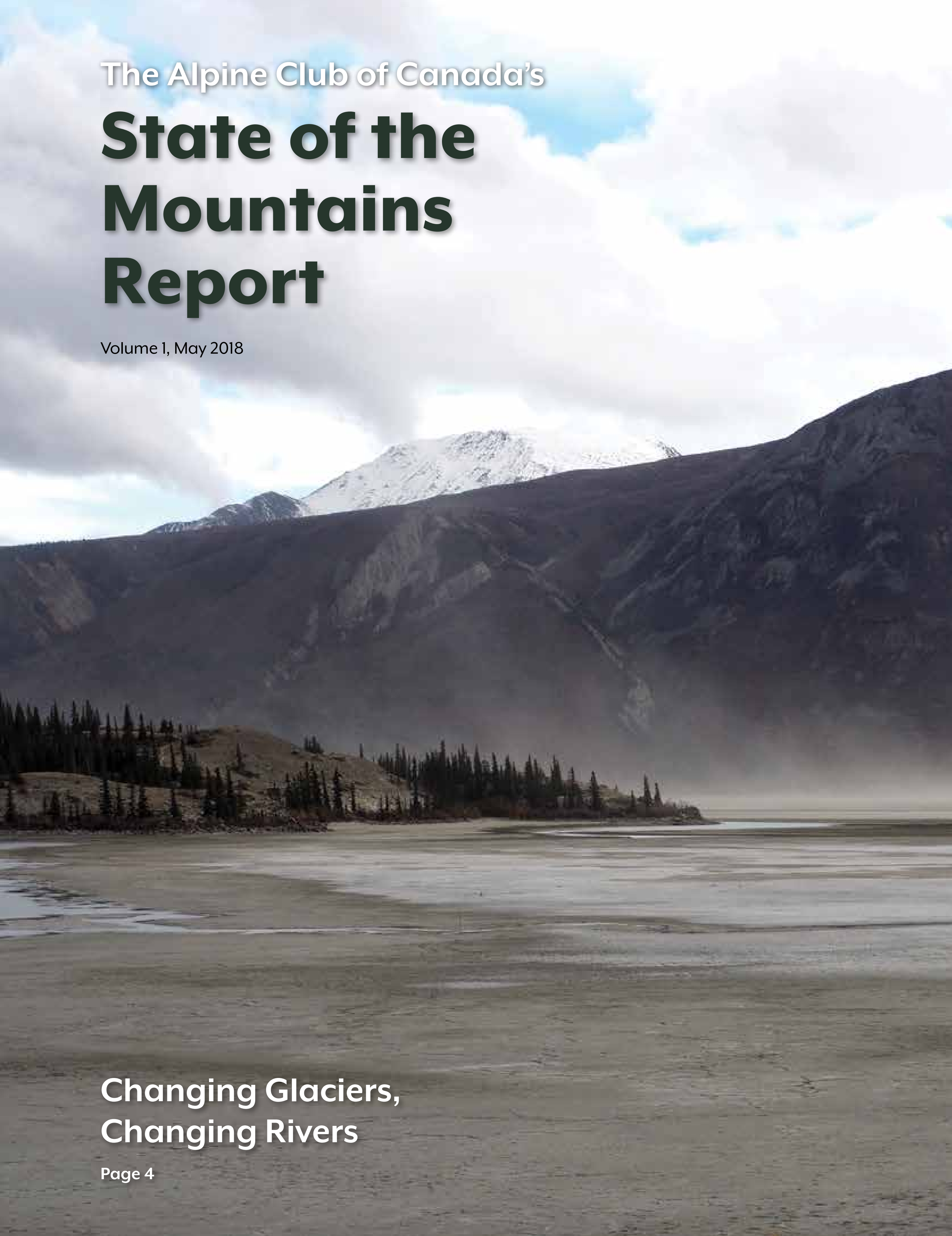

The Alpine Club of Canada's

State of the Mountains Report

Volume 1, May 2018

Changing Glaciers, Changing Rivers

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

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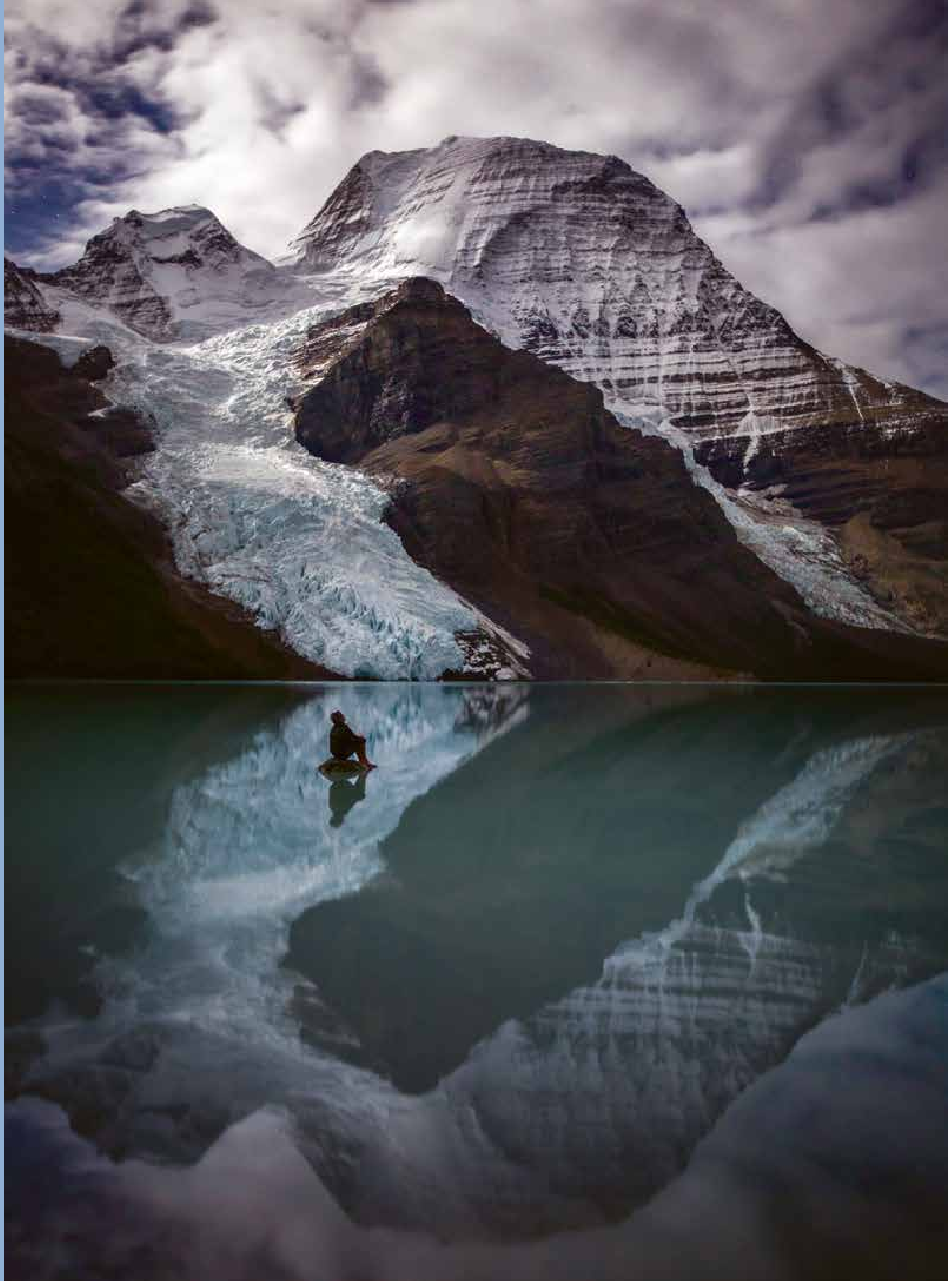
Cover Photo: The Slims River, YT (Ä̀äy Chù) where it flows into Kluane Lake (Lhù'ààn Mân), September 2016.
Photo: Lael Parrott

Inside Cover: Berg Lake, Mt Robson, BC. Paul Zizka



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Mountains Matter

Helen Lake and Dolomite Pass, Canadian Rockies. Photo: Laurie Shannon.

In 2011, The Alpine Club of Canada (ACC) published the first State of the Mountains Report, which highlighted the startling impacts of climate change on the alpine environment of Alberta and British Columbia. As Canada's national mountaineering organization, the ACC has a responsibility to act as a steward of our mountains, and the 2011 report was motivated by a commitment to summarize and better communicate an understanding of the environmental forces affecting these high places.

Globally, mountains matter more than ever. They comprise a quarter of the world's land surface and are home for a quarter of the world's human population.

The 2018 report continues this tradition and is the beginning of an annual State of the Mountains Report, produced by the ACC in collaboration with mountain researchers, community members, and partner organizations. We are particularly grateful to the experts who have provided their insights and perspectives this year, and to the Royal Canadian Geographical Society and *Canadian Geographic* magazine for their contributions. The "On the Map" pages in the May-June 2018 issue of *Canadian Geographic* complement the material in this report, and we hope that these will together provide a valuable resource for learning about Canada's mountains.

Globally, mountains matter more than ever. They comprise a quarter of the world's land surface and are home for a quarter of the world's human population. They hold extraordinary cultural significance for societies around the globe, and are venerated in religion, art, and literature. Mountains can be sites of extraordinary possibility and wealth, but are also regions of debilitating poverty: places on societies' margins, where communications are poor, and infrastructure, jobs, services, education, and health care are lacking. Mountains provide the world with critical ecosystem services, from minerals to forests to unique species of plants and animals. They serve as the headwaters for so many of the world's major rivers, and are the lifelines that connect much of our remote, high-alpine regions to urban populations. Mountains also respond rapidly and intensely to climatic and environmental variation, and are increasingly coming to be recognized by both social and natural scientists as 'sentinels for change.' Mountains truly impact everyone, everywhere.

Across Canada, from coast to coast to coast, mountain landscapes look out over a quarter of our country's landmass – 1.5 million square-kilometres; that's seven times the total area of the European Alps! Our mountains, however, like those around the world, are experiencing a variety of rapid and worrying changes. This 2018 report begins with a feature essay, by Dan Shugar and John Clague, describing the dramatic changes that occur when retreating glaciers abruptly alter the flow of mountain rivers and entire watersheds. In many ways, these observations can be considered a form of time travel into the future, providing a glimpse of some of the consequences associated with the rapid loss of mountain glaciers to come.

This essay is followed by 11 shorter "knowledge highlights," providing expert summaries related to ways that people live in changing mountains, and some of the striking transformations occurring in the physical environment and for plants and animals. A consistent theme throughout is a call for better information about the magnitude, rates, and projected impact of changes that are taking place.

In spite of the serious consequences of some of the changes documented in this report, all of the contributors remain optimistic that Canadians care about our mountains. For example, the current state of mountain literature, film, and digital media in English Canada has never been more vibrant, nurtured by the annual Banff Mountain Film and Book Festival. New research is developing operational tools to help organizations like Avalanche Canada reliably assess avalanche hazard conditions and inform decision-making to improve recreational safety. Scientists at the Canadian Ice Core Archive at the University of Alberta are working with the climbing community in efforts to collect samples from remote alpine environs to better understand the potential release of contaminants stored in glacier ice into the headwaters of major rivers. And numerous opportunities have been developed for volunteers and community-based organizations to participate in efforts to restore endangered high-elevation whitebark pine forests.

Never before in human history have mountains, globally, been in such demand or regarded with such favour as they are today. This widespread reverence, in addition to environmental change, has created unprecedented pressures on mountain environments and communities whose livelihoods and well-being are dependent on mountains. Despite these pressures, there's solace to be taken in the fact that so many care deeply about mountains. In Canada, and around the world, there is a growing recognition of the universal cultural and environmental value of mountains, which has led to the increased conservation and preservation of these special places. And so, *love mountains* — but not merely because they're a valued destination to visit; what is a "playground" to one is a home for another. Cherish these diverse and dynamic landscapes for all that they do, for us, for the planet, and for the future.

In times of change, mountains need stewards more than ever.

Lael Parrott, Zac Robinson, and David Hik
May, 2018

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Zac Robinson is the ACC Vice-President for Mountain Culture, and Associate Professor of History in the Faculty of Kinesiology, Sport, and Recreation at the University of Alberta.

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Neil Bosh, ACC President; Lael Parrott, ACC VP Access & Environment; Aaron Kylie, Editor In Chief, Canadian Geographic; and Zac Robinson, ACC VP Mountain Culture. Ottawa, 2017. Photo: David Hik.

Changing Glaciers, Changing Rivers

A meltwater stream snakes along the front of Kaskawulsh Glacier, draining a lake that formerly fed Slims River. Photo: Dan Shugar

Dan H. Shugar and John J. Clague

Climate warming over the past century is global in scope and unprecedented in the postglacial or Holocene Epoch, which spans about the past 12,000 years. Its magnitude and effects are especially large at high latitudes and in high mountains, where they have been manifested by large reductions in glaciers, ice sheets and permafrost, which are known collectively as the cryosphere.[1] Alpine glaciers are shrinking, ice loss from Greenland and the Antarctic Peninsula is increasing, and permafrost is thawing. Changes in precipitation and snowmelt are altering flow of water in rivers and streams, with potentially large impacts on ecosystems and species such as salmon.[2] All these effects and impacts have been well-documented in the mountains of western North America.[e.g.3,4] Earlier onset of snowmelt in this large region has been accompanied by a greater percent of winter precipitation falling as rain, both of which have led to a decrease in summer stream flows.[5,6] Recently, Beamer et al.predicted that summer runoff to the Gulf of Alaska will decrease by the late 21st century due to the continued loss of snow and ice in the high mountains of northwest North America.[7] These changes will adversely impact a wide variety of organisms. Chinook salmon, for example, may suffer dramatic declines as rising temperatures in rivers push the fish beyond their ability to adapt.[8,9]

As glaciers and permafrost disappear, landslides and debris flows are becoming more common in mountains.

Climate-driven reductions in the mountain cryosphere are having other, more physical impacts. As glaciers and permafrost disappear, landslides and debris flows are becoming more common in mountains.[2] Such a trend has been documented, for example, in Glacier Bay, Alaska.[10] Further, about one-quarter of the rise in global sea level rise caused by the global shrinkage of glaciers over the past half century is believed to come from glaciers bordering the Gulf of Alaska.[11] Deglaciation of Glacier Bay, which began in the early 19th century, has triggered uplift of up to 3.2 centimetres per year in this recently glacier-covered area.[12] Finally, it is possible that a reduction in ice cover over dormant volcanoes in Alaska might depressurize shallow magma chambers and lead to increased eruptive activity.[13]

The current reduction in the cryosphere in northwest North America is now happening at rates higher than at any time in the postglacial period, and were equaled or exceeded only during the preceding Pleistocene Epoch, the period from 2.6 million years ago to 11,800 years ago when large ice sheets periodically formed and disappeared over the Northern Hemisphere.[14] An important effect of the growth and decay of these ice sheets is the disruption and reorganization of rivers. The watersheds of the major river systems of Europe, Eurasia and North America were strongly perturbed and shaped by Pleistocene ice sheets. Among them are the three largest watersheds in the Cordillera of northwest North America – the Yukon, Columbia and Fraser watersheds. Prior to the Pleistocene, Yukon River flowed northward through Yukon Territory, rather than southward as it does today.[15,16] Peel River, which today is a tributary of Mackenzie River, was temporarily diverted into Porcupine River by the Laurentide Ice Sheet during the last Pleistocene glaciation.[17,18] Based on biochemical and morphological evidence, fish now inhabiting Peel River have ancient Yukon River ancestry.[17] Porcupine River itself once flowed into Mackenzie River and became a tributary of the Yukon only when the Laurentide Ice Sheet blocked its easterly flow. Before the Pleistocene, Fraser River drained eastward through the Rocky Mountains, probably via the Peace River valley, whereas today it drains a watershed of some 220,000 square kilometres and empties into an inland sea of the Pacific Ocean (Salish Sea) at Vancouver.[19] Although the exact timing and cause of these subcontinental-scale reorganizations of drainage are not exactly known, and in the Yukon case are probably more complex than was at first thought, it seems likely that glacier ice is implicated.[20]

Watershed reorganization of the magnitude of that driven by the growth and decay of the large Pleistocene ice sheets is not possible today because these ice sheets no longer exist except in Greenland and Antarctica. However, it operates on a smaller scale in mountains that still support large amounts of glacier ice. In May 2016, most of the water feeding Slims River, a headwater stream of Yukon River in southwest Yukon, which flows to the Bering Sea, was diverted into Kaskawulsh River, a tributary of the Pacific-flowing Alsek River.[21] This change happened over the course of a few days and is likely permanent. In this paper, we describe this event together with several known cases of glacial disruption of rivers in the Saint Elias Mountains and northern Coast Mountains of Canada. We also consider other watersheds in northwest North America where similar changes might happen later this century *(Figure 1)*.

