The Alpine Club of Canada's

State of the Mountains Report

Volume 2, May 2019

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CANADIAN CATALOGUING IN PUBLICATIONS DATA

The Alpine Club of Canada's State of the Mountains Report

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ISBN: 978-0-920330-74-6

Cover Photo: Nelson 2017.
Photo: Adrian Wagner Studio

Inside Cover: Evening light on the waterfall at the Hallam Glacier GMC. Photo: Mary Sanseverino

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Foreword

The golden glow at home at the ACC's 2018 Hallam Glacier General Mountaineering Camp. Photo: Mary Sanseverino

The Alpine Club of Canada (ACC), Canada's national mountaineering organization, is committed to providing accessible, current, and accurate information about the forces that affect Canadian mountain places, ecosystems, and communities. This annual State of the Mountains Report is produced by the ACC in collaboration with mountain researchers, community members, and partner organizations. We are grateful to the many experts who have generously provided their insights and perspectives this year, and to the Royal Canadian Geographical Society and *Canadian Geographic* magazine for their continued efforts to help disseminate the report.

Mountains provide critical natural and cultural resources.

Canada's diverse mountains define much of the country. Mountains provide critical natural and economic resources like water, biodiversity, forests and recreational opportunities. They're also home for many people living in small and remote communities. But both local and global changes influence these places in ways that are still not well understood. The ACC's State of the Mountains Report is a contribution to compiling and sharing the best available knowledge about Canada's mountains, from coast to coast to coast.

Several recent global assessments have documented the stressors facing mountains around the world. For example, the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) Global Assessment, released in May 2019, comprehensively summarized the deteriorating health of the world's ecosystems. Mountains play a key role in sustaining biodiversity and critical ecosystem services on which people and all other species depend. Organizations like the Mountain Research Initiative (http://www.mountain-researchinitiative.org) promote international global change research in mountain regions, by helping to improve global collaboration.

Mountain research and education in Canada will be receiving new resources, too. On 16 April 2019, the federal Networks of Centres of Excellence program announced that the Canadian Mountain Network (CMN) will receive $18.3 million in funding over five years (2019–2024). With this new funding, CMN hopes to develop new collaborative programs to identify and respond to changing conditions in Canada's mountainous regions. The 2020 State of the Mountains Report will feature more information about the CMN, but you can visit their website for more details (http://canadian-mountainnetwork.ca).

This 2019 State of the Mountains Report begins with a feature essay, by Dr. Lori Daniels, one of Canada's foremost experts on wildfire. Over the past two years, multiple large wildfires have burned millions of hectares of mountain forests in western Canada. The resulting smoke smothered much of B.C. and Alberta for weeks during the summer, and visitors to the Rockies and Columbias were left to only imagine the peaks surrounding them. The long-term effect of fire on these mountain ecosystems and mountain communities are profound, and Dr. Daniels summarizes the factors that have contributed to these large fires, including the decades long policy of fire suppression and climate change. But optimistically, she also provides a road-map for learning to better manage fire, and to improve forest and community resilience to present and future wildfires.

We also feature a follow-up contribution to last year's feature essay, which described the dramatic changes that occur when retreating glaciers abruptly alter the flow of mountain rivers and their watersheds. Tosh Southwick and Kate Ballegooyen provide a Southern Tutchone perspective on climate and research in the southwest Yukon by describing how climate change impacts the day-to-day lives of people living in remote Indigenous communities and the relevance of Indigenous knowledge to understanding the impacts of these environmental changes.

The 2019 State of the Mountains Report contains ten more Knowledge Highlights. You can read about biodiversity, from the very small (snow algae and pine beetles) to the very large (caribou and bears). How people experience Canada's mountains is the focus of several other contributions, including the challenges of sustainable tourism, the state of the ACC's backcountry huts system, and Parks Canada's visitor safety program.

You can also read about the mountain building and the birth of the Appalachians in Newfoundland and the consequences of the loss of perennial alpine ice patches in the Northwest Territories.

We hope that these summaries, together with the 2018 Report and future annual volumes, will continue to provide a valuable resource for learning about Canada's mountains.

Several recent global assessments have documented the stressors facing mountains around the world.

Lael Parrott, Zac Robinson, and David Hik
May, 2019

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Left to right: David Hik, Lael Parrott, and Zac Robinson – 2018. Photo: Mary Sanseverino

Wildfires: Causes, Consequences, and Coexistence

Syringa Creek Wildfire, 2018. Photo: Ashley Voykin

Lori Daniels

Wildfire has become a wicked problem – complex, challenging, and full of paradoxes. In the summers of 2017 and 2018, intense, fast-moving and uncontrollable wildfires burned through a record-breaking 2.5 million hectares of grasslands and forests in British Columbia (BC) (Figure 1). The 2017 wildfires burned during fire weather that broke 85 maximum temperature records, forced the evacuation of 65,000 people, and triggered a 70-day state of emergency.[1] Multiple large fires burned in BC's southern interior, with the Plateau Complex setting a new record when nearly 20 fires merged to burn an astounding 545,151 hectares in the Cariboo-Chilcotin region. It was shocking that the 2018 wildfires in BC exceeded the area-burned records set in 2017. At the peak of the 2018 wildfire season, 566 fires burned simultaneously. Distributed across all six fire centres in BC, 49 fires of note were highly visible or posed a potential threat to public safety. Mirroring 2017, more than 20,000 people were on evacuation alert for prolonged periods, many had to flee their homes, and, sadly, numerous homes could not be saved. Collectively, the large fires in northwestern BC burned over 575,000 hectares of sub-boreal forests and generated smoke that made air quality in western Canada the most hazardous in the world for several days during August (Figure 2). Relief from many out-of-control fires depended on saturating rains in the fall.

The extreme wildfire seasons of 2017–18 in mountain forests of the Canadian Cordillera are not isolated events.

The extreme wildfire seasons of 2017–18 in mountain forests of the Canadian Cordillera are not isolated events. They are part of a global trend of increasing area burned and extreme fire behaviour resulting in megafires with tremendous ecological, social, and economic costs – as witnessed in recent years in from Ontario to British Columbia, throughout the USA, Argentina, Chile, New Zealand, Australia, Indonesia, India, Portugal, Greece, Spain, Italy, France....[2,3] Over the past 15 years in western Canada, record-breaking heat waves in spring and early summer meant fire seasons started earlier with longer, more pronounced summer droughts – our new reality given ongoing climate change and the fundamental links between heat, drought, and wildfire. Not every fire season will break records, but years like 2017 and 2018 will become increasingly common over our lifetimes.

Importantly, we have learned our mountain forests and the communities within them are not resilient to wildfire and adaptation is urgently needed.[4]

Wildfire: A Diverse and Complex Force of Nature

Understanding wildfire is a necessary first step to ensure adaptation is effective. Wildfire is an essential ecosystem function and evolutionary force that has shaped the ecology of many trees, plants and fauna. The intensity, rate of spread, and behaviour of individual wildfires are determined by weather, topography, and characteristics of the vegetation or fuels that burn. Three general types of wildfires include ground fires that burn organics below the soil surface, surface fires that burn above-ground decomposing organics and small-statured plants, and crown fires that spread between tree tops. The severity or impact on vegetation reflects fire type, location, timing, duration, weather conditions, and elements of chance. A fire regime describes the spatial and temporal attributes of multiple fires in a landscape over time. Wildfires can interact with other disturbances, like mountain pine beetle, with additive or synergistic effects. The timing and sequence of events, and their interactions with weather and climate can result in novel disturbances and ecological surprises.

In temperate and boreal latitudes, historical fire regimes varied along environmental gradients that reflect the interactions between climate and topography, which determine vegetation types (Figure 3). Arid deserts occupy the driest environments, often located in continental rainshadows of mountain ranges. Although the hot, dry

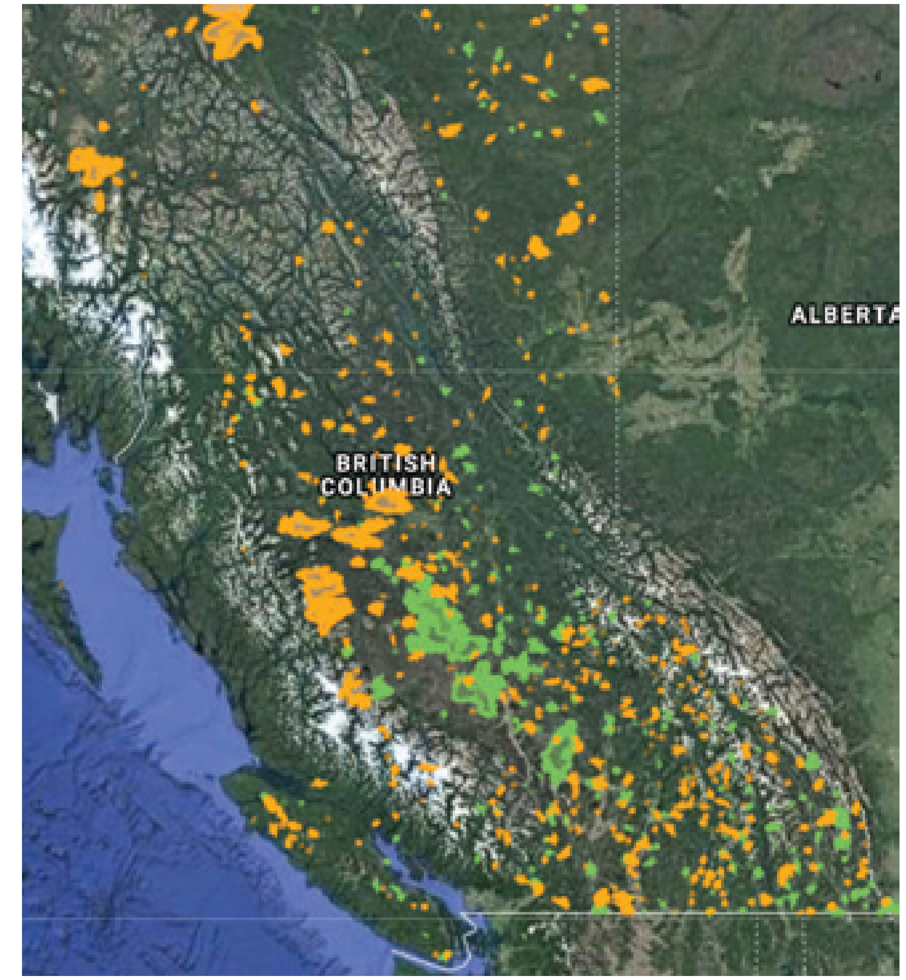
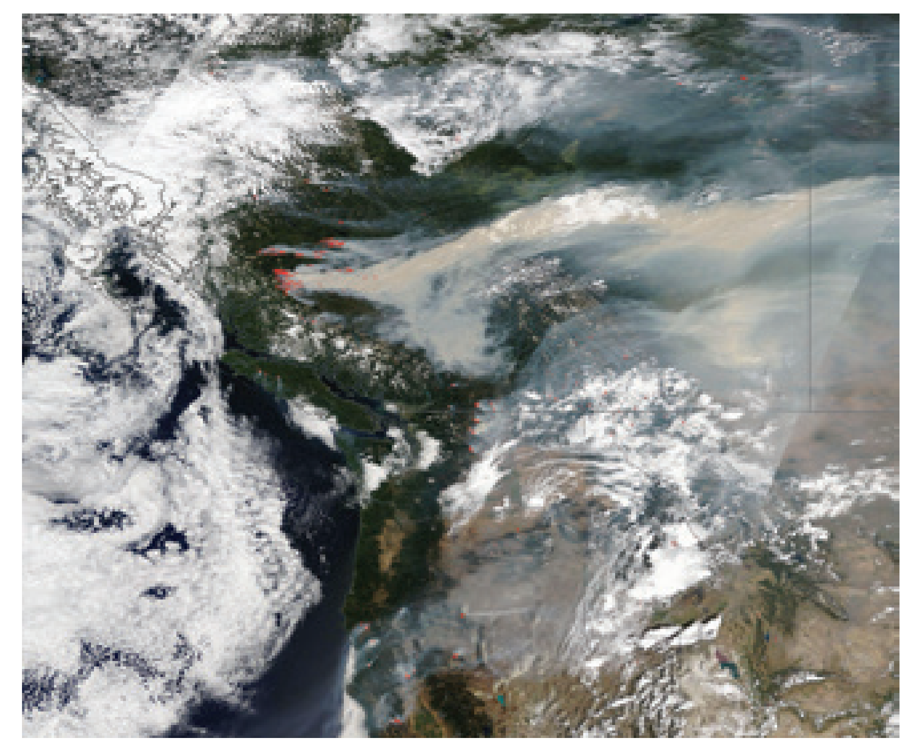


Figure 1 – Wildfires burned 2.5 million hectares in 2017 (green) and 2018 (orange) from grasslands to subalpine forests and from boreal forests to coastal temperate rainforests (source: https://emergency-maps.lightship.works/).

Figure 2 – Satellite view of the smoke generated by fires in British Columbia on August 17, 2018, causing the some of the worst air quality in the world (source: NASA WorldView https://go.nasa.gov/2SbCF2n)



Syringa Creek wildfire, 2018.
Photo: Ashley Voykin

climate is conducive to burning, the vegetation is discontinuous and wildfires are unable to spread. Native plants lack adaptations, so effects are very severe during infrequent fires. At the opposite end of the spectrum, coastal temperate rainforests grow in the wettest environments on the windward side of mountain ranges. These productive forests are susceptible to crown fire only during exceptional droughts. As a result, wildfires are infrequent, with potentially severe effects given the abundance of vegetation that is available to burn.

In the mountains, fire regimes vary along elevational gradients from warm, dry valley bottoms to cold, snowy alpine environments. Although wildfires of a range of severities historically burned at all elevations, fire severity generally increased with elevation. Historically, frequent surface fires maintained grasslands and open woodlands growing in valley bottoms, where warm dry summer weather is conducive to burning in most years. During the short interval between surface fires, typically less than 25 years (often less than 10 years), fuel accumulation was limited so fire severity remained low. Grasses, forbs, shrubs, and some trees are adapted to surface fire by storing biomass and regenerative tissues below ground. Thick, insulating bark protects growing tissues. Some trees may be damaged but survive, forming persistent fire scars in their tree rings, thus providing physical evidence of past surface fires. Repeated high-frequency and low-severity fires maintained forest structures and fuel loads – a feedback that perpetuated the surface fire regime.

Intense crown fires burn at long intervals of one hundred to hundreds of years in high-elevation subalpine forests, similar to many sub-boreal and boreal forests across Canada. In these forests, regional climate strongly influences wildfire frequency and severity through patterns of seasonality, temperature, and precipitation. Given the short summers and cool, mesic climate at high elevations, trees grow and fuels accumulate slowly. Vegetation in mature subalpine forests become susceptible to wildfire during drought. Persistent blocking high-pressure systems bring warm, dry weather conducive to crown fires, especially during windy conditions. Although these fires are severe and kill most trees, surviving trees and island remnants provide habitat refugia and seed sources for the next generation of forest. Natural regeneration forms even-aged forests. Over time and space, periodic crown fires diversify forest composition, structure, and fuels, affecting fire behaviour and forming natural firebreaks – perpetuating landscape diversity and variable fire effects.

Mid-elevation montane forests are considered most diverse and complex, reflecting their mixed-severity fire regimes. Historically, low-to-moderate severity fires burned at intervals averaging 25 to 60 years, reducing burnable surface fuels and understory tree densities, scarring trees, and creating small openings for new cohorts of trees to establish. Higher-severity fires burned at longer intervals of 60 years to many centuries, generating patches of even-aged forests. Within an individual fire and across landscapes, forest patches simultaneously burned at a range of severities. Variations in fire severity over time added to montane forest complexity.

