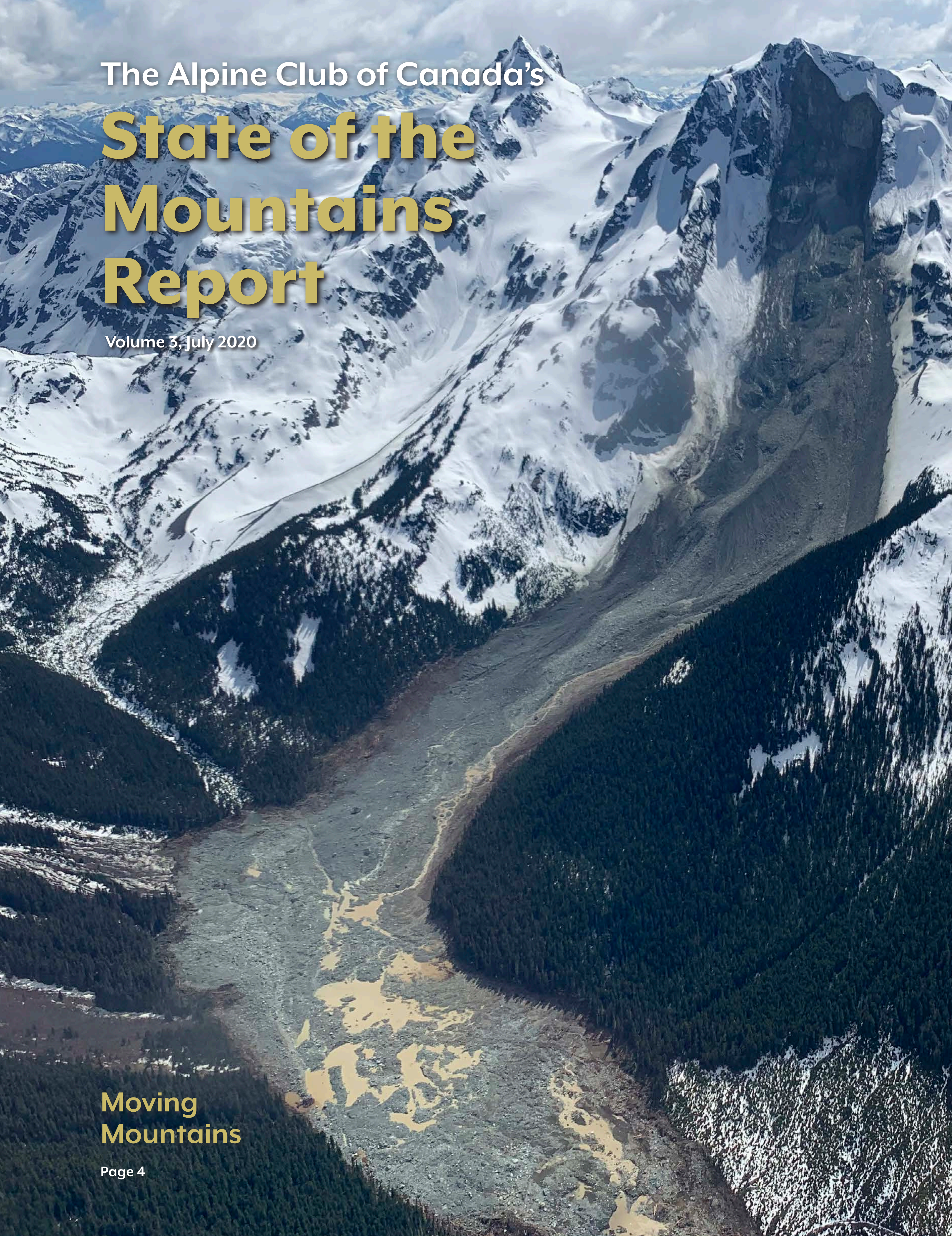

The Alpine Club of Canada's

State of the Mountains Report

Volume 3, July 2020

Moving Mountains

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Cover Photo: Mount Joffre landslide, May 2019. Photo: Wilfried Braun
Inside Cover: Tent Ridge, Kananaskis Country. Photo: Kahli April

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Foreword

Normally bustling Banff Avenue is quiet mid-day in April. The mountain town reliant on tourism and visitors has seen disproportionate layoffs and business closures due to the COVID-19 pandemic. Photo: Todd Korol

Staying Safe and Staying Inspired

This year marks the publication of the third annual volume of The Alpine Club of Canada's State of the Mountains Report. Of course, 2020 will certainly be remembered as a very strange and unsettled year for most of us. Mountains may seem to be immune to human crises and influences, but the Covid-19 pandemic is a stark reminder that all places on our planet are intimately connected.

The pandemic has demonstrated that unpredictable world events have a dramatic influence on our lives.

In these uncertain times, the publication of the 2020 State of the Mountains Report has remained a high priority for the ACC, even while other operations have been severely impacted by the pandemic. For example, in March, as social distancing became a necessary public-health imperative, the ACC closed all of its backcountry huts (see story by Jim Gudjonson in 2019 Report). However, modified operations are planned to resume during summer 2020 with additional measures in place to ensure proper safety etiquette and cleaning practices. And unfortunately, the 2020 Mt. Mummery General Mountaineering Camp had to be postponed to 2021, the first time a GMC has been cancelled since 1906. The pandemic has also had a very significant impact on the livelihoods of Canada's mountain guiding community, and this year we highlight their professional association in a feature by ACMG President Sylvia Forrest.

The pandemic has demonstrated that unpredictable world events have a dramatic influence on our lives. Our feature article this year (Brent Ward, Glyn Williams-Jones, and Marten Geertsema) highlights the potential impacts from catastrophic events in the western Canadian mountains, such as landslides and volcanic eruptions. Hazards in mountainous areas have always presented a significant risk to people and property, and these risks are increasing due to climate change and increased human activity in the mountains.

In this volume, we also highlight a number of other impacts of anthropogenic activity in mountains, including the downstream impacts of mining (Erin Sexton, Chris Sergeant, and Jon Moore), the changes occurring in mountain glaciers (Valentina Radić), and elevational dependent warming in Canada's highest mountain range (Scott Williamson).

We are very pleased to shine a bright light on several new initiatives that will raise the voices of both Indigenous mountain communities and youth, who are strong advocates for conservation and research. Over the past year, the new Canadian Mountain Network formally began operations (Norma Kassi), and the first Canadian Rockies Youth Summit was held in Jasper National Park (Benjamin Green *et al*).

The biodiversity of plants and animals in Canada's mountains are also receiving more attention. Several contributions this year provide insights into our understanding of alpine species interactions (Anna Hargreaves), alpine butterflies (Felix Sperling, William Sperling, and Zac MacDonald), and the critical role of conservation data centres (Bruce Bennett and Syd Cannings).

We also take a closer look at some of the more hidden features of Canada's mountain environments. John Pollack, Christian Stenner, and Chas Yonge take us deep into the caves of Canada's mountains. Last November, Chas Yonge, a remarkable Canadian climber, cave explorer, scientist, and author, was recognized with the Sir Christopher Ondaatje Medal for Exploration from the Royal Canadian Geographic Society. Sadly, Chas passed away in January, just as this contribution was being finalized.

Finally, we take a deep dive to learn more about the submarine mountains in the oceans off of the west coast (Cherisse Du Preez and Tammy Norgard) and east coast (David Piper and Georgia Piper) of Canada. These seamounts are geologically diverse and provide habitats for a remarkable diversity of unique marine species. Other essays this year discuss public avalanche safety (Mary Clayton), changing plant communities (Lauren Erland and Susan Murch), and the geological origins of the cordilleran mountain system (Stephen Johnston).

We have also upgraded the SOTMR website, to make it easier to find, download, and cite all of the contributions since 2018. We see these as a collection of resources that will provide authoritative insight into the cultural, social, economic, biological, and physical state of Canada's mountain environments. Over the past three years, some forty articles have been included in the State of the Mountains Reports, and we will continue to build on this foundation in the coming years. Check them all out, and please let us know if there is some aspect of Canada's mountains that you would like to see included in future reports. If you want to learn more about mountain environments, we can recommend Mountains 101, an award-winning free online course, offered through Coursera (www.coursera.org/learn/mountains-101), that was created by the University of Alberta in partnership with Parks Canada and The Alpine Club of Canada – by July 1, 2020, over 48,000 students from around the world have registered in the course!

Lastly, more than anything, the tumultuous times of 2020 have been a reminder to all Canadians of how fortunate we are to have wilderness spaces in which to recreate and to explore. As we stay closer to home and seek activities that are safe to do in a pandemic, more and more people are rediscovering our parks, trails, and mountain spaces. Let's hope this leads to increased support for protection and conservation of these special places from coast to coast to coast.

Stay safe and see you in the mountains.

Lael Parrott, Zac Robinson, and David Hik
July, 2020

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The tumultuous times of 2020 have been a reminder to all Canadians of how fortunate we are to have wilderness spaces in which to recreate and to explore.

As for so many Canadians during the pandemic, Zoom meetings became a regular state of affairs. The Reports editors preparing Volume 3. Bottom: Lael Parrott; Top (L-R): David Hik and Zac Robinson.

Moving mountains: Landslides and Volcanoes in a Warming Cryosphere

Mount Joffre landslide, May 2019. Photo: Wilfried Braun

Brent Ward, Glyn Williams-Jones, and Marten Geertsema

At 7:40 am on May 13th, 2019, 2.3 million cubic metres of rock hurtled downslope from Mount Joffre in southwest British Columbia. Moving at up to fifty metres-per-second, it traveled four kilometres down Cerise Creek, obliterating backcountry ski trails and climbing routes and destroying swaths of forest. Three days later, a similar volume of material collapsed in a second slope failure on the mountain. These massive events created considerable concern in the surrounding communities, and they were not the first large landslides to cause extensive destruction in the region.

Living and playing in the mountains always has a certain risk.

The Mount Joffre landslide is just one recent, and fortunately non-fatal, example of alpine hazards that surround us. Living and playing in the mountains always has a certain risk. Landslides, snow avalanches, and volcanoes are just some of the hazards in mountainous areas. However, many of these hazards are increasing in both frequency and severity as the climate warms and alpine permafrost melts. In this article, we highlight the emerging hazards of landslides and volcanic activity that are associated with a warming cryosphere in British Columbia. There are many similarities between these examples and the hazards that exist in other mountainous areas around the world.

Throughout history, hazards in mountainous areas have posed a significant risk to people and property. These risks are increasing due to an apparent increase in frequency of events, caused in part by climate change and by increasing population density and infrastructure in the mountains. Simply put, the more people and infrastructure (buildings, roads, power lines, pipelines, telecommunication cables) in warming mountains means an increased likelihood of being affected by these hazards.

Loss of the Cryosphere Causes Mountain Slopes to Fail

The cryosphere is a zone of the Earth where cold temperatures and frozen surfaces prevail, including glaciers, snow, and permafrost (frozen ground). Both permafrost thaw and glacial thinning are thought to play a major role in mountain landslides, and both of these factors are considered preconditioning triggers for sudden slope failures. Permafrost is ground that is at or below zero degrees Celsius for more than two consecutive years, and its degradation can exacerbate hazards. British Columbia has patchy permafrost at low elevations in the north, but also at high elevations throughout the province. Degradation, triggered by warmer winters and summers, causes both small and larger scale hazards. Thawing permafrost reduces rock strength, and it allows meltwater to penetrate into bedrock fractures, which increases pore pressures, further weakening the rock.

More than two-thirds of the large rockslides in northern B.C. have been found to originate from steep cirque faces, where permafrost was likely present. Recent studies have attributed a significant increase in rock avalanches in southeastern Alaska to permafrost degradation in high mountain peaks. Not only were high-elevation rockslides increasing, but peak years correlated with the warmest years on record. Heat advection by the movement of meltwater in bedrock cracks can also lead to increased degradation rates of mountain permafrost, further destabilizing slopes.

When glaciers erode mountain valleys, they impart stresses and fractures into the valley walls, but at the same time provide support for these slopes. So, when glaciers thin, melt, and retreat, these slopes become unsupported (or “debuttressed”), and the fractures widen, sometimes to the point of slope failure. A 2004 study found that landslides were more common in recently deglaciated areas in southern B.C. than elsewhere.

Landslides

“Landslide” is a generic term to describe the downward movement of soil, rock, or other earth material under the influence of gravity. One of the simplest ways to describe a landslide is to name its material and its movement style, such as rock fall, debris flow, or earth slide. Smaller landslides are commonly described in this simple way, but larger ones are usually more complicated. For example, a rock mass can slide down a bedrock slope onto a mountain soil can trigger a debris avalanche. This is referred to as complex landslide, or more specifically in this case a “rock slide - debris avalanche.” An extreme example of a rock slide - debris avalanche is the 2010 Mount Meager landslide, which traveled twelve kilometres.

