall, the standard takes into account techniques to plan for, and implement community drainage systems by including the following parameters: the effects of climate change and changing permafrost regimes; low-cost solutions that are implementable with local capacity and resources; the protection of northern community assets; and the promotion of public health and safety.

Keywords: infrastructure, drainage systems, maintenance, Canada's northern communities

Available Online: http://shop.csa.ca/en/canada/infrastructure-and-public-works/cancsa-s503-15/invt/27037832015

Citation: Canadian Standards Association, 2015. Community drainage system planning, design, and maintenance in northern communities. Canadian Standards Association, CAN/CSA-S503-15, ICS 91.140.80, ISBN 978-1-77139-879-4, 83 p.

8. General

8.1. Yukon Government Initiatives

Embracing Energy Efficiency: Ensuring Yukon Benefits from Climate Moderated Heating Demand

Research Location: Yukon

Publication Type: Report

Publication Date: 2015

Excerpt: Meeting energy demand, either to provide heat, cooling, or electricity, is essential to healthy and comfortable homes in Canada. However, the cost of meeting this demand, either in the form energy prices, fuel costs or infrastructure maintenance, can be expensive. Climate change can reduce this expense by moderating winter temperatures and reducing the amount of energy required by a household to maintain indoor comfort. Such savings may be especially meaningful for Yukon where seasonal warming will result in a substantial moderation of winter temperatures.

Modelling developed to support this study suggests that the number of heating degree days required in Whitehorse annually will decline significantly over the long-term. This moderating influence may be immediately observable. The number of cooling degree days required annually may increase up to 88 per cent by the end of this century. However, given the amount of energy currently required for cooling is negligible, this would not constitute a significant increase in demand. Even a significant rise in cooling demand will not offset the potential savings resulting from reduced energy demand in winter.

Local Relevance: As the climate warms in Yukon, the heating and cooling requirements will change. This report looks at how those heating and cooling requirements may change and offers a series of suggestions on how to best capitalize on the benefits of climate change in regards to energy demand. Overall it is expected that the daily energy consumption in Yukon may decrease by 10-136 GWh/year over the short term, that heating requirements will significantly decrease, and cooling requirements may nearly double. Recommended actions include: researching time-of-use rates and smart grid use in the territory, improving energy use tracking, test cold climate air source heat pumps, energy efficient wood stoves, and commercial wood pellet boilers, continue to develop a biomass policy and industry in the Yukon, and investigate market incentives and subsidies to protect low-income households from unanticipated energy costs associated with heating.

Keywords: energy demand, climate change benefits, energy solutions

Available Online: http://www.energy.gov.yk.ca/pdf/Embracing-Energy-Efficiency-Climate-Moderated-Heating-Demand-Assessment.pdf

Citation: Government of Yukon Energy Branch, 2015. Embracing Energy Efficiency: Ensuring Yukon Benefits from Climate Moderated Heating Demand. Submitted in collaboration with Yukon Energy Corporation to Climate Change Impacts and Adaptation Division, Natural Resources Canada, 18 p.

Energy Strategy for Yukon: progress report 2015

Research Location: Yukon

Publication Type: Report

Publication Date: 2015

Excerpt: This is the third progress report since the 2009 release of the *Energy Strategy for Yukon*. It is an account of the Government of Yukon's substantial progress toward ensuring a sustainable and secure energy sector that meets Yukon's energy needs now and in the future. The *Energy Strategy for Yukon* focused on four priorities for energy in Yukon: renewable energy, energy efficiency, meeting electricity needs and managing responsible oil and gas development. The following pages show how the Yukon government is achieving its targets and goals for these four priorities.

Local Relevance: This progress report looks at how renewable energy, energy efficiency, and oil and gas targets set in the Energy Strategy in 2009 have been met by different initiatives. Renewable energy has largely been increased through increased hydro-electric production and some heating in Yukon resident and Yukon government buildings. Energy efficiency is being met by an energy efficiency rebate program for home appliances, and residential and commercial energy efficiency incentive programs. The next steps required to further meet the 2009 Energy Strategy are discussed as well.

Keywords: renewable energy, Yukon energy production, energy strategies

Available Online: http://www.energy.gov.yk.ca/pdf/energy-strategy-2015-progress-report.pdf

Citation: Government of Yukon, 2015. Energy strategy for Yukon: progress report 2015. Government of Yukon, 20 p.