Tree-Ring Science and Fire History Reconstructions

Surface and crown fires impact forests differently, so multiple lines of evidence are combined to reconstruct fire histories. Tree-ring analyses have been particularly powerful for understanding historically low- and mixed-severity fire regimes that commonly included surface fires.[5,6] Fire scars on individual trees, snags, logs or stumps provide direct evidence of low-severity surface fires that damaged, but did not kill the tree (Figure 3). Old "veteran trees," those that survive at least one fire over their lifespan, can include multiple fire scars over several centuries. Using a method called "crossdating" (see inset box), the exact year of fires can be determined from scars. Compiling fire-scar dates from multiple trees in a forest provides a long-term historical record of fire occurrence, timing, and frequency (Figure 4). Crossdated tree ages, growth histories, and years of death corroborate inferences on fire timing and severity. Within a fire, thin-barked species, small regenerating trees, and even some large trees with thick bark

Figure 3 – Fire scars are evidence of past low-severity surface fires that damaged but did not kill trees. By crossdating, or pattern-matching the rings among trees, we determined this western larch died in 1957, established in 1682, and survived 6 fires over its lifespan. (source: Jamie Myers)

> ***"Crossdating"** is a method that matches the ring width patterns among trees of the same species growing in similar environments to ensure an exact calendar year is assigned to each tree ring. Crossdating increases accuracy of age estimates, pinpoints the timing of growth anomalies like fire scars, and ascertains the year of tree deaths from the outer ring of a snag, log or stump.*

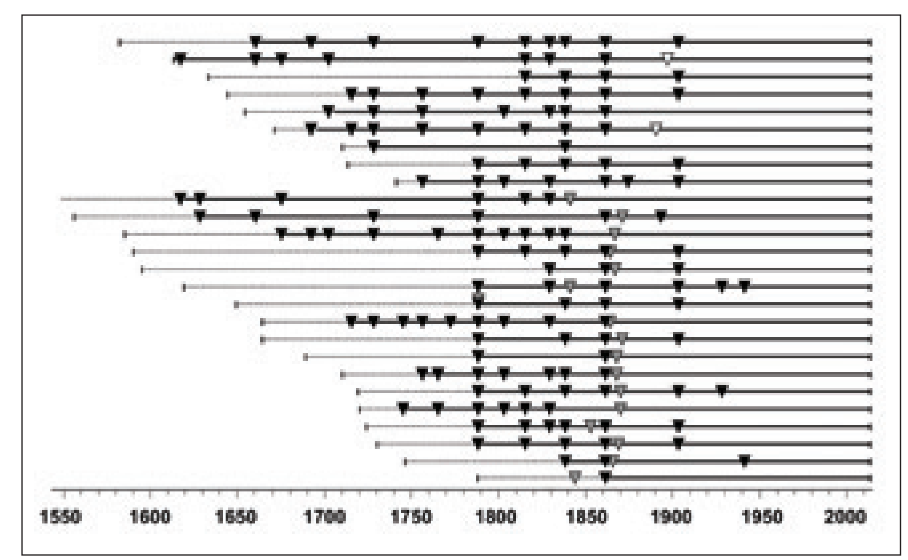


Figure 4 – Fire history of UBC's Alex Fraser Research Forest near Williams Lake, BC shows fires burned once every 15 years from 1650 to 1943, with no fires since then. Each horizontal line represents one of 26 sites. The length of the line depicts the lifespan of the oldest tree sampled at the site. Black triangles are years when surface fire scarred trees; grey and white triangles are years when groups of trees established. After the most widespread fire in 1863, 76% of trees established (source: Wesley Brookes, MSc thesis, UBC-Vancouver).

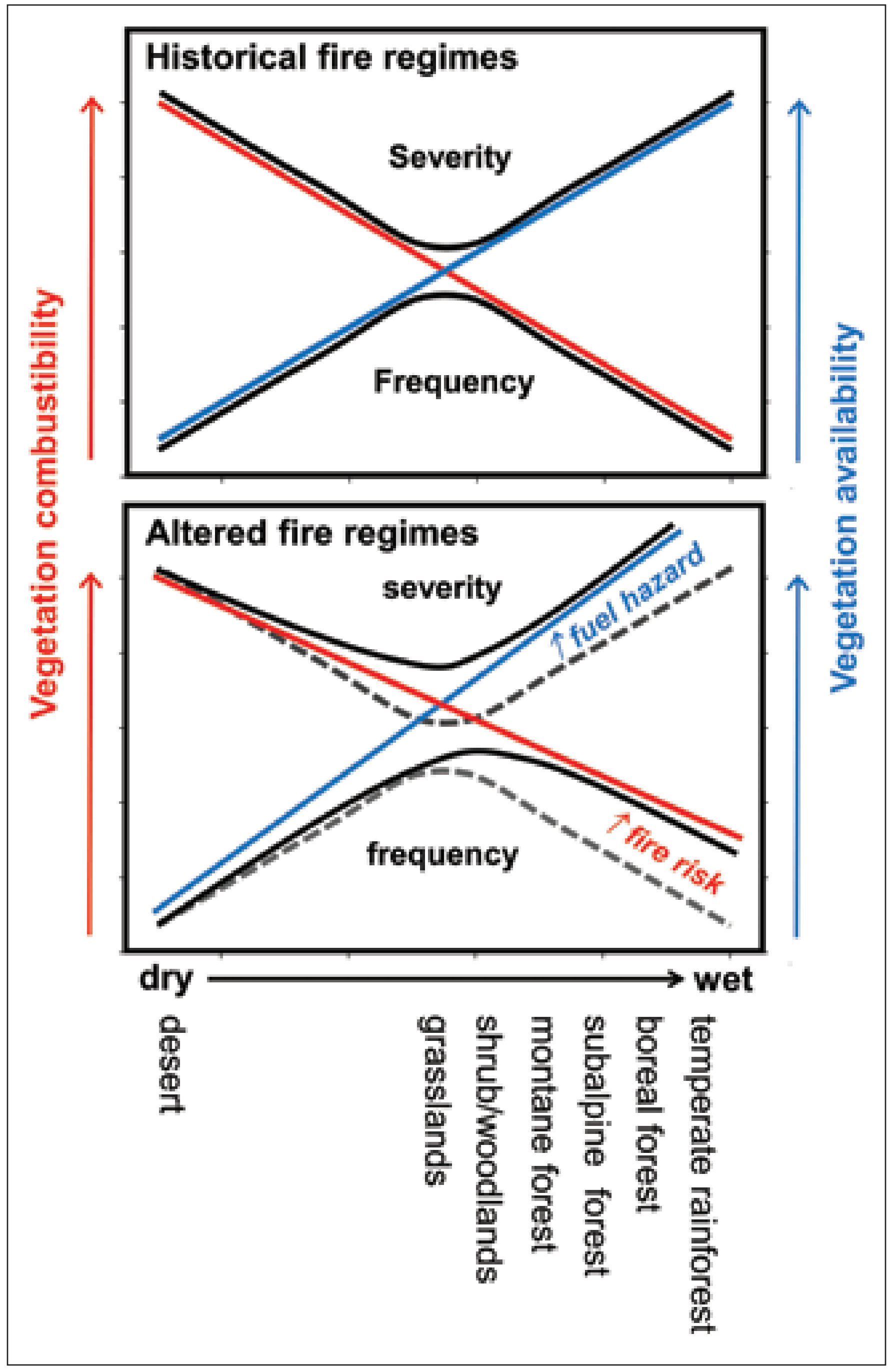


Figure 5 – In historical fire regimes (top), wildfire frequency and severity were inversely related and varied along environmental gradients that influence the combustibility (red) and availability (blue) of burnable vegetation in an ecosystem. Human impacts and climate change have altered fire regimes (bottom). Fuel hazards accumulate due to fire suppression and tree deaths due to drought-stress and mountain pine beetle. Fire risk is enhanced as vegetation dries and becomes more susceptible to burning during prolonged or acute summer droughts.

are killed, creating openings where pulses of trees colonize the resulting forest openings. Ultimately, successive surface fires generate complex forests that include trees of a wide range of sizes and ages and heterogeneous forests across landscapes. In contrast, following high-severity crown fires, regenerating trees are similar in age and size, with few veterans or fire-scarred trees. Across landscapes with high-severity fire regimes, crown fires create a patchwork of forests with distinct boundaries, each initiated by different fires through time. Lastly, to corroborate tree-ring reconstructions of historical surface and crown fires, independent evidence is sought such as oral histories, documentary records, historical photographs, soil chemistry, and charcoal and pollen in lake sediments.

Disrupted Fire Regimes and Unintended Consequences: The Fire Suppression Paradox

There is strong evidence that fire regimes were disrupted during the 20^{th} century (Figure 4). The degree of disruption varies depending on the historical fire regime. Surface fires in Canada's valley-bottom and montane forests have been virtually eliminated, consistent with other forests in western North America.[5] Our fire-scar records consistently show that frequent surface fires ceased between the late 1800s to mid-1900s.[6-10] This disruption resulted from the cumulative effects of European settlement, combined with climatic variation and contemporary wildfire management. Allocation of land to settlers displaced Indigenous people from their traditional territories and laws banning human-set fires decreased cultural fire practices.[11] Changes in land use to agriculture and livestock grazing changed the distribution and continuity of fuels, reducing fire spread. Regionally, the 1940s through 1970s were relatively cool and wet, which is not conducive to wildfire.[12-13] Perhaps the greatest single factor is the systematic detection and active suppression of wildfires, which has continually improved with technological advances.

The "fire suppression paradox" reflects the unintended negative consequences of fire suppression on forest diversity, health, and hazardous fuels (Figure 5). Modern societal perception of wildfire as a destructive force has justified a command-and-control wildfire management approach. Prior to 2010, the mandate of the BC Forest Service Protection Program was to "provide wildfire management and emergency response support to protect life and assets, particularly forest and grasslands (p.7)."[14] Achieving their mandate, the BC Protection Program successfully detected and suppressed 92% of wildfires within 24 hours of ignition and before they exceeded 4 hectares in size. Over several decades, success yielded unforeseen consequences. As easy-to-control surface fires were extinguished, trees encroached into grasslands and forests grew denser. In absence of periodic surface fires, abundant shade-tolerant but fire-intolerant understory trees form "ladder fuels" that conduct surface fire to tree crowns. These changes in forest composition and structure, plus accumulated surface fuel hazards, have increased the chance of severe crown fires in many forests, raising concerns about their resilience after contemporary wildfires.[6-10, 15]

Human impacts on high-severity fire regimes in subalpine and boreal forests are more subtle. Some scientists considered human impacts minor because the period of suppression is shorter than the average interval between crown fires.[16] As well, crown fires continue to burn in many parts of Canada, especially during hot, dry, windy weather and in remote locations north of the zone of managed forests.[17] In BC, where attempts were made to suppress all fires for several decades, forests simultaneously matured forming uniform fuels across landscapes. High-grade logging of large trees in the early 1900s followed by industrial forestry and regeneration of conifer forests have also simplified and homogenized forests. By the 2000s, the expansive mature forests were prime habitat for mountain pine beetle, which impacted 18.1 million hectares in BC and expanded its range east of the Rocky Mountains into Alberta.[18] The beetles increased the ratio of dead-to-live trees and salvage logging added abundant surface fuels. Widespread hazardous fuels contributed to the extreme wildfires of 2017–18 in BC. Abundant, uniform fuels combined with hot, dry, windy weather drove fast-moving wildfires with volatile behaviour and severe impacts that proved difficult to contain and suppress (Figure 3).

Climate Change and Wildfires

Climate change exacerbates wildfires in numerous ways.[19-22] Most obvious are the direct effects of record-breaking maximum temperatures, prolonged droughts, and extreme fire danger driving intense, fast-moving wildfires (Figure 5). In BC, during the summer of 2017, 85 maximum temperature records were set, and fire-weather drought codes reached new highs. Recent cutting-edge research by climate experts on BC's 2017 wildfires shows a >95% probability that this record heat was due to human factors.[23] Fire weather was elevated 3-fold and area burned 9-fold. Indirectly, climate change affects lightning ignitions and length of fire seasons. Many of the 2017–18 wildfires started when thousands of dry lightning strikes ignited 100 to 180 new fires over 1- to 3-day periods. These patterns are foreboding as lightning is projected to increase by 12% for each degree Celcius of global warming,[24] although the percent change will vary among locations.[25] Winter weather also indirectly influences wildfires. Warm winter temperatures lead to low snowpack, early snowmelt and start of the fire season, and more pronounced summer drought.[26] These lagged winter effects contribute to increased regional wildfire activity following warm El Niño winters, increased area burned in the western United States associated with early springs since the 1980s,[26] and projections of more extreme fire danger, longer fire seasons and more frequent and severe fires in western Canada.[19-22]

Wildfires are both driven by and contribute to climate change. The 2017–18 wildfires emitted about 120 and 175 Megatonnes of carbon dioxide[27] — two and three times normal annual emissions for the entire province of

Peachland wildfire, 2018. Photo: Jason Lehoux Photography

Warm winter temperatures lead to low snowpack, early snowmelt and start of the fire season, and more pronounced summer drought.

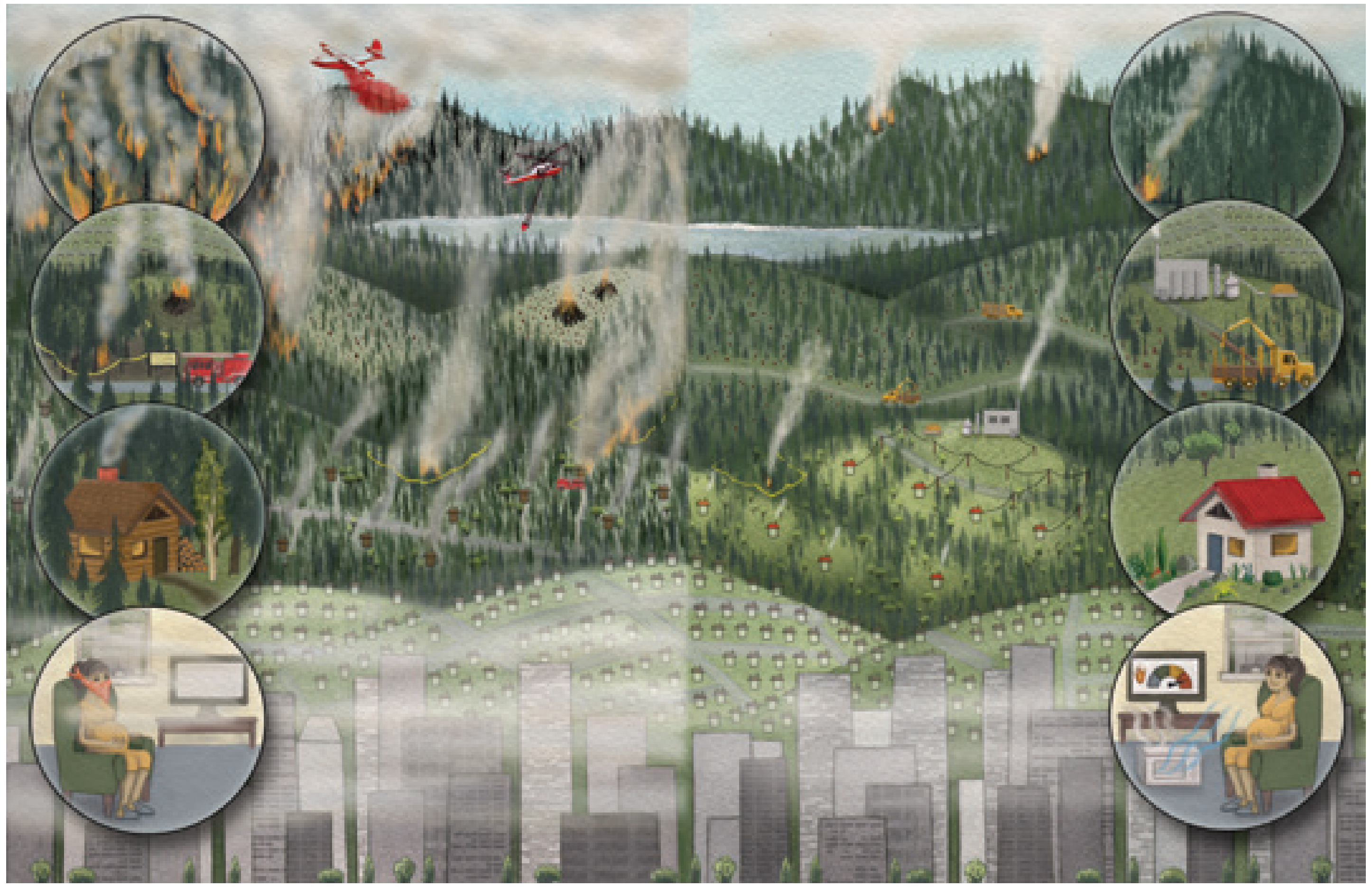


Figure 6 – Transforming from an era of megafires (left) to coexisting with fire (right). Transformative changes to wildfire and forest management (top) and increased participation in Fire Smart by homeowners and citizens (bottom) are essential for our society to adapt to wildfires and climate change (artwork: Jen Burgess / @isolinestudios; source: Bowman et. al 2018, Fire, 1, 27).

BC.[28] Given projections of more frequent and severe fires, the short intervals between fires will result in younger forests, on average, and decrease in the carbon storage. Moreover, summer droughts are reducing survival of regenerating trees and growth of mature trees, and driving tree mortality due drought stress and climate-mediated disturbances like insect outbreaks. In fact, recent reports indicate the combined effects of wildfires, mountain pine beetle, and harvesting make the forests of BC a net source of atmospheric carbon, rather than a sink.[28, 29] More greenhouse gasses drive more warming, elevating wildfire risk and fuel hazards. This feedback underscores the need to meet (preferably exceed) international carbon emission targets in the long term and mitigate emissions by uncontrollable wildfires in the short term.