More than two-thirds of the large rockslides in northern B.C. have been found to originate from steep cirque faces, where permafrost was likely present.

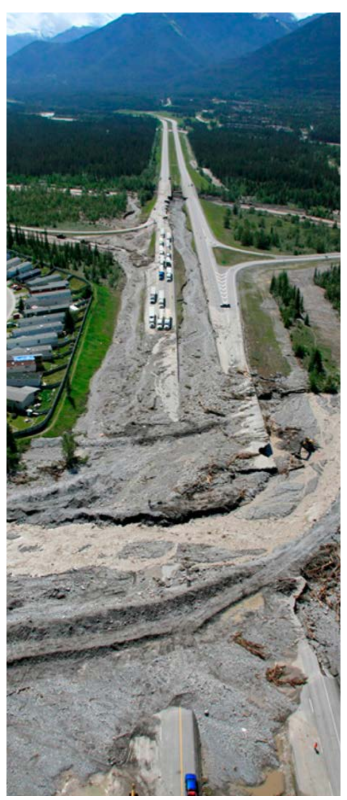
Landslides can also extend their devastation by transforming into other hazards, by creating what’s called “process chains.” For example, on the Alaskan coast, glacial debuttressing in fjords has resulted in some very large landslide-generated tsunamis: a 2015 landslide producing a 193-metre high wave in Taan Fiord, and the 1958 Lituya Bay earthquake produced a mega-tsunami that downed timber up to an elevation of 520 metres at the entrance of Gilbert Inlet. Researchers recently identified an unstable mountain slope above the toe of a rapidly receding glacier near Prince William Sound that has the potential to fail and generate a mega-tsunami of similar size.

Volcanoes

Volcanoes can come in many shapes, sizes, and compositions, but are broadly considered as sites through which magma (molten rock and gases) can reach the Earth’s surface. It may be

Figure 1. Summit crater (left) of Tseax Volcano in northwestern B.C., and its thirty-two-kilometre-long lava flow field (right) in the Nass Valley. Photos: Glyn Williams-Jones, 2019

Figure 2. Cougar Creek during and just after the 2013 floods. The Trans-Canada Highway was blocked. Photos: Town of Canmore



news to many Canadians that the country's west coast, which, as part of the infamous Pacific Ring of Fire, is home to a wide range of dormant and active volcanoes. These include low-viscosity systems that produce lavas similar to those seen in Hawaii (such as at Tseax volcano in the Interior Ranges of northwestern BC), as well as more explosive volcanoes with high-viscosity magmas similar to Mount St. Helens, including Mount Garibaldi, Mount Cayley, and Mount Meager volcanoes in the province's southwest.

Unlike the distinctive volcanoes of Oregon and Washington states, the high rates of tectonic uplift in conjunction with glacier interactions have shaped the volcanoes of the Garibaldi Volcanic Belt into broad and highly-eroded massifs that are difficult to distinguish from the surrounding mountains. By and large, the Canadian volcanoes are relatively "quiet," and remote, with the last eruption in 1800 at Lava Fork volcano in northwestern B.C. This is not to imply that these volcanoes are not dangerous. In fact, a eighteenth-century eruption of Tseax volcano (Figure 1) destroyed a number of villages of the Nisga'a Nation and may have caused as many as two thousand deaths.

Infrastructure and People at Risk

Landslides have a significant effect on communities, disrupting infrastructure by severing lifelines, cutting off contact, delaying the transportation of goods and services, and in some cases, killing and injuring people. With more and more people moving to and throughout the mountains, the risk is increasing. Towns like Canmore in Alberta and Hope and Pemberton in B.C. are seeing increased population growth as people move out of larger urban centres for quality of life, retirement, and job opportunities. Canmore, located just outside Banff National Park's eastern boundary, is a case in point. With restrictions on development in the neighbouring park, Canmore has seen rapid growth, with part of the town built on the alluvial fan of Cougar Creek. The town and associated infrastructure was severely impacted by debris floods in June, 2013: houses and yards were swept away, roads (including the Trans-Canada Highway) were cut, and many people were evacuated (Figure 2). In response, Canmore has recently received approval to build a large protection structure at a cost of about fifty-million dollars. Construction will start this summer and temporary retention nets are in place until the more permanent solution is completed (Figure 3).

The 2013 damage in Canmore was triggered by intense rainfall that exacerbated spring snowmelt. This was a regional event with a large area adversely affected with numerous landslides and flooding, causing extensive damage, notably serious flooding in Calgary, High River, and many other communities. Obviously, this received extensive national media coverage.

But it is not just large events that affect mountain communities. Many smaller events have significant impacts. Areas around Hope, B.C., are affected every ten years or so by individual debris flows with periods of regionally extensive clusters occurring in 1951, 1983/1984, 2007, and 2018. These affect buildings, railways, and the highway, as happened again in November in 2019 (Figure 4). Indeed, January 2020 was the wettest on record since the 1930s, and, at the end of the month, a large "Pineapple Express" hit southwest B.C. These warm moist air masses drop extreme amounts of rain, which can also melt existing snow, liberating even more water. This particular event caused extensive regional disruption: flooding occurred in many areas, debris flows blocked roads, culverts became plugged, and roads washed out, in one case trapping skiers at Hemlock Valley. In the same event, a relatively small debris flow in the Fraser Canyon cut a fiber-optical cable, disrupting phone and internet service in the lower mainland. Pipelines are infrastructure that are also at risk. Large rock-debris avalanches have ruptured a gas pipeline in northwestern B.C. at least four times over the last forty years (Figure 5).

Two Mountains to Watch Closely
1. Mount Joffre

The recent Mount Joffre landslide is a good example of a landslide pre-conditioned by climate warming, and how citizen science and social media assisted with the research. Permafrost was likely present in the initiation zone of the landslide. However, warming over the last few decades may have thawed the permafrost enough to weaken the rock mass.

Figure 3. Temporary retention net installed on Cougar Creek upstream of Canmore. It is designed to slow and capture debris flows before they affect downstream infrastructure. A larger permanent structure is presently being build. Photo: Brent Ward, 2018

In fact, spring 2019 was one of the warmest in over thirty years and caused rapid melting of the snow pack. This rapid melting caused instabilities that were evident to observant locals, who posted pictures on social media (Figure 6). Not quite reaching the Duffey Lake Road (Highway 99), the landslide was first reported by a helicopter pilot. Once reported, landslide researchers traveled to the site, where they documented the failure and noted other areas in the head scarp that could fail. Determining the timing of the landslide was accomplished by examining sequential satellite imagery. However, the more accurate dating of the landslide was made by examining seismic records. Large landslides create "earthquakes" that have a much different seismic signature than that of earthquakes. This landslide was

Figure 4. One of several debris flows that affected the Trans-Canada Highway and the CPR Railway, November 2019. This debris flow blocked both lanes of the highway and the railway line, engulfing a semi-trailer truck. Photos: Matthias Jackob

Figure 5. A 2002 rock slide – debris flow ruptured a natural gas pipeline and resource road adjacent to Zymoetz River. Note the debris fan in the river. Photo: Marten Geertsema

Formed over the last two million years, Mount Meager is also the site of Canada's most recent large explosive eruption about 2,400 years ago.

large enough that it appeared on seismographs hundreds of kilometres away, and thus could be dated to the minute. The second landslide, which occurred three days later, serves as a cautionary tale for all landslide investigators and curious observers; there could have easily been some first responders at the landslide when this failure occurred.

2. Mount Meager

The Mount Meager Volcanic Complex is of particular interest as it is an active volcano 160 kilometres northwest of Vancouver, B.C. Formed over the last two million years, Mount Meager is also the site of Canada's most recent large explosive eruption about 2,400 years ago. The widespread hydrothermal activity (that is, the flow of hot and acidic fluids through the volcano), which is the source of many of the area's hot springs, has also resulted in pervasive geochemical alteration and weakening of the rock. This weak rock has resulted in so many landslides, some fatal, that Mount Meager has been called Canada's "most dangerous mountain." Most of the recorded landslides occurred during heat waves, being triggered by the melting of snow and ice, which saturate and further weaken the rock. Mount Meager is also the site of Canada's largest recorded landslide: a rock slide - debris avalanche, carrying approximately fifty-three million cubic metres of debris, occurred in August 2010 during another heat wave. This failure was so large that it generated an earthquake equivalent to M 2.6, and was recorded in US neighbouring states of Washington and Alaska; it also briefly damned the Upper Lillooet River Valley and forced the temporary evacuation of nearly 1,500 people from Pemberton meadows due to the threat of flooding.

This unstable volcanic mountain will certainly continue to generate landslides. Ongoing satellite radar monitoring has identifued over twenty-seven active slopes with volumes exceeding half-a-million cubic metres of active material. In fact, one of these slopes contains 300-500 million cubic metres of material – for scale, that's ninety-thousand Goodyear blimps – and is moving downslope at three-and-a-half centimetres per month in the late summer. When this slope fails, a nearby hydro-electric facility will be directly impacted, and there is a significant likelihood that, as in 2010, secondary flooding will affect the village of Pemberton sixty kilometres downstream.

Mount Meager is also still very much an active volcano. Its geologically recent explosive eruption only 2,400 years ago was approximately the same size as the 1980 eruption of Mount St. Helens in Washington State, sending an eruption column of fifteen-to-seventeen kilometres into the air. Ash was deposited as far east as Calgary, Alberta. During this eruption, clouds of superheated volcanic gas and debris (a block and ash flow) flowed down the mountain's eastern flank into the Upper Lillooet Valley creating an impermeable welded deposit and a 10-metre high dam, which blocked the Lillooet River and created a temporary lake. The dam subsequently failed, and the resulting outburst flood carved a slot canyon into the dam, now known as Keyhole Falls (Figure 7). While Mount Meager is currently quiet, it is nevertheless still active. Hot volcanic gases, with toxic levels of hydrogen sulphide and carbon dioxide, have melted their way through the Job Glacier on the mountain's northwest flank (Figure 8).

Conclusion

Both landslides and volcanoes pose hazards to the public and infrastructure in British Columbia. Volcanoes can trigger rock slides and mobile lahars (a slurry of pyroclastic material and water) that may impound rivers. Some volcanoes may even erupt. Mountain landslides are increasingly sensitive to climate change, with both permafrost degradation and glacier retreat likely contributing to the increase in the number of large rockslides province-wide. These landslides can harm people and infrastructure, but they can also transform into debris flows or even cause a local tsunami.

Fortunately, there is increasing interest in monitoring these potential hazards. For example, the Centre for Natural Hazard Research (CNHR: http://www.sfu.ca/cnhr/), formed in 2005 and hosted at Simon Fraser University, is conducting innovative research on geophysical processes that are a threat to the population and economic infrastructure of Canada. While CNHR has a western Canada focus, the research and tools developed are applicable to the whole of Canada and the world. By integrating physical science with social policy research, CNHR aims to lead the way in making Canada more resilient to natural disasters.

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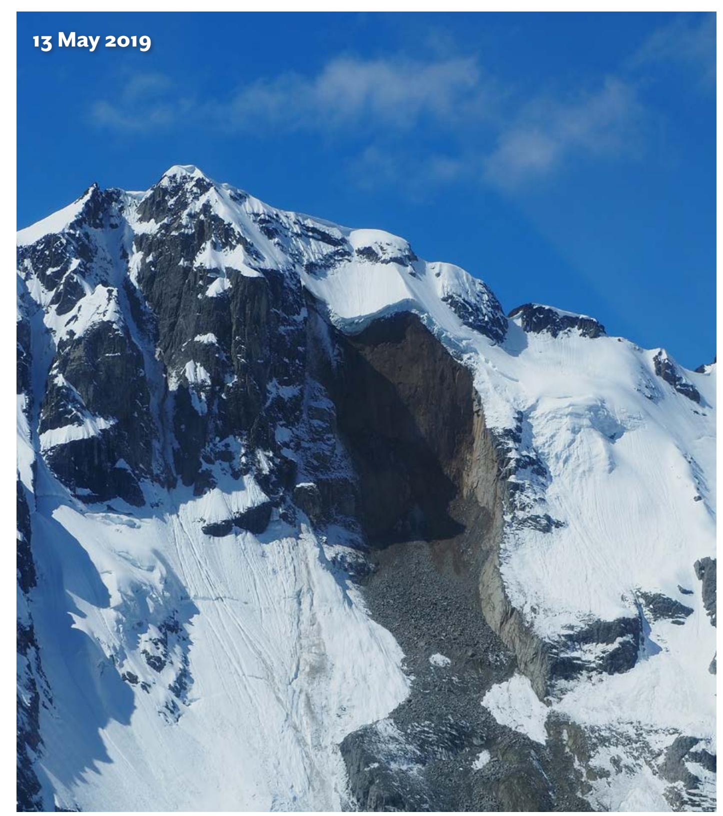
Both landslides and volcanoes pose hazards to the public and infrastructure in British Columbia.