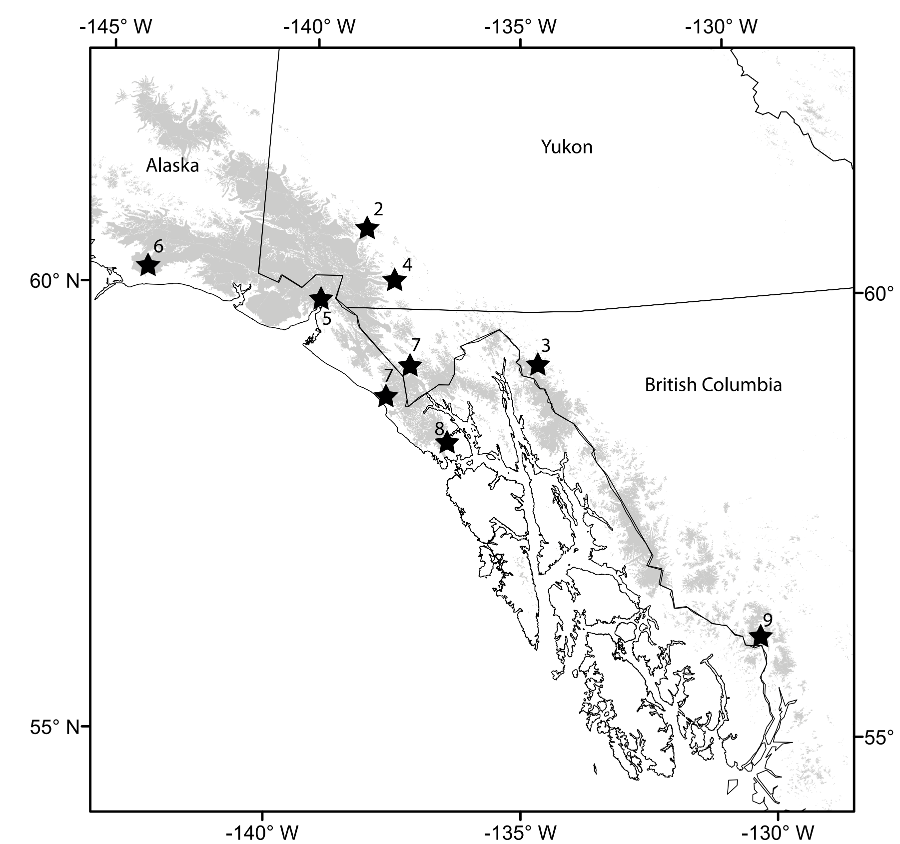


Figure 1. Map of northwest North America showing locations of stream reorganization sites discussed in the text. Numbers refer to figure numbers in the report: (2) Kaskawulsh Glacier/Slims River; (3) Llewellyn Glacier/Atlin Lake; (4) Donjek Glacier/Glacial Lake Alsek; (5) Hubbard Glacier/Russell Fiord; (6) Bering Glacier; (7) Melbern and Grand Pacific glaciers and Alsek and Grand Plateau lakes; (8) Brady Glacier/Oscar Lake; (9) Salmon Glacier. Grey shaded area represents glacier cover from Arendt et al.[22]

A thumbnail sketch of stream capture

On a geologic timescale, the ability of a river to expand its watershed depends partly on geology and partly on topography. All other things being equal, the steeper a watershed, the easier it is for a river to extend its headwaters at the expense of adjacent, less steep ones. Events, however, can disrupt the slow expansion of a watershed. A river might be blocked by lava flows, a landslide, or a glacier advance. If the blockage is sufficiently large and sufficiently long-lived, the lake that forms behind the dam might overflow across a low watershed divide and become set in a new course that is very different from

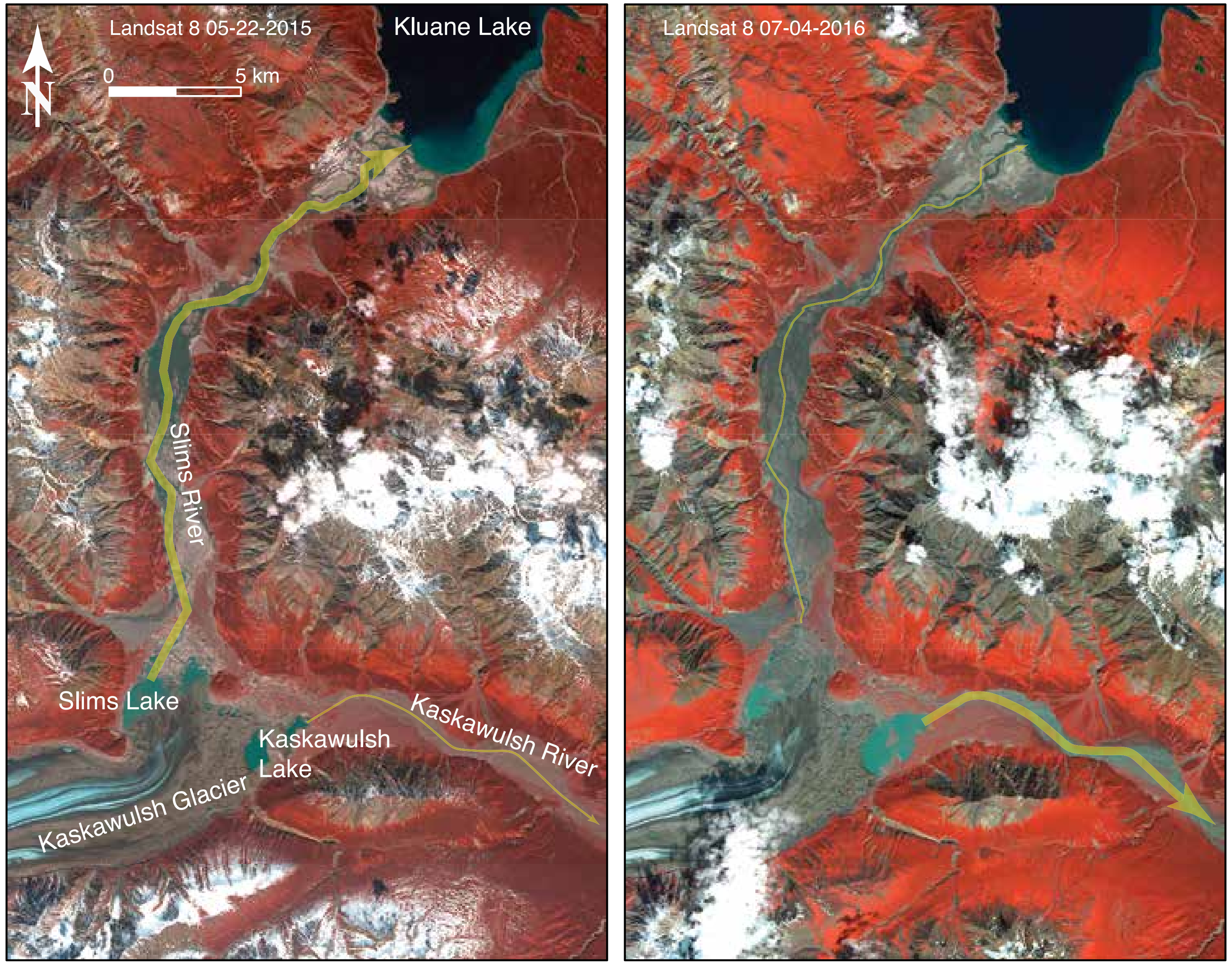


Figure 2. Satellite images showing drainage changes at the terminus of Kaskawulsh Glacier between 2015 (left) and 2016 (right). Yellow arrows indicate main meltwater discharge routes; their sizes reflect relative discharges. Modified from Shugar et al.[21]

the one before blockage. Such a scenario is an example of river rearrangement, and in extreme cases river capture, or "river piracy", where part of a river's watershed is captured by another river.

The 2016 Slims River piracy event

Over the past few hundred years, Kaskawulsh Glacier, one of the largest glaciers in the Saint Elias Mountains, terminated at the divide separating the watershed of Alsek River from that of Yukon River. Historically, a large portion of Kaskawulsh Glacier meltwater flowed north via Slims River into Kluane Lake and thence to Yukon River, reaching the Bering Sea more than 2400 kilometres downstream *(Figure 2)*. The remainder of the meltwater flowed southeast via Kaskawulsh River to Alsek River, which in turn flows to the Gulf of Alaska, about 300 km downstream. In other words, meltwater flowing via Kaskawulsh and Alsek rivers reached the sea over about one-eighth the distance of meltwater originating from the same source but flowing via Slims and Yukon rivers. Even though Kaskawulsh River has a much higher (steeper) gradient than Slims River, it has been unable during historic time to capture all the meltwater flowing from Kaskawulsh Glacier because the glacier itself formed the barrier separating the two rivers at the drainage divide; at least that was the case until the spring of 2016.

In May 2016, set up by over a century of climate warming leading to thinning and retreat of the terminus of Kaskawulsh Glacier, a proglacial lake at the head of Slims River (Slims Lake) drained via a channel through the glacier and into a lower lake at the head of Kaskawulsh River *(Figure 2)*. The sudden emptying of Slims Lake cut off Slims River from its source. Shugar et al.[21] have suggested that, barring a renewed advance of the glacier, which is unlikely in our warming climate, the beheading of Slims River is permanent. Eventually, Kaskawulsh River will extend its watershed northward and could eventually capture all waters flowing into Kluane Lake. Kluane Lake is the largest body of water in Yukon, and the effects of the flow changes are already being felt. In the summer of 2016, lake levels were about 1.7 metres lower than normal and have remained low since then. In 2017, the annual fishing derby at Burwash Landing was cancelled due to access and safety issues at the boat launch.

Although we cannot predict how soon the valley presently containing Slims River will reverse direction and flow south, such a situation is not unprecedented. About 10,000 years ago, when it was warmer than today in Yukon, a lowered Kluane Lake drained south to Alsek River via the same valley that now contains Slims River. During the Little Ice Age about 300 years ago, Kaskawulsh Glacier advanced and built a large sediment fan in the Slims-Alsek divide area, cutting off this southerly route.[23,24] The level of Kluane Lake then rose about 12 metres above its 2006 level and established its present outlet at the north end of the lake.[25,26]

Recent minor and aborted drainage reorganization in northwest North America

We know of no other historic examples of large-scale, permanent river piracy comparable to that at Kaskawulsh Glacier in 2016, however a minor instance of piracy happened at Llewellyn Glacier, an outlet glacier of the Juneau Icefield in the northern Coast Mountains of British Columbia (BC), in 2011. The terminus of this glacier comprises several lobes separated by steep bedrock slopes. Prior to 2011, two of the lobes were bordered by proglacial lakes that drained by two different rivers to Atlin Lake.[27] By 2011, the glacier had retreated enough that the two lakes merged; the surface of the eastern lake fell enough that the river that formerly drained to the east from that lake ceased to flow and all meltwater from the glacier discharged into Atlin Lake via the western river *(Figure 3)*. The mechanism of the Llewellyn Glacier drainage reorganization is similar to that at Kaskawulsh Glacier, but it is less dramatic because meltwater still discharges into the same water body, albeit via a river about 5 km to the east.

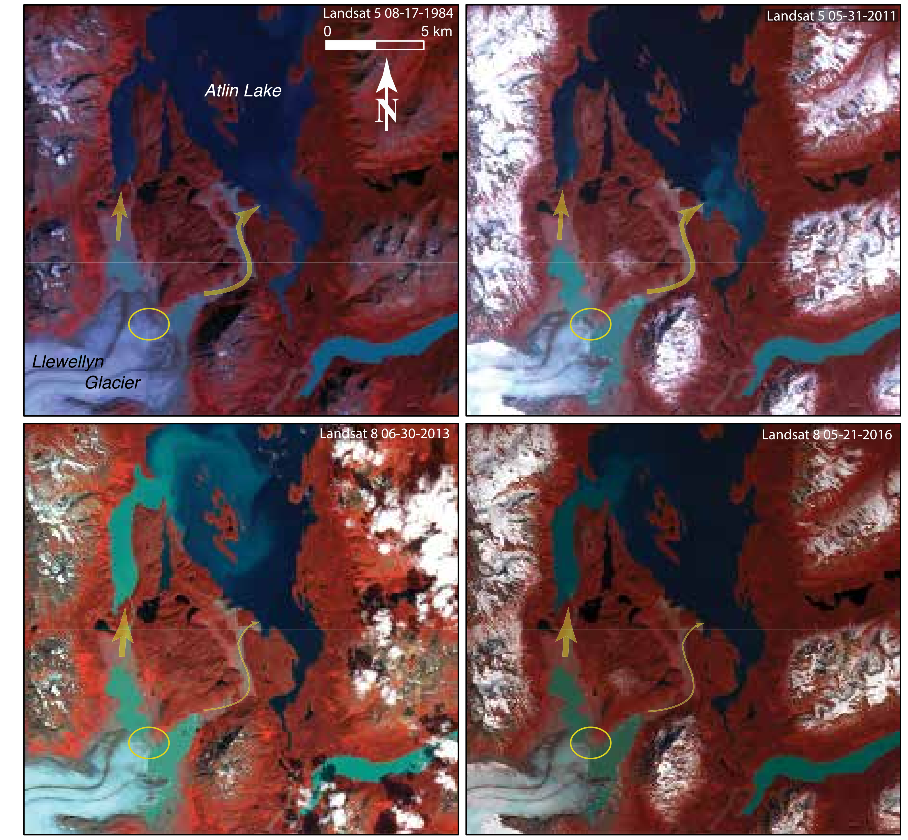


Figure 3. A time series of satellite images (1984, 2011, 2013 and 2016), showing drainage changes at the terminus of Llewellyn Glacier. Yellow arrows indicate main meltwater discharge routes; their sizes reflect relative discharges. Yellow oval shows where the two lakes joined into one in the summer of 2011. Note that the 2011 piracy occurred after the image at the upper right was acquired.

Similarly, at various times over the past 10,000 years, meltwater from Castle Creek Glacier in the Cariboo Mountains of BC drained either north or south due to the glacier's proximity to a hydrologic divide.[28] When the glacier's snout is downvalley of the divide, its meltwater fills On-off Lake, which drains north and then west via Cariboo River to Fraser River. When the snout is upvalley of the divide, as it is today, meltwater flows south via a small creek that eventually joins Fraser River near McBride.