Transformative Change: Learning To Coexist With Fire

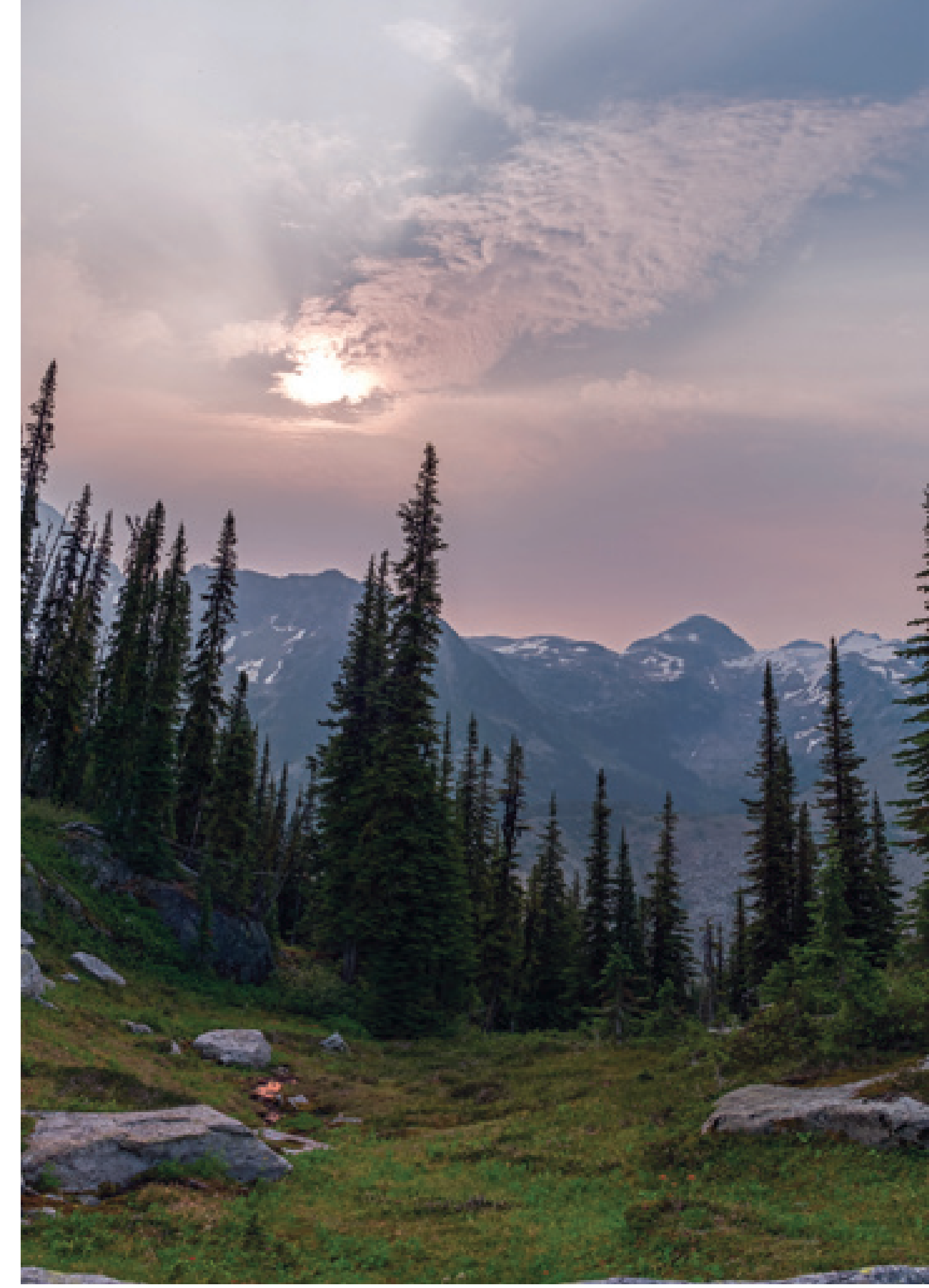
Transformative changes to wildfire and forest management are essential to achieve forest and community resilience to contemporary and future wildfires (Figure 6).[4] In 2012, BC's mandate for wildfire management expanded to encourage sustainable, healthy and resilient ecosystems as well as protecting lives and values at risk.[30] Although it may seem counter intuitive, long-term solutions must include fire on the landscape. Managed wildfire is one strategy that lets wildfires burn if they not pose risk to life and property. These wildfires are key to restoring ecosystem function in naturally flammable landscapes. They are an effective way to reduce and diversify fuels, create natural firebreaks, and lower risk of subsequent uncontrollable wildfires.

__FireSmart__ guides Canadians on how to prepare for and live with wildfire. Being prepared is a responsibility shared by homeowners, forest users, and all levels of government. The seven FireSmart disciplines are education, vegetation management, legislation and planning, development considerations, interagency cooperation, emergency planning, and cross training. For more information visit firesmartcanada.ca

Proactive vegetation management is a surrogate for wildfire closer to communities where we continue to suppress wildfires. In fact, vegetation management is one of the seven pillars of *FireSmart* – a program designed for all Canadians who live in fire-prone environments (see text box). In the wildland-urban interface, the chance of successfully stopping wildfire increases when hazardous surface and ladder fuels are reduced and the canopy opened by thinning and pruning trees. The resulting forest structure is less likely to conduct crown fire and creates a defensible space to aid firefighters in the case of a wildfire. Therefore, all communities surrounded by forests would benefit from proactive management to mitigate fuels, regardless of forest type and degree of disruption to historical fire regimes.

Under the right conditions, fire can do more good than harm — prescribed burning is the ultimate example of "fighting fire with fire."[31] Carefully planned and detailed prescriptions are put into operation only during suitable weather conditions to achieve targeted fire behaviour and effects and to ensure smoke rises and disperses. Broadcast burning is applied across an area, while pile burning reduces fuel in discrete locations but constrains fire spread. Prescribed broadcast burning, combined with forest thinning, is very effective for mitigating surface fuels and reducing the potential for crown fire. Broadcast burning has proven effective to restore fire-prone ecosystems. For example, proactive fire management in many of Canada's national parks includes prescribed burning to restore ecological integrity and improve landscape resilience.[32] Since the 1980s, fire and vegetation management specialists have successfully used managed wildfire and prescribed fire to restore wildlife habitat in grasslands and forests, reduce risk of catastrophic wildfire forests affected by mountain pine beetle, create fuelbreaks to reduce the chance of wildfires spreading into nearby communities, and mitigate hazardous fuels near towns, historical sites and critical infrastructure.

Balancing the costs and benefits of prescribed burning has been a societal concern. The negative smoke effects on air quality, visibility, human health, and greenhouse gas emissions are a tradeoff for the multiple benefits from prescribed burns.[33] However, smoke emissions from prescribed fire are short-term and lower than smoked from uncontrollable wildfires and citizens can be advised in advance of prescribed burning to reduce negative health impacts. Given the size and intensity of wildfires and the distressing amounts of smoke generated in summers 2017–18, the value of prescribed broadcast



Morning sun through smoky skies at the ACC's 2017 Albert Icefield General Mountaineering Camp. Photo: Mary Sanseverino

Peachland wildfire, 2018. Photo: Jason Lehoux Photography

burning is at the forefront of discussions on future wildfire and forest management.

The substantive socio-economic impacts of the 2017–18 wildfires have catalyzed discussions to transform forest management in BC. Of BC's 57 million hectares of forests, 22 million hectares comprise the "timber harvesting landbase."[34] Management for a single value — timber — was intended to develop a strong resource-based economy and support rural communities following the Second World War. Seventy years later, there are several indicators that this approach has elevated forest vulnerability to climate change and climate-mediated disturbances. By focusing on the state of individual forest patches for economic gain, forests have been simplified and homogenized, vital ecosystem functions have been altered, and recognition of cumulative human impacts has been slow.

Learning to coexist with wildfire is critical as our society adapts to climate change.

A holistic, landscape view and transformative changes to wildfire and forest management are required to achieve forest and community resilience to contemporary and future wildfires.[28, 29, 33] In BC, two pilot studies are underway on million-hectare landscapes. Historical fire regime attributes derived from western science and indigenous ecological knowledge provide their foundation. Innovative plans include managed wildfires, thinning, and prescribed burning to create firebreaks at strategic locations, with the goal of altering wildfire behaviour, especially near communities. Diversifying forest management beyond conventional timber products will mean less harvesting in some areas and more variable silviculture to manage forests with complex species mixes and structures. Incentives for green-energy and greater biomass utilization are needed to reduce the amount of medium and large waste wood that is currently mitigated by pile burning. With reduced fuel loads, prescribed broadcast burns would mitigate small-sized surface fuels, create firebreaks, and protect regenerating forests, with low smoke emissions. A long-term perspective is needed when regenerating forests after wildfire or harvesting. For example, it is tempting to plant fast-growing trees at high density to sequester and store carbon as quickly as possible. However, dense forests contributed to the severity of recent wildfires. In many forests, planting fewer trees of mixed species will reduce competition, drought-induced stress, and future accumulation of hazardous fuels as the forest matures. In this case, less is more to increase tree survival and the resilience of our forests in a warming world.

Take-home Message

Learning to coexist with wildfire is critical as our society adapts to climate change.[4,33] For some, accepting managed wildfire and prescribed burning as strategic solutions may seem counter-intuitive. For others, the economic costs of changing forest management may seem prohibitive. Yet, deep understanding of the vital role of wildfire on ecosystem function has revealed the short-comings of past fire suppression and timber production and the tremendous vulnerability of our forests and communities. Tinkering will not be sufficient – now is the time for transformative change, so that our society can safely coexist with wildfire.

Lori Daniels is a professor in the Department of Forest and Conservation Sciences at The University of British Columbia.

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Living and Breathing Change: A Southern Tutchone Perspective on Climate and Research

The dry and dusty Ääy Chù (Slims River) basin in May 2018. Photo: Zac Robinson

Co-written by Tosh Southwick (KFN citizen) and Kate Ballegooyen (KFN staff member)

Looking out at Łù'àn Män (Kluane Lake), it is hard to ignore the impact climate change is having on Kluane First Nation (KFN) Traditional Territory. As we write this, we are nearing the end of November, the temperature is above zero, and the lake, the largest and deepest in the Yukon, is only partially covered with ice. In the not-so-distant past, KFN Elders set nets across the lake, traveling over ice in October to catch whitefish. But this is not the only instance of climate change within the Traditional Territory.

> *Without the close and deep involvement and direction of Kluane First Nation, there can be no real mitigation of the risks, answers to the questions, or solutions to the new challenges posed by climate change.*

In May 2016, the Kaskawulsh Glacier in the Yukon Territory retreated to the extent that it diverted the headwaters of Ääy Chù (Slims River), which previously flowed into Łù'àn Män, into an entirely different watershed, the Alsek River drainage. Water levels have since declined in Łù'àn Män by three metres on average. This instance of "river piracy" garnered international attention from researchers, media and government, but largely ignored the impacts to those most affected by climate change – northern and remote Indigenous communities. The community story was lost in the barrage of media coverage and by many researchers. There cannot be an absence of the community and people who are intricately connected to this place. Without the close and deep involvement and direction of Kluane First Nation, there can be no real mitigation of the risks, answers to the questions, or solutions to the new challenges posed by climate change. Armed with Traditional Knowledge, and generations of traditional practices, it is our citizens and Elders who live and breathe these changes.

Kluane First Nation is one of 11 self-governing First Nations in the Yukon, recently celebrating 15 years of self-governance. This agreement includes a land quantum of approximately 906 square kilometres with surface and subsurface rights. These agreements were the first of their kind in Canada and recognize extensive province-like powers for First Nation governments. Kluane First Nation is based in the community of Burwash Landing on the shores of Łù'àn Män, the territory's largest lake. The people of KFN are of Southern Tutchone ancestry. Kluane First Nation has approximately 250 citizens with approximately 120 people living in the Traditional Territory.

How environment shapes First Nation cultural identity

As KFN citizens, we inhabit an area that our ancestors called home, and like our ancestors, we are innately connected to this land. This land is part of us, and we are part of it. When the land changes, it changes us. Our traditions, our values, and our world views are all shaped by the land and our connection to it.

We have to relearn the lake and our Traditional Territory for it is irrevocably changed, and that means the way we interact with our Traditional Territory must be adapted. We have entered a space where our Traditional Knowledge, which we have relied upon for generations, needs to be updated to reflect the new learnings, observations and realities. We cannot reliably set nets where our great-grandmothers did with confidence that we will have a successful outcome because the lake is dropping, and it is warming up. The fish are adapting to the changes, and we will have to as well.

We cannot rely on the timing or the thickness of the ice in certain spots anymore, meaning we cannot get to our winter fishing and trapping areas in the same ways we did just a few years ago. Kluane First Nation citizens have to find new ways of navigating what are now largely unknown realties on the frozen lake.

What we can rely on is our long and definitive history of resilience and adaptation. Just as our Elders were forced to adapt to the many changes in their lifetimes, our current generations will need to adjust our traditional practices to the changes brought

Grace Southwick, KFN Citizen and Executive Director and KFN Elder Dennis Dickson overlook the Kaskawulsh Glacier in 2018. Photo: Erika MacPherson

Students from Kluane Lake School point to Łù'àn Mān, their home nestled within the headwaters of the Yukon River salmon habitat, 2017. Photo: David Hik

about by rapid climate change. We will need to focus on the changes and learn new ways so we can pass the knowledge on to future generations.

In many ways, KFN is ahead of the curve when it comes to adapting to climate change. We've conducted hazard assessments throughout the Traditional Territory, we've installed solar panels, a biomass district heating system, and soon wind turbines will be constructed to lessen our reliance on diesel. Kluane First Nation has also developed a food security strategy to deal with changes to subsistence harvest levels.

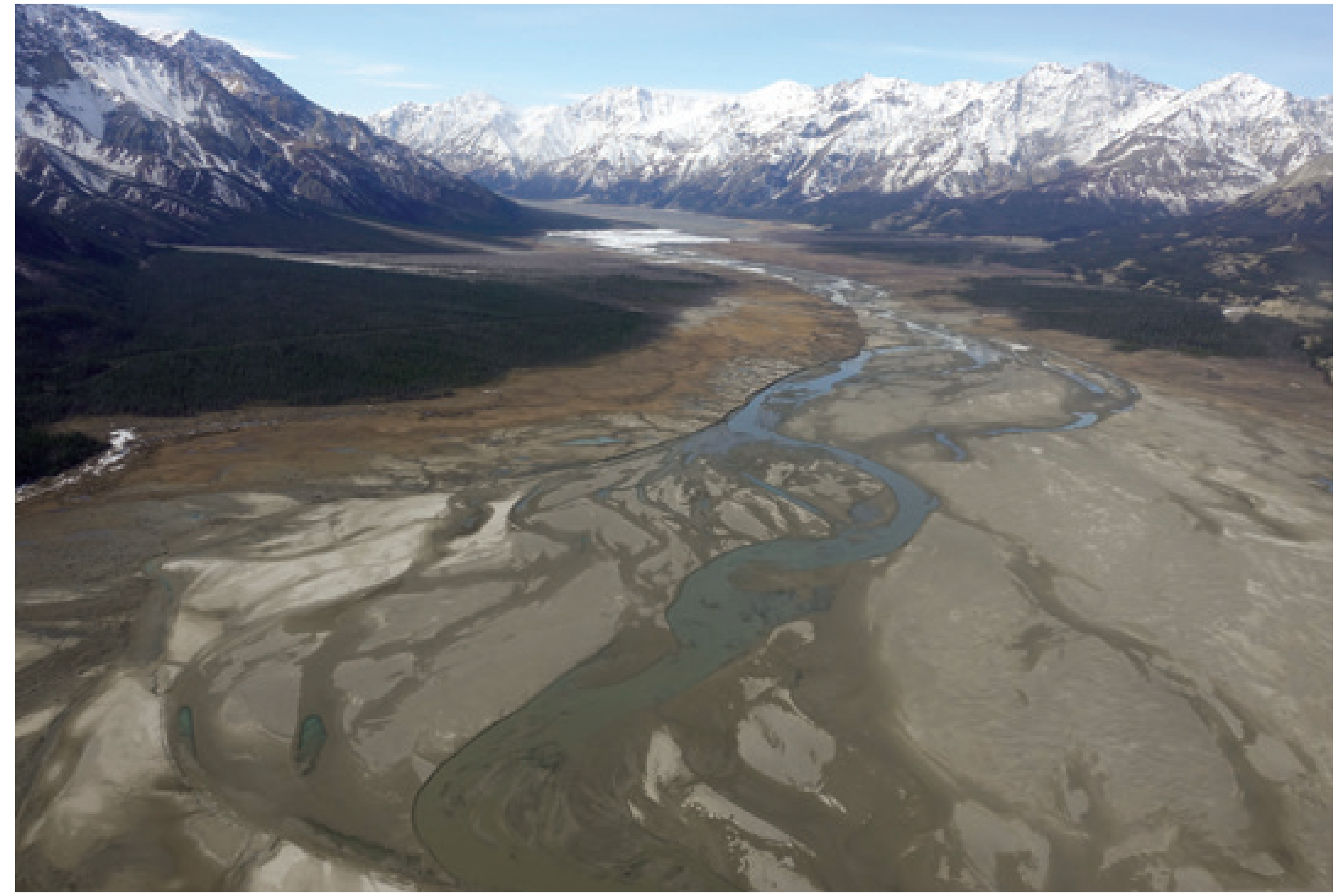
It is a surreal experience when you hear or read others talking about the place that you are part of without so much as a mention of any trace of your community, your people, or your history.