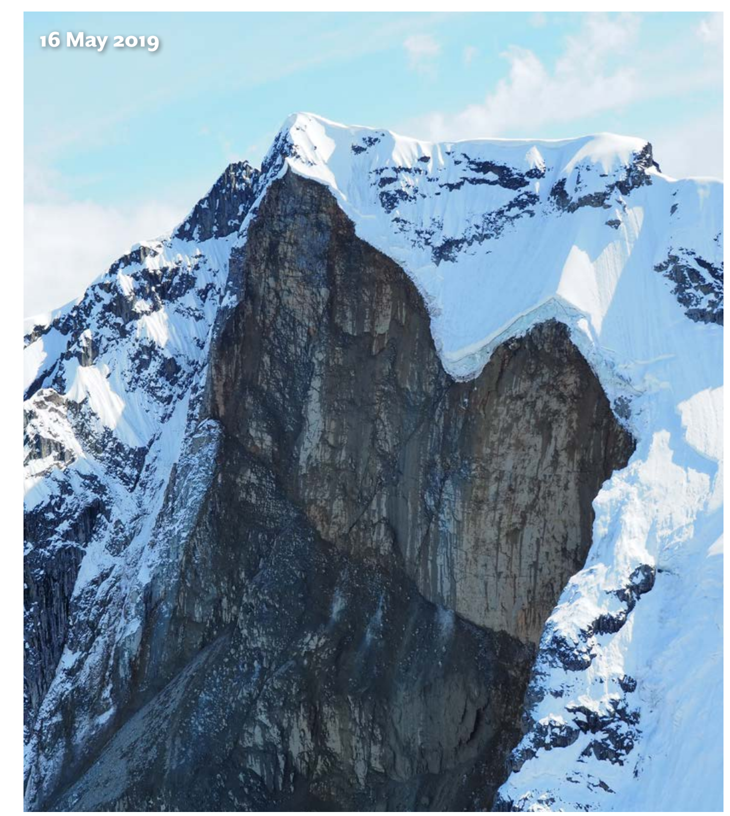


Figure 6. Mount Joffre showing the headscarp after the May 13 and May 16th, failures, giving an idea of the volume of each failure. Photos: Tom Millard

Figure 7. Keyhole falls and slot canyon incised through the welded volcaniclastic deposits in the Upper Lillooet River Valley. Photo: Steve Quane

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Figure 8. Glaciovolcanic cave on Mount Meager's Job Glacier created actively degassing volcanic fumaroles. Photo: Rachel Warwick

Canadian Mountain Network: Training Youth as Stewards for an Uncertain Future

Caribou on a snow patch in the Mealy Mountains National Park Reserve, Labrador. Photo: David Borsih

Norma Kassi

The Canadian Mountain Network (CMN) was launched in January 2019 with the generous support of the Government of Canada's Networks of Centres of Excellence (NCE) Program. This pan-Canadian research network supports the resilience and health of Canada's mountain peoples and places (http://canadianmountainnetwork.ca).

> *The CMN strongly advocates for bringing Indigenous knowledge and Western science together in research partnerships to inform and enhance decision-making.*

CMN's research framework is designed to provide coherence across the Network's investments and maximize their impact. Guided by several years of consultations with diverse researchers and knowledge-users across the country, it sets the stage for Canada's first formal mountain systems research agenda and will build on fourteen projects funded through CMN's first call for proposals.

The CMN strongly advocates for bringing Indigenous knowledge and Western science together in research partnerships to inform and enhance decision-making. This strong emphasis is a first for the NCE program and distinguishes CMN from previous networks that have prioritized the academic sector and Western approaches to research. From the beginning, CMN has provided a third of its research funds to Indigenous-led research projects and additional support for projects that emphasize the value of braiding knowledge systems (known to some as "two-eyed seeing"). Our goal is to grow the percentage of funds allocated to Indigenous-led research to forty percent in the coming years.

As part of our initiative to serve mountain peoples and places, we are working to advance strategic partnerships that will leverage investments in Indigenous Guardians programs in mountain regions. We want to ensure that such programs include not just conservation enforcement and monitoring work, but also the capacity to lead community-based research to understand and adapt to the changes that Guardians see every day on the land and in the waters. We are especially focussed on supporting youth to build their research leadership skills and experience. This is an area where we hope the Government of Canada will respond to calls from the Indigenous Leadership Initiative and many other organizations across the country to improve support for Guardians programs. As we have seen from similar long-running programs in Australia, these investments provide significant socio-economic and environmental benefits. In addition to the knowledge created and mobilized, these programs also offer culturally meaningful employment, relevant skills training, and improve mental and physical health for guardians.

Nationally and internationally, we are beginning to see the development and advancement of sustainability protocols from Indigenous peoples. We see non-Indigenous governments finally recognizing that they cannot do the important work of conservation without Indigenous peoples, and especially their youth, leading the way. Among the Indigenous-led projects across the country supported by CMN, several deal with issues ranging from traditional laws and wildlife management to the development of Indigenous protected areas to the creation of community-led climate change research protocols. In this work, training and preparing our youth is one of the most important aspects of resiliency. Building up our Indigenous youth in the ways of our people, guided by Indigenous spirituality, is what our Elders have been and continue to encourage.

Below are several examples of exciting research projects receiving CMN support that align with these goals and objectives:

Bringing Research Home: Reclaiming Research to tell the story of Climate Change in the Kluane First Nation Territory

This project is centered on the values, knowledge, and needs of Kluane First Nation (KFN) located in Burwash Landing, Yukon. The aim is to collaboratively study how KFN can enhance its ability to actively drive and participate in research in their Traditional Territory. In many ways, work on this topic is well underway; in other ways, it is just beginning. This project will strengthen connections between KFN and multiple Yukon-based research organizations as they work together to develop a KFN-driven research agenda and protocol. It will move the development and usage of tools to understand and share knowledge forward, and it will facilitate knowledge mobilization in a way that empowers KFN to more directly influence and benefit from research and knowledge gathering in their Traditional Territory.

Lingit Kusteeyi (Tlingit Way of Life): Revitalizing Tlingit Law for Land and Wildlife

This project engages constructively with Tlingit

> *Nationally and internationally, we are beginning to see the development and advancement of sustainability protocols from Indigenous peoples.*

Kluane National Park and Reserve, Yukon Territory. Photo: Samantha Titze

Youth learning traditional skills. Photo: Norma Kassi.

> *We see non-Indigenous governments finally recognizing that they cannot do the important work of conservation without Indigenous peoples, and especially their youth, leading the way.*

law, articulates these laws, and applies them as a guiding force to rebuilding the relationship between wildlife and humans in the Taku River Tlingit First Nation (TRTFN) traditional territory in northern B.C. and Yukon. The main objective of this project is to develop a TRTFN Wildlife Protocol and Policy that will be strongly rooted in Taku River Tlingit traditional practices, perspectives, and law. The Wildlife Protocol and Policy will guide the TRTFN internally by articulating what TRTFN's expectations are of its own citizens in terms of how they interact with wildlife. In addition, the policy is also intended to support governance externally as TRTFN engage with Provincial and Federal agencies and other First Nation on wildlife management issues. TRTFN believe that wildlife management needs to be strongly grounded in Tlingit laws and values and that these need to be consistent and well articulated for outside parties to understand. The TRTFN Wildlife Protocol and Policy is an important step in the decolonization for wildlife management and to ensuring that wildlife can once again exist in abundance within the TRTFN Traditional Territory.

Nio Ne Pene – Trails of the Mountain Caribou: Renewing Indigenous Relationships in Conservation

This Indigenous-led program involves research about the relationship between Indigenous well-being and caribou conservation on the backbone of the Mackenzie Mountains straddling the Sahtú Region (Northwest Territories) and Ross River Dena traditional territory (Yukon). For Mountain Dene/Dena of Tulít'a, Norman Wells and Tu Łidlini (the community of Ross River, Yukon Territory), Nío Nę P'ęnę́ encompasses all of nature – it's what holds everything together and attracts wildlife. The area has been a gathering place for people and caribou for thousands of years. The three partnering communities in this program are developing a plan for research, monitoring and land protection to achieve their vision for keeping Dene kədə (language), Dene ts'į lį (ways of life), and Dene ʔeʔa/ʔa (law) strong in co-existence with caribou. The three-year program will support establishment of Indigenous-led Guardian and land protection initiatives, and will help to set the standard for defining the nature of such initiatives in Canada.

Mobilizing Mountain Metrics that Matter: Inuit-Led Environment and Health Monitoring in the Mealy Mountains National Park Reserve

At the core of this project is an emphasis on Inuit knowledge concerning changes in weather and precipitation patterns, wildlife and vegetation, and land and sea ice regimes due to climate change, and how these environmental alterations are affecting Inuit traditional territory in mountain regions. Particular emphasis will be placed on understanding local perceptions and ideas about environmental changes, and locally-developed ideas for monitoring the effects of these changes in the Mealy Mountain Park Reserve in Labrador. This project will also facilitate and enhance intergenerational transfer of Inuit knowledge between experienced knowledge holders and youth within the program, protecting and promoting this knowledge for future generations. The community of Rigolet is a powerful example of the move to Northern-led research, as it continues to take the lead in the expansion of the eNuk app, the use of the weather monitoring stations, and the Monitoring Mentors program through this work. As stated by a community member from Rigolet, Inuit-led monitoring is essential to community knowledge and adaptation, because "the best scientists are the people that's out there."

Norma was raised and educated in Old Crow and is a citizen of the Vuntut Gwich'in First Nation (People of the Lakes) and a member of the Wolf Clan. She gained her depth of traditional, scientific and ecological knowledge in Old Crow flats where her grandfather, mother and the land were the bearers of this invaluable, ancient knowledge. Encouraged by her Elders, she entered politics and in 1985 was elected as Member for Vuntut Gwich'in First Nation in the Yukon Legislative Assembly, a position she held until 1992. From 1995 to 1998 Norma was the Environmental Manager for the Council of Yukon First Nations. In 2007, she co-founded the Arctic Institute of Community-Based Research and served as Director of Indigenous Collaboration until May 2019. In addition to her role as Canadian Mountain Network Co-Research Director and as an Adjunct Professor in the Faculty of Science at McGill University, Norma serves as Senior Advisor to the Indigenous Leadership Initiative that advocates for the creation of Guardians programs. She also serves on the Assembly of First Nations Environment and Climate Change Joint Committee on Climate Action.

The Canadian Rockies Youth Summit: A New Voice in Mountain Conservation

Ben Green, Lucas Braun, Alex Stratmoen and Destinee Doherty

Above: Participants at the Canadian Rockies Youth Summit in Jasper, November 2019. Photo: Ben Green

On a mild November weekend this past fall, forty-five high school students, representing ten communities in and around the Canadian Rockies, gathered for the First Annual "Canadian Rockies Youth Summit" in Jasper National Park. On the agenda were topics ranging from wildlife conservation amidst increasing tourism development to creating meaningful Indigenous reconciliation opportunities within our national parks.

The fact that so many high school students gave up a valuable weekend to meet together to discuss such topics is indeed a rare occurrence. What's even more unique, however, is the fact that this was a Summit completely designed, managed, and hosted by the students, which included us and other attendees. We are four Calgary students, concerned about how the areas in the Rocky Mountains are being managed. We took it upon ourselves to create a meaningful learning experience with experts, stakeholders, and other youth from across western Alberta and eastern B.C. so that we would be more capable of providing input in our own communities, as well as engaging in wider provincial and federal efforts.

We were not sure if we would get any buy-in from other students when we sent the idea out to other schools. However, we learned quickly that we were not the only ones with such concerns. There is something about how these landscapes are changing that inspired students from north to south to want to be more involved. They came from as far south as Crowsnest Pass and the Kainai Reserve and as far north as Grande Cache, Alberta.

Even with the student interest, we were not sure how we would ever get the Summit off the ground in terms of funding, organizing, and all those other things required to host such an event. We could not believe how lucky we were, though, to be supported to pursue this idea from not only our parents and teachers, but by

> *We were not sure if we would get any buy-in from other students when we sent the idea out to other schools.*

Students visiting the Ewan and Madeline Moberly Homestead, Jasper National Park. Photo: Ben Green

conservation and education organizations, such as CPAWS, Y2Y, the Biosphere Institute, Inside Education, the Canadian Mountain Network, government agencies, the Assembly of First Nations, local businesses, post-secondary institutions, and local community foundations and organizations, like the Calgary Foundation, the Jasper Lions Club and Jasper Rotary Club. We think these organizations noticed the concerns we brought forward, as well as the uniqueness of this student-led initiative, and they acted accordingly. We believe there is a lesson to be learned here for all youth seeking to create their own conservation initiatives.