River blockages characteristic of the initial stage of drainage rearrangement have happened many times during the historic and immediate prehistoric periods in the Saint Elias Mountains. For example, glacial Lake Alsek formed many times during the Little Ice Age due to blockage of Alsek River by Lowell Glacier *(Figure 4)*.[29] At one time, several hundred years ago, glacial Lake

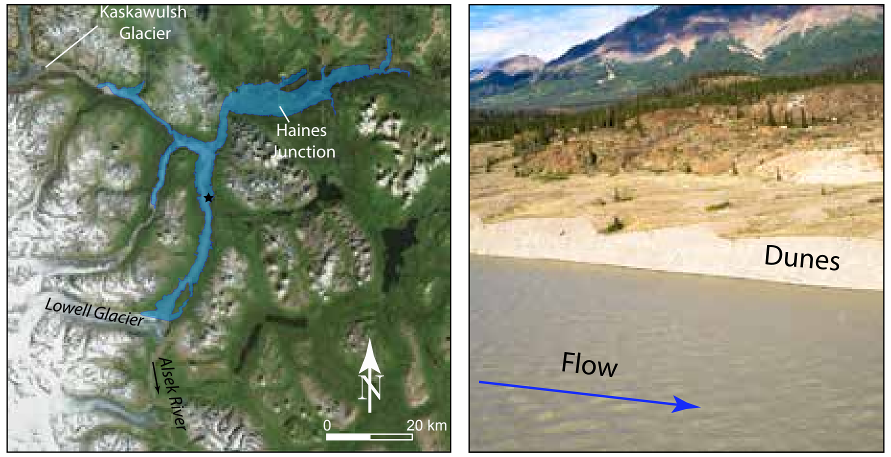
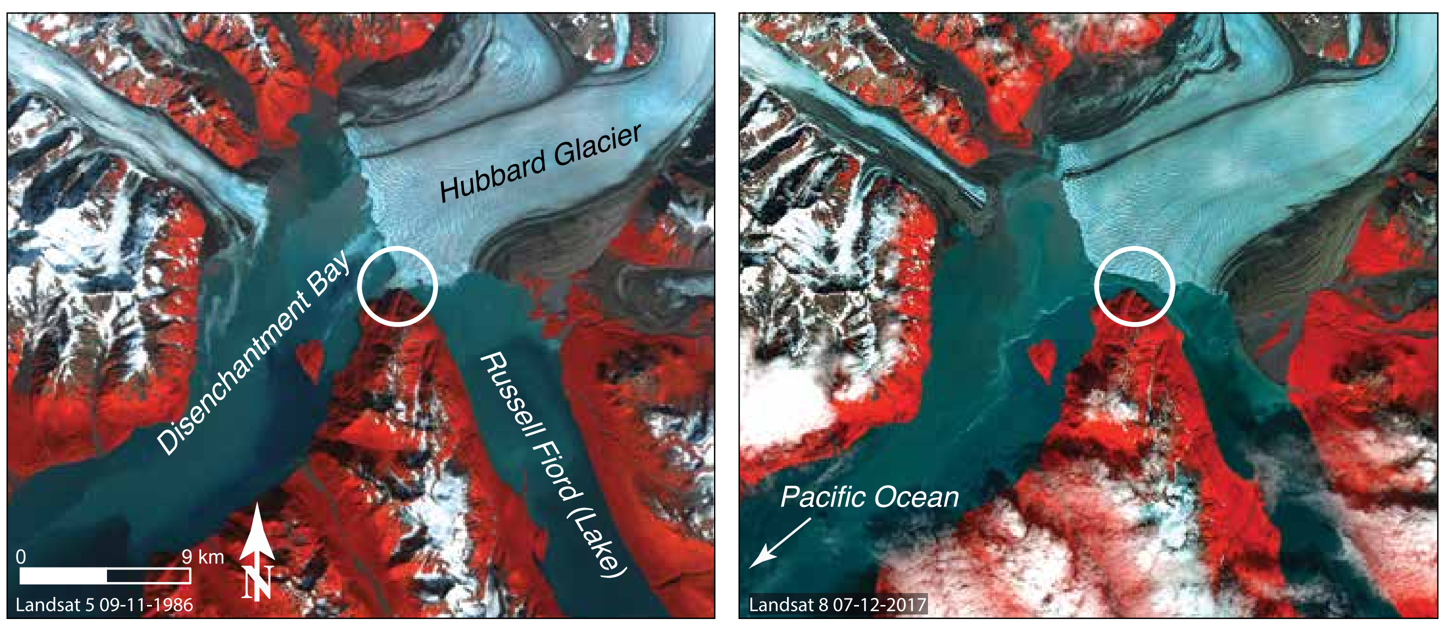


Figure 4. Maximum extent of Lake Alsek. The lake was mapped using the 668 m contour line based on the Canadian Digital Elevation Data (CDED) 30m product. The black star indicates the location of the photo of flood dunes along Alsek River (right).

Alsek was the largest glacial lake in western North America – 200 metres deep at the ice dam, extending more than 80 kilometres up the Alsek, Dezadeash and Kaskawulsh river valleys, and covering an area of about 250 square kilometres, including what is now the village of Haines Junction and a large section of the Alaska Highway. Relict beaches, some with driftwood mats, and huge ice-rafted boulders provide striking evidence of the former lake.[29] Glacial Lake Alsek drained catastrophically when the glacier dam was breached. Huge gravel dunes along Alsek valley, both above and below Lowell Glacier *(Figure 4)*, indicate how fast the lake emptied.

Figure 5. Satellite images of Hubbard Glacier closing off Russell Fiord in 1986 (left) and in a more retracted position in 2017 (right). The point where in 1986 Hubbard Glacier advanced sufficiently to turn Russell Fiord into a lake is circled.



Similar events have happened more recently at the terminus of Hubbard Glacier, the largest tidewater glacier in North America. Hubbard Glacier has advanced since it was first mapped in 1895 by building a protective submarine moraine at the entrance of Russell Fiord. In May 1986, a surge of Valerie Glacier, a tributary of Hubbard Glacier, caused the glacier to block the fiord entrance, converting Russell Fiord into a large glacier-dammed lake (Russell Lake) that ultimately rose to a height of 25.5 metres, drowned 34 square kilometres of forest land, and stored 5.4 cubic kilometres of freshwater *(Figure 5)*. The glacier dam burst out on October 8, 1986, producing a peak flow of 105,000 cubic metres per second (averaged over one hour) into Disenchantment Bay.[30] A similar blockage, albeit by the end moraine of Hubbard Glacier rather than the glacier itself, happened in 2002, and likewise ended in the sudden draining of Russell Lake.[31]

Looking forward: Possible future drainage reorganization due to glacier retreat

There are numerous locations in the mountains of northwest North America where drainage will be perturbed, and possibly re-routed, as glaciers continue to retreat. Lakes that are currently dammed by glacier ice will disappear and the meltwater that feeds them will take different routes. Here we provide a few examples among the many that we have identified during our field investigations and examination of satellite images. We describe here some of the more spectacular cases. A Google Earth kmz file with the locations of all discussed locations and others is included as a Supplementary File with the digital version of this report.

Bering Glacier, Alaska

A lake dammed by an arm of Bering Glacier overtops a divide and drains to the southeast via Kosakuts and Kaliakh rivers *(Figure 6)*. If Bering Glacier thins, as it likely will, the level of the lake will drop, ending flow to Kosakuts River. Eventually water will flow out of the lake into another valley to the west.

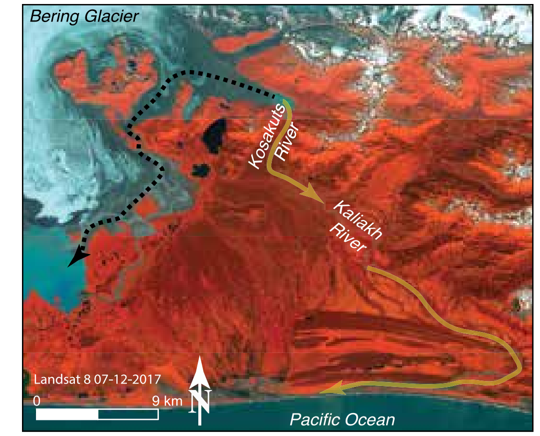


Figure 6. Satellite image showing a possible change in drainage at the southeast side of Bering Glacier. Yellow arrows show the current drainage route; dashed black arrow indicates the possible future drainage path described in the text.

Grand Pacific and Melbern glaciers, BC

Grand Pacific and Melbern glaciers, two of the largest valley glaciers in BC, have decreased over 50 per cent in volume in the past few hundred years. Melbern Glacier has thinned 300-600 metres and retreated 15 kilometres during this period; about 7 kilometres of this retreat occurred between the mid-1970s and 1987, accompanied by the formation of one of the largest, ice-dammed lakes on Earth today – glacial Lake Melbern, which is now 20 kilometres long *(Figure 7)*.[32] Glacial Lake Melbern presently discharges northward into Tatshenshini River immediately above the latter's confluence with Alsek River. This route, however, may be ephemeral, as another, steeper route exists, directly to Alsek River. The lower route might be taken if the moraine impounding Melbern Lake were to breach *(Figure 7)*.

Grand Pacific Glacier, which terminates in Tarr Inlet at the BC-Alaska boundary *(Figure 7)*, retreated 24 kilometres between 1879 and 1912.[32] As Grand Pacific and Melbern glaciers continue to retreat, the divide separating Tarr Inlet and the valley presently occupied by glacial Lake Melbern will become ice-free, potentially allowing the lake to empty into Glacier Bay and an arm of the sea to extend tens of kilometres northwest towards the Alsek River valley.

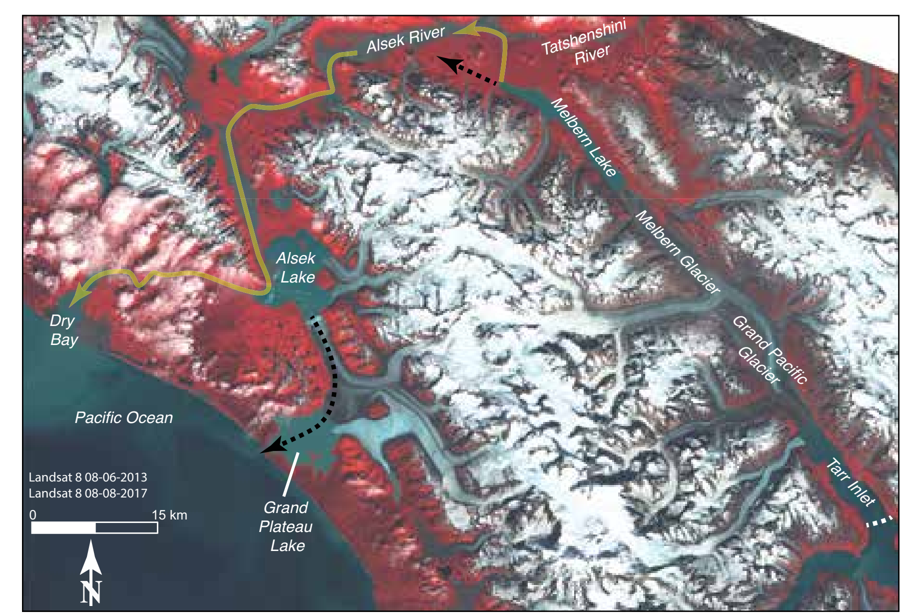
Lake Alsek and Grand Plateau Glacier, Alaska

A stream piracy event may also happen in the future near the mouth of Alsek River. Alsek River makes an anomalous right-angle turn at Alsek Lake and flows 20 kilometres west to Dry Bay *(Figure 7)*. A more direct route to the Pacific Ocean is to the south, but this path is blocked by the North Fork of Grand Plateau Glacier. This glacier, however, is rapidly retreating due largely to calving of its terminus in Alsek Lake and unofficially named Grand Plateau Lake. The latter, which barely existed in the mid-20th century is now 8 kilometres wide, with a surface area of about 28 square kilometres.[33] Between 1984 and 2015, Alsek Lake itself has extended almost 7 kilometres to the southeast on the heels of the retreating North Fork Grand Plateau Glacier, with nearly half of that retreat between 2013 and 2015.[34] If the glacier retreats another 6 kilometres, Alsek River might abandon its current westerly path and flow directly south into the Pacific Ocean via Grand Plateau Lake, 30 kilometres southeast of Dry Bay.

Brady Glacier, Alaska

Drainage at the periphery of Brady Glacier in Glacier Bay National Park, Alaska, will likely be rerouted as the glacier thins. Glacier-dammed Spur and Oscar lakes presently feed Oscar River, which empties into the south arm of Dundas Bay *(Figure 8)*.[35] The outlets of these lakes will be abandoned as the levels of the lakes fall, and the water will drain subglacially. Satellite imagery indicates that Spur Lake has

Figure 7. Satellite image mosaic of possible drainage changes in the lower Alsek River valley and Melbern valley. Yellow arrows show the current drainage routes; dashed black arrow indicates a possible future drainage path described in the text; dashed white line indicates approximate terminus position of Grand Pacific Glacier in 1899.[32]



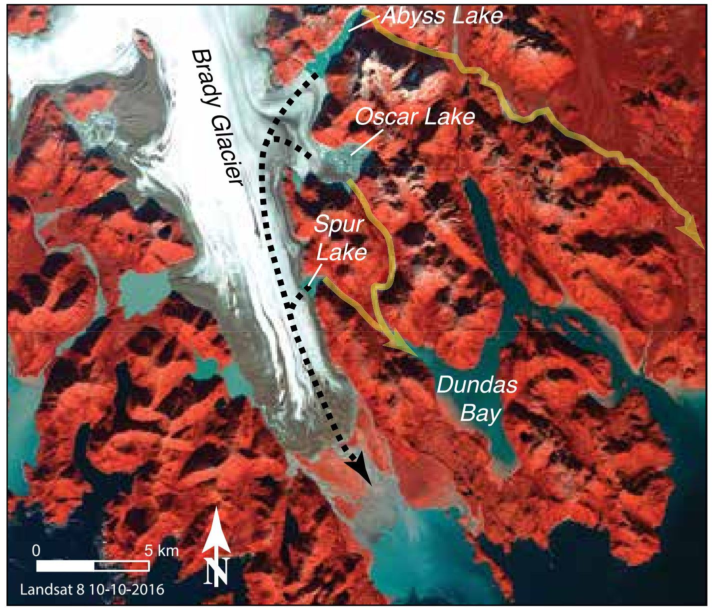
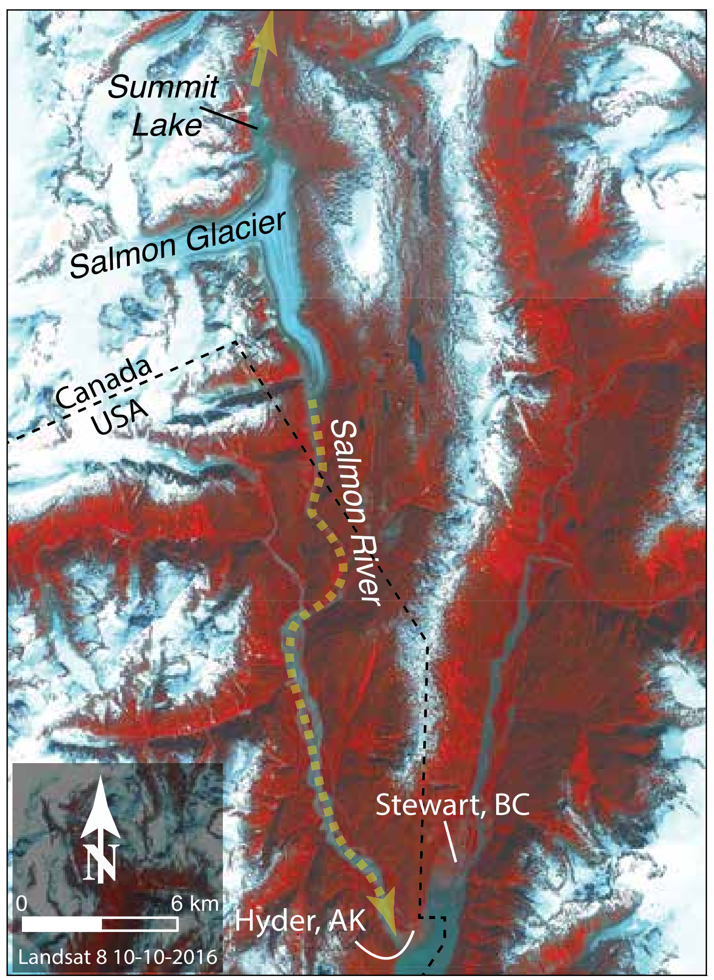


Figure 8. Satellite image showing present-day drainage routes (yellow arrows) and probable future subglacial drainage routes (dashed black arrows) at Brady Glacier.