Kluane First Nation's leadership has always worked towards self-reliance and building a resilient community. This vision has allowed KFN to actively respond to climate change and changes to the Ä̀äy Chù (Slims River) by partnering with researchers from the Department of Fisheries and Oceans, Environment and Climate Change Canada, and the Yukon Government Water Resources Branch to assess effects of climate change on salmon spawning habitat and water quality, and to understand how the lake is responding to climate change. Furthermore, KFN has partnered with researchers from University of Waterloo to put forward a proposal to measure ice thickness throughout the lake to ensure safe travel throughout the winter.

Last year KFN and the Dan Keyi Renewable Resource Council jointly hosted the Kluane Lake Research Summit to review current and past lake research. The Summit encouraged two-way learning opportunities among delegates through presentations, dialogue and activities. The main recommendations from the Summit included engaging in cross-cultural learning, developing KFN research protocols and priorities, and the push to further include Traditional Knowledge in research. Another research summit is planned for spring 2019.

It is a surreal experience when you hear or read others talking about the place that you are part of without so much as a mention of any trace of your community, your people, or your history. It is not a new experience for Kluane First Nation citizens; in fact, it is the norm. As a KFN members, when we are presented with research that has been done in Kluane First Nation Traditional Territory without any partnership of KFN, it is immediately apparent. The research is almost always an incomplete picture of the true narrative. It appears as a disconnected vein of some truth rather than a holistic and comprehensive project based in authentic partnerships. Of course, much of this stems from the fact that KFN, like many indigenous communities, inherits research rather than drives it. There needs to be a fundamental shift in the way we conduct research in the traditional territories of indigenous peoples. For example, it can shift to a process that is grounded in partnership and even one that is directed by the local First Nation. In our experience, communities that drive the research questions being explored are vastly more involved and the research is richer for it. We are starting to see glimmers of hope that this shift is coming. These include the invite to contribute to this very publication, and the genuine attempts by scientists to reach out and start a new way of conducting research.

It quickly became apparent that KFN needs to tell its own story, separate from researchers, media or government. Last fall, the



Looking up the valley of the Ä̀äy Chù (Slims River) from Łù'àn Mān (Kluane Lake), 2018. Photo: Zac Robinson

Prairie Climate Centre out of the University of Winnipeg approached KFN to see if we wanted to tell a story about climate change from the First Nation and community perspective. We partnered to tell the story of the Ä̀äy Chù and dropping lake levels, which they were unaware of. Citizens traveled to the toe of the Kaskawulsh Glacier to witness the change first-hand, which was not an easy feat (image 1). This also involved building capacity amongst KFN youth, who were involved intimately with the filming, interviewing and editing of the film. Elders and community members participated through interviews, speaking not only to recent changes, but also to long- term observations and Traditional Knowledge. We hope to present this film at the next research summit to demonstrate how climate change impacts affect the day-to-day lives of those living in northern remote indigenous communities.

Research in traditional territories needs to be driven in some large part by the people who live there. The agenda needs to shift towards partnership and community questions and solutions. In the North, indigenous communities are on the front lines of climate change. Solutions should come from community members as they know which are best for their communities. It is our hope that, in the future, research is done with Kluane First Nation, that it is guided by our values, goals, and research questions, that our Traditional Knowledge is at the forefront of those studies conducted in the Traditional Territory, and that it is conducted for and by KFN citizens.

Tosh Southwick belongs to the wolf clan and is a citizen of Kluane First Nation. She is currently the Associate Vice President of Indigenous engagement and reconciliation at Yukon College.

Kate Ballegooyen is the Natural Resources Manager, Kluane First Nations (KFN). While her focus is conducting development assessments for KFN, Kate also works to facilitate research projects throughout the Traditional Territory. Kate has been living in Burwash for the past five years.

Parks Canada Visitor Safety Program Focussed on Incident Prevention and Response

Conrad Janzen

The mandate of Parks Canada includes encouraging visitors to experience and enjoy the national parks. Experiencing a mountain park, however, is not without risk.

In the 1950s, two serious accidents on Mount Victoria and Mount Temple in Banff National Park resulted in 11 deaths, and spurred Parks Canada to increase its mountain rescue capabilities.[1] Today, full-time Visitor Safety teams work in the mountain parks of Banff, Yoho, Kootenay, Jasper, Mount Revelstoke, Glacier and Waterton Lakes with the goal of reducing the likelihood and severity of incidents in the national parks.[2]

Mountain park Visitor Safety teams consist of members of the Association of Canadian Mountain Guides (ACMG) and the Canadian Avalanche Association (CAA) who are trained in Search and Rescue (SAR). They also rely on highly-trained avalanche search dogs and handlers, Parks Canada dispatch personnel, helicopter rescue pilots, medical staff and other Parks Canada staff to assist with incident responses. Teams are prepared to respond 24/7 by land, water or air to a variety of incident types in terrain ranging from prairie grasslands to heavily glaciated peaks.

Central to the Visitor Safety program is the concept of shared responsibility. This means that while Parks Canada will help facilitate safe and enjoyable experiences, visitors are ultimately responsible for their own safety.[3] Shared responsibility becomes even more essential in remote or difficult-to-access areas where self sufficiency is crucial, and rescue may be significantly delayed.

The Visitor Safety program focusses on two distinct areas: prevention and response. Prevention of incidents involves educating visitors about hazards, helping them prepare for their experience and informing them of available response services. The goal is to encourage appropriate decision making while enjoying the mountain parks. Prevention measures in the mountain parks include hosting hazard awareness outreach programs, personally answering visitor inquires and developing trip-planning resources for visitors. One example of a prevention strategy is the use of social media to provide visitors with current terrain photos, trail conditions and rescue reports to help with their decision making. This up-to-date information is especially useful for mountain routes with ongoing glacier recession and seasonal snow cover changes.

During the winter, prevention measures include publishing daily public avalanche bulletins to help visitors manage backcountry avalanche hazard and conducting avalanche control on slopes above the highways to protect motorists travelling in and through the mountain parks. Avalanche control is carried out using fixed remote avalanche control systems, explosives deployed by helicopter, and, in Glacier National Park, military artillery control work.

Response to incidents involves determining the location and performing the rescue. Increases in cell phone coverage, new satellite locator devices and satellite phones have made it simpler to call for a rescue and transmit precise coordinates to the rescue team. In many cases, two-way conversations can now be held during incidents. Clear communication helps determine urgency, fine-tune location information and tailor the response to the incident. As a result, response times are shortened, patient outcomes are improved, and resources are minimized. All visitors are strongly encouraged to carry appropriate communication devices for the region they are travelling in.

Performing the rescue involves a variety of tools for access and transport by ground, water or air. Ground travel includes off-highway vehicles such as e-bikes, snow machines and wheeled stretchers, and high-angle rope systems. Rescues requiring water travel use motorized boats, canoes or rafts. Air access is done by helicopter - either by landing nearby or slinging people in and out of the incident site on a fixed-length line below a helicopter.[4]

Currently, helicopter rescue provides the fastest response in most areas of the mountain parks and allows for the use of minimal staff to conduct a rescue, even in technical terrain. Having Parks Canada-certified rescue pilots and helicopters which are equipped for sling rescue nearby and available is key to making helicopter rescues useful and efficient.

The use of drones as a search tool – to assess an incident or to deliver supplies to a subject – is just beginning to be explored in the mountain parks. As drones become capable of longer flight times and able to carry larger payloads, they may play an increasing role in responses.

Partnering with other SAR groups allows for the exchange of knowledge and helps increase response capacity. Visitor Safety teams regularly train with provincial SAR teams, assist with incidents adjacent to the mountain parks, and bring in external SAR groups when more resources are required. In addition, mountain park Visitor Safety teams train with other Parks Canada staff and assist with technical, remote or high-altitude incidents in mountainous areas such as Kluane (Yukon) or Auyuittuq (Baffin Island) national parks.

Reducing the likelihood and severity of incidents remains the primary goal of the Visitor Safety program. Good communication with visitors, implementation of new technologies and strong relationships with partner organizations help achieve this goal and promote enjoyable visitor experiences within the mountain parks.

Conrad Janzen works as a Visitor Safety Specialist in Banff, Yoho and Kootenay national parks. He is also an ACMG certified Mountain Guide, a professional member of the Canadian Avalanche Association, and has a Bachelor in Kinesiology with a major in Outdoor Pursuits from the University of Calgary.

Above: Banff National Park's Visitor Safety team. Back row (L-R): John-Paul Kors, Brian Webster, Lisa Paulson, Tim Haggarty, Ian Jackson, and Steve Holeczi. Front row (L-R): Conrad Janzen and Aaron Beardmore. Missing: Alex Lawson, Grant Statham, Mike Henderson (and Cazz the dog). Photo: Banff Visitor Safety

Opposite: Visitor Safety use a helicopter to sling up to a mountain rescue. Photo: Ian Jackson

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How Can Mountain Tourism Embrace Sustainability? Through Tourist-Operator Collaboration

Sunshine Village Ski & Snowboard Resort in Banff National Park. Photo: Sherpas Cinema

Elizabeth A. Halpenny

Whitebark pine was listed as an endangered species in Canada in 2010.[1] Three years later, Lake Louise Ski Resort cut down 38 individual pines.[2,3,4] The species is susceptible to blister rust, a disease whose proliferation in North American alpine areas is linked with climate change. The removal of the pines, presumably to enhance visitor ski experiences and hill operations, highlighted the need for continued vigilance regarding biodiversity conservation efforts in Canada's Rocky Mountains. The operator of the popular ski destination chose a proactive course of action to address this mistake. It expanded its environmental management programs, hired a full-time environmental manager for the resort, and worked with Parks Canada and consultants to identify and tag the remaining 7,000 whitebark pine on its leasehold.[5] Lake Louise Ski Resort also developed interpretative and environmental education programs for visitors, simultaneously enriching learning opportunities for skiing vacationers and reinforcing corporate commitment to environmentalism. These initiatives, undertaken by one of the last family owned and operated ski resorts in North America, represent an important step towards sustainability, as well as sustainable tourism in Canada's mountains.

Tourism operators need to step up and engage proactively in environmentally-minded management programs that are meaningful and multi-faceted.

In Canada, the Canadian Ski Council estimates $1.373 billion in ski area revenues were generated in 2016/17; total revenues from winter operations in western Canadian ski areas totalled $794 million.[6] Tourism operators, if they wish for long-term relationships with the mountain environments that serve as essential attractants for their clients, need to step up and engage proactively in environmentally-minded management programs that are meaningful and multi-faceted. In return, clients must make informed, mindful choices in their travel decision-making to support sustainability-minded operators.

David Weaver, of Griffith University in Brisbane, wrote about the possibility of mass ecotourism more than a decade ago.[7] Essentially, he argued that large-scale boat tours and similar guided excursions afford important opportunities for tourists to experience nature directly, enhanced by rich environmental education programs, and facilitated by environmentally-sound businesses investments, such as green infrastructure. The opportunity for this occurs in many of Canada's mountain parks. For example, boat tours on Gros Morne's Western Brook Pond, which hosts 35,000+ visitors per year, reported a 17% increase in visitation in 2017.[8] The interpretation that visitors receive on these tours, however, lacks depth and complexity, and often make no 'call to action' that empowers visitors with knowledge of how they can make changes in their everyday life to mitigate climate change, advance biodiversity conservation, and similar environmental agendas. Operators will often explain that visitors do not want to hear negative, worrisome, or guilt-inducing messaging while on vacation. However, more recent strategies designed to help tourists understand complex environmental challenges, and their role as both contributor and problem solver, can be used to enhance visitor experiences through positive, personalized storytelling, that provide tools for visitors to become better informed and take action.[9]

This approach could be used by mass tourism mountain tourism providers who wish to become more engaged in climate change action and environmental justice advocacy. Examples in Canada's Rocky Mountains include the interpretive signage provided by Parks Canada at Mount Edith Cavell's Angel Glacier or Pursuit's iconic buggy tours of the rapidly receding Athabasca Glacier. At both attractions, the demise of the glaciers and links to climate change are provided, but few attempts are made to link these issues with human activity, and no constructive tips are provided for visitors so that they might mitigate their own personal contributions.[10] Similar messaging can be used to increase tourists' pro-environmental behaviours while visiting Canadian alpine destinations. Co-production opportunities exist where operators can invite tourists to collaborate with them to reduce the carbon footprint of their stay. Asking hotel guests to reuse their towels and delay bedding change are simple examples that can dramatically reduce water, energy, and detergent use.[11] However, much more explicit and ambitious programs need to be implemented in Canada's mountain tourism destinations if the tourism sector is to adequately advance the sustainability agenda. Consider Crystal Creek Meadows, located in Australia's Kangaroo Valley, where clients, upon check in, are asked to agree to an environmental pledge, learn about the resort's environmental management efforts, and adjust their energy and water consumption while at the hotel.[12] Guests receive daily updates on their rates of consumption while at the hotel, further inspiring guest awareness and action. In short, guests are actively co-producing carbon footprint reductions with their hospitality provider.

Group tour at the Athabasca Glacier, Columbia Icefield in Jasper National Park, Alberta. Photo: Brewster Travel Canada

Much more explicit and ambitious programs need to be implemented in Canada's mountain tourism destinations if the tourism sector is to adequately advance the sustainability agenda.

This guest-operator collaboration can be expanded in Canada. Currently, the Town of Banff is reviewing a proposed Environmental Master Plan, an important opportunity to impose and support tourism operators' greening efforts.[13] Within the plan, tracking

Visitation to Parks Canada's mountain parks 2011-2018[14]

2012-13	2013-14	2014-15	2015-16	2016-17	2017-18
7,339,978	7,334,558	7,977,977	8,554,610	8,946,690	9,207,562

Notes: Mountain parks include Banff, Jasper, Yoho, Kootenay, Waterton Lakes, and Mount Revelstoke, Glacier. Sources: Parks Canada Attendance 2011-12 to 2015-16, and Parks Canada Attendance 2017-18

Shoreline cruises,
Waterton Lakes National Park.
Photo: Travel Alberta / Katie Goldie

of tourists' carbon footprint is proposed as a means to understand the profound impact of mass long-haul tourism on alpine environments. The 9.2 million visitors that visited Parks Canada's seven mountain parks between 2016/17 and 2017/18 represent both a challenge and opportunity.[14] Co-producing climate change mitigation outcomes through engagement of visitors, and productive partnerships between operators and management authorities, such as the Town of Banff and Parks Canada, are essential ways forward. As an example, Banff's environmental plan outlines the expansion of sustainable transportation through the expansion of cycling lanes and publicly-supported park-buses, which move visitors to and from Calgary. These types of initiatives are indispensable if Canadian mountain destinations wish to maintain their famous snow-capped mountain environments.

> *The 9.2 million visitors that visited Parks Canada's seven mountain parks between 2016/17 and 2017/18 represent both a challenge and an opportunity.*

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Foundations, Past and Future: The Alpine Club of Canada's Hut System

*The Stanley Mitchell Hut.
Photo: Leigh McClurg*

James Gudjonson

> *As soon as prudence will warrant, huts will be built in remote and strategic locations for the convenience of the members, and persons put in charge for the season... giving comfortable access to all the places already known or yet to be discovered.*
>
> *— Elizabeth Parker, ACC co-founder, 1907*[1]

In only three years, The Alpine Club of Canada's (ACC) Abbot Pass Hut will be one hundred years old. Consider, if you will, the history that a century holds, and how much history – stories, laughter, memories, friendship, adventure – that's also then contained by those four stone walls, high on the windswept col between mounts Victoria and Lefroy. The Canadian Pacific Railway's famous Swiss guides, who built the structure in 1922, could not have predicted that nearly a century later their hut would have not only sheltered generations of mountaineers, but become an iconic symbol of refuge to the mountaineering community.[2]

These same Swiss mountain guides also could not have likely envisioned the climate crisis that is today so rapidly changing our mountain environments, or that the ice melting underneath their iconic shelter, threatening its very existence, is linked to climate warming. In August 2018, a group of observant climbers visiting the hut noticed and reported a "ground failure" on the building's north side. The slough appeared to be fractured rock, previously cemented in place by permafrost, abutted by a quickly-disappearing glacier: a challenge for our present times.