State of the Environment Interim Report – 2015: An Update on Environmental Indicators

Research Location: Yukon

Publication Type: Report

Publication Date: 2015

Introduction: State of the environment reports are required by the *Environment Act* in order to provide early warning of potential environmental problems; enable members of the public to monitor progress on achieving the act's objectives; and provide baseline information for environmental planning, assessment and regulation. They provide the most current available information on the condition of Yukon's environment, helping to support decision-making by governments and individuals.

Under the act, the Minister of Environment is required to table a *State of the Environment Report* every three years. In the intervening years, interim reports are tabled that comment on matters contained in the previous *State of the Environment Report*.

The most recent *Yukon State of the Environment Report* was published in May 2014. This interim report updates 27 of the 33 environmental indicators that were presented in 2014. It also provides information

on recent and current government actions to address environmental issues, and includes eleven profile stories that highlight interesting and evolving work in Yukon.

Local Relevance: The 2015 state of environment report looks at two climate change indicators: greenhouse gas emission levels, and changes in temperature and precipitation. This report presents the most recent changes in these indicators, as well as current research and relevant data. Several initiatives that the Yukon Government has undertaken to address climate change are also documented.

Keywords: government initiatives, climate change indicators, environment, Yukon

Available Online: http://www.env.gov.yk.ca/publications-maps/documents/SOE_2015.pdf

Citation: Government of Yukon, 2015. State of the Environment Interim Report – 2015: An Update on Environmental Indicators. Government of Yukon, Department of Environment, 43 p.

The Yukon geothermal opportunities and applications report

Research Location: Yukon

Publication Type: Report

Publication Date: 2016

Excerpt: CanGEA developed this report in partnership with the Canadian Northern Economic Development Agency, the Government of Yukon's Department of Energy, Mines and Resources' Energy Branch (the Energy Solutions Centre), Yukon Energy, and the Yukon Geological Survey, with the primary goal of exploring the possibilities to use geothermal energy for electricity generation and heat applications in the Yukon.

Local Relevance: The first part of this report gives a broad-scale introduction to geothermal energy and its potential applications. The second part provides favourability maps of the Yukon's geothermal potential. The report notes that approximately 100 MW of geothermal resources are available at a depth of less than 2000 m in Yukon, noting that due to a lack of data, this may be an underestimation. The third part looks at the geothermal potential of each of the 17 communities in Yukon. The report ends by discussing different northern case studies of geothermal use and an analysis of potential geothermal use in Yukon.

Keywords: geothermal energy, renewable energy, Yukon

Available Online: http://www.cangea.ca/Yukon-Geothermal-Resource-Estimate-Maps.html

Citation: Canadian Geothermal Energy Association, 2016. The Yukon Geothermal Opportunities and Applications Report. Canadian Geothermal Energy Association, Calgary, Alberta, p.

Yukon Government Climate Change Action Plan: Progress Report December 2015

Research Location: Yukon

Publication Type: Report

Publication Date: 2015

Excerpt: Since developing the *Climate Change Action Plan* in 2009, the Government of Yukon has demonstrated leadership and commitment to addressing climate change. Six years into the plan, the majority of the government's original priorities are either complete or underway. The Government of Yukon approach is guided by the following goals:

1. enhancing knowledge and understanding of climate change,

2. adapting to climate change,

3. reducing greenhouse gas emissions, and

4. leading Yukon action in response to climate change.

The *Climate Change Action Plan Progress Report 2015* describes actions undertaken to date and identifies 28 new initiatives to support our climate change goals moving forward. It highlights the Government of Yukon's actions to reduce greenhouse gas emissions and adapt to the impacts of our changing climate.

Local Relevance: This progress report examines the climate change actions completed to date by the Government of Yukon, and provides 28 new initiatives that will address climate change. Each action and/or initiative works towards the Yukon government's four goals in addressing climate change which are: enhance knowledge and understanding of climate change, adapt to climate change, reduce our greenhouse gas emissions, and lead Yukon action in response to climate change.

