Compendium of Yukon Climate Change Science

2019 Supplement

Northern Climate ExChange
YUKON RESEARCH CENTRE • Yukon College

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Photo Credit: *Government of Yukon*

PROJECT TEAM

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FOREWARD

The purpose of this compendium is to provide an overview of recent climate change work in and relevant to Yukon, Canada. The 2019 version of the Compendium is a supplement to previous versions (2003 - 2018) with climate change work that took place in 2018 and 2019. It contains various types of records including scientific journal articles, presentations, government publications, miscellaneous reports and summaries of ongoing research.

The following sources were used to search for records to include in the Compendium (note that records were not found at all sources searched):

- ASTIS Database
- Academic Search Complete
- Polar Data Catalogue
- Jstor
- Science Direct
- Yukon Biodiversity Database
- Wolf Creek Research Basin database
- Kluane Lake Research Station Bibliography
- Northern Research Institute Fellowship Grants list
- Government of Canada and Government of Yukon websites
- Google Scholar
- Internal knowledge
- NCE Library
- Natural Resources Canada project listing
- Food Secure Canada website
- Arctic Institute of Community Based Research project listing
- Crown-Indigenous Relations and Northern Affairs Canada project listing
- Hydrocarbon impacts database
- Wiley Online

The compendium is not intended as an exhaustive list of climate change related work in Yukon from 2018-2019. A greater emphasis was placed on work available online, and that took place or was published between May 31, 2018 and June 1, 2019. However, work that was completed prior to May 31, 2018 and not included in previous compendium versions was included in this version. The Northern Climate ExChange would appreciate notification of any relevant information that was not included in this version of the compendium, or of any errors made.

The compendium is organized by broad topics, corresponding to broad topics in the compendium database. Many records were assigned multiple broad topics, in this case the broad topic of ‘best fit’ was determined by the compendium editor. Each record is briefly summarized, the ‘relevance’ section highlights Yukon climate change information, and/or describes why the record was included in the Compendium.

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1.0 CLIMATOLOGY

Evaluation of CORDEX-Arctic daily precipitation and temperature-based climate indices over Canadian Arctic land areas

Author(s)
Diaconescu EP, Mailhot A, Brown R, Chaumount D

Keywords
precipitation climate indices, temperature climate indices, regional climate model evaluation, CORDEX experiment, daily precipitation, Canadian Arctic

Summary
Coordinated regional downscaling experiments, or CORDEX is a framework used internationally to produce and analyze climate change projections. In this study, daily precipitation and temperature data is modelled using Arctic-CORDEX data and other data sources and the results of models are evaluated. The researchers find that the effectiveness of regional climate models changes based on the parameters used to construct the model. Regional topography is one of these parameters and makes modelling climate in Yukon challenging. The models analyzed by the researcher were also better at predicting hot extreme temperatures rather than cold extreme temperatures, and only some models could effectively predict precipitation. The authors of this paper are reanalyzing CORDEX data to measure the effective of various climate models at predicting climate.

Relevance
While there are many pitfalls identified in this research to using regional climate models to predict future climates the authors identify many improvements to these models that can make them more effective. In order to mitigate and/or adapt to climate change foreknowledge of what that climate will be is needed. Climate models are complex, and computationally intensive and adaptation requires accurate models, therefore rigorous testing of models is needed. In each iteration of testing these models are improved. In this paper, several improvements to climate models for Yukon are identified such as; there is not enough data, and the data is often collected at a scale that differs from the model (the data is collected at a finer resolution, like a single weather station, while the model operates on an entire region); and complex topography limits models.

Citation
Diaconescu, Emilia Paula, Alain Mailhot, Ross Brown, and Diane Chaumont. Evaluation of CORDEX-Arctic Daily Precipitation and Temperature-Based Climate Indices over Canadian Arctic Land Areas. *Climate Dynamics* 50, no. 5–6 (2018): 2061–2085. https://doi.org/10.1007/s00382-017-3736-4.

Recent summer warming in northwestern Canada exceeds the Holocene thermal maximum

Author(s)
Porter TJ, Schoenemann SW, Davies LJ, Steig EJ, Bandara S, Froese DG

Keywords
precipitation climate indices, temperature climate indices, regional climate model evaluation, CORDEX experiment, daily precipitation, Canadian Arctic

Summary
In the Eastern Beringia region it is possible to create a reconstruction of the full Holocene Climate. Typically, these reconstructions use pollen or midges as a proxy for temperature information which produces conflicting results. To improve understanding of Holocene climatic conditions, this study uses precipitation information from isotopes found in permafrost. The authors find that the reconstruction based on midges agrees with their model, and that modern warming has exceeded the warmest period of the Holocene.

Relevance
There is some disagreement among historic climate reconstructions. By using an alternative technique, it becomes possible to confirm, or add to the information gained by other reconstructions. As more and more methods are used to reconstruct historical climates trends among methods will be easier to spot. Historical climate information has relevance for the modern climate. Effective past reconstructions can be used to build a better picture of the future climate. Additionally, some of the impacts of historical climate shifts are stored in archeological, geologic and other ‘records’. These records can be used to gain insight about potential future climate impacts.

Citation
Porter, Trevor J., Spruce W. Schoenemann, Lauren J. Davies, Eric J. Steig, Sasiri Bandara, and Duane G. Froese. Recent Summer Warming in Northwestern Canada Exceeds the Holocene Thermal Maximum. *Nature Communications* 10, no. 1 (2019): 1–10. https://doi.org/10.1038/s41467-019-09622-y.

2.0 AIR/ATMOSPHERE

Snowmelt, glacial and atmospheric sources of mercury to a subarctic mountain lake catchment, Yukon, Canada

Author(s)
Zdanowicz C, Karlsson P, Beckholm I, Roach P, Poulain A, Yumvihoze E, Martma T, Ryjkov A, Dastoor A

Keywords
mercury, snow, glaciers, subarctic, lake, atmosphere

Summary
Mercury is a neurotoxin emitted by many human activities with the ability to disperse far from an emission source. The weather systems of mountain lakes form 'cold traps' collecting mercury where it bio-accumulates in aquatic and terrestrial food chains or is stored in frozen water and soil. Mercury emissions are stabilizing or even declining in many regions, but much mercury from the past remains deposited in the environment as 'legacy mercury'. In the North 'legacy mercury' contained by permafrost and glaciers is being released as the climate warms and is contaminating downstream systems.

This document presents the results of an investigation into mercury sources of Kusawa Lake, separating atmospheric sources from ice and glacial sources to try to isolate 'legacy mercury' impacts. Snow and ice samples were collected in the alpine uplands of the Kusawa Lake catchment area, and analyzed for mercury content. A hydrological model was used to determine the snow and ice meltwater supply for Kusawa Lake. To determine atmospheric mercury contamination another model was used that estimated monthly mean mercury deposition over the entire catchment area. Based on the results of their research the authors suggest that more mercury is deposited into Kusawa Lake via 'legacy mercury' from melting permafrost and glaciers than newly deposited atmospheric mercury. As the climate warms and mercury once sequestered by frozen soil and ice enters aquatic systems, understanding the movement and sources of mercury will become more and more important.