Being the second-highest habitable structure in Canada, the Abbot Pass Hut has endured many challenges over the past century. The hut was nearly destroyed in 1968 after falling into disrepair, but refurbishment in both 1969

> *Being the second-highest habitable structure in Canada, the Abbot Pass Hut has endured many challenges over the past century.*

The Abbot Pass Hut circa 1923. Photo: Glenbow Archives

and 1984, and designation as a National Historic Site in 1997, preserved the hut for another generation. Thankfully, due to quick and decisive action from Parks Canada and ACC staff, the most recent crisis has been averted with the stabilization of the hut. Once again, the stone structure will soon provide refuge for climbers.

The Abbot Pass Hut is not the only historic hut for weary mountaineers to find shelter, share food and stories, and plot their next day's adventure. The A.O. Wheeler, Elizabeth Parker, Stanley Mitchell and Conrad Kain huts are all justly celebrated in shared mountain culture and history. They are part of a wider ACC hut system, with thirty-three huts in locations that span the continent, from the Adirondacks to Vancouver Island. It's the largest backcountry hut system in North America. While the majority of the huts are located in the Canadian Rockies and Columbia Mountains, the recent addition of the 5040 Peak Hut, in Pacific Rim National Park, now brings the number up to four in the B.C. coastal zone; and with the Spearhead Huts Project well underway near Whistler, there are a few more world-class facilities on the western horizon. East from the BC coast, the ACC has constructed, acquired, or refurbished three huts over the past four years. The Louise and Richard Guy Hut in Yoho National Park, the Cameron Lakes Shelter in southern Alberta, and the Bon Echo Hut in Ontario are all helping address the growing need for more remote shelters. Attendance rates in ACC huts has increased thirty-three per cent over the past four years – a ringing endorsement for our facilities, but also a strong sign that mountain culture and recreation is thriving across the country.

The Abbot Pass Hut in September 2018 showing remediation efforts underway. Photo: Tetra Tech Inc.

With expansion, though, comes the need to carefully consider our impacts on the sensitive alpine and sub-alpine ecosystems, and recognize that the alpine – even in the remotest of settings – is always a shared space. For example, the Louise and Richard Guy Hut, built in 2015 to a very high efficiency and sustainability standard, highlights the Club's commitment to environmental stewardship and the overarching ethos of its membership. Located high above treeline on the western side of the Wapta Icefield, the small ski hut incorporates many state-of-the-art technologies intended to reduce its carbon footprint and increase the longevity of the facility. However, usage is restricted to only the winter months. Just south of the Guy Hut is sensitive habitat for grizzly bears. Always in close consultation with our proud partner, Parks Canada, the ACC thus closes this particular facility between May and November.

Preserving and cultivating our connection to our wild mountain spaces is a duty the ACC takes seriously – and it's important work. Aldo Leopold, the great American ecologist and conservationist, speaking of the cabin in which he and his family sought refuge "from too much modernity," described the labour involved in its preservation: "On this sand farm in Wisconsin, first worn-out and then abandoned by our bigger-and-better society, we try to rebuild, with shovel and axe, what we are losing elsewhere. It is here that we seek – and still find – our meat from God."[3] This "meat from God," or the connection to our wild homes, in which so many discover solace and wholeness, is linked to creating and preserving spaces that allow this discovery. "When we see land as a community to which we belong," Leopold continues, "we may begin to use it with love and respect."[4]

The ACC hut system is an example of this transformative process: stewardship values have developed over generations through Club members' connection with the mountain environment, in turn affect how we develop and maintain our facilities in these places that we are connected to. The Alpine Club of Canada will continue to incorporate more than a hundred years' worth of connection to the mountains in decisions that will affect generations of mountaineers to come.

Jim Gudjonson is the Vice President for Facilities of The Alpine Club of Canada, as well as the Director of Environment and Sustainability at Thompson Rivers University in Kamloops. He is an accredited ACMG/IFMGA Mountain Guide.

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The Louise and Richard Guy Hut at Mont des Poilus. Photo: Eric Petersen

Rapid Loss of Perennial Alpine Ice Patches, Selwyn and Mackenzie Mountains, NWT

Figure 1 – Researchers work at alpine ice patch KfTe-1 in 2007, which had nearly completely melted by 2017. Photo by Tom Andrews/GNWT

Alpine ice patches in the Selwyn and Mackenzie Mountains hold an incredible archive of the millennia-long relationship between perennial ice, northern mountain caribou, and pre-contact Shúhtagot'ine hunters.

Glen MacKay, Leon Andrew, Naomi Smethurst and Thomas D. Andrews

On August 16, 2017, we made our annual visit to an alpine ice patch known as KfTe-1 as part of the Northwest Territories (NWT) Ice Patch Monitoring Program in the Selwyn and Mackenzie Mountains. Our project team – a long-term partnership between archaeologists from the Prince of Wales Northern Heritage Centre and Shúhtagot'ine Elders from the Tulita Dene Band – had stopped at this site almost every year since 2005 to observe its condition and collect archaeological artifacts and biological specimens melting out of the ice (Figure 1). We were struck by how different the ice patch looked compared to past visits. Although it was still obscured by a thin skiff of snow left over from the winter snowpack, it was apparent that the underlying ice had deteriorated significantly. When we returned from the field, we continued to monitor KfTe-1 using publicly available imagery from the European Space Agency's Sentinel-2 satellite. By October 1, the snow from the previous winter had melted away, and it looked like the underlying ice patch had almost completely disappeared.

Alpine ice patches in the Selwyn and Mackenzie Mountains hold an incredible archive of the millennia-long relationship between perennial ice, northern mountain caribou, and pre-contact Shúhtagot'ine hunters.[1] Caribou seek out ice patches on hot summer days to cool off and escape the hordes of parasitic and biting insects that infest the alpine tundra and forests. Melting ice patches are ringed by a thick black band of caribou dung accumulated by many generations of caribou. For human hunters, ice patches were predictable places to find and kill caribou during the summer, and now, melting ice patches are revealing perfectly preserved hunting weapons – some thousands of years old – that were lost or abandoned during the hunt (Figure 2). Ice patches do a good job of preserving artifacts and biological material not only because they are frozen, but also because they are relatively static. Like glaciers, ice patches accumulate through winter precipitation, forming over time as wind-blown snow builds up on the leeward slopes of mountains.[2] Perennial ice patches tend to form on north-facing slopes, where the snow drifts are most protected from direct sunlight. In contrast to glaciers, they do not typically obtain enough mass to move downslope, meaning that fragile artifacts are not crushed or ground to pieces by physical movement of the ice.

At KfTe-1, one of the oldest known ice patches in the Selwyn Mountains, this repeated pattern of winter snow accumulation and summer use by caribou has created stratified layers of ice separated by thin lenses of caribou dung. In 2008, a 3.5-metre-long ice core extracted from the thickest section of KfTe-1 revealed eight distinct layers of dung that dated sequentially from about 700 to nearly 5,000 years ago.[3] Scientists have used these frozen dung layers to study patterns of caribou diet over time, climatic and vegetation changes in the alpine landscape, and even ancient plant-infecting viruses.[4,5] Researchers have also used ancient DNA extracted from caribou bones collected from ice patches to study the population dynamics of caribou in the Selwyn and Mackenzie Mountains.[6]

In addition to being valuable archaeological and environmental archives, alpine ice patches are also ecological hotspots in the alpine landscape. While the link between mountain caribou and ice is the most important dynamic at these sites, ice patches also provide habitat for small mammals and birds, such as marmots, ground squirrels and ptarmigan. One of the most unique artifacts collected from KfTe-1 is a thousand-year-old ground squirrel snare that was likely set by hunters while they were waiting for caribou (see Figure 2). Wolverine bones and wolf feces found at KfTe-1 indicate that ice patches are also important for scavengers and predators.

If KfTe-1 is indeed on the precipice of melting completely away, it will mean that it has melted more over the last few years than it has in approximately 5,000 years. This rapid loss of perennial ice patches

In addition to being valuable archaeological and environmental archives, alpine ice patches are also ecological hotspots in the alpine landscape.

Figure 2 – Archaeological artifacts collected from melting ice patches in the Mackenzie and Selwyn Mountains: a) Detail of a complete arrow (approx. 340 years old); b) Dart point with attached sinew (approx. 2,400 years old); c) Detail of a ground squirrel snare (approx. 1,000 years old). Photos by Susan Irving/GNWT. Layout assistance by Dot Van Vliet, GWNT.

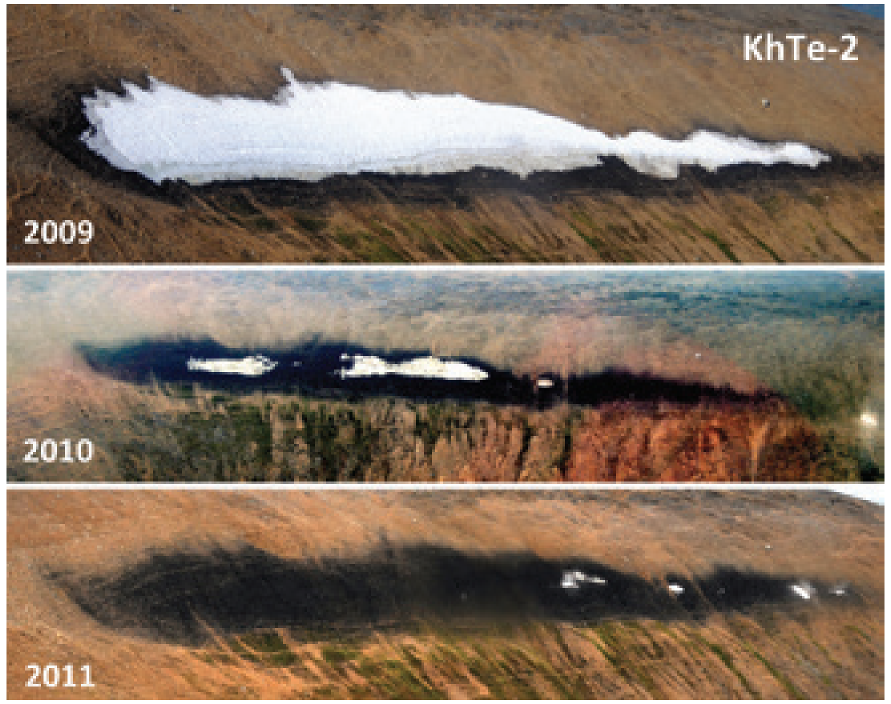

Figure 3 – Rapid melt of KhTe-2 occurred between 2009 and 2011. By 2011, all that was left of the patch was a 300-metre-long streak of caribou dung across the mountainside. Photos by Tom Andrews/GNWT.

is not unprecedented in the Selwyn and Mackenzie Mountains. Between 2009 and 2011, we witnessed the demise of a smaller ice patch called KhTe-2 (Figure 3). An ice core extracted from this site in 2007 showed that at least part of the ice patch was close to 3,000 years old.[7] Surprised by its rapid loss, we hypothesized a tipping point at which the amount of heat absorbed from the sun by the ever-increasing amounts of black dung exposed at the edges of the melting ice patch accelerated the melting of the remaining ice.

> *Fragile archaeological artifacts released from the ice will degrade rapidly if they are not immediately collected.*

With climate change tipping the balance towards the catastrophic melt of alpine ice patches, it is important to take stock of what will be lost. Fragile archaeological artifacts released from the ice will degrade rapidly if they are not immediately collected. At large ice patches like KfTe-1, the stratified dung layers will collapse into a single layer, making them much less useful for studying environmental change through time. Important relief habitat for mountain caribou will also be lost at a time when they are already trying to adapt to a rapidly warming alpine environment. The rapid loss of alpine ice patches in the Selwyn and Mackenzie Mountains highlights the need for sustained research on ice patches wherever they may exist in Canada's mountain ranges.

Glen MacKay is the Territorial Archaeologist with the Government of the Northwest Territories, based at the Prince of Wales Northern Heritage Centre in Yellowknife. MacKay has participated in the NWT Ice Patch Project since 2005. Leon Andrew is a widely respected Shúhtagot'ine elder and researcher with extensive experience in the Selwyn and Mackenzie Mountains. Andrew lives in Norman Wells, and has participated in the NWT Ice Patch Project since 2005. Naomi Smethurst is the Assessment Archaeologist with the Government of the Northwest Territories, based at the Prince of Wales Northern Heritage Centre in Yellowknife. Naomi has participated in the NWT Ice Patch Project since 2016. Thomas D. Andrews, PhD, is principal and co-owner of Spruceroot Group Heritage Consulting and former Territorial Archaeologist at the Prince of Wales Northern Heritage Centre in Yellowknife. Andrews has participated in the NWT Ice Patch Project since 2005.

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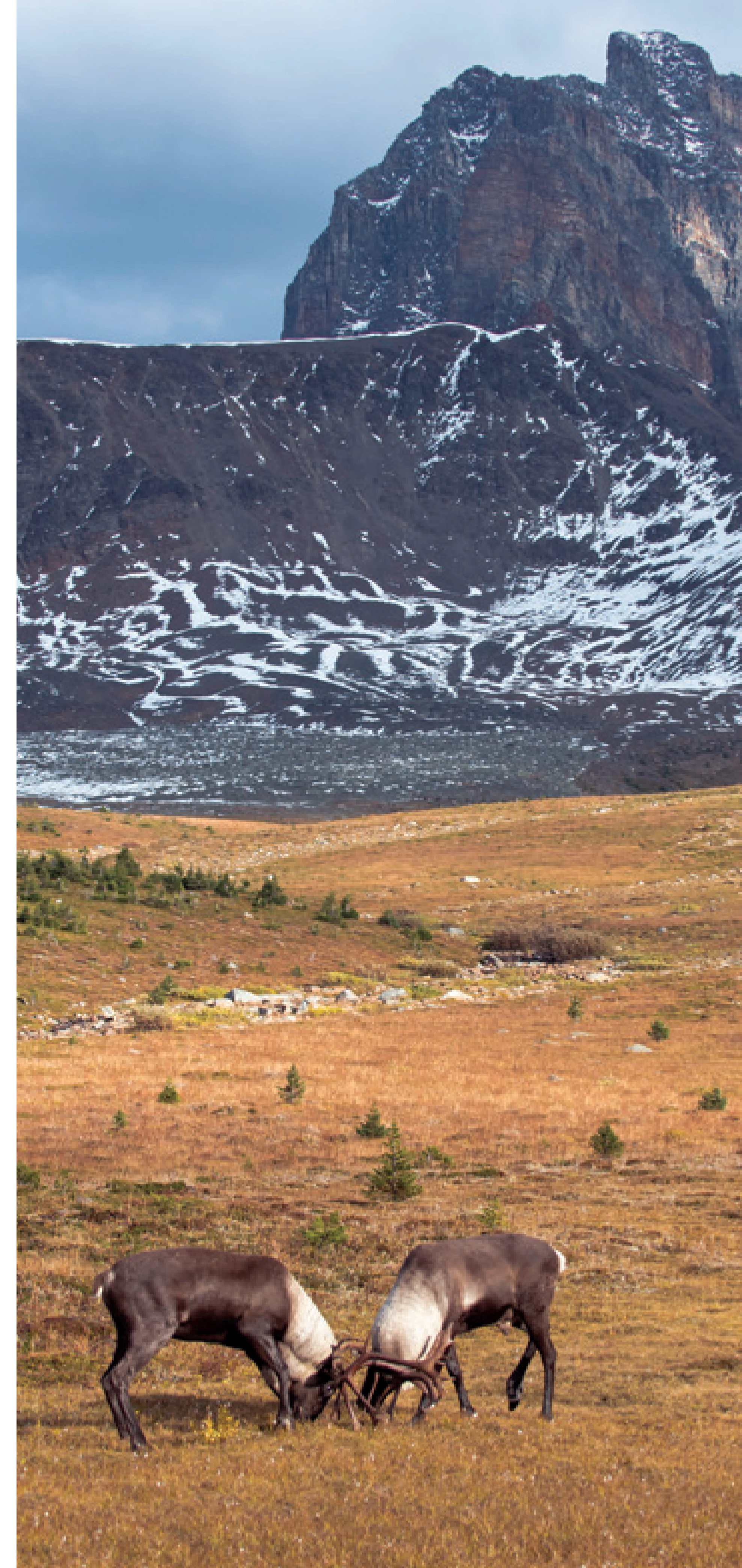
Southern Mountain Woodland Caribou in Jasper National Park

Layla Neufeld

In 1878, English peers Algernon and Alice Heber-Percy wrote a short book on an 1877-78 trophy hunting trip, *Journal of Two Excursions in the British North West Territory*. Their travels had brought them to the Rockies, and to Henry House specifically (near present-day Jasper, Alberta), where they recorded details of excursions involving long ascents, glaciers, precipitous cliffs, fresh caribou tracks, and their ultimate success in hunting a group of caribou in the Maligne Range. One bull specimen was described as having a "splendid head of twenty-five points, with the broad palmated tyne in front of the forehead well developed."[1] Of course, the mountains of Jasper were different then, with a long history of Indigenous use but significantly less impact from non-Indigenous settler populations relative to the present day. *Endangered species* was a designation of the future for mountain caribou.