Figure 9. Satellite image showing historic Summit Lake overflow north into the Bowser River drainage basin (solid yellow arrow) and the route of episodic outburst floods into Salmon River and Portland Canal at Hyder, Alaska. As Salmon Glacier recedes, it will no longer dam Summit Lake at all, and all meltwater from the glacier will flow southward. Dashed black line delineates the Canada-US boundary.



already become disconnected from its outlet stream. Abyss Lake, which, when sufficiently high, overflows via Dundas River into Dundas Bay, will drain subglacially as Brady Glacier thins.

Salmon Glacier and Bowser River, Alaska/BC

Salmon Glacier, located about 25 kilometres north of Hyder, Alaska, dams Summit Lake, which, prior to 1961, drained north into the Bowser River watershed *(Figure 9)*. In December 1961 following a long period of glacier thinning and retreat, Summit Lake emptied suddenly through an ice-walled channel at the base of Salmon Glacier.[36,37] Continued glacier flow sealed the tunnel, and the lake refilled over a period of 27 months. However, following a second emptying of the lake in November 1965, the lake never again filled high enough to overflow into the Bowser River watershed. Thereafter, Summit Lake emptied annually and then sporadically into Salmon River, which drains into Portland Canal at Hyder, near Stewart, BC. As the glacier retreats farther, Summit Lake may cease to exist and all meltwater issuing from Salmon Glacier will flow unimpeded into Salmon River.

Conclusions

Advancing glaciers blocked valleys, and in some cases rerouted entire river systems, when ice sheets formed over the Northern Hemisphere. As we move toward a world with far fewer glaciers and smaller ice sheets, land that has been covered continuously by ice for many tens of thousands of years will become ice-free. As it does so, many rivers in high mountains will be redirected via more hydrologically expedient paths to the sea. In most instances, the redirection will be inconsequential. In other cases, however, the changes might have more significance. For example, Dry Bay currently supports three small lodges, a floating fish processing plant, and an airstrip that serves a commercial rafting company. If Alsek River ceases to flow into Dry Bay, business and infrastructure there will have to be relocated or abandoned. In the case of the Slims River piracy, Kluane Lake may become a closed basin and, in the future, reestablish a southerly route to the Gulf of Alaska, with concomitant effects on the ecology of the lake and the people and communities that depend on the lake for food and recreation. Glaciers are an important part of the landscape of western Canada, and many of the largest rivers of BC and Alberta are fed by glacier melt. These rivers are sustained in dry spells by meltwater when other sources of water are scarce. However, recent history has shown that river reorganization due to climate change can, in some cases, have large consequences for people and ecosystems.

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Willoughby Ridge in 2015, regenerating after the 2003 Lost Creek Fire, Crowsnest Pass. Photo: Mary Sanseverino.

Community Resilience

Kevin Hanna

It would be difficult to underestimate the impact that climate change will have on mountain regions. The vulnerability of mountain landscapes and the people that rely on them for their livelihoods has been highlighted as a distinct area of concern in international development, and noted for special recognition in international efforts to combat climate change.[1]

As other chapters in this report show, Canada's mountain regions will hardly be immune from the impacts of climate change. For high country communities this means that adaptation and resilience will become key parts of responding to new climate uncertainties and the disturbances that will accompany them. Mountain people are hardly strangers to harsh climate and the challenges that come with working and living in rugged country. But climate change will impose new demands.

It can be hard to predict what a new climate reality will look like. While there is broad scientific consensus that climate change is a reality, the changes it will bring to specific places are difficult to predict with great accuracy. This makes planning hard for communities. But we increasingly understand general trends and probable outcomes and this information can help. It's fair to say we are already experiencing some of the effects of climate change. We know that Canada's glaciers and ice fields will shrink and some will even vanish, snow and rain levels and patterns will change—likely declining over time for many regions—and severe weather events will be more frequent and more powerful. But almost half the world's population relies on mountain water, and in western Canada hydropower depends on mountain water sources, as do most of its cities and towns.

Drier conditions will also change forested landscapes. British Columbia's 2017 fire season was the worst since the 1950s. Across the Coastal ranges, the Rockies, and the Kootenays the mountains were rarely seen for weeks; not because they were shrouded in mist or cloud, but in wood smoke. Tourism, travel and health were affected, but 2017 may be a harbinger for summers to come. As the ecosystems, biodiversity, and hydrological systems that support mountain communities are transformed, so will the economies and identities of mountain regions.

Many parts of society have become increasingly disconnected from each other and the environment.[2] But mountain communities rarely forget that their economies and cultures are profoundly intertwined with nature. Living in a rough landscape builds resilient qualities, which provide an advantage for people facing uncertainties and change.

Houses damaged along the edge of Cougar Creek in Canmore, Alberta. Widespread flooding caused by torrential rains washed out bridges and roads prompting the evacuation of thousands in June 2013. Photo: Jack Borno.

Resilience and adaptation are connected. Resilience starts from the understanding that humans and nature are linked in one social-ecological system. It is the capacity of linked natural and social-economic systems to deal with significant change and continue to function and progress. Resilience is concerned with how humans and nature can use shocks and disruptions like climate change, or even an economic crisis, to generate renewal and innovation.[2]

Adaptation is about putting resilience into practice. Adaptation is strategic and action oriented—it encompasses the activities that help reduce and mitigate the negative impacts of climate change.[3] Adaptation measures increase the resiliency of communities. Adaptation is anticipating how our physical, social and economic environment will likely change and what we need to do to make it resilient. On the ground, this means building infrastructure that anticipates the hazards of severe flooding, drought, new avalanche dynamics, rock and mudslides, and forest fires. Adaptation requires that a community invest in making the systems that provide transportation, freshwater, waste management, and social services more resilient. It is also identifying those parts of a local economy that will be most affected and deciding what changes need to be made, or indeed if it will need to be wholly reimagined.

For Canada's mountain communities—many of which are dependant on vulnerable sectors such as tourism, forestry and agriculture—climate change will bring adaptation challenges best met with early acknowledgement and planning. Resilience will require information and knowledge, and will involve building community adaptation literacy to understand the risks and actions needed for endurance and success. Forewarned is forearmed.

Adaptation is about putting resilience into practice.

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Mountain Writing, Film, and Digital Media in Canada

Stephen Slemon, Joanna Croston

All Canadians, wherever they live, have an investment in mountains.

In the two sections that follow, Joanna Croston, Programming Director for the Banff Mountain Film & Book Festival, provides a snapshot of the state of mountain literature, film and digital media in English Canada. It is clear from Croston's account that Canadian writers, publishers and filmmakers engage in the work of mountain representation for multiple, and often contradictory, reasons: nationalism and national identity; support for and celebration of sport, recreation and travel; support for industry and development; worries about ecological sustainability; love of the life outdoors; concern for Canada's mountain cultures, including its many Indigenous mountain peoples. It is also clear that greater dialogue between these interests and concerns will become increasingly necessary in the future.

Forty years ago, according to a note recently posted online by Katie Ives, editor of *Alpinist*, an international journal for mountaineering and its various cultures, Dave Cook, a celebrated political activist and rock climber in the UK, had this to say about one of mountain writing's most salient literary genres, climbing literature:

> *Climbing writing is crying out for the interconnections between work, relationships, art and scaling mountains. It's crying out for outpourings of emotion, not buttoned-down stiff upper lippery. It's crying out for the reassertion of some of the values of humanity and fellowship against the imperial colonization of the hills by hi-tech climbers. It's crying out for the insights of feminisim to challenge its restrictive and dehumanizing male imagery. It's crying out for a bit of poetry even.*

Many Canadian writers and filmmakers have been working towards the modes of interconnectedness that Dave Cook is calling for. And as that force of representation moves forward, the distinction between "mountain" and other categories for writing, art, film, and digital media will continue to diminish, and the barriers of separation break down. All Canadians, wherever they live, have an investment in mountains. Croston's account of Mountain Writing in Canada, and Mountain Film and Digital Media in Canada, locate some of the places where that investment, and that process of change, is now taking place.

Stephen Slemon is a Professor Emeritus in the Department of English and Film Studies at the University of Alberta.

Bernadette McDonald receives the Jon Whyte Award for Mountain Literature at the 2017 Banff Mountain Film and Book Festival ©Banff Centre for Arts and Creativity.

Mountain Writing

The emergence of small, mountain focused publishing houses and magazines in recent years is promising as well. Heritage House Publishing Group's Rocky Mountain Books imprint remains the country's most prominent publisher of mountain themed non-fiction annually while Canmore, Alberta based, Imaginary Mountain Surveyors publishes one mountain fiction title annually or bi-annually.

Bernadette McDonald, arguably Canada's most celebrated author of mountain literature continues to make waves internationally whenever her pen touches paper. Her most recently book, *Art of Freedom: The Life and Climbs of Voytek Kurtyka,* won no less than three international mountain literature awards in the course of three weeks in autumn 2017 including the Boardman Tasker prize and the coveted Jon Whyte Award at the 2017 Banff Mountain Film and Book Festival. Alberta author Gisèle Villeneuve took home the mountain fiction award at this year's festival for her book *Rising Abruptly: Stories.*

Beautifully crafted and designed periodicals such as *Kootenay Mountain Culture Magazine, Coast Culture Magazine, Mountain Life* and the *Canadian Rockies Annual* continue to gain momentum in the market with quality writing and visual work. Newly published Québec-based *Beside* magazine focuses on storytelling that reconnects outdoor enthusiasts with nature in an environmentally conscious way.

The Alpine Club of Canada's *Canadian Alpine Journal* celebrated its 100th year in 2017 and is the dominant source of annual reporting for avid mountaineers of first ascents both at home in Canada and abroad. Top Canadian climbers such as Vikki Weldon, Joshua Lavigne and the late Marc-Andre Leclerc contributed articles to the 2017 edition. On December 11, 2017, in celebration of Canada 150, and International Mountain Day, the ACC made the whole CAJ -- it's entire run -- publicly accessible in an open online and searchable format accessed from the ACC website.

In the more mainstream media realm, mountain literature authors in Canada seems to be pressing into a broader readers' group with a diversity of national publications taking on mountain themed content. For example, *The Walrus* recently devoted a full cover and feature article to Canadian mountain athlete Will Gadd with Katherine Laidlaw's article "This Will End Well" convincingly showing the demand for mountain-based content in a broad national readership. Similarly the Calgary Herald's *Swerve Magazine* also featured world renowned Canadian ice climber Raphael Slawinski in a piece entitled "Independent Study" by Lyndsie Bourgon about balancing his professional life as a physics professor with his climbing ambitions.

In 2017, Banff-based photographer and RCGS fellow Paul Zizka released his second coffee-table style book of photography, The Canadian Rockies: Rediscovered, as well as four Rockies photo/travel books in celebration of Canada 150 (all published by Rocky Mountain Books).

Mountain Film and Digital Media

Environmentalism in film in Canada remains a strong and consistent theme annually

Canadian film production companies such as Sherpas Cinema and Switchback Entertainment continue to lead the charge in the ski film industry. Sherpas Cinema's short film *Imagination: Tom Wallisch* became an instant internet sensation with more than 2 million views at the time of writing, not to mention has since picked up several awards from international film festivals from around the globe. Switchback Entertainment's *Kilian* was made in conjunction with outdoor industry giant Salomon. Both Canadian production companies have seen the immense viewership return in creating short films for online consumption as is also evidenced by the MEC supported episodic series *Seeking Nirvana.*

Foreign ski production companies including Red Bull Media House and Matchstick Productions are continuing to choose to film segments in Canada's mountains on an annual basis because of relatively consistent winter conditions and big terrain feature appeal.

Historical climbing films such *Hobnails and Hemp Rope* and *Expedition Yukon: 50 Years Later* were productions that celebrated anniversary milestones in the climbing world. Evidence of ethnic and gender diversity in mountain culture content remains challenging but films such as *Journeys to Adäka, Bison Return* and *Eyes of Society* , which have had widespread broadcast or theatrical release, suggest an industry desire to rectify the situation and give life to Indigenous stories for an outdoor audience.

Environmentalism in film in Canada remains a strong and consistent theme annually. The recently released *Living with Wildlife* and *Hunting Giants* films focus on solutions based storytelling to showcase the plight of both animals and landscapes in the mountainous regions of Canada.

British Columbia based Biglines.com and climbing site Gravsports-ice.com continue to lead the outdoor web from a referential standpoint by providing up to date information about mountain conditions and trip reports. Crowfoot Media's website provides broader based digital mountain culture content, everything from gear and book reviews to archival reportage and online photo exhibitions. Gripped magazine's website is an often used online reference for climbing news from around the world.

Joanna Croston is the Programming Director for the Banff Mountain Film and Book Festival at the Banff Centre for Arts and Creativity.

Big White Ski Resort.
Photo: Michael Pidwirny

Climate Change Challenges for Alpine Ski Resorts in Western Canada

Michael Pidwirny, Kalim Bahbahani and Shane Pedersen

By the end of the 21st century, the Intergovernmental Panel on Climate Change (IPCC) predicts that the continued emission of greenhouse gases by human activity will significantly increase surface air temperatures and change patterns of precipitation on our planet at local, regional, and global spatial scales. Being able to forecast how climate change will influence socio-economic systems is important to assess potential impact to humans. Understanding this impact will also allow for the development of effective adaptation and mitigation strategies to minimize the negative effects of climate change.

Time Period / Scenarios 30-year Average	Carbon Dioxide Parts Per Million	Methane Parts Per Billion	Nitrous Oxide Parts Per Billion
1901 to 1930	302	955	282
1981 to 2010	362	1708	312
2071-2100 Best-Case (RPC4.5)	532	1645	367
2071-2100 Worst-Case (RCP8.5)	807	3566	415

Table 1. Historical and future forecasted concentrations of carbon dioxide, methane and nitrous oxide in the atmosphere.

Analysis of the climatic impacts associated with human caused climate change at alpine ski resorts is quite straightforward using recently developed techniques which mathematically interpolate measurements from weather stations to other nearby locations. The research presented here uses spatially interpolated climate data which is generated by the software databases ClimateBC and ClimateWNA.[1] These climate software databases can produce data for the historical period 1901-2015 and future climate forecasts for the 21st century generated by climate simulation models used in the Fifth Assessment Report of the IPCC.