Relevance
Yukon is home to glaciers, continuous permafrost, and discontinuous permafrost all of which are potential sites for mercury storage. Yukon is also experiencing climate change, and the subsequent changes to permafrost regimes and glaciers. Mercury potentially stored in frozen systems could enter natural and abiotic systems impacting ecosystems and from there enter human diets.

Citation

Zdanowicz, C., P. Karlsson, I. Bekholmen, P. Roach, A. Poulain, E. Yumvihoze, T. Martma, A. Ryjkov, and A. Dastoor. Snowmelt, Glacial and Atmospheric Sources of Mercury to a Subarctic Mountain Lake Catchment, Yukon, Canada. *Geochimica et Cosmochimica Acta* 238 (2018): 374–393. https://doi.org/10.1016/j.gca.2018.06.003.

A long-term hydrometeorological dataset (1993–2014) of a northern mountain basin: Wolf Creek Research Basin, Yukon Territory, Canada

Author(s)

Rasouli K, Pomeroy JW, Janowicz RJ, Williams TJ, Carey SK

Summary

This paper presents the results of long-term weather and water monitoring work in the Wolf Creek Research Basin. This dataset can be used to create and test the effectiveness of climate models in subarctic, mountainous regions. Data were collected at different elevations throughout the research basin and will continue to be collected for the foreseeable future.

Relevance

Long term, detailed weather and water monitoring datasets are few and far between in the North, particularly at higher elevations. The Wolf Creek Research Basin is relatively accessible to researchers, highly diverse, and has operated for many years making it an important research location. These types of datasets are important for understanding how the climate will change in the future, and understanding the limitations of projections constructed from less complete data sets. Additionally, the Wolf Creek Research Basin has extensive snow and water measurements allowing researchers to understand some indirect effects of climate change. The datasets, maps, elevations, and site itself are useful tools for a range of research projects.

Citation

Rasouli, Kabir, John W. Pomeroy, J. Richard Janowicz, Tyler J. Williams, and Sean K. Carey. A Long-Term Hydrometeorological Dataset (1993-2014) of a Northern Mountain Basin: Wolf Creek Research Basin, Yukon Territory, Canada. *Earth System Science Data* 11, no. 1 (2019): 89–100. https://doi.org/10.5194/essd-11-89-2019.

3.0 WATER/ICE

Landslide response to climate change in permafrost regions

Author(s)
Patton A, Rathburn SL, Capps DM

Keywords
landslides, climate change, permafrost thaw, hazards

Summary
Rapid permafrost thaw decreases the stability of hillsides making landslides more likely to occur. This paper reviews literature to address five questions used to evaluate landslide processes and inform management decisions. The five questions are:

- As permafrost changes, will the style of slope failure also change (in a way that matters to ecosystems and managers)?
- Will the frequency of landslides increase along with an increase in 'mass movement magnitude' (how far material moves)?
- How long will it take for systems to adjust, will this happen in 'human scale' time?
- How does human activity impact slope stability, and what is the best way to stabilize thawing slopes?
- How does increased permafrost slumping, and mass movements influence carbon budgets, and will increased landslide frequency release more carbon or act as carbon storage?

Not only is there potential for more frequent landslides in permafrost regions as the climate warms, they are more difficult to predict as the impact of climate change on landslides is not well understood. In permafrost systems surficial soil that is not frozen year-round is known as the active layer. Active layers are vulnerable to landslides as the frozen soil beneath them creates a low friction sliding surface. As permafrost thaws the depth of the active layers increases, creating pathways for erosion and landslides. Additionally, soil, once thawed loses cohesion, again decreasing the friction against the frozen soil beneath it. Increased landslides, decreased slope stability, and thermokarst erosion have far reaching impacts for both human and natural systems. Downstream sediments loads may increase after landslide activities, structures and road systems may be threatened, and natural communities will change. As precipitation and temperature regimes change, the fire regime changes driving further modifications to permafrost. The. The impacts of these interactions combined with landslides are not well understood.

Relevance
The permafrost, and landslide impacts noted above are particularly relevant to high altitude and high latitude areas common to Yukon. As a literature review this research covers landslides generally, as well as other related conditions found in Yukon. Thermokarst slumping and landslides

have occurred in Yukon and will likely occur again, threatening infrastructure and local ecosystems, and are of concern for managers. Several pieces of literature reviewed in this document also describe research that took place in Yukon.

Citation
Patton, Annette I., Sara L. Rathburn, and Denny M. Capps. Landslide Response to Climate Change in Permafrost Regions. *Geomorphology* 340 (2019): 116–128. https://doi.org/10.1016/j.geomorph.2019.04.029.

Seeing water like a state?: Indigenous water governance through Yukon First Nation self-government agreements

Author(s)
Wilson NJ

Keywords
Yukon, Canada, governmentality, Indigenous water governance, Indigenous-state relations, self-government agreements, Indigenous law

Summary
First Nations in Yukon and the water in their Traditional Territories experience a variety of social, political, economic and environmental pressures. Land claims and self-governing agreements give First Nations a right to water quality, quantity and flow on their settlement lands, and some legal authority to enforce those rights. These water rights are typically asserted as part of environmental impact assessment and water licensing processes, however Yukon First Nations with self-governing agreements in place can also enact legislation that supersedes territorial legislation. At this time no Yukon First Nation has implemented legislation. This paper examines the water management strategies and environments of 3 Yukon First Nations:

- The Champagne and Aishihik First Nation (CAFN)
- Carcross Tagish First Nation (CTFN)
- Tr'ondëk Hwëch'in First Nation (THFN)

Water is regarded as a relative or family member, rather than a resource, by many Yukon First Nations (CAFN has drafted a strategy that recognizes their First Nation's 'great and deep respect' for water and duty to protection and conservation within their Traditional Territories). This relationship will need to be captured by any water legislation or management. This perspective conflicts with other, National and Provincial/ Territorial, water legislation which asserts ownership (by the Crown) of water. Lack of capacity to author, implement and enforce legislation is a barrier to First Nation

water management and to navigating the interface of Indigenous and non-Indigenous water management strategies and legislation.

Relevance

This paper studies water management in 3 Yukon First Nations with self-governing agreements. These agreements are common throughout Yukon First Nations, creating a unique water management regime that, as water becomes a more important resource to both First Nations and other people, will have to be navigated by First Nations and non-Indigenous governments in Yukon. This paper provides an overview of how to manage conflicting perspectives about the nature of water management and reports on strategies that have been successful and less successful in other jurisdictions.

Citation

Wilson, Nicole J. 'Seeing Water Like a State?': Indigenous Water Governance through Yukon First Nation Self-Government Agreements. *Geoforum*, no. December 2018 (2019): 1–13. https://doi.org/10.1016/j.geoforum.2019.05.003.