More than anything else, the Canadian Rockies Youth Summit proved that there is a tremendous desire from youth to be involved with the management and planning of our collective mountain places.

At the end of the Summit, we collaborated to write a report outlining our commitment to sustainable development in the mountain ecosystems now and in the future. You can read that report by visiting the conference website: https://canadianrockiesyouthsummit.weebly.com.

The document highlights our main concerns as youth growing up in and around the Canadian Rockies, and our ideas for solutions to some of the issues facing this region. Each community penned their own section of the document with their respective ideas and concerns in mind, allowing for every student to have an impact on the final working draft.

Here is a summary of our conclusions and recommendations: Youth are worried about the increasing pressures of human activities on some sensitive areas – both protected and unprotected areas. Youth want to be meaningfully engaged in decision-making. Youth want to be more involved in the management of these areas regardless of the jurisdiction. In order to make this an effective and accountable decision-making body, work should be done to increase stewardship education to youth. Indigenous youth should be a focus of future co-management of spaces, industries, and management plans. Youth should have more opportunities to take part in active stewardship through their schools, as well as conservation mentorship programs.

All Canadian students should learn more about their natural areas, including the Rocky Mountains. Education should be a priority for management. More educational facilities are needed so that more youth can develop strong connections to the land and protected spaces. The amount of people accessing these mountain areas is exponentially rising. However, nobody seems to know exactly by how much – there is no large-scale baseline data to show who is coming and what they are doing in the mountains. More information is needed. Youth want to be part of this science.

Indigenous people have been historically mistreated in the management of these areas, and this is something that Canadians do not know about. This needs to change. Indigenous groups should have more input in the management of these areas, especially protected areas like provincial and national parks.

Industry – whether it's tourism or the natural resource development sectors – must work more closely with stakeholders to create a shared vision of sustainability in these areas. Science and traditional knowledge must guide the work.

Wildlife exists in increasingly fragmented portions of these mountain regions. These areas are only marginally habitable for many species that require room to move and thrive, like grizzly bears, for example. More protected areas should be established that connect mountain regions to the prairie for the sake of many species.

Climate change will see an end to most alpine glaciers within our lifetime. All students should have the opportunity to see and learn about them before they are gone.

More user-funding collection options should be considered for provincial parks and crown land.

The necessity for B.C. Parks, Alberta Parks, and Parks Canada to provide a youth engagement process for management decisions is essential.

Support is necessary to run the Second Annual Canadian Rockies Youth Summit.

More than anything else, the Canadian Rockies Youth Summit proved that there is a tremendous desire from youth to be involved with the management and planning of our collective mountain places. We are hoping that those reading this will reach out to their networks and find a way to help us be part of the conversation, for today, and for the future.

Ben Green, Lucas Braun, Alex Stratmoen, and Destinee Doherty are students in the Energy and Environmental Innovation class at Central Memorial High School in Calgary, Alberta. Adam Robb, their teacher, helped with the editing of this article.

Milestones: Past, Present and Future of the Association of Canadian Mountain Guides

Sylvia Forest

Speciality guiding on Mount Norquay's Via Ferrata, Banff National Park. Photo: Norquay, 2013.

Mountain exploration, travel, and tourism have been an important element of national culture for much of Canada's history. In the late 1800s, the increasing popularity of mountain tourism prompted the Canadian Pacific Railway to hire professional mountain guides to ensure the wellbeing and safety of their guests. These guides were recruited from Europe, as this was the nucleus of mountain guiding.

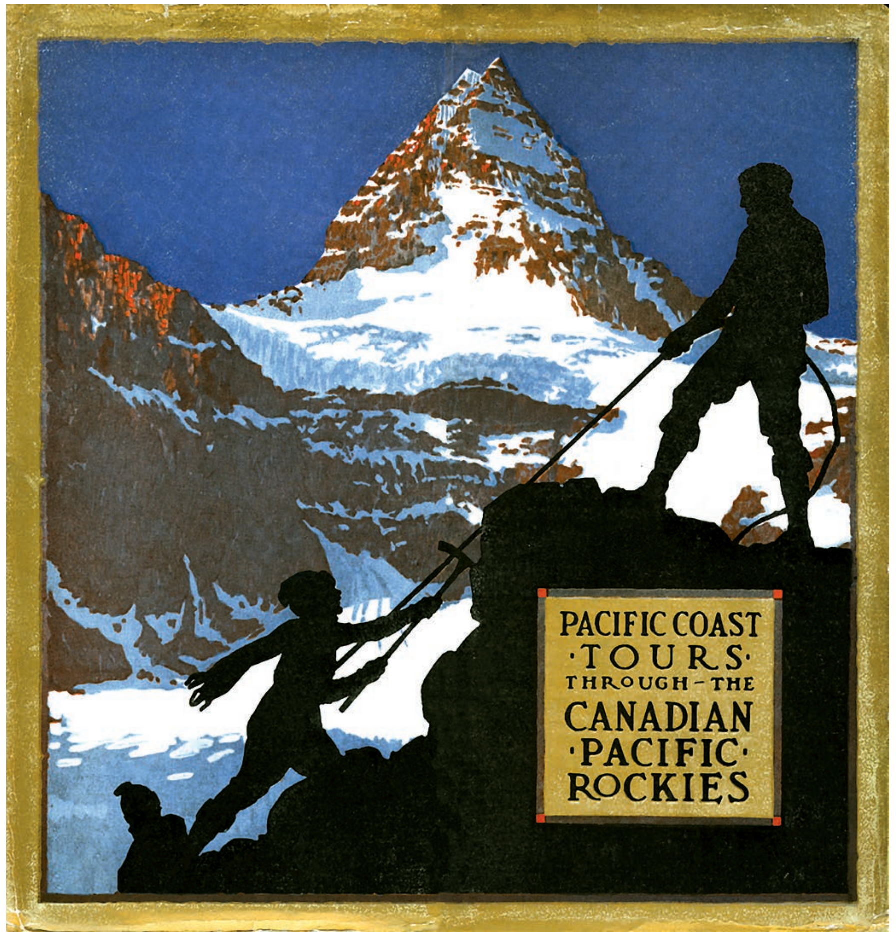
The Association of Canadian Mountain Guides (ACMG) was formed in 1963. Because of the strong European influence, it wasn't until 1966 that Canada developed its first national mountain guide training and certification courses. Even so, for several years, they were run by European mountain guides, who also had a strong influence over the development of mountain rescue.

In 1972, Canada became the first non-European country to become a member of the International Federation of Mountain Guides Associations (IFMGA), the international body that sets professional standards for mountain guides worldwide. Since then, Canada has sponsored other countries to gain acceptance into the IFMGA.

The organization and structure of the ACMG is different from that of many other IFMGA associations in that the ACMG recognized that specialty guiding is an effective pathway for delivering guiding services. The impetus for this shift came from Canada's pioneering of the heli ski industry, because an individual can become a competent ski guide without necessarily becoming a full mountain guide. Now, in addition to the ski guide specialty, the ACMG provides training and certification in several specialty areas, including hiking, gym and top rope climbing, alpine guiding, snow shoe guiding, and, most recently, via ferratta guiding. The ACMG sets technical standards for guiding and instructor certification in each of these disciplines at a level at, and often above, international standards.

The ACMG has grown significantly in the past few decades, both in membership, and in complexity.

The ACMG has grown significantly in the past few decades, both in membership, and in complexity. In addition to ever changing technical standards, procedures, and equipment, the association faces several rising social issues.



While the name "ACMG" indicates a national association, most of members live and work in Alberta and B.C. Recently, the ACMG has developed better ties with members east of Alberta, particularly through a new Board position and a partnership with Rando-Quebec. The ACMG has held specialty hiking guide exams and professional development courses in the east, and inclusion of Eastern Canada into the ACMG is a priority going forward.

Of equal priority, the ACMG recognises most of its members are a mono-culture of primarily white males in their thirties and forties. While this is not unreasonable, it is the association's goal to include greater diversity among its members, including gender, LGBTQ, and visible minorities. The intent is to become a more inclusive, understanding, and welcoming association, while maintaining required technical standards. Very recently, the ACMG, in partnership with the Canadian Avalanche Association (CAA), the Canadian Ski Guide Association (CSGA), and Helicat Canada, with the facilitation of Watershed Consulting, created the "Inclusive Mountain Culture Initiative" (IMCI). This is the first time these four entities collaborated on a single initiative for the betterment of the collective professional mountain community. The ACMG also struck a Diversity and Inclusion Committee, whose mandate is to foster education, inclusion, and diversity in our workplaces.

Left: Why go to Switzerland if there are more mountaineering opportunities in the Canadian Rockies? An early CPR advertisement highlights guided mountaineering with the "Matterhorn of North America," Mount Assiniboine, as the backdrop. CP Archives, A.17295

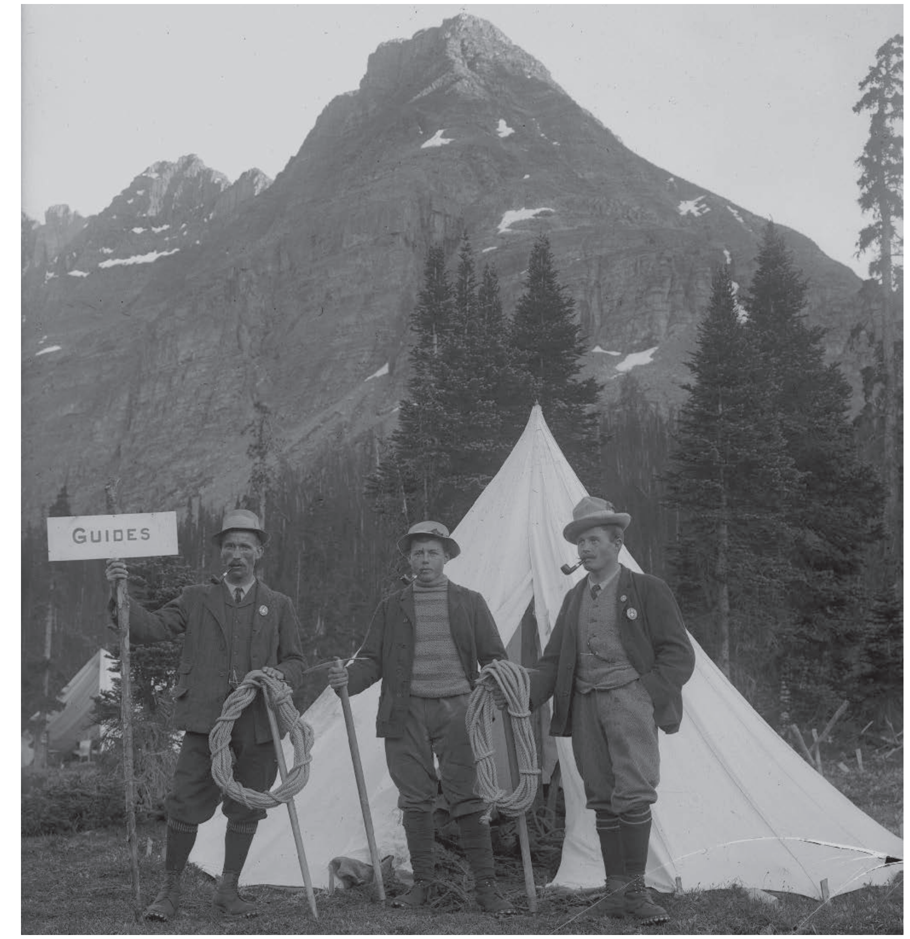
Below: Heli-ski guide training at CMH Bugaboo Lodge. Photo: Marc Piché, 2012.

Another core concern of the ACMG is the state of the environment and the repercussions of climate change. Some effects of global warming on the guiding industry include, for example, the rapid glacial recession resulting in changing mountain access due to loss of ice mass. There's the subsequent exposure of rock that has been covered for millennia, which is un-weathered and unstable, increasing rock fall hazard. And there are many others. As a result, some traditional alpine routes are no longer safe, or even feasible, to climb. As the landscape is changing annually, if not monthly, this progression affects all mountain recreationists, but the guiding community must be a step ahead, anticipating these geographical and climatic shifts, in order to keep clients safe.

In a similar vein, ACMG members have had major discussions about the impact of guiding on the environment, from the responsible use of resources to driving electric vehicles. The association has created a Stewardship and Access Committee to search for ways to reduce its impact on the environment while maintaining a viable mountain business.