Alpine ski resorts in western Canada receive considerable year-to-year variation in surface air temperature and snowfall during the winter season. This variability can sometimes hide trends when the data record is short. Figure 1 illustrates the variation in winter mean temperature for Cypress Ski Resort located just north of Vancouver, BC for the period 1901 to 2015. Over this 115-year period, we can observe an obvious warming trend for winter mean temperature of about 1.5 degrees C. It is important to note that the winter mean temperature of 2015 was warm enough to cause this resort to close down for most of that ski season.

Trying to forecast how future climate change during the 21st century will affect Cypress Ski Resort and other resorts in western Canada can also be accomplished by using ClimateBC and ClimateWNA. However, the exact nature of this climate change is somewhat uncertain because it will depend on our future efforts to reduce greenhouse gas emissions into the atmosphere. Table 1 describes the estimated future atmospheric concentrations of the main greenhouse gases under a best-case (called RCP4.5) and a worst-case (called RCP8.5) scenario available in ClimateBC and ClimateWNA. The best-case scenario correlates to a warming of the Earth's surface globally of about 2.0 degrees C relative to pre-industrial greenhouse gas levels. Many climate scientists believe this scenario can be achieved if nations act soon to reduce emissions primarily through reforestation, other carbon capture techniques, increased

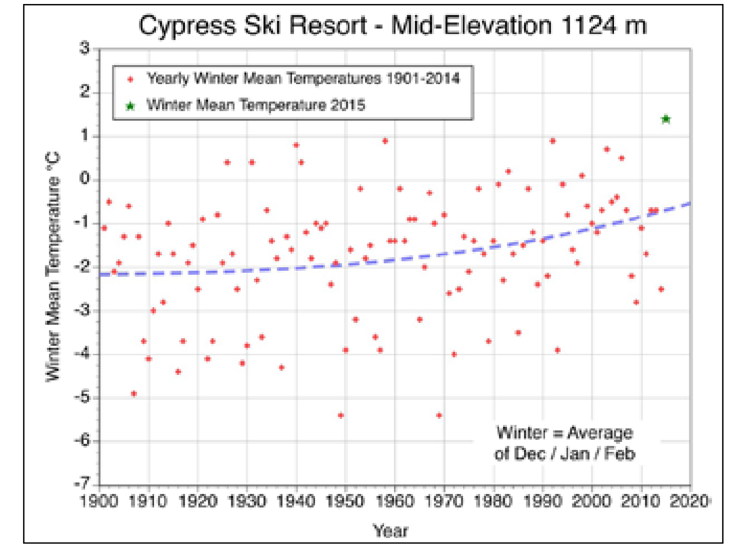

Figure 1. Observed winter mean temperatures from 1901 to 2015 at Cypress Ski Resort, elevation 1124 meters. The segmented blue line describes the best-fit trend line through the 115 observations. This graph also identifies with a green star the year 2015, the warmest winter in the history of Cypress.

Big White Ski Resort. Photo: Michael Pidwirny

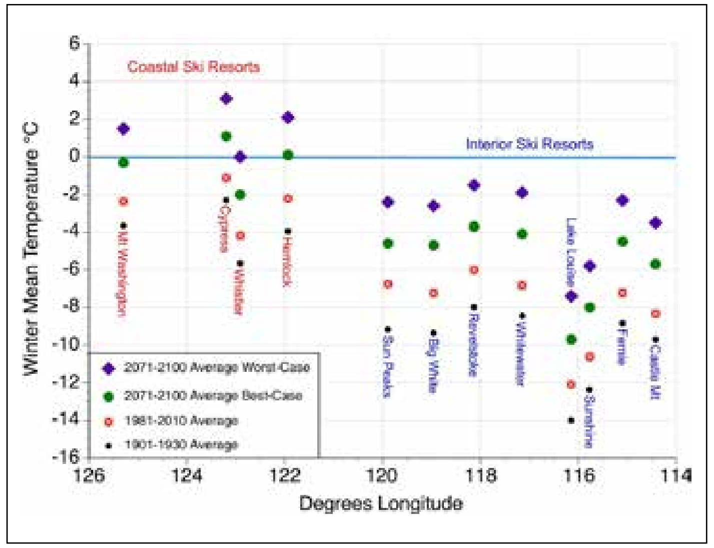

Figure 2. Historic and future forecasted changes in winter mean temperature for 12 selected ski resorts in western Canada. Values displayed based on data generated by ClimateBC or ClimateWNA for the mid-elevation of each ski resort.

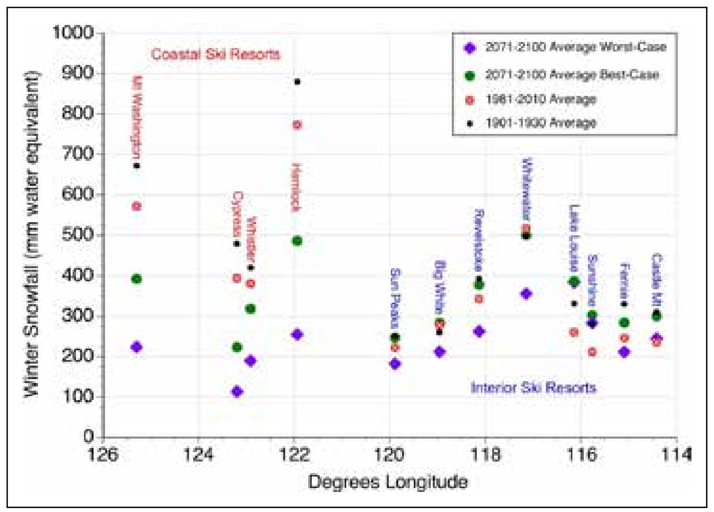

Figure 3. Historic and future forecasted changes in winter snowfall for 12 selected ski resorts in western Canada. Values displayed based on data generated by ClimateBC or ClimateWNA for the mid-elevation of each ski resort.

energy-use efficiency and switching to renewable based energy generation. The worst-case scenario corresponds to a future pathway where greenhouse gas emissions continue to increase exponentially, and average global temperature becomes between 3.0 to 5.0 degrees C warmer by 2100.

Figures 2 and 3 describe historical and future forecasted changes in winter mean temperature and winter snowfall for 12 ski resorts along a longitudinal gradient from Vancouver Island to western Alberta. For winter mean temperature, we can see the selected resorts have already experienced between 1 to 2 degrees C of warming from 1901-1930 to 1981-2010.

Figure 2 also shows the anticipated future warming for the best-case and worst-case scenarios. Under the best-case scenario, the coastal ski resorts of Mount Washington, Cypress and Hemlock will probably become too warm to support skiing and snowboarding by the end of the 21st century. Whistler's winter mean temperature will resemble the climate of 1981-2010 at Mount Washington under this scenario. Under the worst-case scenario all of the coastal resorts will become much too warm to support winter recreation. The best-case scenario will make the winter mean temperatures of the interior ski resorts about 2.0 to 3.0 degrees C warmer than what was experienced in 1981-2010. The worst-case scenario will add yet another 2.0 degrees C.

Figure 3 suggests that the coastal ski resorts will face significant declines in winter snowfall in the future for both the best-case and worst-case scenarios. Most of the interior ski resorts will experience no change or slight increases in snowfall under the best-case scenario. The worst-case scenario will cause less winter snowfall for Sun Peaks, Big White, Revelstoke and Whitewater interior ski resorts.

In conclusion, human caused climate change in the near future is predicted to result in warmer winter temperatures and changes in snowfall for the alpine ski resorts of western Canada. How detrimental these changes will be to the ski industry in western Canada depends on whether governments can implement meaningful reductions in the future emissions of greenhouse gases.

Michael Pidwirny is an Associate Professor and Kalim Bahbahani and Shane Pedersen are students in the Department of Earth, Environmental, and Geographic Sciences, University of British Columbia, Okanagan.

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Snowmobiler, Castle Mountain area, Alberta. Photo: Stevin Tuchiwsky.

Snow Avalanches

Pascal Haegeli

Snow avalanches are a serious mountain hazard in Canada. Between 1980 and 2018, 446 people died in Canada in 314 avalanche accidents. This is roughly twice the number of fatalities from any other single meteorological or geological natural hazard (Figure 1 & 2). While most of these fatalities occurred in western Canada (British Columbia: 71 percent; Alberta: 20 percent; Yukon: 2 percent), fatal avalanche accidents also happened in Québec, Newfoundland and Labrador and Nunavut. Apart from two fatalities at outdoor worksites, all avalanche fatalities during the last decade were winter backcountry recreationists either making their own decisions (92 percent) or professionally guided (8 percent). Among the self-directed recreational fatalities, 50 percent were mountain snowmobile riders, 23 percent backcountry skiers, 5 percent out-of-bounds skiers and 22 percent pursued other winter backcountry activities. In addition, avalanches affect important Canadian industries (e.g., forestry, mining, hydroelectric generation) and critical infrastructure (e.g., transportation corridors, transmission lines, pipelines). Every winter, the threat from avalanches causes traffic hazards and substantial economic loss through temporary closures of highways, railways and resource roads.

The risk from avalanches is managed through a combination of avalanche safety planning and operational programs. Avalanche safety planning identifies general exposure to avalanche hazard and designs solutions to either eliminate the risk

The risk from avalanches is managed through a combination of avalanche safety planning and operational programs.

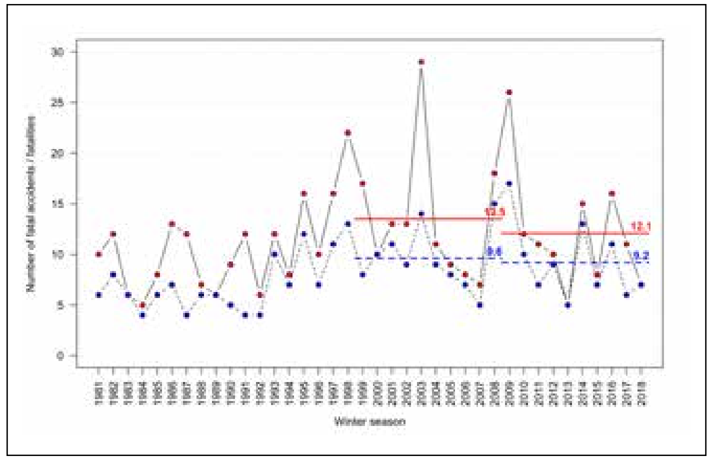

Figure 1. Annual number of fatal avalanche accidents (blue dots with dashed line) and avalanche fatalities (red dots with solid line) in Canada from winters 1981 to 2018 (Avalanche Canada (nd). Horizontal lines indicate 10-year averages of annual accident (blue dashed) and fatality (red solid) numbers.

(e.g., avoidance through land use regulation), or reduce the risk to an acceptable level. Risk reduction may take the form of engineering solutions (e.g., snow nets, deflection dams, avalanche sheds) and/or operational avalanche safety programs. These programs manage avalanche risk in real-time by continuously monitoring conditions and choosing short-term mitigation measures (e.g., temporary closures, artificially triggering avalanches) to meet organizational objectives, such as keeping a road open, securing a ski run at a resort, or choosing safe backcountry terrain for guests. To provide private recreationists with avalanche safety information for planning trips into the winter backcountry, a combination of non-government (Avalanche Canada, Avalanche Québec) and government (Parks Canada, Alberta Parks) agencies issue daily public avalanche forecasts for about 20 forecast regions in western Canada, and the Chic Chocs in Québec throughout the winter.

Considerable efforts are currently underway to reduce avalanche closure times along the Trans-Canada Highway

Considerable efforts are currently underway to reduce avalanche closure times along the Trans-Canada Highway (TCH). Recent installations of snow nets (Cougar Corner west of Rogers Pass, Figure 3), remote avalanche control systems (e.g., Three Valley Gap) and avalanche detection systems will increase highway reliability substantially by allowing avalanche safety teams to control avalanche hazard more efficiently. Between 2016 and 2018, the overall avalanche protection related capital expenditures along the TCH will exceed $15 million.

Since it is ultimately people deciding when and where to expose themselves to avalanche hazard, improving avalanche safety depends on an in-depth understanding of both the physical phenomenon and the intricacies of the human interaction with it. Avalanche safety research in Canada is therefore taking an interdisciplinary approach that incorporates perspectives and methods from natural, social and medical sciences to examine the factors that lead to avalanche accidents more comprehensively. The close collaboration between academic researchers and avalanche safety practitioners in Canada has created a unique environment for developing practical, evidence-based tools that allow people—both professionals and recreationists—to make better informed decisions about avalanche risk.

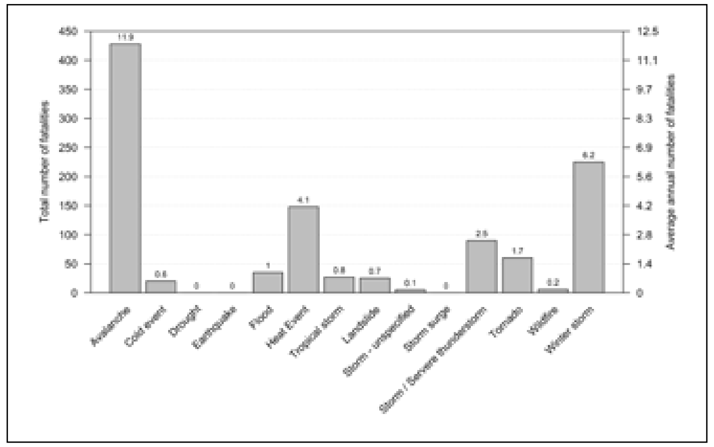

Figure 2. Total and annual average number of fatalities from meteorological or geological natural hazards in Canada between Oct. 1, 1980 and May 8, 2018 (Avalanche Canada (nd): avalanche fatalities'; Public Safety Canada (nd): all other fatalities). Note: Number of fatalities due to cold events and heat events likely underestimated as events with less than 10 fatalities might not be included in Canadian Disaster database.

The vastness of the Canadian mountains poses a substantial challenge for providing up-to-date avalanche hazard assessments wherever needed. Many industrial applications and transportation routes are remote, and substantial recreational use occurs in areas where the lack of a reliable stream of observations and assessments prevents the publication of public avalanche bulletins.

Recent Canadian research linking numerical snowpack models with weather forecast models has shown that this approach can simulate the snowpack structure at point locations (Figure 4) and the large-scale spatial patterns of critical snowpack layers reasonably well.[2,3,6] Current research aims to develop operational tools to reliably assess avalanche hazard conditions and inform decision making in otherwise data-sparse regions.

The recreational backcountry community (Figure 5) has not only grown dramatically in recent years, but it is also becoming increasingly diverse. Since each user group is unique, an in-depth understanding of their interactions with the mountain landscape, their avalanche awareness levels and their preferred information channels is critical for developing effective safety initiatives. While past research has provided valuable insight, more human dimensions research is required to design activity-appropriate avalanche safety guidance and ensure effective delivery.[4,5]

These are just two examples of avalanche safety research directions presently being pursued in Canada. While current avalanche safety initiatives have managed to keep the annual number of avalanche fatalities steady despite the tremendous increase in recreational backcountry activities and users, innovative solutions will be required to support the continued growth of economic and recreational activities in Canadian mountains.