Although interesting, sparse anecdotes like the Heber-Percys' aren't useful indicators of the historical status of caribou herds. Measures of wildlife numbers or trends from eighty years ago or more were usually guesses; but of value from the many of the early accounts is the confirmation that caribou were historically more widely distributed.

Similarly, the role of national parks was different. In 1907, when Jasper Forest Park was established under the Dominion Lands Act, tracts were set aside and protected from development, but tourism promotion and wildlife viewing soon became a keen focus. And while visitor experience and enjoyment remain a key role of national parks, the current mandate also includes significant focus on maintaining "ecological integrity." Ecological Integrity is defined by parks as a state where the ecology of an area is intact



Two bulls sparring in the alpine. Photo: Layla Neufeld

Caribou in wildland flowers.
Photo: Layla Neufeld

and the ecosystem functions on its own, maintaining the suite of species that have lived there for millennia, and the processes (like migration or dispersal) that support those species' life histories.

A declining species at risk in today's Jasper National Park means we're in danger of losing ecological integrity. And it leaves us with questions: how did we get here, why is it continuing, and what should we do?

A declining species at risk in today's Jasper National Park means we're in danger of losing ecological integrity.

To answer these questions, we need good data. We are now able to accurately document herd sizes and trends, branching into novel techniques like matching individual genotypes across two annual samples and then estimating a population size. There's nuance in many of the approaches, but they tell the same story: caribou are close to being extirpated from southern Jasper National Park.

As is true of many species at risk, caribou are sensitive to environmental change and reproduce slowly. Reproductive not until age 3, probably not every year, and producing only one calf at a time, caribou populations don't weather large changes in predation pressure very well. In southern Canada, predators, mainly wolves, don't rely on caribou for survival, but impacts of increased predation on caribou herds can be swift and substantial. Wolves are doing what nature programmed them to do: hold territory, hunt, find mates, and reproduce. If they're good at the first three items, the fourth comes naturally. When wolves have more prey, as it has in caribou ranges across much of Canada because of shifts in forest age due to industrial land-use and a glut of high quality food for ungulates in these young regenerating forests, wolves can raise more pups. Because there are more of them, wolves increase their hunting reach and caribou become bycatch. More wolves equal more wolf-caribou encounters – and caribou lose.

Without extensive landscape change in Jasper National Park, why have caribou declined in this region? A large contribution has been the park's management history, which manufactured a poor ecological system for caribou. In the early years of the forest park, when wildlife viewing was a priority, the park implemented a harsh attitude towards predators. Extensive predator control programs were put in place, and they continued to varying degrees until 1959. Staff were hired specifically for predator removals, and baits and poisons were used throughout the farthest reaches of the backcountry. Predator numbers were considered "in hand" throughout this time. At the same time, in 1920, elk were reintroduced after having been extirpated in the late 1800s. They flourished in a predator-free landscape, from less than a hundred head to thousands by the mid-1930s. Elk removal programs were necessitated, as elk started noticeably affecting their own environment through overgrazing. By 1959, when predator control stopped, elk populations were hovering around 2,000, and elk were observed throughout high alpine meadows, in places that we'd be surprised to see them today. Wolves came back to a world full of naive and healthy elk; excellent conditions to reproduce.

Wolf numbers are notoriously hard to measure. When people were regularly in the backcountry, repeated observations enabled us to coarsely estimate wolf numbers and density. Today, we still use observation to estimate wolf numbers, but we also use technology. A grid of remote cameras across Jasper National Park allows detection of individuals, pack colours and compositions, and enables us to delineate pack territories throughout the park. This simple technique, combined with careful eyes and attention to detail, has become a reliable method of estimating changing wolf numbers. It has taken a long time for wolves to decrease, but they have steadily declined since 1970, and would have done so faster if not for supplemental feeding on roadkill up to 2006. From 2005 to present, wolves have declined from 5.9 to 1.5 wolves/1000km².

Photo: Layla Neufeld

Research tells us that caribou herds do best when wolf density is less than 3/1000km² and when wolves are not given ease of access to caribou habitat via packed trails. Only since 2013 have we reached this density threshold in Jasper National Park. Unfortunately, caribou herds had become very small by this point, and because of biological constraints are now unable to recover without help. Parks Canada continues to examine the feasibility of augmenting populations of this iconic mountain species within Jasper National Park; an exciting project that aims to give this species the bump it needs to allow national parks to continue to protect and present intact mountain ecosystems, including their natural suite of species.

Wolf numbers are notoriously hard to measure. When people were regularly in the backcountry, repeated observations enabled us to coarsely estimate wolf numbers and density.

Layla Neufeld is the Caribou Biologist for Jasper National Park of Canada. The caribou program also includes Karly Savoy (Communications and Outreach Education Officer) and Jean-Francois Bisaillon (Project Manager, Mountain National Parks Caribou Conservation Program).

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Mammals of the Mountain Slopes

Jason T. Fisher and Alina C. Fisher

Mountains are one of the last bastions for large mammals in North America. They are, in a way, ecological citadels where native species have been allowed to persist. Large ungulates – deer, moose, elk, sheep, and goats – have not been replaced by livestock; large predators have a refuge from persecution. However, the Anthropocene has not spared mountain environments from climate change and landscape change – which has encroached upon those fortress walls with mammals feeling those effects.

The Canadian Rocky Mountains are a special case of this global phenomenon. The western Canada sedimentary basin sprawling eastwards from the Rockies' is rich in oil and gas, and its extraction fuels modern economies. Forest harvesting – and fire suppression to protect those resources – has been a mainstay of mountain environments for over a century, resulting in changed disturbance regimes. As per capita wealth has increased, recreation has both increased in popularity and changed from low-impact activities to high-impact ones, such as RVs and ATVs. The leisure industries, and the hyper-development that so often accompany them, have arrived at the mountains at last.

The landscape change spurred by human activity has radically outpaced our ability to track those effects on mammal communities, or to understand their root causes. Consequently, the mountain mammal community has been changing, with us unaware. But technology is catching up here, too. Remote camera trapping has rapidly evolved over the last decade from a fun pastime into a vital scientific tool. Digital cameras can capture thousands of images, and when networked in an array of scores of cameras, yield insights undreamed of a decade ago. For the first time, we can effectively measure where mammals are on a landscape – and more importantly, where they are not, but should be. We can now reliably estimate the populations of multiple species in the same landscapes, to understand predator-prey interactions. We can measure their daily activity patterns, and even changes in their behaviours. For the first time, we can scientifically investigate the effects of the multiple forms of landscape change on entire mountain mammal communities. And the news, as one might assume, is a mixed bag of good and bad.

Grizzly bears are an iconic species at risk on the east slopes of the Rockies. A hunting moratorium in Alberta has stopped those population losses, but meanwhile road access has increased, resulting in bear deaths related to interactions with people. Even on the less developed British Columbia side, land-use that creates bear food (orchards, for instance) lures grizzlies in, and increases their chances of being killed – creating an ecological trap.

But grizzlies may not have the worst of it. The real canary in the coalmine is the wolverine. Wolverines used to inhabit multiple ecosystems spanning the entirety of Canada and the northern United States. European settlement reduced wolverine distribution, limiting their ranges to the Arctic and those mountain citadels. Generational amnesia has led many to believe that wolverines are a mountain species – but only inasmuch as mountains (and for now, some parts of the boreal forest) are the only places south of the Arctic we've left them to persist. As landscape change advances into mountain valleys and up the slopes, those areas are no longer wolverine refuges; and we are certain of this loss thanks to remote camera traps.

Research on Alberta Rocky Mountain wolverines started fifteen years ago in the Willmore Wilderness and the adjacent working landscapes of the east slopes and foothills. Cameras, along with hair capture and DNA analysis, showed that wolverines were doing fairly well in the Willmore, but were shockingly sparse in working landscapes: only five wolverines were found on that entire land base, three of which were likely a single family. In the 2010s, a collaboration of scientists expanded this research into Banff and Yoho national parks and the adjacent Kananaskis Country and Ghost Wilderness, spanning over 12,000 km^2. Unfortunately, the same pattern occurs there: wolverines were doing well in the national parks, but outside, they were alarmingly sparse. In all of Kananaskis – long an icon of wolverine habitat – only seven wolverines were found, nicknamed "the Magnificent Seven." In comparison, scores of wolverines lived in same-sized areas in the national parks.

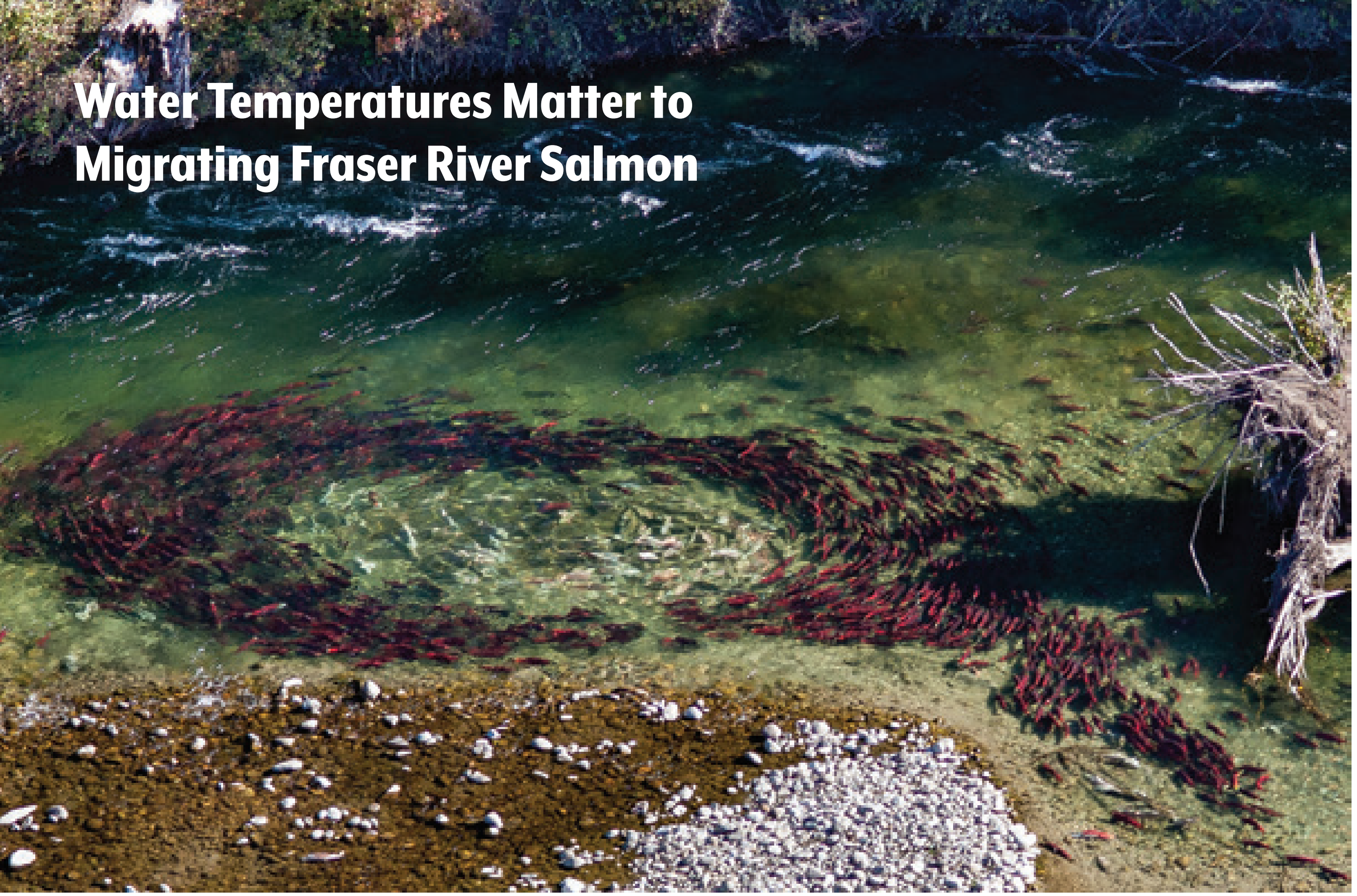
The news is consistent all along the east slopes of the Rockies: wolverine range has contracted under our noses, and likely continues to do so. Careful analysis shows that the cumulative effects of climate change and landscape change – including forest harvesting, petroleum extraction transportation, and recreation – is to blame. Why this is happening is still being researched.

Yet good news remains. The same analysis on the entire carnivore community showed that the magnitude of these effects is not yet felt across all species. Lynx, cougars, bobcats, and other species still seem to be persisting, at least for the time being. However, even they showed signals of negative responses to extensive landscape change on the east slopes. How species will respond to near-future change is uncertain, but what is clear is that landscape management and protection is needed to ensure mountains remains citadels of refuge for mountain mammals.

Jason Fisher is an Adjunct Assistant Professor in the Faculty of Environmental Studies at the University of Victoria and Senior Research Scientist with InnoTech Alberta. Alina Fisher is an ecologist, freelance science writer and science communications researcher based in Victoria.

Images of moose, bears, cougars, and caribou were captured in their natural environs by motion sensing wilderness cameras. Photos: Jason Fisher

The landscape change spurred by human activity has radically outpaced our ability to track those effects on mammal communities, or to understand their root causes.



Water Temperatures Matter to Migrating Fraser River Salmon

Above: Spawning Adams River sockeye salmon, 2010. Photo: Ian Guthrie.

Below: Figure 1 – Malcolm Nicol, snow survey technician with the British Columbia Ministry of Environment performs a manual snow water equivalent verification at Chilliwack River Alpine Snow Water Station. Photo: Ted Litke, BC Ministry of Environment

Mike Lapointe, David Patterson, Maxine Forrest, Kendra Robinson, Angus Straight

High in the Coast Mountains, 1,600 metres above the Fraser Valley, Malcolm Nicol makes one of several visits to the Chilliwack River station to measure the alpine snowpack (Figure 1). Nicol's station is part of a network of stations visited during the late winter and spring each year that monitor the snowpack, which melts each summer and drains into British Columbia's many watersheds (Figure 2).[1] While districts and municipalities are often focused on the consequences of snow melt for flood risks during spring freshet, staff at Fisheries and Oceans Canada's (DFO) Environmental Watch Program (E-Watch) and the Pacific Salmon Commission predict the impact of snowmelt and other factors on summer Fraser River temperatures and flows, and the expected success of sockeye salmon migrating to their natal spawning areas.[2]

Warm temperatures in the Fraser River have been associated with poor migration success (Figure 3). While the discrepancies in Figure 3 result from a variety of factors (in addition to mortality during migration), the physiological effects of warm water temperatures on migrating salmon have been well documented.[3] Warm waters contain less oxygen than cool waters, and Fraser River salmon appear to have adapted the capacity to do the most work at river temperatures they have experienced historically.[4] Prior to the 1990s, average river temperatures in excess of 18°C occurred infrequently – less than fifteen percent of years (Figure 4). Thus, it is not surprising that salmon would experience mortality when temperatures rise above this level. After all, upstream migrating salmon are doing a lot of work, effectively swimming the equivalent of a marathon a day against the river's current. Spring snowpack levels and seasonal weather forecasts are used to generate expectations for summer river flows and water temperatures, and this information is communicated to fisheries managers to aid in pre-season fishing plans.[5] These long-range forecasts of river conditions, however, are imprecise due to unpredictable weather events such as heavy rain events.

To counteract these sources of uncertainty, managers of Fraser River salmon also use short-term, ten-day forecasts of river temperature and flow, which are produced twice a week each summer by DFO's E-Watch program. These forecasts rely on weather forecasts provided by Environment Canada and a series of real-time river temperature and flow data loggers located in key locations in the Fraser watershed.[6] Staff at the Pacific Salmon Commission then use management adjustment models that relate past river conditions (temperature and flow) to historical discrepancies (Figure 3) to predict the expected discrepancy in the current year based on the combination of observed and forecast river conditions.[7] These predictions inform management decisions; it is common for available harvest levels to be reduced to compensate for expected mortality, providing greater assurance that the target number of fish will reach spawning areas.