Increasing tourism is another major factor affecting how the ACMG and its members navigate the landscape. As the mountains become more crowded, true wilderness is becoming increasingly difficult to find. While Canadian guides depend on tourism for employment, they also rely on wilderness. It is a paradox that all outdoor enthusiasts must manage as the mountains become even busier.

Since its inception in 1963, the ACMG has gradually shifted from a primarily member-focused organization to being more global-minded. This shift has resulted in the creation of products like the Mountain Conditions Report (MCR), designed to assist the public in decision making in the mountains. It has also led to greater collaboration with its sister organizations and with government agencies. Looking forward, the ACMG is well poised to manage these and other challenges that face our industry, both locally and internationally, while maintaining the high technical standards and international respect it has achieved over the past fifty-plus years.



Sylvia Forest is an IFMGA mountain guide, and President of the ACMG, living in Golden, BC. She worked as a Visitor Safety Specialist for Parks Canada for twenty-three years, and managed the Visitor Safety program in Revelstoke and Glacier National Parks for eight years. She teaches professional avalanche courses for the Canadian Avalanche Association, including international courses; frequently guides for the Alpine Club of Canada, and guides full time for a small heli-ski company. She has a degree in physical geography from the University of Calgary.

Early Swiss mountain guides on loan to the ACC's summer mountaineering camp from the Canadian Pacific Railway. Photo: Byron Harmon, c. 1910. Courtesy of the Whyte Museum of the Canadian Rockies V263-NG-0071.

The author (center, kneeling) with Club members on the ACC's 6-Pass Ski Traverse Camp. Photo: Erin Revell-Reade, 2016.

Public Avalanche Safety in Canada

A large avalanche runs over skiing terrain in the mountains of the Bow Valley. Photo: Avalanche Canada

The Avaluator is a decision aid for travelling in avalanche terrain and one example of the science-based tools developed in Canada for winter backcountry recreation. This tool is the foundation for the entry-level Avalanche Skills Training 1 course. The Avaluator and the AST 1 curriculum is used in seven other countries and has been translated to four other languages.

Mary Clayton

Canada has taken a unique path in developing public avalanche safety for backcountry recreation. Europe's alpine nations, where avalanche science was born, have focused on a rapid response to incidents and accidents, developing teams and techniques for professional rescue. In Canada, our expansive geography and relatively scarce population makes that approach unworkable. Instead, in this country, the focus has been on avalanche accident prevention.

Accident prevention means supporting backcountry users with training and tools that help them make good decisions in avalanche terrain, and providing them with the ability to respond to their own incidents effectively. Recreational avalanche training was first developed in the late 1980s, through the Canadian Ski Patrol Society and the Canadian Avalanche Association. Over the decades, the program and its curriculum evolved. Administration of the program was taken over by Avalanche Canada in 2004. Today, some 12,000 students take a course every winter.

Avalanche Canada's training program is the national standard for recreationists, with a curriculum founded on science-based decision-making tools. The courses were originally developed for English-speaking backcountry skiers. A separate curriculum was developed for snowmobilers to address the specific needs of that user group, and the courses are also now provided in French.

Professional avalanche training is standardized in Canada as well, and provided through the Canadian Avalanche Association (CAA), the organization representing professional avalanche workers in Canada. The courses within the CAA's Industry Training Program are internationally recognized and essential to anyone in Canada pursuing a career in snow and avalanche safety.

These national standards of training contribute to the strong safety net that has been developed for winter backcountry users in the mountains of western Canada. Language, techniques, and tools are consistent throughout the educational progression for both recreational and professional training. Material introduced at the basic level forms a strong foundation, allowing further education to build and expand on core concepts.

Standardization is a basic tenet of effective risk communication, and one of the great strengths of Canada's system. The consistent language found throughout the training programs is also found in the daily public avalanche forecasts. Different agencies provide daily avalanche forecasts in Canada, but all are accessed from one website – avalanche.ca – the "one-stop shop" for all avalanche-safety related information in Canada.

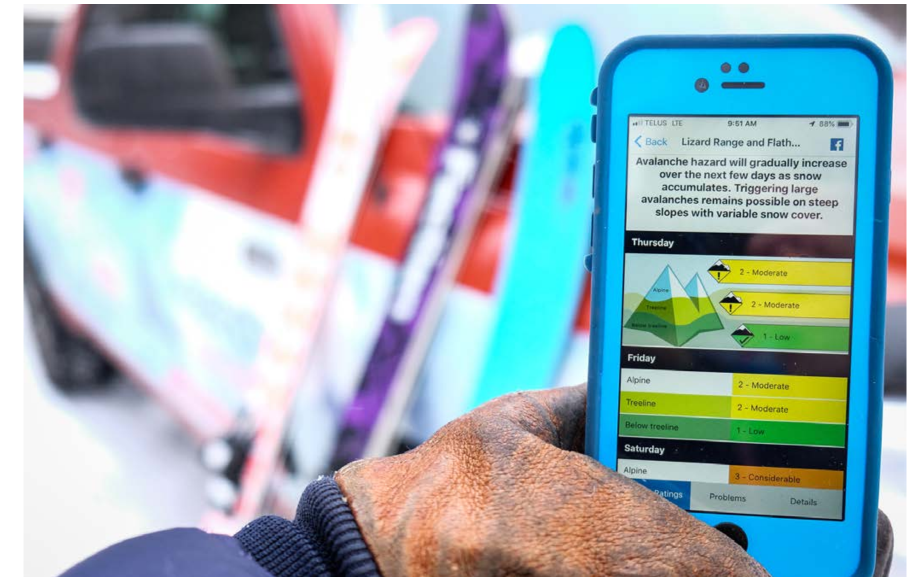
Avalanche Canada provides forecasts for fourteen regions that cover more than 300,000 square kilometres. In terms of area, this is the largest avalanche forecasting program in the world, by far. Parks Canada covers the mountain national parks, Alberta Parks forecasts for Kananaskis Country, and Avalanche Québec covers the Chic-Chocs in Québec's Gaspé region.

All these forecasts are found on the same website, and all use the same forecasting software. This ensures users have a consistent format to work with. No matter the region, the structure of the forecast is the same, so users know exactly how and where to find their critical information.

But snowpack information is just one part of the avalanche safety equation. Equally important is understanding the complex interplay between the snowpack conditions and the terrain. One of the most important tools developed to help backcountry users learn how to identify avalanche terrain is the Avalanche Terrain Exposure Scale (ATES). ATES provides a simple, three-point description of how much a given piece of terrain is exposed to potential avalanche hazard, providing users with an important guideline for their decision-making process.

All of the popular backcountry trips in the mountain national parks are ATES rated, as are many of BC Parks. All of BC's managed snowmobile areas are also ATES rated. However, the process of rating terrain with ATES remains fairly labour intensive and expensive. Within the next few years, we hope to be able to automate this system, which would give us the ability to provide ATES ratings for all the terrain being used for winter backcountry recreation.

Avalanche accident prevention also means developing a culture of avalanche safety within user groups. This allows peers to influence behaviour within their own community, encouraging a responsible and respectful approach to the winter mountain landscape as the norm. As backcountry users become more numerous and diverse, a healthy culture of safety and support becomes even more imperative.



The Avalanche Canada app allows users to access important avalanche safety information from their mobile devices.

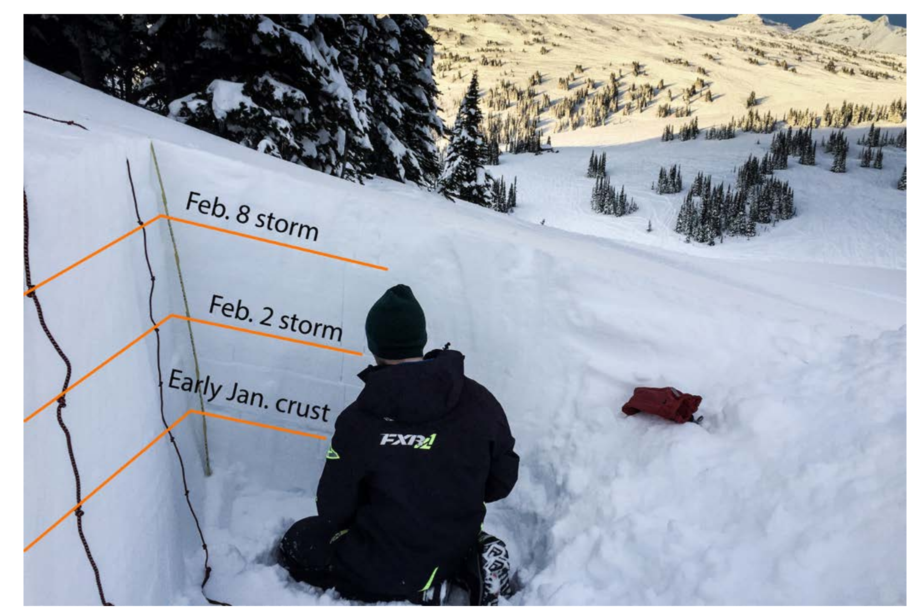
This is where outreach plays an important role – bringing awareness of the avalanche problem to those who are new to the mountains, or new to our avalanche safety culture. There is no single message that fits all our target audiences. At Avalanche Canada, we work hard to connect with recreational users where we can. Traditional media, social media, workshops, seminars, and parking lot get-togethers, all play a role in developing this culture.

All this work is being noticed. Other countries are licensing our curriculum, translating our tools, and collaborating with Canada to keep building on this strong foundation. The concept of avalanche accident prevention, by empowering users with information and tools to make their own decisions, is proving effective both here and abroad. It's extremely rewarding to have our programs emulated, and we look forward to the innovations the next decade will bring.

Mary Clayton is the Communications Director for Avalanche Canada.

Avalanche Canada provides forecasts for fourteen regions that cover more than 300,000 square kilometres.

Social media plays an important role in our communication strategy. Posts such as this one are an effective method of conveying current snowpack conditions to local users.



ARCTIC Change: An ACC Environment Fund Supported Expedition to Resolute and Iqaluit, Nunavut

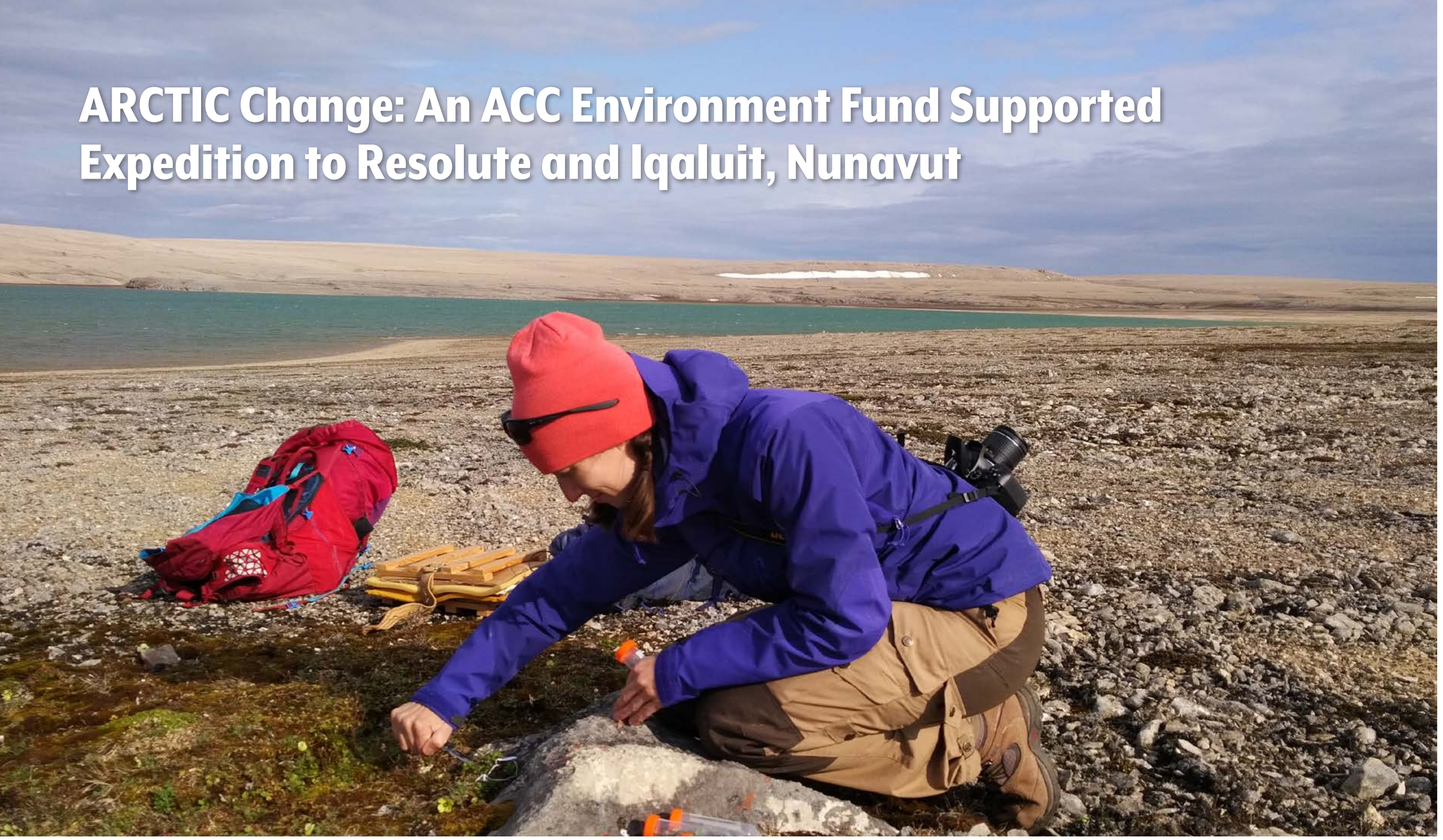


Figure 1. Lauren Erland collecting samples near 5 Mile Lake outside of Resolute, NU.