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Figure 3: Installation of snow nets in Cougar Corner, 10 km west of Rogers Pass (source: Brian Gould, Alpine Solutions Avalanche Services)

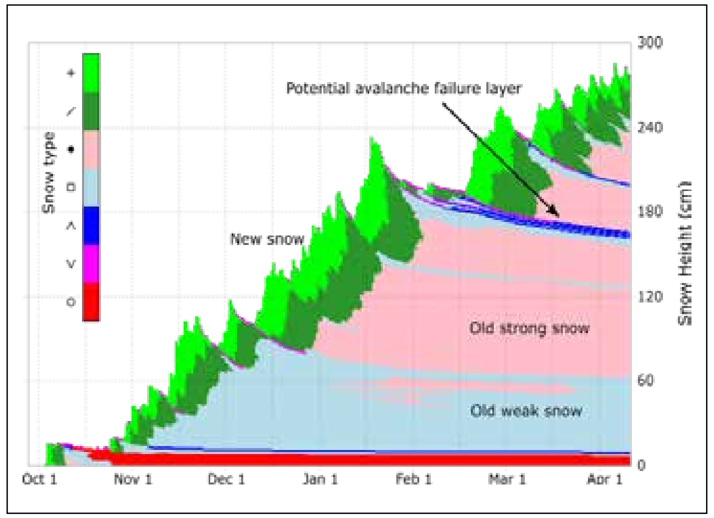

Figure 4. Simulated evolution of seasonal snowpack (source: Simon Horton)

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Eric Higgs in 2012 photographing the Kaskawulsh Glacier in Kluane National Park and Reserve, Yukon, to compare with the same image taken by James McArthur in 1900 as part of the International Boundary Commission. Photo: The Mountain Legacy Project 2012

The Mountain Legacy Project: Exploring 150 Years of Landscape Change in the Canadian Mountain West

Mary Sanseverino and Eric Higgs

For 20 years the Mountain Legacy Project (MLP; mountainlegacy.ca), based at the University of Victoria in the School of Environmental Studies, has been using repeat photography to explore change in Canada's mountain landscapes. Utilizing historical photographs of remarkable fidelity, MLP teams seek to determine the photo locations, go to the same place, and re-photograph the images as accurately as possible. The historic and modern images are then aligned, analyzed, used by MLP for research, and made available to scholars, students, government agencies, the public at large – in fact, anyone interested in exploring Canada's mountain heights.

Working with long-running partner Library and Archives Canada / Bibliothèque et Archives Canada (LAC/BAC), UVic Libraries, the Canadian Mountain Network, and other agencies and organizations, MLP researchers endeavour to understand how and why mountain ecosystems, landscapes, and human communities change over time. Key project funding and engagement comes from the Alberta Ministry of Agriculture and Forestry and the Social Sciences and Humanities Research Council.

With approximately 120,000 historic photos, almost all of which are glass plate negatives, Canada is home to the world's largest collection of systematic historic mountain imagery. Most of the ranges in BC, Alberta, and the Yukon have extensive coverage. The earliest photographs date back to 1861 and are from the Canada/USA International Boundary Commission survey along the 49th parallel. But the vast majority come from topographic mapping efforts carried out between 1888 and the 1950s. Most of the images are kept at LAC/BAC in Gatineau, Quebec, the BC Archives in Victoria, and the Whyte Museum in Banff.

As of 2017 MLP teams have repeated more than 7,000 of these photographs. The image pairs, along with thousands of as yet unrepeated historic photos, are published in searchable format online at explore.mountainlegacy.ca. Since its inception, MLP researchers have developed and improved techniques for acquiring the modern retakes, for curating and analyzing the image pairs, and for publishing the results.

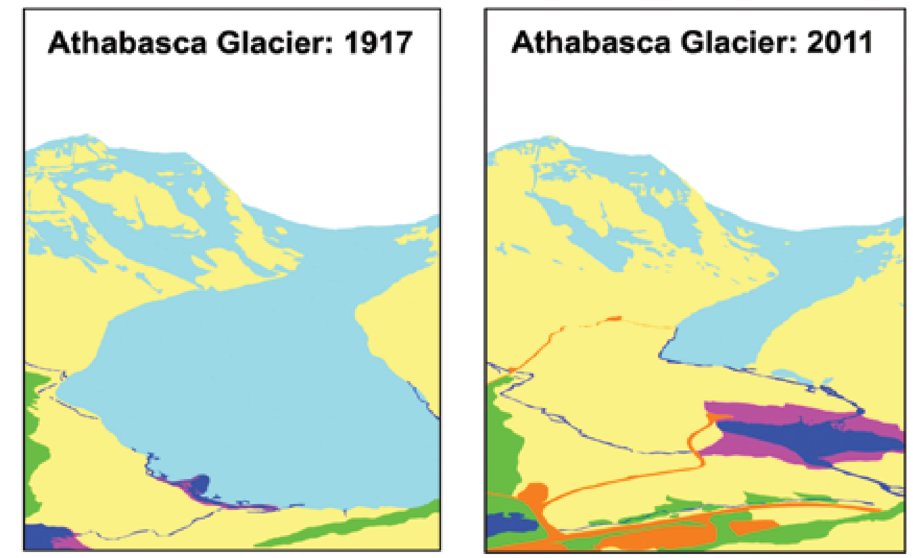
MLP has informed many research projects over the years, which means that selecting just a few landscape change themes is never easy. However, the following are evident in many image pairs:

1) **Loss of glaciation.** Figure 1 shows the Athabasca Glacier. The loss of ice between A.O. Wheeler's 1917 and MLP's 2011 images is startling. Figure 2 is based upon the same images, but demonstrates an analysis with MLP's Image Analysis Toolkit, which was developed to help researchers better visualize and quantify change between and within image pairs.[1,2]

2) **Alpine Treeline Ecotone (ATE) advance.** Figure 3 from east of the Highwood Ranges in southern Alberta shows trees infilling and the treeline moving upslope. As past MLP research has shown, there are many questions around the mechanisms driving ATE advance and the changes it brings to alpine ecosystems.[3]

The Athabasca Glacier from Wilcox Pass, Jasper NP, Alberta.
Historic B&W: 1917, A.O. Wheeler, Interprovincial Boundary Survey.
Modern image: 2011, Mountain Legacy Project.

Figure 1: Dramatic loss of glacial ice.



Classifications	% of class in image (1917)	% of class in image (2011)
Roads/Buildings	0.0 %	4.6 %
Water	1.4 %	3.9 %
Upland Herbaceous	2.5 %	6.2 %
Snow / Ice	57.2 %	16.7 %
Rock / Scree	38.3 %	64.9 %
Fluvial	0.6 %	3.7 %

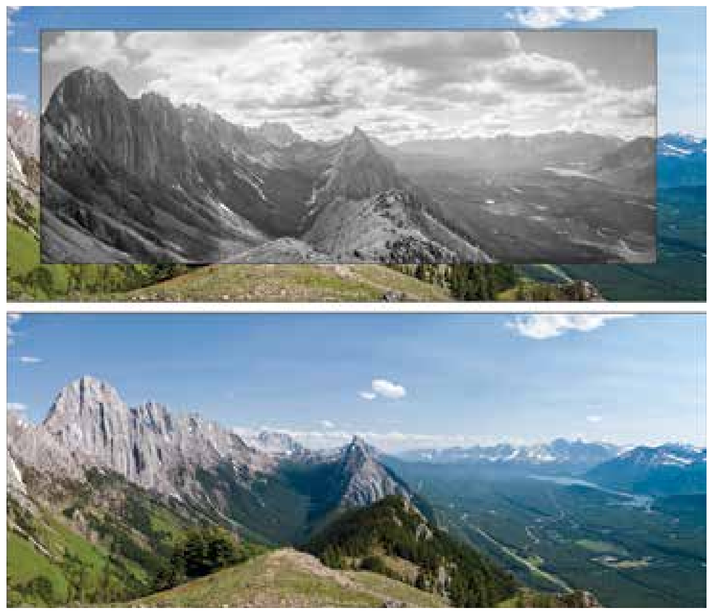
Intersection of 1917 and 2011 Images

Classifications	% of class in common
Roads/Buildings	0.0 %
Water	0.1 %
Upland Herbaceous	2.0 %
Snow / Ice	16.0 %
Rock / Scree	30.5 %
Fluvial	0.0 %

Figure 2: Historic and modern images segmented into classification categories. Each category is shown as a percentage in a given image. The intersection of categories between images indicates what has remained the same in the intervening 94 years. For example, 16% of the snow and ice category is in the same place in the 2011 image as it is in the 1917 photo.

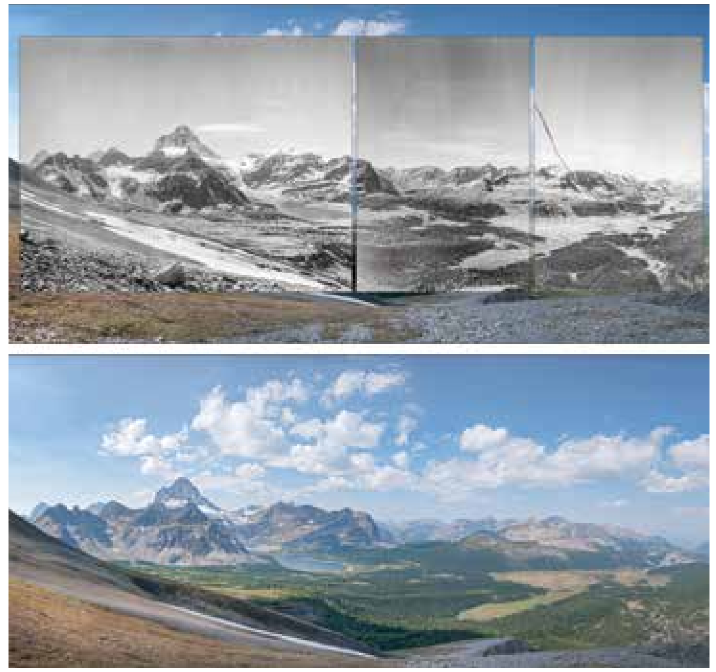
Bull Creek looking west into the Highwood Range, Southwest Alberta.
Historic B&W: 1916, D. Nichols, surveyor.
Modern Image: 2012, Mountain Legacy Project.

Figure 3: Notice how the treeline has changed in these images.



Looking south from King Creek Ridge, Kananaskis Country, Alberta.
Historic B&W: 1916, D. Nichols, surveyor.
Modern image: 2012, Mountain Legacy Project.

Figure 5: Notice how the fire burned both the west and east slopes (right and left) in the centre of the image but jumped the top of the ridge.



Looking west from Mt. Cautley shoulder over the Mt. Assiniboine massif, Mt. Assiniboine Provincial Park, British Columbia.
Historic B&W: 1916, A.O. Wheeler, Interprovincial Boundary Survey.
Modern Image: 2017, Mountain Legacy Project.

Figure 4: Notice how the density of trees has increased in the modern image.

3) **Infilling and encroachment of vegetation – especially conifers.** The forest in Figure 4 surrounds Lake Magog and the Mount Assiniboine massif. The 2017 image shows a much denser forest – a possible wildfire concern in a warming world.

4) **Evidence of wildfire on the landscape.** Figure 5 from King Creek Ridge in Kananaskis Country, Alberta, shows how fire – possibly from the big 1910 fire season – has moved on the ridge.

The Mountain Legacy Project evolves to reflect new questions and interests of concern to the research community and all those concerned with mountains. We look forward to new partnerships and projects that make use of these internationally distinctive collections.

Mary Sanseverino is a Research Associate with The Mountain Legacy Project.

Eric Higgs is a Professor at the School of Environmental Studies at the University of Victoria.

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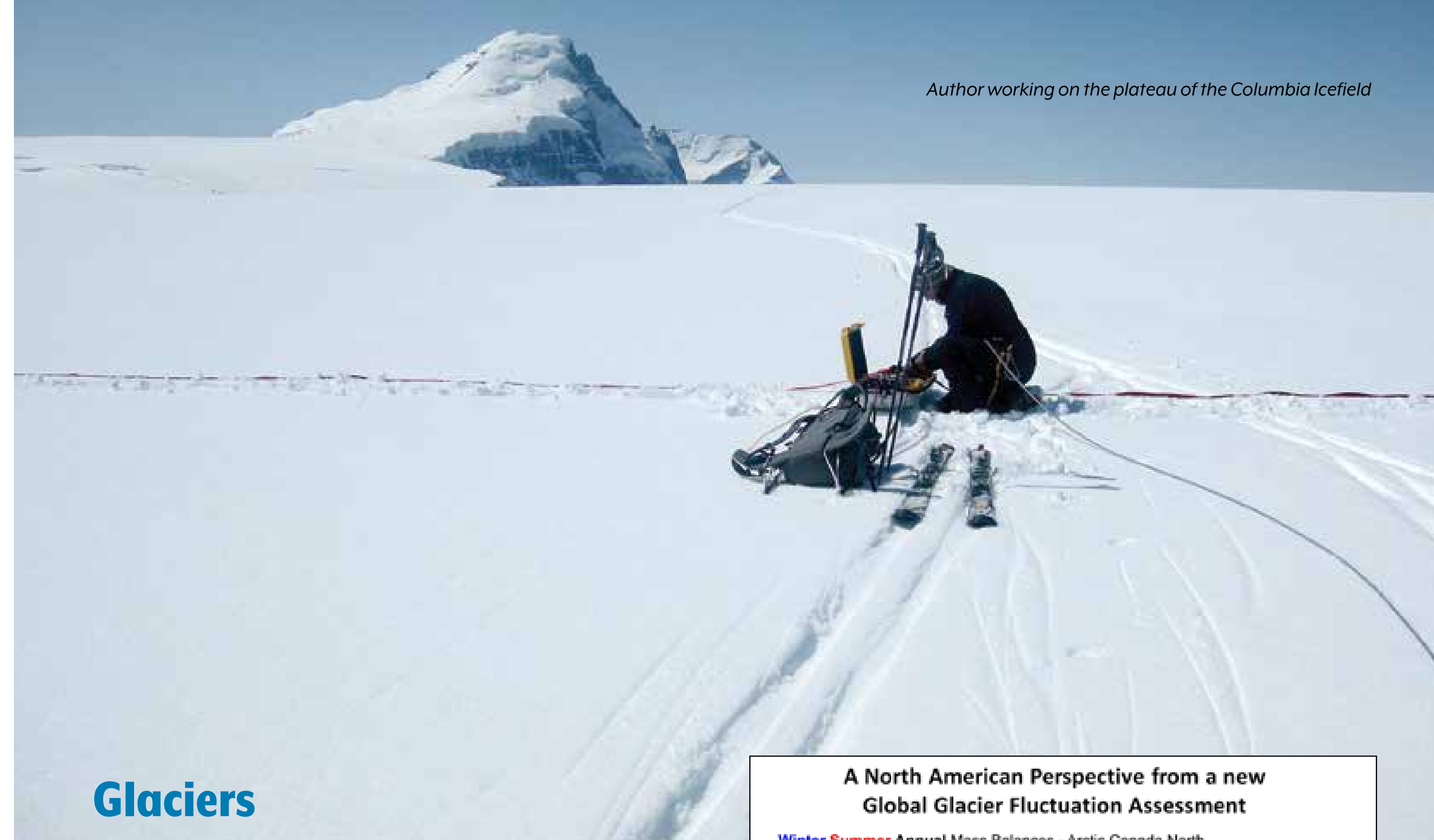


Author working on the plateau of the Columbia Icefield

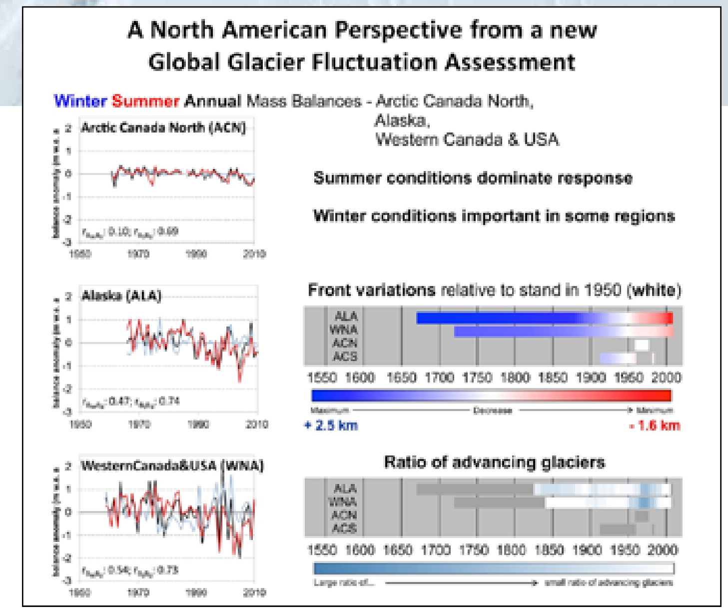
Glaciers

Mike Demuth

Canada's contemporary glacier cover is found almost exclusively in temperate and Arctic mountain environments. Outside of the ice sheets of Antarctica and Greenland, Canada has more glacier cover than any other nation — some 200,000 square kilometres — one quarter of which is found in the mountain west including Vancouver Island and the remainder in the Canadian Arctic Archipelago.[1] There are also small glaciers in northern Labrador.