Monitoring surface changes in discontinuous permafrost terrain using small baseline SAR interferometry, object-based classification, and geological features: a case study from Mayo, Yukon Territory, Canada

Author(s)

Mohammadimanesh F, Salehi B, Mahdianpari M, English J, Chamberland, J, Alasset P

Keywords

permafrost, interferometic SAR, small baseline subset, RADARSAT-2, random forest classification, geology

Summary

Much of the Yukon is underlain by permafrost and northern infrastructure including roads, buildings, pipelines and cables can be damaged as permafrost laden ground melts and deforms. Changes to permafrost are becoming more and more common as the climate warms leading to a greater need to understand where permafrost is located. This research uses radar to locate areas where the ground has shifted because of permafrost, combines this information with land cover classes to identify infrastructure potentially at risk of damage by shifting permafrost. This study builds on a variety of other permafrost monitoring methods to improve the quality of monitoring.

Relevance

Since much of Yukon is underlain by permafrost, it follows that much of the infrastructure in the territory is potentially threatened by changes to permafrost regimes. As the climate warms permafrost is changing at a greater rate necessitating a greater understanding of baseline permafrost conditions as well as projections of what future permafrost regimes may look like. This information can be used to protect current infrastructure and plan the development of future infrastructure.

Citation

Mohammadimanesh, Fariba, Bahram Salehi, Masoud Mahdianpari, Jerry English, Joseph Chamberland, and Pierre Jean Alasset. Monitoring Surface Changes in Discontinuous Permafrost Terrain Using Small Baseline SAR Interferometry, Object-Based Classification, and Geological Features: A Case Study from Mayo, Yukon Territory, Canada. *GIScience and Remote Sensing* 56, no. 4 (2019): 485–510. https://doi.org/10.1080/15481603.2018.1513444.

Water is medicine: Reimagining water security through Tr'ondëk Hwëch'in relationships to treated and traditional water sources in Yukon, Canada

Author(s)

Wilson NJ, Harris LM, Joseph-Rear A, Beaumount, J, Satterfield T

Keywords

community-based research, drinking water, hydrosocial, Indigenous Knowledge, settler colonialism, political ontology, Two-Eyed Seeing, Yukon, Canada, water security

Summary

In this article, in order for water security to be considered complete, it must account for not only the technical or material aspects, but also the social and relational aspects of water. Indigenous people have different relationships to water than non-Indigenous people, essentially regarding some water sources more highly than others and placing more value on their relationship with various water sources. This paper looks at the water security of the Tr'ondëk Hwëch'in, and their relationship to traditional and treated water sources. Traditional water sources are important to the mental and spiritual health of community members. The author argues that the spiritual/traditional/cultural aspects of water and the relationships of Indigenous people with it need to be considered in any discussion about water security. Many Indigenous communities value water taken from the land, or from traditional sources more than water from the tap despite risks associated with untreated water. Many water management strategies fail to consider the non-material side of water security for First Nations people.

Relevance

Water security related to climate change is an on-going issue for many communities. While generally, it is not a concern for Yukon communities, examining relationships with water as availability changes will become important in the future if water security changes. For example, some Labrador First Nations are struggling with water security despite the availability of tap water; residents choose water from the land, which is becoming less available or expensive, imported, bottled water which is a financial burden. Examining the relationship of community members with tap water can lead to increased water security in the future by incorporating the spiritual and cultural aspects of water into planning. The authors of this paper used a Yukon community as a case study. While different communities and individuals will have different relationships and ideas about water, many of the ideas captured in this research can be used to lead research in other communities.

Citation

Wilson, Nicole J., Leila M. Harris, Angie Joseph-Rear, Jody Beaumont, and Terre Satterfield. Water Is Medicine: Reimagining Water Security through Tr'ondëk Hwëch'in Relationships to Treated and Traditional Water Sources in Yukon, Canada. *Water (Switzerland)* 11, no. 3 (2019): 1–19. https://doi.org/10.3390/w11030624.

Unprecedented increases in total and methyl mercury concentrations downstream of retrogressive thaw slumps in the western Canadian Arctic

Author(s)

St. Pierre KA, Zolkos S, Shakil S, Tank SE, St. Louis VL, Kokelj SV

Summary

Rapidly thawing, ice rich permafrost can create features known as retrogressive thaw slumps (RTS). Typically, these are large thermokarst features occurring on riverbanks that can deposit large amounts of sediments and other materials downstream. The impacts of RTSs on mercury concentrations downstream is not well known. In this project the researchers measure mercury levels in waterbodies downstream of RTSs and find that mercury concentrations are typically higher downstream of slumping and that there are a variety of factors that determine the extent of contamination such as the shape of the slump, season, and river characteristics. The researchers suggest that as much as 5% of total mercury stored in permafrost could potentially enter biologic, or hydrologic systems due to climate change driven thermokarst formation.

Relevance

Yukon is underlain by permafrost, and is already experiencing RTSs, or thermokarst slumping in some locations. As the climate warms this behaviour may increase. Because of this, understanding

how downstream concentrations of mercury will change, and what impact those changes will have on ecosystems is important adaptation information in Yukon. Throughout much of the world strict environmental controls in recent decades have reduced atmospheric mercury levels, however in the North atmospheric mercury levels have declined at a much slower rate. Climate change in the Arctic is driving changes to the landscape that could further hinder mercury reduction efforts.

Citation

St Pierre, Kyra A., Scott Zolkos, Sarah Shakil, Suzanne E. Tank, Vincent L. St Louis, and Steven V. Kokelj. Unprecedented Increases in Total and Methyl Mercury Concentrations Downstream of Retrogressive Thaw Slumps in the Western Canadian Arctic. *Environmental Science and Technology* 52, no. 24 (2018): 14099–14109. https://doi.org/10.1021/acs.est.8b05348.

Detecting spatial variation in hydrology and carbon export across a lack-rich permafrost landscape, Old Crow Flats, Yukon, Canada

Author(s)

Hughes D

Keywords

permafrost, water isotope tracers, water chemistry, spatial analysis, carbon

Summary

The Old Crow Flats are a large ‘lake rich’ landscape in permafrost terrain. In recent decades changes to lake and river systems have been noted by both local residents and in scientific research. This thesis uses water chemistry measurements and spatial analysis to understand climate change modifications to the landscape of Old Crow Flats. Other changes to the landscape of Old Crow Flats include permafrost slumps and increased shrubification. These changes all combine to have a series of impacts on water chemistry, and the physical structure of the lakes. Using river isotope signatures other landscape changes are identified upstream, which when combined with information collected within the Old Crow Flats allows the researchers to understand how the downstream landscape will be affected by climate change. In essence, the researchers seek to use river water properties to examine variability in run off from the Old Crow Flats and how climate change influences this.

Relevance

The Old Crow Flats is an important area for the Vuntut Gwitchin First Nation. Effective monitoring is important to understand how the hydrology, nutrients and ecology of the region will respond to climate change. Moreover, lake rich, permafrost landscapes are common throughout the North, making this research applicable to other regions. The North is warming at a much greater rate than many other regions of the world, and therefore experiencing climate change impacts sooner.

Adaptation efforts in the North are confounded by limited capacity, remoteness and lack of baseline understanding. Research such as this improves our understanding of northern systems, and in particular describes rapidly changing ecosystems and landscapes, while also providing insight into their future state.