Lauren Erland & Susan Murch

Inuit Nunangat is a unique cultural, political and geographic zone that encompasses Nunavut and the northern most regions of Canada. This is one of the world's harshest environments, and in this region, climate change is accelerating at four-times that of more southern regions.[1] The arctic ecosystem shares many traits with high alpine environments. Plants growing in high latitudes and high altitudes have adapted to survive extreme cold, drought, short growing seasons, high UV exposure and winds, and generally low soil nutrient availability. This has led to unique adaptations. For example, willow trees in the high arctic grow only a few centimetres in height and spread along the rocky tundra due to the short growing season and high wind. Plants in alpine and arctic environments are facing similar challenges in the face of changing climates associated with unexpected climatic events and increased warming, making them a valuable subset of global diversity for study. Understanding how these unique plants respond to these new challenges will inform plant conservation priorities in both environments.

There have been relatively few studies of the plants of the Inuit Nunangat, and little is known about how these plants will perceive and respond to changing environments.

There have been relatively few studies of the plants of the Inuit Nunangat, and little is known about how these plants will perceive and respond to changing environments. Some plant species are likely to thrive, while others are likely to become at-risk as they fail to adapt or are crowded out by the expanding ranges of more southern species. It is estimated that twenty percent of the world's plant diversity is threatened, with climate change a significant factor.[2] Conservation of biodiversity is essential not only to the inhabitants of the surrounding areas where it may play roles in culture, social identity, and/or spiritual practices, but also provides services for the greater population by maintaining human health and well-being via plant-derived products (including foods and medicines) and participation in nature-based activities.

In the summer of 2019, the Alpine Club of Canada Environment Grant supported our expedition to Iqaluit and Resolute, Nunavut, with the goals of: (1) establishing relationships with local Inuit; (2) collecting seeds, tissues, and vouchers of Canadian arctic plants; (3) depositing these collections into Canadian and International seed banks; and (4) establishing species that do not produce viable seeds in an in vitro living germplasm bank. We collected eighty-three Herbarium vouchers (pressed specimens), seventy-four seed samples, and sixty-five live collections, representing >forty species (some examples of collections are given in Figure 1).

"Nothing about us, without us"

It has long been the practice of southern scientists to travel north, gather knowledge and specimens, and return little to the northern communities they visit. The National Inuit Strategy on Research was released in 2018 with the overall aim of changing this southern (colonialist)-centric approach to research to an Inuit-centric approach through five key priority areas: (1) advance Inuit governance in research; (2) enhance the ethical conduct of research; (3) elign funding with Inuit research priorities; (4) ensure Inuit access, ownership, and control over data and information; (5) and build capacity.[3] The first and most important objective of our work was to establish relationships to understand Inuit priorities and how the Inuit people are experiencing changing climates.

Resolute Bay, Qausuittuq ᖃᐅᓱᐃᑦᑐᖅ

Resolute is in the Qikiqtaaluk (Baffin) region of Nunavut. Qausuittuq, meaning the "place with no dawn," experiences twenty-four-hour night from mid-November to February, and inversely twenty-four-hour light from mid-May to mid-August, and is a high arctic desert with historical summer highs of two-to-four degrees Celsius (Figure 2). The majority of plants here grow only centimeters in height. Key observations included local knowledge of abnormal patterns of plant growth associated with climate disruptions. There was an unusual summer season in 2018, and flowering of some plants was delayed or did not occur at all. Other plant species did not produce any seeds. Some of the plants are growing taller than they used to, and others are more abundant.

One particularly interesting observation was the identification of a disturbance in the permafrost, an almost perfectly round circle (two-and-a-half metres in diameter) with a surface temperature of eighteen degrees at the centre, ten degrees warmer than the surrounding ground. Botanical composition around this spot was significantly altered, with more grasses and fewer native plant species growing at the centre of the disturbance. Detailed studies of this and related sites, in collaboration with Inuit observations and Traditional Ecological Knowledge, will provide important data to predict which alpine and arctic plants communities are vulnerable and which are resilient.

Figure 2. Some species collected in and around Resolute and Iqaluit, NU. Top from left to right: alpine bearberry (Arctous alpina, kublak, kallat), crowberry Empetrum nigrum, paurngait), mountain cranberry (Vaccinium vitis-idea subsp minor, kimminait). Bottom from left to right: arctic poppy (Papaver sp, igutsat niqingit), mountain sorrel (Oxyria digyna, qunguliit), nodding campion (Silene uralensis, pulluliujuit).

Figure 3. Inconsistency in the timing of seed twisting in mountain avens (Dryas integrifolia; malikkaat, isuqtannguat, isurramuat). Twisting traditionally signaled the coming of fall; however, it is happening inconsistently throughout the year. These photos were taken within days of each other in the Iqaluit area and show untwisted seed (left), twisted seed (bottom right), and a single plant with flower, twisted, and untwisted seed (top right).

Iqaluit

Iqaluit, meaning "place of many fish," is the territorial capital of Nunavut and also in the Qikiqtaaluk Region, at the southern end of Baffin Island. The vegetation (diversity and abundance) is relatively abundant compared to Resolute. The climate here is more moderated and experiences twenty-four-hour light for only about one month of the year with the growing season extending further into the fall. Many species that grow in southern regions of Canada could also be found, for example *Vaccinium* species, such as mountain cranberry, bearberry, and blueberries.

Local knowledge suggests significant changes in plant physiology are associated with the increasing instability, unpredictability, and warming of weather in Iqaluit, leading to significant cultural and commercial impacts for local residents and governance bodies (Figure 3). For example, due to warming, willows are growing five-to-ten centimetres taller, which has implications for not just the botanical landscape, but also wildlife and human interactions.

We appreciate the kindness and generosity of our Inuit guides sharing their knowledge of this unique ecosystem. We are now working to process our collections, and to establish our living plant collections in the lab. These collections will enable fundamental scientific research to help understand the mechanisms which determine climate change resiliency in diverse plant species, but particularly arctic and alpine plants. We hope the results of these studies will enable conservation efforts in both arctic and alpine ecosystems.

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Beyond species: How will global change affect species interactions?

Anna Hargreaves

Species responses to rapid global change have been summarized, somewhat caustically, as "adapt, move, or die." But each species is embedded in a web of interactions with those around it. Species depend on some interactions (plants on pollinators for reproduction, predators on prey for food, screech owls on woodpeckers for nesting cavities) and harmed by others (competition, parasitism, being someone's meal). Whenever species adapt, move, or die out, the effects ripple through ecosystems via these interactions.

It is hard enough to predict the effects of global change on single species; it might seem impossible to foretell the future of species interactions.

It is hard enough to predict the effects of global change on single species; it might seem impossible to foretell the future of species interactions. Nevertheless, a few big-picture predictions can be made:

Prediction 1: Effects on species interactions will often dwarf direct effects

For example, warmer winters have facilitated population explosions of mountain pine beetles in Western Canada.[1] But it is not the beetles themselves we notice, but their devastating effect on forests, now estimated at two million square kilometres. On the flip side, restoring interactions can have equally large, positive effects. A famous example is the reintroduction of wolves to national parks (by humans to Yellowstone; by wolves themselves to Banff), which forced elk away from easily-hunted lowlands. Few park visitors will see wolves, but many will see the lush streambank vegetation and higher bird diversity their hunting has enabled.[2-3]

Prediction 2: Alpine species and interactions are most at risk from climate warming

As the climate changes, species are moving to track their preferred climate. When biologists compare modern and historical field surveys on mountains around the world, they find species have moved upslope to cooler elevations far more than expected by chance, and have moved farther

Alpine paintbrush (Caslleja species) add splash of colour to mountain meadows. They also provide rich nectar for pollinators and steal nutrients from the roots of neighbouring plants. Photo: Anna Hargreaves

Caterpillars are significant herbivores for mountain plants, and can kill many seedlings each spring. Photo: Anna Hargreaves

Climate change can tip the balance of interactions, and may often tip in favour of small organisms, including pests.

where local climate has warmed the most.[3]

The effect of moving up depends on where species start from. Lowland species tend to gain mountain territory, but mountain-top species get squeezed as they eventually run out of mountain to climb.[4] Biologists have long feared this "escalator to extinction" will push high-elevation specialists off mountain peaks, and last year, the first such local extinctions were documented.[5] Eight previously common birds have been lost from a 4000-metre peak in Peru since 1985. Some of the missing high-elevation birds ate insects, others dispersed seeds; we don't yet know whether these interactions have been replaced by the mid-elevation birds that moved in.

Prediction 3: Forced migrations will reshuffle interactions

While mountain species are moving upward overall, different species are moving at very different rates.[4] When communities do not move in synch, existing interactions break up, and novel interactions emerge. New interactions may simply replace old ones: for example, if a newly arrived insect pollinates local plants. Or novel interactions might reshape communities. An innovative experiment from the Alps simulated climate warming scenarios where plant communities either tracked climate together or pulled apart.[6] When communities were shuffled and new interactions created, plants from lower elevations consistently outcompeted those from higher elevations. Thus, species that stay put may be outcompeted by new arrivals, even if they can stand the heat.

Prediction 4: Disease and pests will add insult to climate injury

Climate change can tip the balance of interactions, and may often tip in favour of small organisms, including pests. Why? First, climate stress makes plants and animals more susceptible. An excellent example is the modern die-offs of endangered Whitebark pines. While many trees died from blister rust pathogen or bark beetles, recent work using tree rings to reconstruct growth rates suggests trees were more susceptible due to the effects of climate change, including drought, warming, and reduced snowpack.[7] Second, small organisms tend to have bigger populations and faster reproduction, making them evolutionarily adaptable and thus better poised to cope with rapid change. Recent genetic work suggests that evolution helped mountain pine beetles take advantage of warmer winters to cross the Rocky Mountains.[8] Finally, as insects are "cold blooded," their activity and populations increase in warmer temperatures, as anyone caught in a warm day on the tundra knows. Global experiments suggest that insects currently play relatively small roles as predators[9] and herbivores[10] at high elevations and latitudes, but we should expect their role to increase in warmer times.

Prediction 5: Some interactions will prove resilient

Rapid change will disrupt the mountain ecosystems we know, but many interactions will prove resilient. Interactions are often generalized (most pollinators visit many flower species, for example), such that species on the move may functionally replace each other. Mountains naturally have highly variable climates due to their complex topography and weather patterns. Mountain species may therefore be adapted to cope with considerable upheaval, resilience that could buffer their interactions. Such resilience was proposed to explain why the longest running experiment of its kind found that glacier lily pollination stayed constant over almost three decades in Colorado's Rockies, despite measurable climate change during that time.[11] It's worth noting that this example comes from protected private land, where lilies have only one stress – climate change – to deal with at a time.

Conserving interactions

Species interactions are the glue that holds ecosystems together, and robust webs of interactions are more resilient to the insults of global change. The same conservation actions that will preserve the mountain wilderness so many Canadians love will help protect the interactions that wilderness depends on. Reducing the pace and extent of climate warming, preserving large tracts of intact natural land to maintain large populations, and connecting those lands to each other will help slow the rate of change and give species room to adapt and move.

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Species interactions are the glue that holds ecosystems together, and robust webs of interactions are more resilient to the insults of global change.

Waterton Wildflowers, Canadian Rockies. Photo Celestine Aerden

Mining in the Mountains

Teck Coal operates extensive mining operations in the Elk River Valley of southeastern British Columbia. Photo: Garth Lenz

Erin Sexton, Chris Sergeant, and Jon Moore

Scattered throughout the mountains of western Canada, often hidden behind locked gates at the end of gravel roads, are mines. Although they are concealed from much of society, it is worth highlighting the role of mining in these rapidly-changing, remote landscapes.