The professional observation and analyses of glacier fluctuations usually concerns itself with glacier mass change because seasonal and annual mass changes are a direct result of changing precipitation, air temperature and cloudiness — that is, weather and climate. Most casual observers, however, will readily note changes in the dimensions and extent of the glacier after the delayed and complex process of dynamic readjustment to mass changes; if conducted over long enough intervals over which the effect of the dynamics is filtered out, are also excellent indicators of the cumulative effects of climate change.

A recent landmark study considering the fluctuation of reference monitoring glaciers around the world concludes, in part, that *"The rates of early 21st-century mass loss are without precedent on a global scale, at least for the time period observed [more than a century] and probably also for recorded history, as*



- *Cumulative annual front variation observations:*
  - *dark blue for maximum extents (+2.5 km)*
  - *dark red for minimum extents (−1.6 km)*
  - *all relative to the extent in 1950 as a common reference (i.e. 0 km in white)*
- *Ratio of advancing glaciers:*
  - *white for years with no reported advances*
  - *dark blue for years with a large ratio of advancing glaciers*
  - *periods with very small data samples are masked in dark grey*
  - *figures are based on all available front variation observations and reconstructions excluding absolute annual front variations larger than 210 m / year to reduce the impression of calving and surging glaciers*

Figure 1: Left panel: seasonal and annual mass balances for reference monitoring glaciers in North America with Pearson correlation coefficients indicating the relative role of Summer versus WInter conditions; Right panel: summary of glacier front variations relative to their position in 1950 and the ratio of advancing versus retreating glaciers. Front variations greater than 210 m/year were excluded to reduce the influence of calving and surging glaciers. After Zemp and the National Correspondents to the World Glacier Monitoring Service, 2015 [ref. 2].

As is true for the vast majority of glaciers worldwide, the Peyto Glacier in Banff National Park has been retreating rapidly, especially since the last half of the 20th century, and has reportedly lost 70% of its mass since it was first measured. Photo: Ian Holmes.

indicated also in reconstructions from written and illustrated documents. This strong [negative] imbalance implies that glaciers in many regions will very likely suffer further ice loss, even if climate remains stable".[2] Numerous glaciers in Canada are part of this internationally coordinated effort. Several recent site and regional analyses confirm the matter that Canada's glaciers are in a state of negative mass imbalance fuelling unprecedented glacier deflation generally and that both winter and summer conditions contribute to specific responses (Figure 1).[3, 4, 5, 6] There is also evidence that year-to-year variability is increasing in some regions[7]. For example, within the span of a decade (2007-2017), many glaciers in western Canada experienced record mass gains one year, record losses several years later and, most notably, by 2017, many glaciers and icefields lost all or nearly all of the accumulated firn pack in their upper reaches — in effect, new ice was not being generated.

The presence of glaciers influences a wide variety of natural processes and mountain heritage attributes.[8] Foremost is their provision of water and aquatic services, particularly when other seasonal sources of water are in decline (snowmelt) or absent outright (rain). Glacier runoff and its promotion of often severe hydraulic conditions aids in the development and maintenance of habitat for numerous aquatic species adapted to cold, turbulent waters.[9] Glaciers provide travel corridors for wildlife, connecting regions that are seasonally sought out for preferential habitat and climate conditions. For humans, glaciers also provide vantage points for exploration, access to technical mountaineering terrain, and interlaced high level ski and walking corridors.

Their contemporary decline with reference to Holocene variability, and in terms of both mass, thickness and area-wise extent, is considered a hallmark indicator of climate change with wide-ranging impacts. In the Rocky Mountains, for instance, water resource and ecosystem integrity considerations must contend with the loss of Little Ice Age "bonus water"which may have given the impression of water "abundance" during the early 20th century; and in the Canadian Arctic Archipelago, recent mass losses have contributed more to global sea-level rise than that attributed to the wastage of the Greenland ice sheet over the same period.[1,4,8, 9, 10 ,11,12]

With reference to recent modelling efforts projecting sobering glacier contraction in western Canada by the close of this century, it is noted that "Mountains are monuments to what water can make".[13,14]

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The presence of glaciers influences a wide variety of natural processes and mountain heritage attributes

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The State of Canada's Ice Core Archive

Canada, a proud part of the 2017/18 Antarctic deep drilling program in Wilhelm II Land. Photo: Alison Criscitiello.

A significant collection of ice cores, totalling ~1.5 kilometres in length was built up as a result, and some of these cores incorporate ice that was formed during the last continental glaciation of North America more than 20,000 years ago.

Martin Sharp and Alison Criscitiello

A number of ice cores have been drilled through ice caps and glaciers in the Canadian Arctic Islands and on Mount Logan since the first Canadian core was retrieved by scientists from the Polar Continental Shelf Project from the Meighen Ice Cap in 1965. Sadly, the Meighen Ice Cap is now on the verge of disappearing as a result of high melt rates in recent decades. Most recently, coring activities were led by scientists in the Geological Survey of Canada (GSC), and some also involved collaborators from Canadian universities as well as other countries. A significant collection of ice cores, totaling ~1.5 kilometres in length was built up as a result, and some of these cores incorporate ice that was formed during the last continental glaciation of North America more than 20,000 years ago. Sites cored include the Devon Island Ice Cap, the Agassiz Ice Cap and Prince of Wales Icefield on Ellesmere Island, Mount Logan, and the Penny Ice Cap on Baffin Island (the last vestige of the Laurentide Ice Sheet).

Recently, the GSC transferred ownership of the core collection and the associated ice coring and analytical equipment to the University of Alberta (UA). The collection was moved to Edmonton in January 2017. To accommodate and manage the collection and facilitate research on the cores, a new ice core storage and analysis facility, the Canadian Ice Core Archive (CICA), was constructed on the UA North Campus, with funding from the *Canada Foundation for Innovation* and the *Government of Alberta*. The facility consists of a -40 degree C storage freezer where the cores are kept, a -20 degree C working freezer where cores will be imaged and processed prior to analysis, and a room temperature analytical laboratory, where chemical and other analyses of core samples can be performed. CICA also has partnerships with a range of other chemical and biological analytical labs on campus that will allow a diverse array of research to be conducted on the cores. This research will focus on such areas as past climate variability and change, aerosol and particulate (dust and volcanic ash) deposition from the atmosphere, the depositional history of organic and inorganic contaminants (i.e. black carbon, heavy metals and organochlorine compounds), and the microbiology and biogeochemistry of glacier ice.

CICA is intended to be a national facility available to any qualified researcher who has a scientific interest in the material held in the collection. It will also host a digital archive that will contain all available information about the cores in the collection, including descriptions and line scan images of each core segment, and the results of all analyses conducted on them. This will allow the collection to be managed in a way that avoids duplication of effort and encourages sharing of information. CICA is managed by its Technical Director, Dr. Alison Criscitiello, and Scientific Director, Dr. Martin Sharp.

One goal of CICA will be to undertake new coring activities that will allow us to grow

Drilling for ice core samples. Photo: Alison Criscitiello.

Photo: Martin Sharp

One goal of the CICA will be to undertake new coring activities that will allow us to grow the ice core collection and be involved international ice coring activities.

the core collection and be involved in international ice coring activities. Thus, during the winter of 2017-18, Alison Criscitiello will be a driller on an Australian project to collect new deep ice cores from the rarely visited Indian Ocean sector of Antarctica, and she will join colleagues from the University of Maine within the next couple of years to drill new cores on Mount Logan. Discussions are also underway for new drilling on Ellesmere Island with US and UK colleagues, and there is a possibility of drilling in the Canadian Rockies as part of the international *"Ice Legacy"* project (led by U. Grenoble, France) which aims to collect pairs of ice cores from glaciers around the world that are shrinking rapidly and may disappear within the foreseeable future. Shallow ice coring carried out on four ice caps in the Canadian high Arctic over the past three years, led by Dr. Criscitiello, will help lay the groundwork for future deep coring efforts in these under-studied regions. We are hoping that it may be possible to engage the climbing community in efforts to manually sample the faces of ice cliffs in locations such as Snow Dome, where lengthy records of snow and ice accumulation are directly exposed, to study issues including the release, by melting, of contaminants stored in glacier ice into the headwaters of major rivers that are sourced in glaciers and icefields.

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Alison Criscitiello is the Technical Director of the Canadian Ice Core Archive at the University of Alberta.

Alison Criscitiello and her Australian and Danish team, drilling to 300m in East Antarctica, Christmas Day, 2017.

Conservation of Mountain Ungulates in Canada

Mountain goats in Jasper National Park. Photo: Jeff Bartlett.

Marco Festa-Bianchet

There are three species of mountain ungulates in Canada: bighorn sheep *(Ovis canadensis)*, thinhorn sheep *(Ovis dalli)* and mountain goats *(Oreamnos americanus)*. Thinhorn sheep include two subspecies. One, the Dall's sheep, is pure white and found in an arc from extreme northwestern BC through northern Yukon and into the Northwest Territories. The other, Stone's sheep, is much darker and mostly found in northern BC. There is a gradient in coloration in the mountains of central Yukon. Bighorn sheep are found in the Rocky Mountains of Alberta and BC, and in mountain ranges in south-central BC. Mountain goats are found in most mountains in western Canada.

The greatest threat facing bighorn sheep is pneumonia

All three species occupy most of their historic range in Canada. Local extirpation has occurred in central BC for bighorn sheep and in the extreme southern part of the distribution of mountain goats in both BC and Alberta. There have been a few reintroductions of both bighorn sheep and mountain goats in Canada, and Canadian populations have been the source of many introductions and reintroductions in the USA, in particular for the "interior" ecotype of bighorn sheep. All three species are hunted in most of their distribution outside protected areas, and in some areas they are an important source of food and ceremonial items for First Nations.

The greatest threat facing bighorn sheep is pneumonia, likely caused by *Mycoplasma ovipneumoniae* and transmitted by domestic livestock, particularly sheep but also goats and possibly cattle. Mortality can be over 80 per cent and all-age die-offs are typically followed by many years of very poor lamb survival as lambs are infected by surviving adults. In Canada, there has been limited grazing of domestic sheep within bighorn sheep ranges. The main exception to this is central BC, where contact with domestic

Bighorn sheep, Canadian Rockies. Photo: Travel Alberta

sheep remains an ongoing concern, despite many successful efforts by governments and local organizations to prevent it. Use of goats as pack animals is a concern for this disease. Thinhorn sheep do not have a history of die-offs but are highly susceptible to pneumonia. Any attempt to keep domestic sheep within thinhorn sheep range should be seen as a major threat to the species. Wild sheep will closely inspect domestic sheep, increasing the chance of contagion. Because rams of both species can roam over very large areas and sometimes away from their traditional ranges, the establishment of wide buffer zones where domestic sheep cannot be kept is essential for the conservation of mountain sheep. Mountain goats do not appear as susceptible to exotic diseases, perhaps because they are less likely to come into close contact with livestock.

Another threat is habitat loss and fragmentation, particularly by the construction of barriers such as reservoirs, major roads, fences and other human developments that prevent demographic and genetic exchange among herds. This is an important issue because many mountain ungulates exist in small populations that would be vulnerable to inbreeding without the genetic exchange provided by roaming males that will travel tens of kilometers searching for breeding opportunities. Habitat loss is also possibly linked to climate change, particularly with the encroachment of forest on alpine tundra and other open grassy areas used by mountain sheep and mountain goats to forage. Prescribed fires are a widely used and very effective tool to counter this threat.

All three species are subject to sport hunting. Mountain goats cannot tolerate a harvest greater than about 2 per cent, possibly because of their late age of primiparity and the difficulty of distinguishing the sexes. Harvests can include 30 to 60 per cent of females. Better hunter training programs can decrease the proportion of females in the harvest. Hunting of mountain goats in Alberta and most of BC is based on quotas and is generally sustainable. Very few mountain goats are harvested in the territories. Mountain sheep are managed as trophy species, and harvest in most of their distribution is based on regulations that set a minimum degree of horn curl for a "legal" ram, with no quota for provincial or territorial residents. There are quotas for nonresident hunters, who pay outfitters upwards of $30,000 for a sheep hunt. The unlimited number of permits issued to resident hunters leads to an artificial selective pressure against rams with rapidly growing horns. Genetically-based declines in horn size have been demonstrated for one intensively studied population in Alberta. Declines in ram horn size consistent with artificial evolution of small horns through intense trophy hunting have been reported in the scientific literature for bighorn sheep in Alberta and central BC, and for heavily-hunted Stone's sheep in northern BC. These undesirable consequences of selective hunting can be remedied by lowering the harvest pressure and shortening the hunting season, allowing rams from unselected populations in national parks to move into hunted areas for the rut and swamp the selective effect of the hunt. Currently, hunting seasons lasting until late October allow hunters to kill an unknown proportion of rams that exit the national parks looking for breeding opportunities.

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Baby bighorn lamb in Alberta. Photo: Philipp Haupt.

Another threat is habitat loss and fragmentation, particularly by the construction of barriers such as reservoirs, major roads, fences and other human developments

The State of Canada's Mountain Birds

Canada Jay. Photo: Nick Parayko

White-tailed ptarmigan in the Purcell Mountains, British Columbia. Photo: Zoltan Kenwell.

Kathy Martin

Mountain habitats have been identified as important habitat year-round for many of Canada's birds, but only five species, including White-tailed Ptarmigan and Gray-crowned Rosy-Finch, are considered to be alpine specialists, breeding exclusively in the high mountains. However, more than 55 species are elevation generalists, occurring in both high and low elevations (e.g. Savannah Sparrow, Golden Plover). Knowledge of the population status of most birds breeding in Canada's mountains is limited, but there is evidence that mountains provide birds with high quality habitats for breeding and migration, a role that becomes increasingly important given the more rapid loss of lower elevation habitats. For example, mountain habitats support stable populations for generalist species, such as Horned Lark, a species showing rapid declines at low elevations across North America.