Citation

Hughes, Daniel. Detecting Spatial Variation in Hydrology and Carbon Export across a Lake-Rich Permaforst Landscape, Old Crow Flats, Yukon, Canada, 2018.

Permafrost stores a globally significant amount of mercury

Author(s)

Schuster PF, Schaefer KM, Aiken GR, Antweiler RC, Dewid JF, Gyziec JD, Gusmeroli A, Jafarov E, Krabbenhoft DP, Liu L, Herman-Mercer N, Mu C, Roth DA, Schaefer T, Striegl RG, Wickland KP, Zhang T

Summary

Permafrost thawing due to climate change can alter the mercury (Hg) cycle. In this experiment, the amount of mercury held in permafrost is measured at sites throughout the Arctic to produce an estimate of total Hg held by permafrost worldwide. It is suggested by this study that previous measurements had underestimated the amount of Hg frozen in permafrost and underrepresent the thawing Arctic in global Hg cycles.

Relevance

Mercury (Hg) in frozen ground is potentially biologically available but the time scale is such that it is of little concern. However, permafrost is thawing at an increasing rate in Yukon, and the time scale for Hg to enter biological systems if unfrozen is only about 70 years. Given that the authors of this study find that permafrost ground could contain much more Hg than previously expected, and eith the rapid thaw of Yukon permafrost, the Hg contained could enter biological systems where it is potentially toxic. Also, Hg is not particularly biodegradable and can accumulate in biological systems potentially exposing humans to it as well. This is particularly of concern for Yukon First Nations whose traditional diets could expose them to potentially toxic levels of Hg.

Citation

Schuster, Paul F., Kevin M. Schaefer, George R. Aiken, Ronald C. Antweiler, John F. Dewild, Joshua D. Gryziec, Alessio Gusmeroli, et al. Permafrost Stores a Globally Significant Amount of Mercury. *Geophysical Research Letters* 45, no. 3 (2018): 1463–1471. https://doi.org/10.1002/2017GL075571.

4.0 ANIMALS

Hares and small rodent cycles: a 45-year perspective on predator-prey dynamics in the Yukon boreal forest

Author(s)
Krebs CJ, Boonstra R, Kenney AJ, Gilbert BS

Keywords
population cycles, boreal forest, snowshoe hares, mice, voles, Yukon

Summary
Populations of hares, mice and voles have been monitored in the Kluane region of Yukon from 1973-2017. This dataset provides insight into the population fluctuations of these species, and how these fluctuations are changing over time. Using both experimental and observational methods the authors attempt to expose some of the mechanisms that drive population fluctuations and changes to these fluctuations. Snowshoe hare numbers were found to fluctuate based on predation pressure; direct predation removes animals from the population while the stress associated with predation reduces the fecundity of hares indirectly reducing the population. Vole populations were observed to fluctuate much more frequently than hare populations (3-4 years vs. 10 years). Several reasons for fluctuation of vole populations are presented in this paper but they all are inconclusive. No pattern of population fluctuation was observed for mice in this study. Mice were in fact absent from the study area for many years and the authors have no strong hypothesis for what drove this phenomena. This research shows the need for long term population monitoring projects to understand population cycles, suggesting that most projects of 2-4 years are inadequate or only provide a limited understanding.

Relevance
Hares and small mammals are the main prey item in Yukon food webs. Understanding the dynamics of their populations and what drives changes to these dynamics as climate changes provides important understanding of how ecosystems functioned historically and are changing. The need for long term, baseline data is identified throughout climate change literature. This study also identifies a series of research gaps, or additional questions that can be addressed and comments on the issue of making management decisions based on short term data.

Citation
Krebs, Charles J., Rudy Boonstra, Alice J. Kenney, and B. Scott Gilbert. Hares and Small Rodent Cycles: A 45-Year Perspective on Predator-Prey Dynamics in the Yukon Boreal Forest. *Australian Zoologist* 39, no. 4 (2018): 724–732. https://doi.org/10.7882/AZ.2018.012.

Impact of climate change on the small mammal community of the Yukon Boreal forest

Author(s)
Krebs CJ, Boonstra R, Gilbert BS, Kenny AJ, Boutin S

Keywords
community change, long-term study, population cycles, trophic dynamics, voles.

Summary
Research reporting on 46 years of small mammal monitoring in southern Yukon boreal forest. Population density changes in small mammals were monitored with density estimates based on trapping activity in 3-5 areas each spring and autumn. Ten species were trapped, responsible for 9% and growing to 38% of the total energy in the ecosystem. Despite the small size of small mammals, they are a large source of energy for ecosystems, as found in this study, making them an important component to understand and monitor as the climate changes. Of the 10 species trapped 4 species were dominant. This trend stayed relatively stable until the early 2000's when the dominant species started to shift. The researchers suggest this change may be driven by climate change induced increases in ecosystem productivity and an increase in predator abundance. The researchers also expect that these changes to the ecosystem may not be stable and that climate change is potentially shifting boreal ecosystems towards a fundamental state change.

Relevance
Small mammals form the basis of trophic systems, feeding and supporting a range of larger animals and species. Changes to their abundance and distribution can have impacts that reverberate through food webs. However, their populations can also fluctuate dramatically, or conversely remain relatively stable in the short-term. By using data collected over 46 years this project captures population trends and changes that may not be observed in short-term projects, indicating a need for continued long-term monitoring to understand climate change impacts to small mammal populations and indirectly to entire ecosystems.

Citation
Krebs, Charles J., Rudy Boonstra, B. Scott Gilbert, Alice J. Kenney, and Stan Boutin. Impact of Climate Change on the Small Mammal Community of the Yukon Boreal Forest. *Integrative Zoology*, 2019, 1749–4877.12397. https://doi.org/10.1111/1749-4877.12397.

Some broad-scale effects of recent and future climate change among migratory birds in Beringia

Author(s)
Winker K, Gibson DD

Keywords
Asia, Beringia, continental colonization, migration, North America, range shifts, time limitation

Summary
The Beringian region, part of which lies within Yukon, is important breeding and nesting habitat for a variety of migratory bird species. Climate change predictions indicate that Beringia, and Yukon, will experience a large degree of warming and an extended growing season which could have large impacts on both local and migratory species. Birds are, when compared to other species, highly mobile and capable of traveling long distances. They are also commonly used as indicators of overall environmental health. However, this mobility means that migratory birds will likely be one of the first species to show changes to their range and distribution because of climate change. As the range of migratory birds expands, a variety of impacts may be experienced including intercontinental parasite transfer and new interspecific competition. This research lists some potential ecosystems impacts as migratory and non-migratory birds shift their ranges in response to climate change and also lists species of birds that have been found with expanded ranges.

Relevance
Yukon is part of the Beringia region, and as such it serves as important migratory and breeding habitat for many different species of birds. As the ranges of these species change and new species are added due to climate change the authors expect to see a change in the composition of ecosystems. As birds are often easier to monitor than other species, tracking changes in ranges of migratory bird species can help provide insight into broader changes to natural systems due to climate change.