Mining operations target valuable mineral resources, such as coal, copper, or gold, that are locked away in earth's geology. A mine begins with prospecting, the process of locating economically-viable concentrations of minerals. After securing financial support, mining operations then extract the rocks from mountains to access the minerals. Such extraction may entail tunnelling underground, digging massive open-pits, removing the tops of mountains, or sifting through surface sediments. The mined rock is then mechanically and chemically manipulated to isolate the tiny concentration of targeted resources from the "waste" rock. For example, in southeastern B.C., Teck Coal produces 840 million tonnes of waste rock annually to access twenty-seven million tonnes of steelmaking coal that underlies the Canadian Southern Rockies.[1]

Mining activities disturb landscapes and mobilize toxicants that are otherwise locked away in rocks.

Mining provides important jobs to remote communities and resources for humanity, but mines and their related infrastructure can pose substantial environmental risks. Mining activities disturb landscapes and mobilize toxicants that are otherwise locked away in rocks. One common impact from mines is acid rock drainage, whereby sulfur-rich rocks are exposed to air and water, resulting in acidic runoff to downstream waters. Mining can also release metals, like arsenic, copper, and selenium, that can persist for centuries, if not millennia. Remnants of Roman Empire mining still pollute European rivers.[2] To contain toxicants, waste rock and processed slurries from mining are often stored in tailings facilities—or simply placed in river valleys—in perpetuity. But valleys filled with waste rock result in the permanent burial of stream headwaters, and tailings storage reservoirs can fail. These failures can be subtle, such as toxicants leaching out in groundwater, or catastrophic, such as the partial breach of Mount Polley's tailings dam that released over seven million cubic meters of contaminated slurry downriver and into a sockeye salmon rearing lake in the plateau country of B.C.[3]

While there have been advances in mining remediation and technology, some mines perpetually harm ecosystems because mitigation practices fall short in addressing long-term environmental impacts.[4] Below, we discuss several unique challenges for the environmental sustainability of mining in western Canadian landscapes.

First, the rugged nature of western Canadian mountains can exacerbate the impacts and risks of mining. These are some of the steepest, wettest, and snowiest places on Earth. Avalanches, landslides, and other natural hazards can damage mines and the infrastructure they have in place for risk mitigation. To address such challenges, mining in mountains relies upon marvels of engineering that push the limits of technology and infrastructure. For example, the proposed KSM mine crossing the Unuk and Nass River watersheds would require over five billion US in capital expenditures to create three open pits, four dams for tailings ponds – including what would be one of the highest dams in North America – and twin twenty-three kilometres of sub-glacial tunnels for transporting ore.[5] Access to remote mountain mines demands the creation of new roads and power systems in otherwise roadless, high-elevation landscapes. In an extreme example, the currently operating Brucejack Mine in the Unuk River watershed is accessed via an eleven-kilometre-long road on a glacier.

Occurring in the headwaters of western rivers, mountain mines can pose downstream risks. Mountains are the birthplace of clean cold water, gravel, and other resources for downstream communities and ecosystems. Even high in the mountains where fish do not exist, mining impacts can spread downstream into important fish habitats and human communities. An extreme example of such downstream damage was the historic flood of 1908 that carried five-and-a-half million cubic metres of toxic sludge, laden with arsenic, lead, zinc, and copper, over just under two-hundred kilometres downstream from a massive copper mining complex in western Montana.[6] These downstream risks can even cross international boundaries, complicating effective mining oversight.[7] Communities in southeastern Alaska dependent on healthy salmon populations are concerned that they are bearing the burden of environmental risks posed by upstream Canadian mines and have repeatedly called for their stricter regulation, oversight, and enforcement.[8]

There is increasing global pressure to further extract mountains' minerals. The United States recently identified the amounts, types, and sources of minerals that would enable them to keep up with their growing consumption. On the top of the list of sources, second only to China, was Canada.[9] The "golden triangle," a region of northwestern B.C., whose rivers drain through the coast mountains into southeastern Alaska, is experiencing a modern-day gold rush; companies spent $165 million in exploration in 2018, nearly twice the investments made in 2016.[10] With the rapid retreat of glaciers and permanent ice due to climate change, mining companies are further exploring these newly

Avalanches, landslides, and other natural hazards can damage mines and the infrastructure they have in place for risk mitigation.

Reaching Brucejack Mine in the Unuk River watershed shared between British Columbia and Alaska requires traversing an 11 km road over Knipple Glacier. Photo: Garth Lenz

The tailings reservoir for Red Chris Mine sits in the headwaters of the Stikine River watershed shared between British Columbia and Alaska. Photo: Garth Lenz

exposed landscapes for the next big mineral deposit. We anticipate that there will be continued pressure for mining in the mountains.

The diverse community of people who care about the future of mountain ecosystems in western Canada are facing important questions. Some are technical: how can evaluation, regulation, and operations of mines be improved to decrease risks to important species and ecosystems? Some questions are value-based and demand that we weigh the costs and benefits of mines: for example, are there areas that are too ecologically-sensitive or important to risk with mining? Other questions are politically sensitive: given that mining companies consistently donate millions of dollars to B.C. governments, making them some of the biggest corporate donors, are mining benefits and risks fairly considered in decision-making?[11] Looking forward, we face difficult decisions and potential trade-offs: can gold mining co-exist with grizzly bears? Coal with caribou? Steel with salmon? These difficult decisions should be made with the best available science and with balanced accounting of the risks and benefits of mountain mining.

Looking upstream on the mainstem Tulsequah River, a large tributary to the Taku River on the traditional lands of the Taku River Tlingit First Nation. The red building on the right side of the photo marks the location of Tulsequah Chief Mine, which ended operations in the 1950s and has been leaking acid mine drainage. Photo: Chris Sergeant/ Flathead Lake Biological Station.

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Canadian alpine butterflies deserve better monitoring

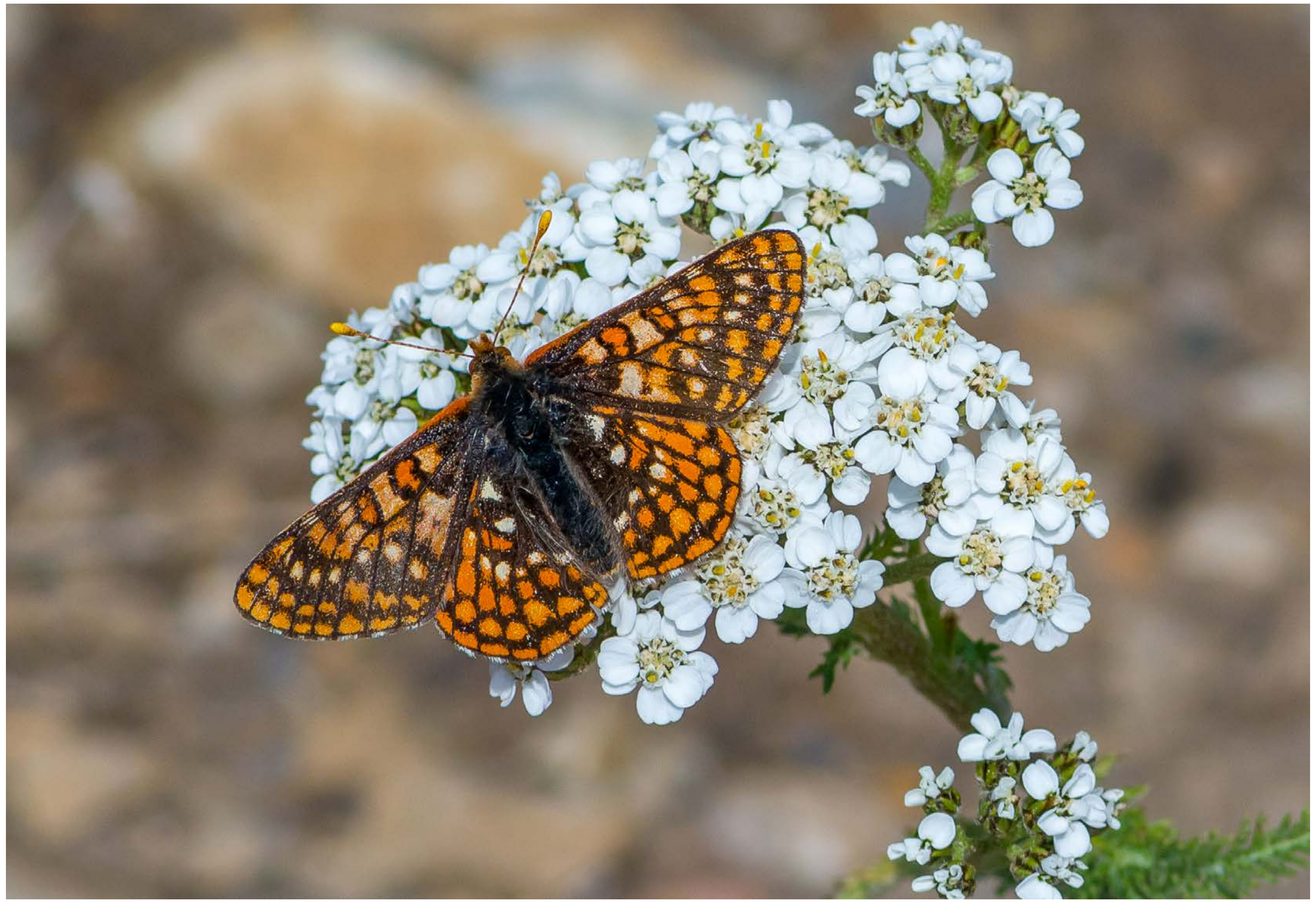
Felix Sperling, William Sperling, and Zac MacDonald

Rocky Mountain parnassian, also known as Rocky Mountain apollo, (Parnassius smintheus) female at Plateau Mt., Alberta. 2018. Photo. Z. MacDonald.

Alpine butterflies are easy to love for their exuberant animation across scree slopes and mountain meadows. While most of us only encounter alpine butterflies on sunny, summer days, they are far from being limited by such agreeable conditions. Their fragile butterfly bodies hide tenacious adaptabilities that have allowed them to persist in extreme environments for millennia, while glaciers ebb and flow around them, with genetic changes slowly being recorded in their DNA and the patterning of their wings. In our part of the world, alpine butterflies range in size from the six-centimetre wingspan of parnassians (Figure 1), with a creamy background highlighted by bright red eyespots, to just two centimetres of patterned gray and white in grizzled skippers. Populations inhabiting different regions, ranges, or even single isolated mountains are often given different names due to slight differences in genetics, appearance, and behaviour. Each has scientific value, with much to tell us about how environmental changes are affecting alpine habitats. Indeed, with warming temperatures around the world, many alpine butterflies are moving both northward and up mountain slopes, while others are simply disappearing. Such changes can only be detected by monitoring these alpine gems before they are literally swept off a cliff, with no way to return.

Populations inhabiting different regions, ranges, or even single isolated mountains are often given different names due to slight differences in genetics, appearance, and behaviour.

Most of the forty-odd species of alpine butterflies that occur in Canada may be found somewhere in the mountains of Alberta, British Columbia, and the Yukon. Many, like Edith's checkerspot (Figure 2), are restricted to the southern reaches of Alberta and B.C., having survived south of the ice sheets during the last glacial maximum, some 30,000 to 11,000 years ago.[1] Other species, like Eversmann's parnassian, are restricted to the northern half of B.C. and the Yukon, having braved the last glacial cycle in the nearby Beringian refugium. Most butterflies with Beringian or northern arctic distributions, like Ross's alpine, have larvae that feed on grasses



Edith's checkerspot (Euphydryas editha) on yarrow flower at Plateau Mt., Alberta. 2018. Photo. Z. MacDonald.

and sedges, which suggests that these regions had more steppe-like habitats during the last glaciation, rather than the wet tundra habitats observed today. In these ways, studying the unique distributions and life histories of alpine butterflies provide many insights into the nature of ancient alpine environments.

Alpine butterflies are also sensitive indicators of recent and ongoing environmental change. We already knew in the 1990s that Edith's checkerspot has been shifting its range toward the north into Canada.[2] Since then, considerable evidence has shown that other alpine species are doing the same.[3] But each species has its own particularities. The Rocky Mountain parnassian is a well-studied alpine butterfly that frequents dry alpine slopes where stonecrop, its larval food plant, is found. In the front ranges of the Rocky Mountains of southern Alberta, some twenty years of monitoring have shown that extreme temperatures and lack of snow cover in early winter, when the butterfly is in the egg stage, are better predictors of population numbers than any general climate index.[4] Much less is known about the environmental factors that affect this butterfly throughout B.C. and the Yukon, where three other subspecies are recognized. Many lepidopterists (those who study or collect butterflies and moths), including ourselves, are trying to fill these knowledge gaps. And yet, this species is but one of many that illustrate the complex interplay of past and current factors that structure alpine butterfly communities.