Birds breeding in mountain habitats experience dramatic swings in temperature and precipitation, yet still must maintain the same warm, sheltered environment to rear young as birds breeding at low elevation. Each year, alpine songbirds have half as much time to breed and produce only half as many offspring compared with the same species at lower elevations. Nestlings develop more slowly at higher elevation (spending two to four more days in the nest) than those at low elevation, increasing their exposure to nest predation. However, there are advantages to breeding at high elevation. Some songbird and grouse populations have 10 to20 per cent higher annual adult survival than their low elevation populations, offsetting at least some annual reproductive disadvantages. Thus, high mountain birds have shifted to a slower life history where time to breed is short and development takes longer, but higher annual survival enables them to have stable populations.

For mountain habitats, autumn is the period of highest avian biodiversity, when many birds arrive in search of food to fuel their long migratory flights. Fall surveys (August to October) of mountain habitats demonstrate a remarkable diversity of birds (over 100 species in more than 30 families) using montane forest, subalpine, and alpine habitats in British Columbia. These include birds that breed at high elevation, but also waterfowl and shorebirds from northern habitats, forest songbirds and open country songbirds. During autumn, a veritable food web ascends skyward as many birds move upslope to feed on the abundant insects, flowers and fruits available in mountain habitats at this time, while avian and mammalian predators move up to pursue their prey. The earlier arrivals (late August) tend to be long distance migrants on their way to South America, while most birds arriving later in fall are short distance migrants that will spend their winter in North America. Some resident birds that breed and winter in the local valleys such as nuthatches and woodpeckers move up to treeline or above for several weeks. And stopping in mountains returns dividends for these migrants; songbirds stopping in higher elevation habitats fatten more quickly than birds refueling in lower elevation sites.

Alpine habitats are experiencing globally significant increases in temperature, extreme weather and climate-induced habitat loss, but it is difficult to predict what will happen to birds because there is so little background information about the extent and nature of avian use of alpine areas. Regarding abilities to cope with climate variation, alpine songbirds cope well with typical daily mountain weather events, while multi-day colder storms lead to reduced nesting success. Mountain habitats are naturally fragmented landscapes that function as "sky islands". Currently, alpine ptarmigan maintain viable and genetically diverse populations despite low population densities, but estimates show that suitable habitat for alpine ptarmigan in the BC coastal mountains will decrease by 50 to75 per cent by 2080 due to climate-induced changes. Such changes will further reduce connectivity across already fragmented mountain habitats.

Overall, mountain habitats serve as biodiversity refugia for birds during both breeding and migration. About 35 per cent of Canada's breeding bird species use high mountains for migration stopovers at least three months of the year, a period equivalent to the length of the breeding season for most species. One quarter of the bird species using our mountains are on national or continental lists of conservation concern, such as the Bicknell's Thrush, Rufous Hummingbird and Western Meadowlark. We have much to learn about the coping mechanisms and enabling factors that birds use to live in mountains, and which environmental and ecological factors pose the greatest challenges for them. Since our mountain habitats are threatened by local, regional and global anthropogenic disturbances, it is critical to determine the vulnerabilities of mountain birds to environmental change so that we can manage for their persistence and implement effective conservation actions.

Clark's Nutcracker at Moraine Lake, Banff National Park. Photo: Gunnsteinn Jonsson.

About 35 per cent of Canada's breeding bird species use high mountains for migration stopovers

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Figure 1: Diverse treelines across western and central Canada. (a) Coast Mountains of BC (photo credit: Andrew Trant), (b) Printer's Pass Valley, Ruby Range, Kluane National Park, YT (Katherine Dearborn), (c) Goodsir Pass, Kootenay National Park, AB (Emma Davis), and (d) Mackenzie Mountains, NT (Steven Mamet).

Shifting States of Alpine Treelines in Canada

Carissa D. Brown

Picture a Canadian mountain. What images come to mind? A steep slope with low vegetation, loose rocks or scree, topped with sharp, glacier scoured ridges. Backcountry skiers slice through the unbroken snowpack, reaching the lower forested slopes where they dodge trees as if on a slalom run. Iconic images of the Rocky Mountains – but are they ones that will persist?

Tree populations are not systematically moving up mountain slopes with warming

As northern latitudes such as Canada continue to warm, as summers become longer, and harsh high-elevation environments ameliorate, we expect that forests that have historically been restricted to the climatic conditions of low-elevation slopes will expand upwards in elevation. With continued global change and no other barriers in place, one might expect trees to reach the summit of mountains across Canada in the coming decades.

If that were to be the case, trees would overtake alpine meadows and with no other habitat for the alpine plant species to colonize, populations would be greatly reduced, and some alpine species even extirpated or lost altogether. Animal species relying on alpine ecosystems, such as the bighorn sheep or pika, would be under the pressure of decreasingly available habitat.

Are trees the central antagonists in a story of the conservation of alpine meadows? Yes, some treeline populations are encroaching into alpine ecosystems and the conservation concerns that come with tree invasion of alpine communities are warranted. Yet, globally, just over half of treelines are shifting in the direction predicted by recent warming[1] — upslope in mountain systems — and they are doing so more slowly than we expected. In Canada, alpine treelines are responding to recent warming in every way imaginable, where expansion rates range from slow to rapid and seem to be tree species-specific[2,3].

The variable responses of Canadian alpine treelines is occurring not only in the iconic Rocky Mountains of Alberta and British Columbia, but in mountain systems across the country (Figure 1), from the western-most Coast Mountains in B.C., north to Kluane National Park and Reserve and the Ogilvie Mountains of Yukon, all the way to our eastern-most mountain range, the Appalachians, which span (in Canada) from southern Québec across the island of Newfoundland (Figure 2). Southern Québec is not the usual environment one imagines a treeline, but treelines can also be studied as tree species lines — where the elevational distribution of one tree species ends, transitioning to high alpine forests (e.g., sugar maple/balsam fir alpine slopes).

What have we learned from such diverse mountain systems across Canada? Yes, a suitable climate is necessary for trees to establish beyond their current distribution along mountain slopes. Yet, we know that many things beyond a suitable climate are required for a tree to establish and survive in any given location, and alpine treeline researchers in Canada are compiling evidence of factors that may facilitate, slow, or prevent tree species from expanding their ranges upslope.

At present, we have observational and experimental evidence of non-climatic factors influencing individual trees' abilities to establish upslope at each life stage (Figure 3). For example, nearby adult trees need to produce viable seeds that escape pre-dispersal seed predation and are then dispersed into the new, upslope habitat[4,5]. That habitat needs to have the right kind of substrate (plant cover and soil) for the seed to germinate and establish.[6,7,8] The newly emerged seedling needs to eat and drink, requiring sufficient light, soil nutrients, and soil moisture, all of which can be affected by topographical attributes such as aspect[2,9] and geomorphology[6] (Figure 4). Acquiring nutrients from the soil often involves a partnership with microbes and fungi living

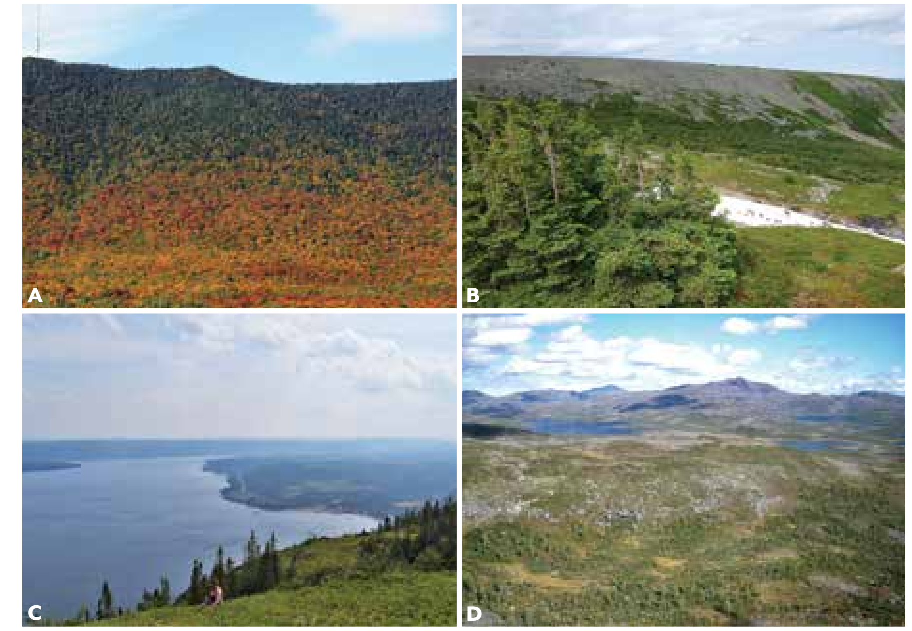

Figure 2: Span of the Canadian Appalachian range in (a) Parc nationale du Mont Mégantic, QC (photo credit: Mark Vellend), (b) Chic Choc Mountains, QC (Sébastien Renard), (c) Long Range Mountains, Great Northern Peninsula, NL (Anna Crofts), and (d) Mealy Mountains, NL (Brian Starzomski).

Figure 3: Factors that may complicate a tree's response to climate warming include herbivory, which we can test using herbivore exclosure cages shown here on (a) Fortress Mountain, Kananaskis Country, AB (photo credit: Emma Davis) and (b) Mackenzie Mountains, NT (Steven Mamet). Other species interactions can prevent a tree from establishing across life stages, via processes such as (c) seed predation (Anna Crofts) and (d) pathogens infecting and killing adults (e.g., spruce bark beetle; Katherine Dearborn).

Figure 4: Treeline expansion can be slowed down by (a) harsh conditions in the winter that can damage individuals via snow scouring, killing emerging branches (Mealy Mountains, NL; photo credit: Brian Starzomski) and (b) geology and geomorphology, when there simply may not be any soil substrate present for trees to expand onto (Chic Choc Mountains, QC; Sébastien Renard).

in the soil; if those fungi are absent, the seedling may not have access to enough nutrients to succeed[10,11]. The seedling needs to survive the winter, which comes with a different set of challenges: snow scouring, exposure to strong winds, and exposure to extreme temperatures if insulating snow does not protect the seedling[12] (Figure 4). Even with all of these pieces of the puzzle in place, a seed or seedling is still at risk from enemies, be it seed predators, seedling herbivores, pathogens, or the footprint of the lesser-spotted alpine hiker[8,13].

Tree populations are not systematically moving up mountain slopes with warming; treeline advance is occurring slowly on some mountains and not on others. Treeline researchers are continuing to advance our understanding of where, and under what circumstances, upward expansion of trees will occur by incorporating the many factors beyond climate that influence a tree's ability to establish and survive.

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Scattered dead whitebark pine in high-elevation forest on Mount Davidson, south of Vanderhoof in central British Columbia. Photo: Alana Clason.

A Crisis in Subalpine Forest Health

Philip J. Burton and Vernon S. Peters

The shoulders of western Canada's magnificent mountain ranges are wrapped in a shawl of natural and wild forests. These forests are dominated by Engelmann spruce and subalpine fir in the Rocky Mountains and other interior ranges, with the addition of mountain hemlock and Pacific silver fir in coastal mountains. Logging is widespread on lower slopes where not protected in parks, and is gradually accessing higher elevations and isolated valleys as time progresses. Forests at higher elevations are cut for the occasional ski resort or mining road, but are primarily exposed to natural disturbances such as wildfires, landslides, and snow avalanches.

Although appearing uniform and ageless from a distance, there is considerable diversity and ongoing dynamics in high-elevation forests. The ecotone (ecosystem boundary or interface) marking the transition to treeless higher elevations is typically a complex mosaic of meadows and tree islands rather than a discrete "tree line" following an elevational contour. Trees may advance or recede, depending on favourable weather conditions and seed production (see page 35). The native balsam bark beetle often kills subalpine fir trees individually or in small clusters, creating gaps that facilitate the release of smaller trees and the overall maintenance of old-growth forest. Lodgepole pine often dominates after fire, though rarely extends to, or persists at tree line. Other less common species such as alpine larch add diversity and seasonal colour that draws visitors to locations such as B.C.'s Cathedral Provincial Park. Lesser known, yet critical to wildlife, tree species are also found at high elevations, including whitebark pine and limber pine, which can take on bonsai-like growth forms where they persist on dry windswept edges.

Although appearing uniform and ageless from a distance, there is considerable diversity and ongoing dynamics in high-elevation forests.

It is the fate of those latter two species, whitebark pine *(Pinus albicaulis)* and limber

White pine blister rust expression on a whitebark pine sapling. Photo: Alana Clason

pine *(Pinus flexilis)*, that is of great concern to forest ecologists in western North America[1] today. These two subalpine species are suffering from the onslaught of an invasive fungal pathogen known as white pine blister rust. Originating in central Asia where native pines developed resistance to its pathological effects, the rust was imported from Europe to North America on contaminated nursery stock more than a century ago and continues to expand its range in the western half of the continent.

Forest decline varies greatly regionally and between the pine species. Infection and mortality levels are generally higher in southern portions of their Canadian range but are increasing more rapidly in northern regions. Infection occurs when fungal spores penetrate the needles and grow filamentous strands that deplete plant sugars while spreading to the trunk. The presence of bark lesions ("blisters") on the trunk signals another tree will die a lingering death over several decades. Simultaneously, infected trees disperse spores to native current and gooseberry bushes *(Ribes spp.)* that commonly serve as intermediate hosts before the disease infects new trees. Threats to these pine species include not only white pine blister rust, but mountain pine beetle, fire suppression, and climate change.

The risk of losing some of Canada's most iconic and distinctive woodlands has led to rigorous reviews at provincial and federal levels for both species. Alberta listed both species as endangered (2008), receiving protection under the provincial Wildlife Act, while B.C. put whitebark pine on the threatened list in 2013, and listed limber pine as endangered the next year. Federally, whitebark pine has been protected in Canada since 2014 under the Species at Risk Act, while limber pine is pending federal review in 2018. More than 30 bird and mammal species depend on cone crops from these trees as a food source, making these big-seeded pines keystone species in many mountain ecosystems. The Clark's nutcracker (see page 33) physically removes the seeds, and literally plants them to retrieve later, but forgetting some that go on to germinate.[2] Simply put, the bird that plants the seed, grows the tree, that produces the cone, that the squirrel collects, that feeds the bear.

Humans also need these high-elevation pines to slow snow melt, and stabilize the banks of mountain streams, in order to safely inhabit downstream communities. Such ecological dependency of human and natural systems highlights the need for coordinated restoration initiatives to ensure these pines persist. Our societal mandate to develop recovery plans for threatened species has led to the search for blister rust resistant individuals (genotypes) as one of several key recovery strategies. Researchers have identified a form of single-gene disease resistance in a southern Alberta limber pine population, and multi-gene resistance that slows disease expression and pathology is more widely distributed. Cone collections from disease resistant trees allows for the propagation of resistant trees. Numerous opportunities exist for volunteers to participate in local restoration efforts; contacting the Whitebark Ecosystem Foundation of Canada (www.whitebark-pine.ca) is a good place to start. We all recreate in these high-elevation forests and derive far-reaching benefits from them; taking personal ownership of their restoration is a great way to ensure their persistence.

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ACC participants at the 2017 Albert Icefield General Mountaineering Camp. Photo: Mary Sanseverino.

The State of the Mountains Report

Never before in human history have mountains been in such demand or regarded with such favour as they are today. This widespread reverence, in addition to environmental change, has created unprecedented pressures on mountain environments and communities whose livelihoods and well-being are dependent on mountains. The Alpine Club of Canada's 2018 State of the Mountains Report brings together contributions from some of Canada's leading social and natural scientists, describing the pressures and rapid changes occurring in our mountainous regions. Following in the tradition of the Alpine Club of Canada's commitment to disseminating knowledge concerning mountain environments, this report will inspire all Canadians to cherish and protect these special places.

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