Unfortunately, as other researchers have documented the rapid recession of

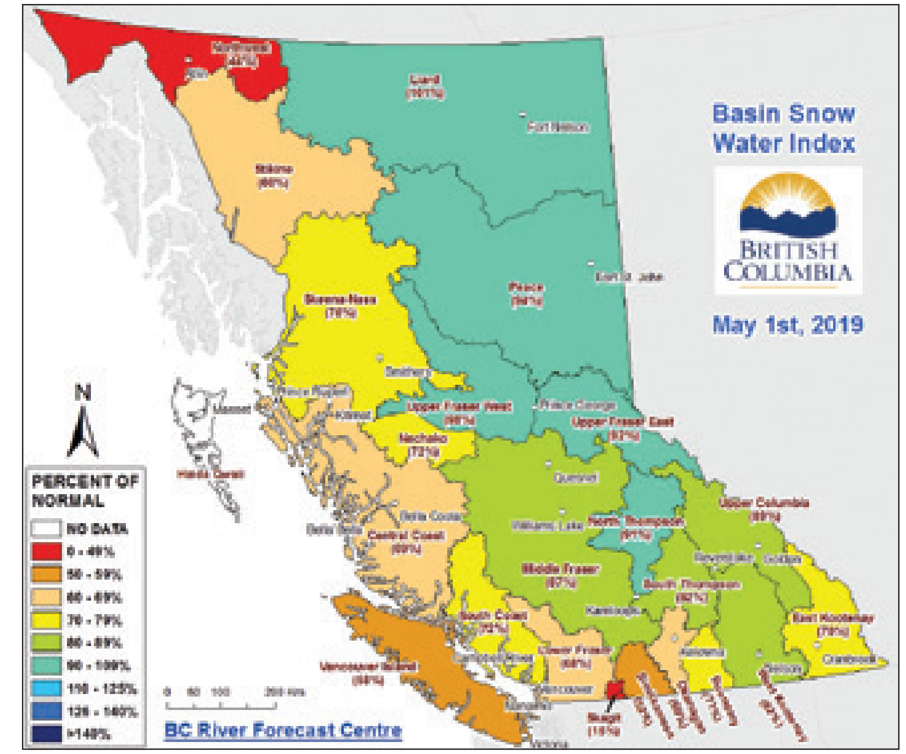


Figure 2 – British Columbia Snow Survey Map denotes snow water index levels for May 1, 2019. Map used with permission from the Government of B.C., Ministry of Forests, Lands, Natural Resource Operations and Rural Development – River Forecast Centre.

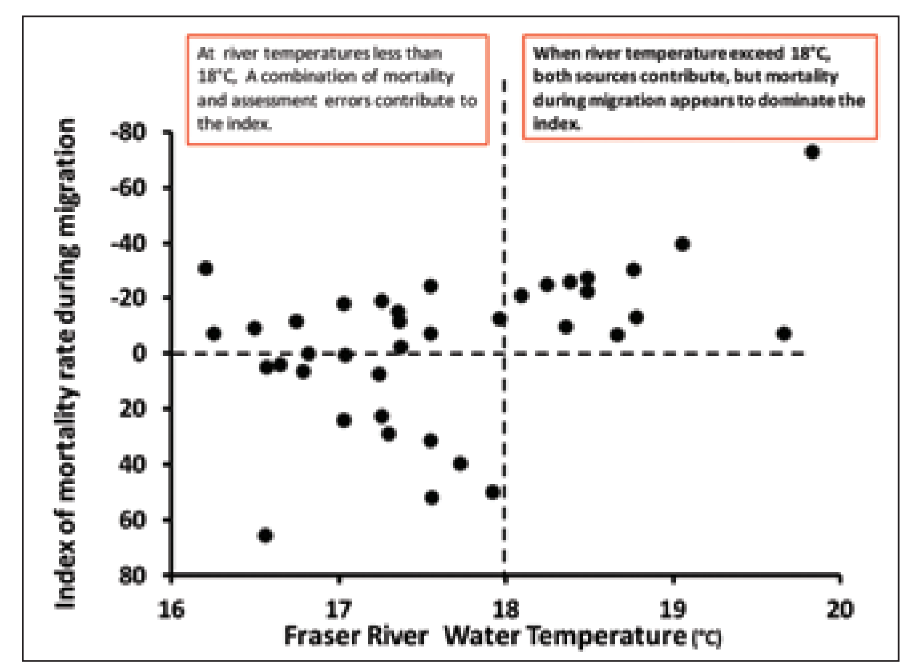


Figure 3 – The relationship between the percent difference between estimates of Fraser River sockeye salmon reaching their natal spawning areas in upstream locales and entering the lower Fraser River, and Fraser River water temperatures (black dots). River temperatures represent 31-day averages centred around each year's peak of the migration of Fraser River sockeye in the lower Fraser River. Dashed lines delineate river temperatures greater and less than 18°C and when percentage differences are either greater or less than zero. When Fraser River temperatures exceed 18°C, percentage differences have always been less than zero; indicating that mortality of fish is the major factor contributing to the discrepancy in the estimates between the two sites where abundances are estimated. When river temperatures are less than 18°C, mortality may still occur, but it may be masked by errors in estimates of abundance that occur at both sites.*

**Data shown are for the group of Fraser sockeye stocks known as the Summer-run, excluding the Harrison River stock. This group contributes the most to the total Fraser River sockeye return in three out of every four years*

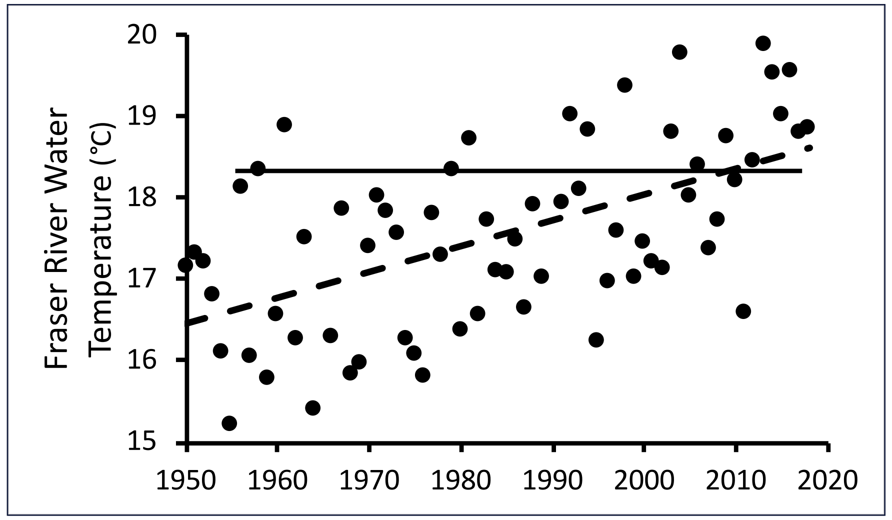


Figure 4 – Mean Fraser River water temperature during the month of August. Black dots are the annual average temperatures for the month of August plotted for each year, 1950-2018. The dashed line is the best fit regression line. The time trend in Fraser River temperatures is highly statistically significant and the R2 value indicates that nearly one third of the variation in Fraser River temperatures during this nearly 70-year period can be "explained" by a simple linear increasing time trend of 0.3°C per decade. The solid horizontal line delineates river temperatures greater and less than 18°C.

mountain glaciers, Fraser River temperatures are increasing. The timing of peak snowmelt and spring freshet is shifting to occur earlier in the season, which leaves less cool water to buffer the river from warm summer air temperatures. In the forty-year period prior to 1990, there were only five years when the average Fraser River water temperature exceeded 18°C (less than 15 per cent of years). In the twenty-eight years since 1991, the average Fraser water temperatures exceeded 18°C in fifteen of those years (greater than 53 per cent), including every year since 2012 (Figure 4). Average Fraser River temperatures during August have increased by more than 2°C since 1950 (Figure 4).

Will Pacific salmon adapt to these changing conditions? Experience in hatcheries and evidence from other locations (such as sockeye salmon in the Okanagan basin) suggests that salmon have the evolutionary capacity to adapt, but their response will likely depend on how fast their environments change relative to the speed of their adaptation.[8]

Tough going for this Adams River sockeye salmon, 2010. Photo: Ian Guthrie

Mike Lapointe was Chief Biologist with the Pacific Salmon Commission (PSC; he retired in February 2019, after 27 years of service). David Patterson has been lead biologist for Fisheries and Oceans Canada's Environmental Watch (E-Watch) Program for more than 15 years. In addition to leading PSC's management adjustment models, Maxine Forrest manages the PSC's scale lab based in Vancouver, BC. Kendra Robinson, a biologist, and Angus Straight, a graduate student, work with Patterson in the E-Watch program, which is located on the campus of Simon Fraser University in Burnaby, BC.

Acknowledgements

The development of management adjustment models and their implementation is a team effort. In addition to those listed in the references, we thank Keri Benner and her staff for their upstream assessments; Fiona Martens, Cory Lagasse and their teams which generate hydroacoustic estimates of abundance of salmon reaching the lower Fraser River at Mission, BC; Water Survey of Canada and others for their help with data loggers located the throughout Fraser River and its tributaries; and past members of DFO's E-Watch team who provided forecasts of daily Fraser River temperature and flow values twice each week during the summer salmon migrations. Lastly, decisions regarding the formal adoption of management adjustment factors are the purview of the Fraser River Panel, an advisory body of the Pacific Salmon Commission that is charged with decisions regarding the harvest of Fraser River sockeye and Pink salmon.

The Adams River, British Columbia. Photo: Ian Guthrie

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Will Pacific salmon adapt to these changing conditions?

Mountain Pine Beetles on Rockies Eastern Slope Offer Improved Perspectives

View south from Old Fort summit, Jasper. Photo: Z. MacDonald

Felix Sperling

Mountain pine beetles *(Dendroctonus ponderosae)* are now threatening pine forests along the full length of the eastern slopes of the Canadian Rockies. But that doesn't mean it is clear what we should do about them. Their populations expanded across the western states and British Columbia in the 1990s and 2000s, driven by a combination of global climate change, forest management and fire suppression practices. The beetles overwhelmed lodgepole pine and other pines across BC, peaking in 2005 and killing more than half of all merchantable pine in BC by 2012.[1] In Alberta, beetle flights in the north went far past Grand Prairie in 2006, while in the south they reached Canmore and Banff. More recently, beetles have swept across Jasper National Park toward Hinton, creating a new front. Small infestations have now also been detected in the previously untouched area between Hinton and Canmore, including near Rocky Mountain House.[2] Like in BC, the extensive, mature lodgepole pine forests of west-central Alberta may not survive long, and mountain pine beetles could then sweep across the boreal jack pine forest into eastern Canada.[1]

This slow-building crisis has brought out several conflicting visions of what the forests of the eastern slopes of the Rocky Mountains should do for us.

This slow-building crisis has brought out several conflicting visions of what the forests of the eastern slopes of the Rocky Mountains should do for us. The region provides tourism and ecosystem services, such as watershed regulation, in addition to wood products that keep commercial forest industries globally competitive. These are all important for employment that keeps local communities viable. It is not evident which of these uses is most important, and trade-offs are obviously necessary, as the new Bighorn Country proposal demonstrates.[3] The challenge is to find the right balance without repeating past mistakes.

Mountain pine beetle management is complicated by population threshold effects. In the endemic phase, bark-boring larvae survive in weakened trees that are widely scattered through a forest. But with drought stresses and the even-aged, mature stands of trees that fire control encourages, populations switch to an epidemic phase where, like a fire reaching a critical temperature, beetles can overwhelm trees that would normally never have succumbed. So, the strategy for controlling beetles is to get them early, monitoring carefully to see if trapping with pheromones and removing single trees is called for, or whether proactive harvesting is needed, essentially fighting fire with fire. But such strategies may not be effective on the long term, since cold winters could be the only factor sustainably holding down beetle numbers, even if intensive logging retards outbreaks on the short term.[4] So is such logging worth the potential environmental cost?

British Columbia has learned much about mountain pine beetles, including that salvage logging of beetle-damaged forests may create new habitat conditions that preclude a return to the original state.[5] Further, some evidence indicates that extensive salvage logging could disturb watersheds and exacerbate flooding by allowing more snow accumulation with increased snow melt in spring, and altered stream flow later in summer.[6,7] So, this is not only a problem for upland communities, but also cities such as Edmonton and Calgary that rely on rivers from the eastern slopes for their water supply. Such ecosystem services could outweigh the benefits of wood production.

Another question is whether mountain pine beetles are adapted uniformly to conditions throughout their range and will respond the same way everywhere. Genetic studies show that southern populations in BC and Alberta are different from northern populations, with intermediates occurring in Jasper National Park.[8] This can be used to infer the source populations of new expansions, but it remains to be seen whether mixed beetles in Jasper and Hinton are more or less viable than those to the north or south. The genetic diversity of these beetles means that there is potential for adaptability under new conditions, with added complexity contributed by different species of blue stain fungi that work with the beetles to overcome a tree. There is no guarantee that mountain pine beetles in a new area will behave the same way they did elsewhere.

It might also be helpful to reconsider even the most self-evident assumptions. One common belief is that beetle-killed trees present conditions that are significantly more prone to fire; for example, the first goal of a Town of Hinton advisory committee on mountain pine beetle was to protect the community from wildfire.[9] A survey across the western US, however, suggests that fire risk may not actually be elevated by beetle damage.[10] So a primary concern with fire may be misplaced and removing beetle-killed trees might be mainly cosmetic.

These studies show that we are still learning a lot about mountain pine beetles, their role in the environment, and what our best interests are. The potential for more beetle outbreaks on the eastern slopes of the Rockies therefore gives us a new opportunity to reconsider – and improve - how we respond to them.

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A tree in the Lake Edith area of Jasper killed by the mountain pine beetle. Photo: Z. MacDonald

Some evidence indicates that extensive salvage logging could disturb watersheds and exacerbate flooding by allowing more snow accumulation with increased snow melt in spring, and altered stream flow later in summer.

Watermelon Snow: A Microscopic Serengeti

Figure 1 – Watermelon snow below the toe of the Lava Glacier, Mt. Garibaldi, BC. Photo: Casey Engstrom

Casey B. Engstrom and Lynne M. Quarmby

Each summer, alpine snowfields across Canada undergo a startling transformation from white to pink, orange, or a startling red, known as watermelon snow. These blooms of microscopic algae are vast enough to show up on satellite imagery—in some regions covering more than a third of the snow surface.[1] In recent years, snow algae have attracted attention for their possible impact on global climate and local water cycles: red snow absorbs more solar energy, driving faster snowmelt—indeed, mountain travelers can observe that the red snow often melts trenches substantially deeper than the surrounding white snow.

Microscopic examination reveals a hidden ecosystem that is stunningly beautiful and surprisingly complex.

Microscopic examination reveals a hidden ecosystem that is stunningly beautiful and surprisingly complex. We see algae, fungi, bacteria, ciliates and rotifers, and from molecular work we know archaea and viruses are also present.[2,3] Although specifics are not yet known, the snow algae microbiome undoubtedly comprises a web of grazers, parasites and symbionts. A favourite micrograph from our collecting trips in the mountains of southwestern B.C. shows a tardigrade with a belly full of red algae. Another image shows a row of chytrid fungi attached to an algal cell appearing to sip the energy-rich fatty red pigment through hyphae protruding into the alga. The algae themselves are brilliantly coloured, from ruby-red to yellow or orange, often encased in translucent shells with flanges, spikes or turrets. If snow algae are anything like their well-studied temperate cousins, some species may look quite different at various stages of the life cycle: tiny biflagellate green swimmers may grow into ruby-red armored cysts, or into brown hulking cells we have dubbed "motherships"—each one harbouring dozens of small green progeny.

It remains a mystery how cells colonize the fresh snow surface each spring. By late summer this ephemeral ecosystem has melted, leaving behind red pools of water and small putty-like clumps of cells on the rocks. We've observed that these clumps contain what appears to be a microcosm of the core snow algae microbiome—algae, fungi, bacteria—possibly a "seed" to inoculate the pristine spring snow. If so, the organisms will need to survive the heat and desiccation of summer as they lie exposed on rocks, followed by a freezing dark winter under a new field of snow. Some species may colonize the spring snow by swimming to the surface (an epic migration for an organism 1/100th of a millimetre in diametre), while other species may be deposited on the snow surface by the wind. No one has yet identified the reservoirs from which snow surfaces are colonized each year.