Citation
Winker, Kevin, and Daniel D. Gibson. Some Broad-Scale Effects of Recent and Future Climate Change among Migratory Birds in Beringia., 2018, 432–440. https://doi.org/10.21199/SWB3.23.1.

5.0 VEGETATION

Arctic tundra plant phenology and greenness across space and time

Author(s)
Assmann JJ

Summary
It is predicted that the rapid warming of the Arctic associated with climate change will increase the productivity of tundra vegetation and bring about changes to phenology. These impacts can drive larger ecosystem changes and alter carbon and nutrient cycles. In this thesis, ecological monitoring data, satellite imagery and drone imagery are used to investigate changes to tundra plant productivity and phenology. These observations are considered at a variety of scales to determine if scale has an impact on the detection of changes. Along with changes to temperature, snow-melt and sea ice are identified as major environmental controls that influence both productivity and phenology. Their impact on tundra plant productivity and phenology is investigated at multiple sites across the Arctic. According to the author spring phenology is best explained by spring air temperatures and when snowmelt occurs.

Relevance
Changes to plant productivity and phenology are often linked with deeper changes to ecosystems. Because of this, understanding these changes is crucial to predicting future ecosystem states and the impact of changes on global systems. However, the observation of many of these changes is limited by scale. Since changes to snow-melt, one of the primary drivers of productivity and ecosystem changes, are highly localized, landscape scale observational methods are unlikely to detect them. Local scale methods are hampered by difficulties associated with travel, cost, and capacity to conduct observations. However, this research identifies the importance of collecting small scale observations in order to understand changes to systems at larger scales.

Citation
Assmann, Jakob J. Arctic Tundra Plant Phenology and Greenness across Space and Time, 2018.

Resilience of southern Yukon boreal forests to spruce beetle outbreaks

Author(s)
Campbell EM, Antos JA, vanAkker L

Keywords
spruce beetle outbreaks, boreal forest, white spruce, Yukon, forest resilience.

Summary
Using permanent, long term research plots the resilience of boreal forests to large spruce beetle outbreaks is examined. Spruce beetle outbreaks are expected to increase as the climate warms and could act as a driver of large scale ecosystem changes in Yukon, as they do at more southern latitudes. Additionally, spruce beetle outbreaks can also increase the severity of fires by leaving large stands of standing dead trees, again increasing the potential scale and frequency of disturbance. The goal of this research is to determine how Yukon forests are responding to spruce beetle outbreaks; are they resilient enough to return to pre-outbreak ecosystem types or are they changing? To do this, measurements were taken in 21 different stands of spruce trees over a period of about 15 years. In these stands the spruce beetle outbreak reduced the size and the density of spruce trees, but spruce trees remained the most common type of tree. This potentially indicates that some other factor is limiting spruce beetle outbreaks rather than availability of trees to infest and suggests that Yukon forests may be resilient to increased spruce beetle outbreaks.

Relevance
Climate change is modifying disturbance patterns, like spruce beetle outbreaks and forest fires, in Yukon. These changes could drive ecosystem scale changes to boreal forests that characterize Yukon. In more southern systems several studies have observed that boreal forests are shifting to hardwood dominated forests. In Yukon it appears that beetle outbreaks are limited not by presence of spruce to infest but other factors. This indicates that Yukon boreal forests may not experience the same changes as southern boreal forests. The impacts of future climate changes to disturbance regimes may have larger effects on Yukon forests, however to what degree is unknown. Understanding the behaviour of Yukon forests to current and past impacts can lead to less uncertainty about future impacts.

Citation
Campbell, Elizabeth M., Joseph A. Antos, and Lara vanAkker. Resilience of Southern Yukon Boreal Forests to Spruce Beetle Outbreaks. *Forest Ecology and Management* 433, no. November 2018 (2019): 52–63. https://doi.org/10.1016/j.foreco.2018.10.037.

Climatic drivers of tree growth at tree line in Southwest Yukon change over time and vary between landscapes

Author(s)
Dearborn KD, Danby RK

Summary
As the climate warms trees are expected to expand their range northwards and into higher elevations. While this trend is generally true there is observed temporal and spatial variation that is

not well understood that makes projecting future growth patterns difficult. White spruce trees were sampled at the tree lines on north and south facing slopes on two mountain ranges in southwest Yukon. The width of tree rings in these samples was analyzed with climate data to discover, and possibly explain variations over time and at different locations. This analysis revealed that increased air temperature is not linked to increased growth, and that a warmer climate may in fact reduce growth rates. Growth rates are linked to the moisture content of soil in the spring, which is linked to the depth of snow in the winter (among other things); snow depth is expected to decrease as the climate warms. The study also concludes that regional or broader scaled climate studies are somewhat limited because they do not do a good job of including the small scale, or local variations in growth patterns and responses.

Relevance

This research takes place in Yukon, and examines the relationship between climate change and white spruce trees. It calls attention to the need for fine scaled understanding of ecosystems, and their responses to changes. Forests are typically managed at a regional scale, but management and research at this scale does not provide the understanding needed to explain how forests will change as the climate warms. Furthermore, it finds that while rising air temperatures do not have a direct impact on how white spruce growth rates change, it does find that rising air temperatures have indirect impacts on growth rates. This, again, calls attention to the need for increased understanding in order to adapt to a changing climate.

Citation

Dearborn, Katherine D., and Ryan K. Danby. Climatic Drivers of Tree Growth at Tree Line in Southwest Yukon Change over Time and Vary between Landscapes. *Climatic Change* 150, no. 3–4 (2018): 211–225. https://doi.org/10.1007/s10584-018-2268-1.

Climate as a driver of shrub expansion and tundra greening

Author(s)

Myers-Smith IH, Daskalova G, Angers-Blondin S, Criado MG, Bell N

Summary

Interim report from the Team Shrub research group. Temperatures in the Arctic are increasing at about twice the rate of the rest of the world, leading to a longer growing season and shrubification. This goal of this project is to improve understanding of how arctic vegetation is changing and the possible impacts of these changes. On Qikiqtaruk, or Hershel Island, the researchers are studying what, specifically, drives changes to arctic vegetation. Parameters studied include air temperature, snowmelt, soil disturbance and interactions with other species of plants and animals. Qikiqtaruk was chosen as a study site because it is the very edge of the range of many arctic plants. Preliminary

findings indicate that shrub height is increasing, plants are 'greening' earlier in the spring and staying greener longer into the fall, the density and abundance of shrub species is increasing, the species composition is changing, the permafrost regime is changing, and there are more muskoxen on the island.

Relevance

Climate change, with associated warming temperatures can be considered the direct, or ultimate cause of changes to arctic shrub growth. However, there are many indirect changes associated with climate change such as changes to permafrost or soil, changes to snow melt, changes to wind and changes to community structure. Understanding the impacts of these indirect changes can lead to a larger understanding of how ecosystems will respond to climate change. In some cases, ecosystem modification could occur at such a rate that the ecosystem will be driven to a new state driving changes to ecosystem function, carbon and other nutrient cycles, and species composition.