Keywords: action plan, Government of Yukon, climate Change

Available Online: http://www.env.gov.yk.ca/air-water-waste/documents/CCAP_progressreport_eng_2015.pdf

Citation: Government of Yukon, Department of Environment., 2015. Yukon Government Climate Change Action Plan: Progress Report December 2015. Government of Yukon, 49 p.

Yukon Biomass Energy Strategy

Research Location: Yukon

Publication Type: Report

Publication Date: 2016

Excerpt: The intent of this strategy is to reduce Yukon's dependence on imported fossil fuels by optimizing the use of Yukon-harvested wood to meet the territory's heating needs using modern biomass energy systems.

There are many advantages to adopting biomass energy systems in Yukon. A transition to a biomass economy has the potential to reduce heating costs for Yukoners, create new jobs in the local forest and heating industries, reduce greenhouse gas (GHG) emissions, and move the territory towards sustainable renewable energy and greater energy self-sufficiency.

Local Relevance: The biomass strategy looks at the different ways the Yukon can go about reducing the nearly $50 million per year that is spent on imported fuel and electricity to generate heat. The strategy highlights use of biomass as a way to reduce imported fuel costs through following six actions: 1) commit to using biomass energy in government infrastructure; 2) develop regulations, policies and programs for biomass energy industry; 3) manage biomass facility emissions to protect public/environmental health and safety; 4) facilitate private sector development in biomass energy; 5) manage and regulate Yukon forests sustainability; and 6) ensure biomass fuel security and quality.

Keywords: biomass energy, wood heat, renewable energy, strategic plan, Yukon

Available Online: http://www.energy.gov.yk.ca/pdf/Yukon-Biomass-Energy-Strategy-Feb2016.pdf

Citation: Government of Yukon, 2016. Yukon Biomass Energy Strategy. Government of Yukon, 19 p.

Yukon Greenhouse Gas Emissions: The transportation sector updated report 2015

Research Location: Yukon

Publication Type: Report

Publication Date: 2015

Excerpt: The purpose of this research project is to produce a clear and detailed picture of the sources of greenhouse gas (GHG) emissions from the transportation sector in the Yukon. The approach taken was to build on the March 2013 version of this report titled *Yukon Greenhouse Gas Emissions: The transportation sector* along with updated data from Environment Canada, Statistics Canada, Yukon Bureau of Statistics and YG Finance.

This report has findings in two key areas:

1. Data Accuracy: Environment Canada's reporting of GHG emissions is accurate for the purposes of Canada's commitment to meet international United Nations' reporting requirements. However, the results both substantively under-report Yukon emissions (actual emissions are an average of 75% higher than reported from 2009 through 2012) and are subject to very large revisions in subsequent years. Under-reporting is prevalent across all Yukon sectors, not just transportation.
2. Emissions Re-calculations: Transportation emissions: According to re-calculations of the Yukon's 2012 emissions based on high-quality YG Finance data, known transportation uses accounted for 57% of total GHG emissions (This does not include off-road transportation that the data do not allow us to distinguish from other off-road uses). On-road gasoline use accounts for 25% of the Yukon's total emissions and 44% of known transportation emissions. On-road diesel use also accounts for 25% of total emissions.

Local Relevance: The Greenhouse Gases (GHGs) emitted from the transportation sector in the Yukon are analyzed using data from Environment Canada, Yukon Bureau of Statistics, and Yukon Government Finance. From this data, it is found that the Environment Canada National Inventory Report of GHGs emitted from Yukon is underreported by 75%. A series of recommendations to correct this reporting is given. The second product of this report is an emissions recalculation of Yukon GHG emissions from the transportation sector using Yukon Government Finance data. Based on these calculations, a series of recommendations to reduce GHG's in the transportation sector are provided, as well as ways to improve GHG reporting.

Keywords: transportation, GHG, Yukon baseline GHG emissions

Available Online:
http://www.energy.gov.yk.ca/pdf/yukon_transportation_sector_ghg_emissions_final_march_2015.pdf

Citation: Taggart, M. and Pearson, F., 2015. Yukon greenhouse gas emissions: the transportation sector – updated report 2015. Prepared by Malcolm Taggart, Research Northwest, Marsh Lake, Yukon, in association with Forest Pearson, 43 p.

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Index

F

G

H

I

J

K

L

M

N

O

P

Q

R

S

T

U

V

W

X

Y