Snow algae thrive on the snow, growing best at near-freezing temperatures. The algae flourish when both liquid water and nutrients are released from melting snow. We don't yet know how the bulk of the bloom avoids being carried away with the meltwater. Biofilms may play a role, as may an intriguing family of molecules known as ice-binding proteins. When secreted, these molecules could anchor the cells to the rounded snow granules. Inside the cell they may offer protection by preventing the growth of damaging ice crystals.

A significant challenge to photosynthetic life on the snow is the bombardment with more solar energy than can be handled by the biochemical reactions of carbon fixation, which are slowed by the cold temperatures. The consequence is a surfeit of free radicals with the potential to damage the cell. It is thought that the red pigment (astaxanthin) does double duty as a light shade and antioxidant. Given the fatty nature of the astaxanthin molecule, we wonder whether it might also serve as a store of energy to launch development in the spring, possibly from the darker reaches of deep snow.

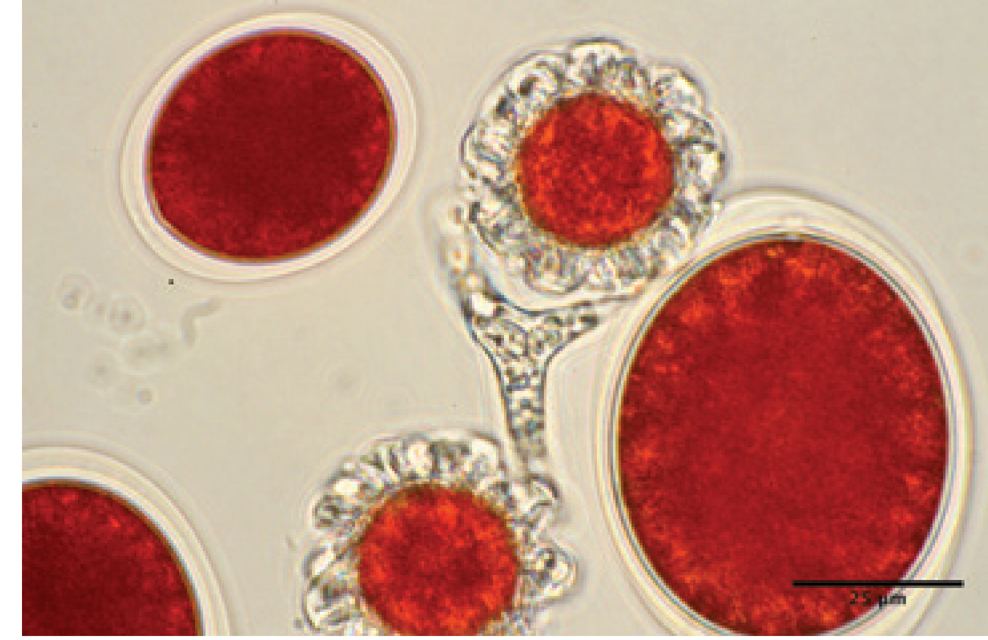

Figure 2 – Microscopic image of two turreted Chlamydomonas cf. nivalis cells with three massive Chlainomonas sp. and the fungus Chionaster sp. in center. Scale bar is 25 microns. Photo: Casey Engstrom.

Might snow algae be abundant enough to significantly alter global warming and the global carbon cycle? One study estimated that one fifth of the seasonal melt on an Alaskan snowfield was due to the presence of algae. Given the patchiness of blooms and their transience, gauging global impact will be difficult. Similarly, their contribution to the global carbon cycle is difficult to calculate. We hypothesize from our field observations that the bulk of the snow algae bloom is eventually deposited into alpine soil and lakes, potentially acting as a carbon sink. Whatever roles snow algae may have played in maintaining the ecological balances of the past 10,000 years, it is inevitable that this microbiome will be an early casualty of global warming as alpine snowfields diminish on a warming Earth.

Casey Engstrom is a graduate student in the lab of Dr. Lynne Quarmby in the Department of Molecular Biology and Biochemistry at Simon Fraser University. If you would like to learn more about snow algae, please visit www.quarmby.ca.

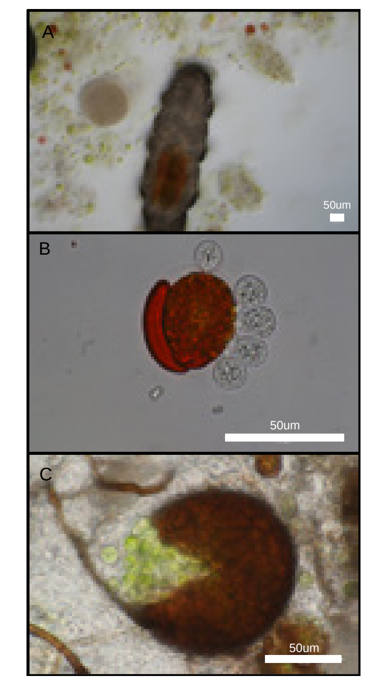

Figure 3 – A. Tardigrade with stomach full of snow algae. B. Chytrid fungi attached to the outside of a snow algae cell. C. Hatching "mothership" of unknown species. Photo: Casey Engstrom.

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The Birth of a Mountain Range in the Appalachians of Newfoundland

John W. F. Waldron

Origin of mountains: History of ideas

In changing times, it's easy to focus on changes in the mountain landscape that are caused by humans, but mountains have been growing and changing for billions of years. Only by understanding the slow, inexorable geological changes that mountains undergo, can we come to grips with the rapid pace of modern changes to the landscape.

The founders of geology were awed by mountains but had no easy way to explain their formation. Nineteenth century geologists observed that many mountains are made of enormous piles of sedimentary rock, and suggested that sediment-filled troughs, or "geosynclines," thousands of kilometres long, must have somehow been squeezed to form mountain belts or *orogens*. Geosynclines were postulated along both the eastern and western margins of North America, to explain the Appalachians and the Cordillera.

However, geologists aspire to explain the ancient world in terms of present-day processes. Modern geosynclines proved quite elusive, so geologists struggled to find an explanation for the origin of mountains.

Plate tectonics: How mountains are made

Two developments changed this picture in the late twentieth century. First, geophysical techniques allowed researchers to image the crust below the continental shelf and continental slope. The thicknesses of strata were enormous; for example, off eastern Canada, about twelve kilometres of sedimentary strata have accumulated since the start of the Jurassic Period, about 200 million years ago.[1]

The second development was the discovery of plate tectonics[2], and particularly the process of *subduction*, in which one plate of the Earth's outer shell, the lithosphere, slides beneath another and is eventually absorbed back into the mantle.

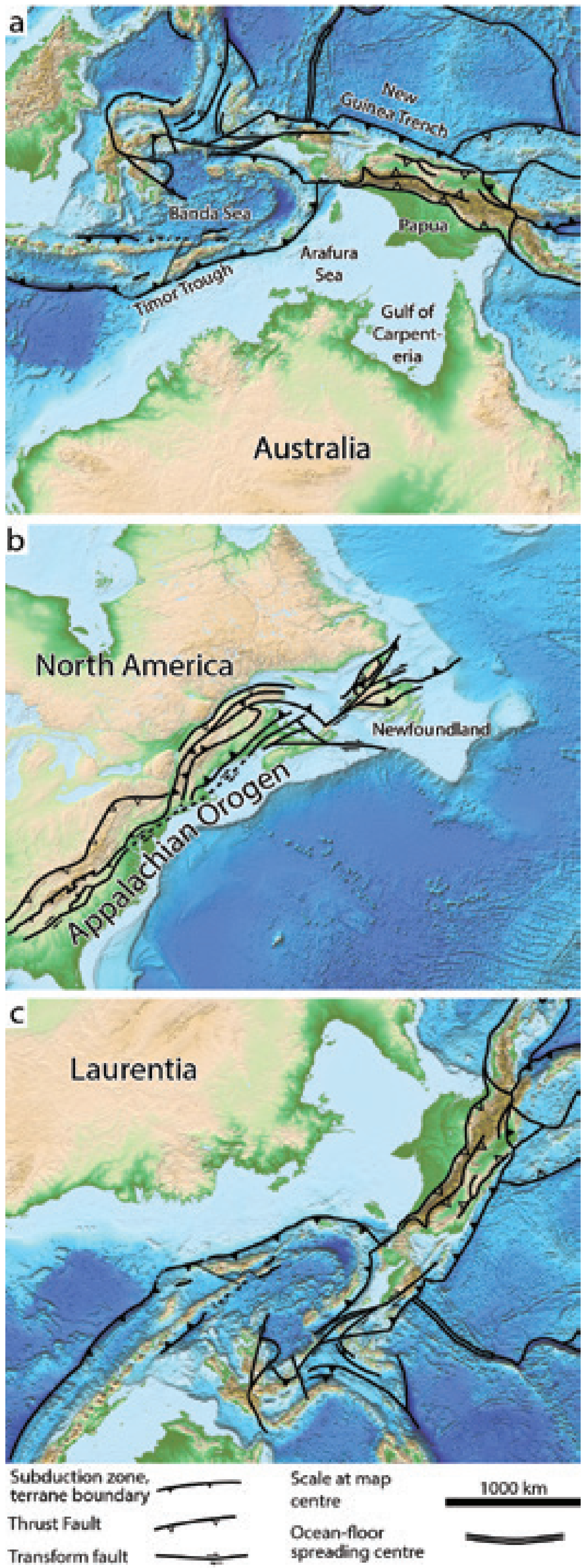

Figure 1

(a) Map of present-day northern Australia and Paua New Guinea showing the complex plate boundaries and other faults (black) that mark the ongoing process of continent-arc collision[3].

(b) Map of eastern North America showing major faults marking ancient plate boundaries within the Appalachian Orogen.

(c) Map showing possible of geography and plate configurations that existed in the nascent Appalachian Orogen during the Middle Ordovician Period, about 460 million years ago, based on rotated and reflected version of map (a)[4].

In a subduction zone, the over-riding plate, the one that is not subducted, typically carries a curved chain of volcanoes called a "volcanic arc." Along the edge of the over-riding plate, piles of sediment derived from the volcanoes are also enormously thick.

One process whereby plate tectonics can initiate a new mountain belt is called "arc-continent collision." This happens when a continent is dragged into a subduction zone. The continent is too buoyant to be subducted, so it gets telescoped against the volcanic arc, and eventually subduction stops. The process squeezes one huge pile of sedimentary strata, from the continental margin, against another pile of sedimentary and volcanic rock, from the arc, deforming both and producing a new orogen. We can see arc-continent collision in progress in Taiwan, and along the northern margin of the Australian Plate in Papua New Guinea (Figure 1a). These are orogens in the early stages of growth; eventually, much larger ranges (e.g. the Himalaya) may form by continent-continent collision.

Mountain building in the Newfoundland Appalachians

The mountains of western Newfoundland form part of the Appalachian Orogen (Figure 1b), which extends from Alabama to the east coast of Newfoundland. The Appalachians are part of an even larger belt, that extended through Pangea as far as northernmost Norway and Greenland.

The Appalachians started to develop about 480 million years ago, around the end of the Cambrian Period, as the ancient *Iapetus Ocean* began to close by subduction. Around 470 million years ago, the precursor of the North American continent, known as *Laurentia*, felt the first effects of deformation as a subduction zone collided with its eastern margin (Figure 2). Evidence for this collision occurs throughout western Newfoundland, particularly in the spectacular "arms" (fjords) and peaks of the Bay of Islands (Figure 3a) and Gros Morne National Park.

The old continental margin is represented by thick piles of limestone, deposited on a continental shelf. They contain reefs built by corals and sponges, and other fossils, that clearly show that Newfoundland lay in the tropics at the time. In the Middle Ordovician Period, the shelf started to subside as the edge of the continent approached a subduction zone. The limestones were overlain by sandstone, containing grains derived from the advancing volcanic arc.

Next, the continental margin was pulled beneath a deformed mass of sedimentary and igneous rock, known as the Humber Arm Allochthon ("allochthon" is from two Greek words meaning "from another foundation"). At the top of the pile was a slab of ocean floor, representing the collided

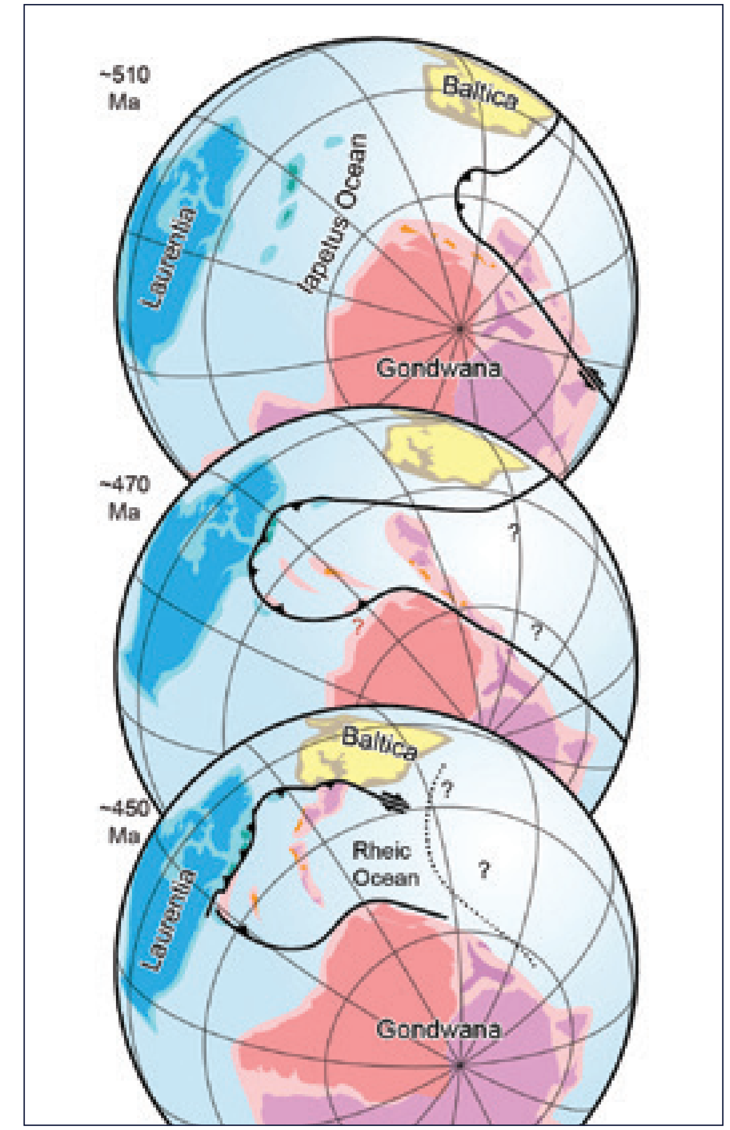

Figure 2. Maps showing the possible positions of major continental blocks from Cambrian to Late Ordovician times[5]. Major plate boundaries are shown in black. At about 470 Ma (million years ago) a subduction zone collided with the eastern margin of ancient North America (Laurentia), initiating the building of the Appalachians[5].

The founders of geology were awed by mountains but had no easy way to explain their formation.

Figure 3 – View over the Bay of Islands from Blow-Me-Down Mountain, Newfoundland. The rusty orange rocks are peridotite, a rock rich in iron and magnesium, representing an overthrust slab of the Earth's mantle. The low ground in the distance is occupied by softer rocks of the ancient margin of Laurentia.

Millions of years of erosion have sculpted the landscape, so that we can see the interior of the former mountain range.

volcanic arc; remnants of this make up the present-day highlands, including the Lewis Hills (the highest point on the island), Blow-Me-Down Mountain (Figure 3), and the famous Tablelands in Gros Morne National Park. By about 460 million years ago, ancient Newfoundland must have looked very much like a flipped around version of modern Papua New Guinea, as shown in Figure 1c. Mountain building was to continue for another hundred million years, as the super-continent Pangea was assembled.

Uplift and erosion - a continuing story

The spectacular structures we see in western Newfoundland and elsewhere in the Appalachian Orogen were formed by deformation deep within the mountain belt as it formed. Millions of years of erosion have sculpted the landscape, so that we can see the interior of the former mountain range. Some of the most rapid erosion was geologically very recent: in the last two million years, glaciers carved the deep valleys and fjords into the west coast of the island. As the ice receded, the continuing buoyancy of the continental lithosphere has allowed it to rise. As is true in mountains over the world, the present-day elevation of the peaks is the result of a delicate balance between uplift and erosion, which continue to compete with one another.

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Participants and staff at the 2018 Hallam Glacier General Mountaineering Camp. Photo: Paul Zizka

The State of the Mountains Report

Canada's diverse mountains define much of the country. Mountains provide critical natural and economic resources like water, biodiversity, forests and recreational opportunities. They're also home for many people living in small and remote communities. But both local and global changes influence these places in ways that are still not well understood. The ACC's State of the Mountains Report is a contribution to compiling and sharing the best available knowledge about Canada's mountains, from coast to coast to coast.

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