Citation

Myers-Smith, Isla H., Gergana Daskalova, Sandra Angers-Blondin, Mariana García Criado, and Noah Bell. Climate as a Driver of Shrub Expansion and Tundra Greening. TeamShrub, 2019.

Climate versus site controls on tundra shrub expansion – a common garden experiment

Author(s)

Myers-Smith IH, Daskalova G, Criado MG, Bell N

Summary

Interim report from the Team Shrub research group. The productivity and timing of shrub growth is changing as the climate warms. While rapid shrub expansion and changes to phenology have been observed throughout Yukon and the North, the changes are not uniform. This project seeks to use a common garden experiment to understand changes to shrub growth, collect measurements on growth and phenology, and understand how the shrub community interacts with the rest of the ecosystem.

Relevance

Changes to shrub growth, timing and density can have affects throughout ecosystems such as altering snow melt, impacting the carbon cycle, and habitat and food for animals. As the climate warms and shrubification continues ecosystems could be driven to new states.

Citation
Myers-Smith, Isla H., Gergana Daskalova, Mariana García Criado and Noah Bell. Climate versus Site Controls on Tundra Shrub Expansion – a Common Garden Experiment. TeamShrub, 2019.

Eighteen years of ecological monitoring reveal multiple lines of evidence for tundra vegetation change

Author(s)
Myers-Smith IH, Grabowski MM, Thomas HJ, Angers-Blondin S, Daskalova GN, Bjorkman AD, Cunliffe AM, Assman JJ, Boyle JS, McLeod E, McLeod S, Joe R, Lennie P, Arey D, Gordon RR, Eckert CD

Keywords
climate change, community composition, greening, growth, permafrost, phenology, tundra, warming

Summary
Rapid warming has been observed throughout the arctic tundra, as has increased shrub density and changes to phenology. However, the specific mechanisms driving these changes are not well understood. This research reports on a long-term ecological monitoring program aimed at improving the understanding of these changes. Monitoring took place on Qikiqtaruk/Hershel Island, which is the latitudinal 'tall shrub line'. Ecological monitoring took place over 18 years and found that spring 'green-up' occurs nine days earlier, plant height has increased two fold, the abundance of shrubs and grasses has also increased two fold while ground covering plants have decreased in abundance. These changes were observed and integrated with satellite imagery suggesting that a longer growing season and warmer active soil layer are driving increased plant growth rather than air temperature alone.

Relevance
Long term, consistent monitoring of study sites is important to detect long lasting trends. This type of monitoring allows the impact of indirect climate change effects to be detected as well as direct effects. Complex local factors determine how shrubs and other plants will respond to climate change, making it difficult to isolate overarching drivers of changes to vegetation unless specific sites are monitored for long periods of time. A series of indirect environmental changes caused by warming air temperatures can result in a series of ecosystem changes that may cause dramatic changes to ecosystem function and state. Understanding the impacts of these indirect changes can lead to a larger understanding of how ecosystems will respond to climate change providing insight into the future of tundra ecosystems.

Citation

Myers-Smith, Isla H., Meagan M. Grabowski, Haydn J.D. Thomas, Sandra Angers-Blondin, Gergana N. Daskalova, Anne D. Bjorkman, Andrew M. Cunliffe, et al. Eighteen Years of Ecological Monitoring Reveals Multiple Lines of Evidence for Tundra Vegetation Change. *Ecological Monographs* 89, no. 2 (2019). https://doi.org/10.1002/ecm.1351.

6.0 HUMANS

YIC4 – Yukon Indigenous climate change champions project

Author(s)
Arctic Institute of Community Based Research

Summary
This publication is a newsletter from a 2018 Yukon Indigenous climate change champions project. Twenty-six youth and three renewable resource council members from across Yukon, NWT, and Nunatsiavut participated in a training project to develop climate change and community based research skills. The training program included 'after training' support to plan and implement a community assessment. The community assessment will become a guide to develop youth and community projects to take climate change adaptation actions throughout the Arctic.

Relevance
Communities in Yukon are experiencing climate change driven impacts to their lifestyles and cultures. Actions that enable adaptation are needed to preserve their lifestyle, maintain their culture as well as improve conditions within their community. The training associated with this project enables community members, particularly youth, to take action in their community to adapt to climate change.

Citation
AICBR. YIC4 -Yukon Indigenous Climate Change Champions Project. University of Edinburgh, 2018.

Indigenous community food security in Yukon Territory

Author(s)
Kassi N

Summary
The Artic Institute of Community Based Research is an independent, not for profit research organization. It was established in 2007. This presentation expresses the importance of food security strategies for Indigenous communities as the climate changes. Indigenous communities have a unique perspective on food security that is central to their culture. Community based research is used to explore food security, relationships and future options engaging community members in the research process.

Relevance
Food security is an important topic for Indigenous communities in Yukon, especially as climate changes and the availability of traditional food sources is changing. Community based research projects empower communities to develop and maintain food security strategies that are locally based, and culturally appropriate. Youth are identified as important resource; by training and hiring them for community based research not only is the food security of the community improved, the youth gain important skills. This presentation also considers other food security options for communities such as micro-enterprises and economic opportunities.

Citation
Kassi, Norma. Indigenous Community Food Security in Yukon Territory. 2018.

Mapping Yukon climate change and northern food system assets

Author(s)
Pratt M

Summary
Traditional food sources are culturally important to Yukon Indigenous people and connected to their mental, physical, emotional and spiritual health and wellbeing. In this four-year project the way Yukon communities are mitigating and adapting to climate change impacts to traditional food sources is explored. Online inventory maps cataloguing climate and food system 'assets' are used to share important information, adaptation initiatives, resources and connect people and organizations. There are a 178 climate change 'assets' displayed on the maps grouped under the themes adaptation, mitigation and monitoring. The northern food system map documents 1048 'assets' grouped by the themes of production/harvest, transportation, distribution/exchange, consumption, food skills/knowledge/culture, and food system coordination/policy/networks. The project focused on community level initiatives as climate change impacts are generally experienced at a local level and require action based on the skills and experiences of local people. Ultimately the goal of this project is to enable knowledge sharing, collect climate change information and assets in one location and to share success stories.

Relevance
Asset inventories that highlight the strengths and challenges of climate change adaptation are important tools for communities to address climate change and share success. By collecting a broad range of climate tools into a series of accessible maps, knowledge can be shared with communities, members of the public, and policy makers hopefully leading to action. This project addressed a gap in the consolidated understanding of adaption action and mitigation taking place across communities and placed this information in an accessible repository. It captured not only formal

projects and assets but informal and ad-hoc adaptation measures. This work is not only important to capture the current state of climate change adaptation in Yukon communities but to drive future projects in the direction that will produce the best results.

Citation
Pratt, Molly, and Mobilize Knowledge Consultation. Mapping Yukon Climate Change and Northern Food Systems Assets, 2019.

The impacts of climate change on traditional and local food consumption in the Yukon

Author(s)
Sheedy A

Summary
Many people in Yukon, particularly those in more isolated regions rely on Traditional or local, as well as store purchased food sources. These food systems have been impacted by climate change thereby affecting the food security, culture and health of people. Climate change impacts to food systems compound with other social inequities and issues. Communities suffering from food insecurity have the greatest potential for negative impacts. Yukon communities have the third highest food insecurity rate in Canada. Because of this, climate change adaptation planning and strategies in Yukon needs to consider the specific needs of Indigenous people. This report is phase 1 of a 3-phase project supporting climate change adaptation, food security, and traditional food sources. It identifies the current understanding of food and climate change in Yukon, knowledge gaps, collects baseline data, reviews methods of improving understanding and makes several recommendations. Several research gaps are identified, notably the lack of information on community based, climate change adaptations related to food in the North.

Relevance
Remote and Indigenous communities in Yukon have unique needs and challenges that can make climate change adaptation difficult; in particular food insecurity can make effective adaptation impossible. Climate change impacts both locally obtained and market foods, impacting both parts of the mixed food system common in many communities. This research provides insight into food consumption patterns, possible adaptation strategies and areas where knowledge is missing. It also paves the way for future work in this area.

Citation
Sheedy, Amanda. The Impacts of Climate Change on Traditional and Local Food Consumption in the Yukon, 2018.

7.0 LANDSCAPE PROCESSES

Impacts of past and future coastal changes on the Yukon coast – threats for cultural sites, infrastructure, and travel routes.

Authors
Irrgang AM, Lantuit H, Gordon RR, Piskor A, Manson GK

Keywords
Arctic coastal dynamics, permafrost coast, shoreline projection, Inuvialuit cultural features

Summary
The northern coast of Yukon on the Beaufort Sea contains cultural sites, infrastructure and travel routes that are vulnerable to coastal erosion. Climate change is impacting the rate and location of this erosion. Satellite imagery of 210km of coastline was used to construct projections of future erosion, which can be used with socioeconomic and cultural information to identify potential sites at risk. The region is underlain by permafrost, which serves to stabilize coastal features; as the climate warms permafrost is lost, reducing its ability to mitigate coastal erosion. The authors predict that 850 to 2660ha of shoreline could erode by the year 2100 causing a loss of 45-60% of coastal cultural features and infrastructure.

Relevance
Yukon historic and cultural sites are threatened by coastal erosion. As permafrost melts, due to climate warming, the coastline becomes more susceptible to erosion, increasing the risk to coastal historic and cultural sites. By moving gravel bars and shifting sediments, coastal erosion also threatens land and water based transportation routes.

Citation
Irrgang, Anna M., Hugues Lantuit, Richard R. Gordon, Ashley Piskor, and Gavin K. Manson. Impacts of Past and Future Coastal Changes on the Yukon Coast — Threats for Cultural Sites, Infrastructure, and Travel Routes. *Arctic Science* 5, no. 2 (2019): 107–126. https://doi.org/10.1139/as-2017-0041.

8.0 POLICY/GOVERNANCE

Canada's changing climate report

Author(s)
Bush E, Lemmen DS

Summary
This is a national scale report that discusses climate change impacts at a broad scale. It focuses on impacts or changes that experts have a high confidence will take place. Some of these impacts, or changes are: the climate has warmed, and will continue to warm; northern Canada is warming at double the rate of the rest of the world; oceans are warmer, more acidic and have less oxygen in them; the effects of warming have been observed throughout Canada and will increase; it will rain more; the availability of freshwater will be reduced; extreme weather events will be more common; sea ice is shrinking; coastal flooding will increase; different emission scenarios have vastly different outcomes for Canada. The goal of this report is to encourage 'collective action', and participation in global climate change and emission reduction programs to minimize the impacts of climate change. The first step to achieving this goal is to identify how Canada's climate will change, and what these changes mean for the people, environment and economy. Therefore, this report serves as a foundation for future national scaled climate change impact assessment projects.

Relevance
While national scaled, this report identifies northern Canada as a distinct region with unique environmental, social, and geographic conditions. A chapter of the report discusses changes to snow and ice, including permafrost, and lake and river ice. Yukon is underlain by permafrost in many regions and frozen lakes and rivers are important travel routes. Changes to permafrost are having a large impact on infrastructure in the territory. Snow cover is also diminishing in Yukon, as discussed in this report, compounding permafrost melt and lake/river ice reductions. Much of the information in this report is not targeted specifically at Yukon, however, shifts in permafrost and surface ice will have sweeping impacts across the territory, relevant at both local and national scales.

Citation
Bush, Elizabeth, and Donald S Lemmen. Canada's Changing Climate Report, 2019.

Sustainability and Indigenous interests in regional land use planning: Case study of the Peel Watershed Process in Yukon, Canada

Author(s)
Caddell E

Summary

Project level environmental and social assessment is typically used by Yukon Government to meet their assessment requirements for Yukon First Nations. However, applying a local, or project scaled assessment process to a larger geographic and/or temporal scale is not ideal. In order for assessment to function at a larger scale Regional Land Use Plans (RLUP) are necessary, and in some cases being implemented. However, the ability of these plans to meet the needs of Yukon First Nations is questioned by the author of this project. To assess RLUPs the author creates an evaluation framework and then applies it to the Peel Watershed planning process comparing how the two competing plans perform (Peel Watershed Planning Commission vs. Yukon Government).

Relevance

Climate change impacts can compound with other social, economic, political and ecological changes. For Yukon First Nations, climate change and other impacts are addressed via a project level impact assessment process. Because of the limited scale these assessments operate at, large scaled and long term needs or impacts are often not addressed. Because of the limitations of project level impact assessment Regional Land Use Planning is an important tool to ensure that the interests of all parties are better met. However, their effectiveness at balancing sustainability and the interests of Yukon First Nations has yet to be evaluated. This project creates a framework that is then used to evaluate the planning processes around the Peel Watershed, and how these processes met the needs of First Nations. The ability to objectively evaluate planning processes is important to ensure the desired outcomes of all parties are met, or failing that, to what degree desired outcomes are met. For example in the Peel Watershed, according to this framework, the plan proposed by the Peel Watershed Planning Commission meets 77% of criteria of Yukon First Nations while the plan proposed by Yukon Government met only 3%. Without a framework to evaluate processes stakeholders are unable to effectively determine if their needs are in fact met.

Citation

Caddell, Emily. Sustainability and Indigenous Interests in Regional Land Use Planning: Case Study of the Peel Watershed Process in Yukon , Canada, 2018.

Climate change action plan update

Author(s)

Climate Change Secretariat

Summary

In 2009 the Government of Yukon published the Climate Change Action Plan. This document was updated with progress reports and on-going action commitments in 2012 and 2015. The 2018 update reports on the progress of commitments made and provides a summary of action taken. This

is considered an interim document as a new strategy combining climate change, energy and the economy is planned for 2019 release. The 2018 update describes actions to mitigate greenhouse gas emissions, adapt to a changing climate and other steps the government has taken since the creation of the plan in 2009.

Relevance
This document reports on the actions the Government of Yukon has taken to mitigate, adapt and respond to climate change.

Citation
Climate Change Secretariat. Climate Change Action Plan Update 2019. Government of Yukon, 2019.

Evaluating the effectiveness of hazard mapping as climate change adaptation for community planning in degrading permafrost terrain

Author(s)
Flynn M, Ford JD, Labbe J, Schrott L, Tagalik S

Keywords
climate change, permafrost degradation, hazard mapping, adaptation evaluation

Summary
Hazard mapping is an important tool for community planning in areas with permafrost. It allows planners to identify existing infrastructure that may be threatened by changes to permafrost and plan new infrastructure that will not be vulnerable to permafrost changes. The Incorporating Climate Change into Land Development (ICCiLD) terrain analysis project uses synthetic aperture radar to classify the suitability of land for development and identify areas at risk. In this research the effectiveness of ICCiLD is analyzed, in a case study in the community of Arviat, by looking at the output of the radar, and interviewing creators and users of hazard maps. While ICCiLD is considered to be an effective tool by the authors of this study, communication, data interpretation and implementation were identified as challenges to fully realizing the value of ICCiLD.

Relevance
Yukon is underlain by both continuous and discontinuous permafrost. As the climate warms the nature of permafrost laden soil changes leading to slumping, changes to drainage and other effects that can be detrimental to infrastructure built on permafrost. In many communities in the far North permafrost is relied on to stabilize soil for roads and buildings. Climate change is impacting permafrost soils across Yukon and hazard mapping is a technique that can be used to identify terrain that will be subject to changes as the climate warms. This information can be incorporated into

planning and decision making to minimize risks. While the process of hazard mapping is established as an effective planning tool, this project identifies potential barriers to incorporating hazard mapping into the planning process and evaluates how the products of hazard mapping are used in the decision making process. This research provides a tool or framework to evaluate mapping projects prior to inclusion in the decision-making process.

Citation

Flynn, Melanie, James D. Ford, Jolène Labbé, Lothar Schrott, and Shirley Tagalik. Evaluating the Effectiveness of Hazard Mapping as Climate Change Adaptation for Community Planning in Degrading Permafrost Terrain. *Sustainability Science* 14, no. 4 (2019): 1041–1056. https://doi.org/10.1007/s11625-018-0614-x.

Yukon state of the environment interim report 2019

Author(s)

Government of Yukon

Summary

Interim report produced by Yukon Government summarizing many environmental indicators and trends. Information in the report is divided into the categories of climate change, air, water, land, and fish and wildlife. Information in this report was collected up until the end of 2018, and trends are compared with 2016 data. Environmental indicators are measurements that are used for monitoring and to describe and interpret changes. In each section of the report over-arching trends are reported, actions are detailed, and the quality of the data is described.

Relevance

Baseline information provides an important ‘platform’ for understanding how the environment is changing, and what the environment may be like in the future. By using baseline information collected over time, trends and patterns in environmental changes can be identified allowing future climate predictions. Baseline data and effective climate projections are important tools for climate change adaptation. By collating the data collected, and summarizing trends in a report the general state of the environment can be effectively communicated and used for adaptation planning throughout Yukon.

Citation

Kostelnik, Janine, Jennifer Smith, Kelsey Russell, Piia Kukka, Meghan Larivee, Oliver Barker, Jessica Elliot, and Amy Law. Yukon State of the Environment Interim Report 2019, 2019.

Policy, plans and processes for developing and improving the use of hazard maps in climate change adaptation for Yukon Communities.

Author(s)
Pike SN

Summary
Hazard mapping is a tool used during adaptation planning to assess the risk of future climate change impacts. While useful, training and education is required in order to use hazard maps effectively, limiting their usefulness to communities. Using case studies in Burwash Landing, Destruction Bay and Old Crow, hazard mapping is connected with the needs of these communities and used to identify areas where adaptation and mitigation are needed, as well as new opportunities are presented. Community members are interviewed on the subject of climate change, hazard maps and recommendations. The interviews were analyzed, and through this analysis the following recommendations were identified:

- Include GIS map layers into pre-existing maps.
- Use language that is accessible to communities.
- Communicate with stories.
- Provide consistent, and on-going education for communities.
- Develop an adaptation strategy framework.
- Support community based research.

The most important role of hazard mapping for communities is incorporating community scaled risk management strategies into climate change adaptation planning. However, it is important to also recognize that hazard maps are a guide, or one of the first steps in a many stepped adaptation strategy. Communication is a major barrier to implementing hazard mapping. While a large amount of research takes place in the North, there is no mechanism to ensure results are shared, or even available. The development or implementation of hazard mapping processes is left to individual communities, there is no over-arching government policy that directs the use of hazard mapping in planning.

Relevance
Community scaled climate change adaptation and planning research is generally lacking throughout Canada and Yukon leaving planners, policy makers and community members with a limited understanding of impacts at a community scale and on socio-economic systems. Hazard mapping can be used to incorporate scientific research into climate change adaptation planning, providing community members with knowledge of risks and changes. This process is important for isolated, and capacity-limited Yukon communities. Uncertainty is a large factor in any climate change adaptation planning initiatives. Research done at large scales may or may not capture the complexities of how communities change and respond locally. Each community is subject to its own

unique local conditions, attitudes, history, culture and economy, all of which play a role in how that community can respond to climate change. Community level hazard mapping provides insight into the risks and vulnerabilities communities must incorporate into planning processes.

Citation

Pike, Stephanie. Policy, Plans and Processes for Developing and Improving the Use of Hazard Maps in Climate Change Adaptation for Yukon Communities, 2019.

9.0 ENERGY

Integrated inexact energy systems planning under climate change: A case study of Yukon Territory, Canada

Author(s)
Chen JP, Huang G, Baetz BW, Lin QG, Dong C, Cai YP

Keywords
energy modeling, system analysis, optimization, climate change, GHG emission

Summary
In order to develop regional energy system decision making and reduce carbon emissions an 'inexact optimization' model is used. Effective energy planning is hampered by many environmental, economic and social factors which introduce a series of uncertainties. Because these uncertainties can make effective decision making difficult, an energy systems model that can include uncertainty is needed. The model described in this paper is used in three scenarios to produce energy generation solutions. The trade-offs of each system in terms of cost, carbon emissions and renewable energy use were analyzed, and the authors propose the model as an effective energy system planning method.

Relevance
Yukon uses a variety of energy sources including hydropower, diesel, LNG, biomass, gasoline and wind. It is only partially served by an energy distribution network with many communities relying on local energy sources. Additionally, it is at the 'edge' of its maximum power generation capacity, and thus planning and developing additional capacity that balances cost, future generation needs, environmental considerations and a rapidly changing climate is needed. This paper introduces a model that can be used as part of the planning process for future energy generation systems in Yukon despite environmental uncertainty.

Citation
Chen, J. P., G. Huang, B. W. Baetz, Q. G. Lin, C. Dong, and Y. P. Cai. Integrated Inexact Energy Systems Planning under Climate Change: A Case Study of Yukon Territory, Canada. *Applied Energy* 229, no. November 2017 (2018): 493–504. https://doi.org/10.1016/j.apenergy.2018.06.140.

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