Alpine butterflies are also sensitive indicators of recent and ongoing environmental change.

Many human influences can affect butterfly distributions, some more obvious than others. In combination with global climate change, fire suppression has resulted in visible encroachment of trees in alpine meadows across Alberta and B.C. (Figure 3). Rising treelines don't just mean less habitat, but also diminish the number of butterflies flying between mountains. Such dispersal events are needed to rescue isolated and dwindling populations or boost their genetic diversity. Factors like changing snowpack, or the death of high-elevation pines due to mountain pine beetles or introduced blister rust,[5] can also have profound influences on mountain hydrology and the diversity of nectar sources and larval food plants. Even seemingly distant threats like pesticides can condense and become more concentrated in the cooler temperatures of alpine and arctic habitats.[6] It is clear that many human-mediated factors influence alpine butterflies, but the inaccessible and fragmented nature of butterfly habitats has left much to be discovered.

Fortunately, the attractive nature of alpine butterflies may yet contribute to their use as valuable sentinels of alpine habitats. With ever-growing interest in backcountry exploration, monitoring of alpine butterflies can be greatly aided by taking a few minutes to snap and upload a good photo, or even packing a small net to bring back samples for genetic work. We already have accessible databases of historical museum specimens for Canada.[7] Now, new citizen-science observations and photos are easily compiled on digital repositories like *iNaturalist* (www.inaturalist.org) or *eButterfly* (www.e-butterfly.org). Information for alpine and arctic butterflies is still sparse, and yet they are likely to be among the best indictors we have of the profound changes that their habitats are beginning to experience.

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Fortunately, the attractive nature of alpine butterflies may yet contribute to their use as valuable sentinels of alpine habitats.

View to the southeast from Mt. Faith, near Christina Lake, B.C. 2019. Photo. W. Sperling.

The Role of Conservation Data Centres for Documenting and Monitoring Mountain Biodiversity

Figure 1. Bioblitz participants surveying the mountains in Kluane National Park. Photo: Syd Cannings

Figure 2. Examining alpine lichens during the Tombstone Territorial Park Bioblitz. Photo: Bruce Bennett

Bruce Bennett and Syd Cannings

Mountains are naturally diverse places, with different animals and plants living in forests and in the alpine, on windward and leeward slopes, in wet and dry meadows. With the latest advances in technology, it has become easier to document this diversity, but the sheer numbers of species to keep track of make this a daunting task. Where to start and how to set priorities?

NatureServe, and its member programs, have been tackling this issue for more than forty years. NatureServe is a network of eighty-six governmental and non-governmental programs in Canada, the United States, and Latin America. Network Programs in Canada – often called Conservation Data Centres (CDCs) – and their staff work to document, protect, and conserve the plants, animals, and ecosystems in their provinces and territories. They list every species in their jurisdiction, rank each according to their conservation status, and then focus data collection efforts on those species that need special attention. Rare or threatened species are mapped as precisely as possible.

With the help of partners such as Environment and Climate Change Canada, Parks Canada, and the Nature Conservancy of Canada, CDCs undertake biological inventories to document rare species and ecological communities. CDC staff also gather and analyze conservation data, provide tailored information products and services, and strive to make data widely available. A CDC serves as the source for reliable and up-to-date scientific information for the plants, animals, fungi, and ecological communities within their respective jurisdiction.

Increasingly, the NatureServe network has been working with the citizen science project *iNaturalist* (www.iNaturalist.ca) to help gather spatial data on wild species. It is the goal of *iNaturalist* to connect people to nature through technology with the specific goals of: increasing natural history literacy, understanding, and interest among the public; generating high-quality biodiversity data for science and conservation; and increasing the excellence and international coverage of the Network through new memberships with effective organizations.

As *iNaturalist* grows in popularity, more and more amateur naturalists and citizen scientists are uploading their photos and seeking confirmation of their identification. Yukon Conservation Data Centre (YCDC) staff assist in this effort by providing expert identifications, and also contracting other experts to review and identify photographs and sounds.

The YCDC and partners used photo-based observations in combination with an intense period of biological surveying in an attempt to record all the living species within a designated area, known as a “bioblitz,” to create a benchmark of the biodiversity of an area. The mountainous areas in and around Kluane National Park and Reserve (2017) and within Tombstone Territorial Park (2018) were the focus of YCDC-coordinated bioblitzes. On one summer weekend, the Kluane Bioblitz recorded a total of 891 species (only thirteen of which were exotic!), 346 of which were vascular plants. Sixteen participants provided 1,060 observations to *iNaturalist* of 353 species. The 2018 Tombstone Bioblitz recorded over 1,008 species. Vascular plants once again topped the list with 328, but mosses and liverworts had 192 species represented – one-third of all species ever recorded in Yukon. The participation in *iNaturalist* increased to 22 with 357 species captured though 856 observations. The uptake for *iNaturalist* in the 2019 Watson Lake Bioblitz increased dramatically. Although fewer people attended (sixty-five at Watson Lake versus 108 in Tombstone), more than half submitted observations resulting in 3,404 observations of 725 species.

The growth and popularity of *iNaturalist* is not showing any signs of slowing down, increasing the number of local, regional, and national discoveries. Although the Watson Lake Bioblitz did not result in any new species for Canada (so far), there were several new species recorded for Yukon, including the House Wren, Goblin’s Gold (Schistostega pennata), and Sanderson Bumble Bee (Bombus sandersoni). Long after the bioblitz was over, other new records for the territory were discovered through the review of the *iNaturalist* posts, including an orchid, White Adder’s Mouth (Malaxis monophylos), and a butterfly, Purplish Copper (Lycaena helloides).

In a time of a warming climate, with species’ ranges changing, the NatureServe network will continue to assist with gathering, documenting, and monitoring mountain biodiversity. For more information or to contribute your observations, contact the Yukon CDC yukoncdc@gov.yk.ca , call (867) 667-5331, or visit our website: https://yukon.ca/biodiversity.

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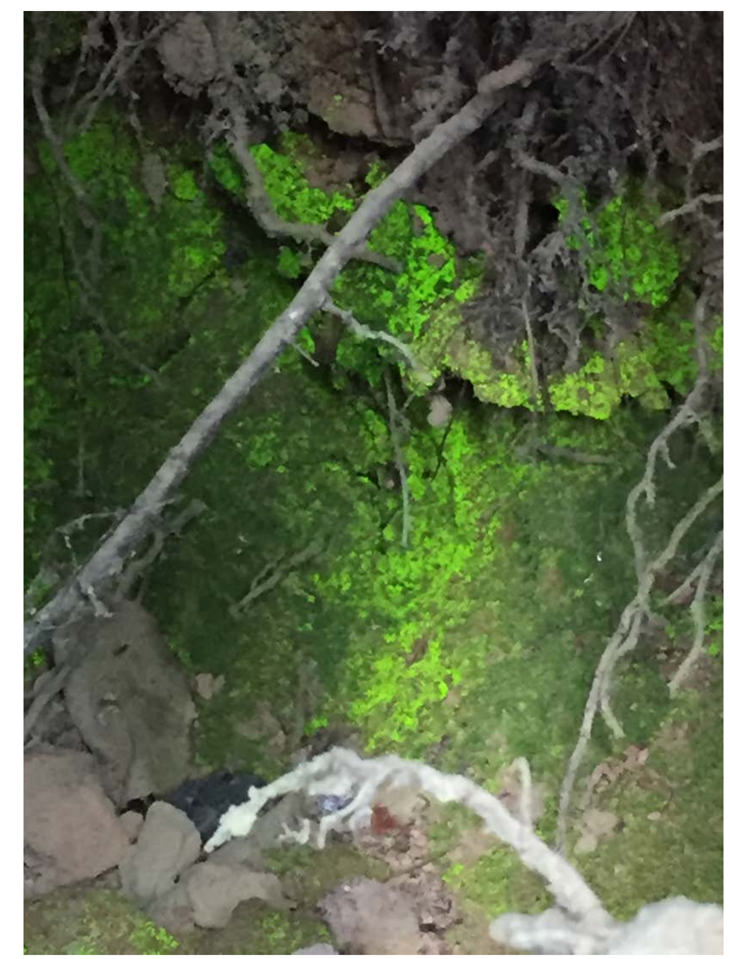


Top: Figure 3. White adder’s mouth (Malaxis monophyllos), a terrestrial orchid found during the 2019 Bioblitz. Photo: John Reynolds

Bottom: Figure 4. Goblin’s Gold (Schistostega pennata) a bioluminescent moss glows in the cavity under a fallen tree. Photo: Bruce Bennett

Life on Mountains in the Sea

Figure 1. We explore life on mountains in the sea using deep-sea submersible robots. This is the first submersible dive ever to Explorer Seamount (2018), Canada's largest underwater volcano. The illuminated glass bugle-like sponges are the biological structures that create Spongetopia and are a brand new species. Credit: Ocean Exploration Trust, the Northeast Pacific Seamount Expedition partners.

Cherisse Du Preez and Tammy Norgard

We lose sunlight quickly. Thirty meters down is already pitch black. The area illuminated by the beams of our lights seems modest for our mission. Imagine mapping the Rocky Mountains at night by flashlight. What we do is similar (Figure 1), but, for the full effect, imagine an unexplored Banff is hidden below three kilometers of water.

Our expeditions take place hundreds of kilometers offshore of British Columbia, in Pacific Canada's *other* great alpine environment, the mountains in the sea (Figure 2). As we descend into the ocean, illuminated passersby become alien-like. The dark abyss is speckled with the bioluminescence of lantern fish, squids, and gelatinous critters of all shapes and sizes. Passing below one thousand meters depth, we enter the ocean's midnight zone. While the base of the mountain can be another one to two thousand meters deeper, the water is already near freezing and the pressure a hundred times greater than that experienced at sea-level.

During a seamount expedition, we routinely start our dives on a gentle-sloping flank and "climb" to the steep summit using a submersible robot – picture a gondola ride up a mountain, but equipped with banks of lights, high-resolution video and still cameras, dexterous arms, manipulators, arrays of sensors, and instruments (Figure 1). This equipment allows us to document and study the extraordinary life found on and around seamounts.

When lava from a large deep-sea volcanic eruption forms a giant seamount, the abrupt edifice drastically change the local conditions, creating a hidden underwater island oasis of life in the otherwise open ocean. Rocky seamounts rise kilometers above the surrounding mud that covers the majority of the world's ocean floor. The flanks act as a ramp, driving up cold, nutrient-rich bottom-water, which can cause a cyclonic flow to form around the summit. The mixing of upwelled bottom water at the shallower sunlit depths is the perfect recipe for phytoplankton blooms (microscopic plant-like organisms), which fuel the marine food web. These conditions attract a diversity of life, from the cold-water corals and sponges that colonize the deep pillows of volcanic lava to transient whales, sharks, and seabirds that feed on the high concentration of prey (Figure 3). The positive effects spill over, and crabs, sea stars, fish, octopuses, and many other species abound. The abundance of animals, biological diversity, and structural complexity found on a seamount can rival that of tropical coral reefs.

As we descend into the ocean, illuminated passersby become alien-like.

Because they are a hotspot of life, seamounts can play an essential role in ocean health and sustainability. However, for the same reasons, seamounts worldwide are under increasing threat from overexploitation and climate change. In the Canadian Pacific, conservation concerns include bottom-contact fishing, shipping traffic, oxygen depletion, and ocean acidification. In the High Seas, concerns also include the prospect of underwater mining. That said, the Government of Canada is committed to protecting seamounts.

To safeguard a complex of three incredible seamounts, the Council of the Haida Nation and the Government of Canada established the SGaan Kinghlas-Bowie Marine Protected Area (MPA).[1] Located offshore of Haida Gwaii (Figure 2), the largest seamount stands over three kilometers tall and rises within twenty meters of the surface (nearly triple the height of Banff's iconic Mount Rundle). Its summit is so shallow that it is home to kelp forests and coastal animals (some threatened), providing an offshore refuge for life to thrive in the absence of near-shore pressures. Traditional knowledge and scientific evidence tell this seamount was once a volcanic island that has since eroded back into the sea. The Haida have experienced an intimate interconnection with SGaan Kinghlas since time immemorial.

The near-shore tectonic activity found in the Canadian Pacific is a globally-rare phenomenon, and Canada is fortunate to have an abundance of seamounts and other associated deep-sea environments in its Pacific waters (and jurisdiction).

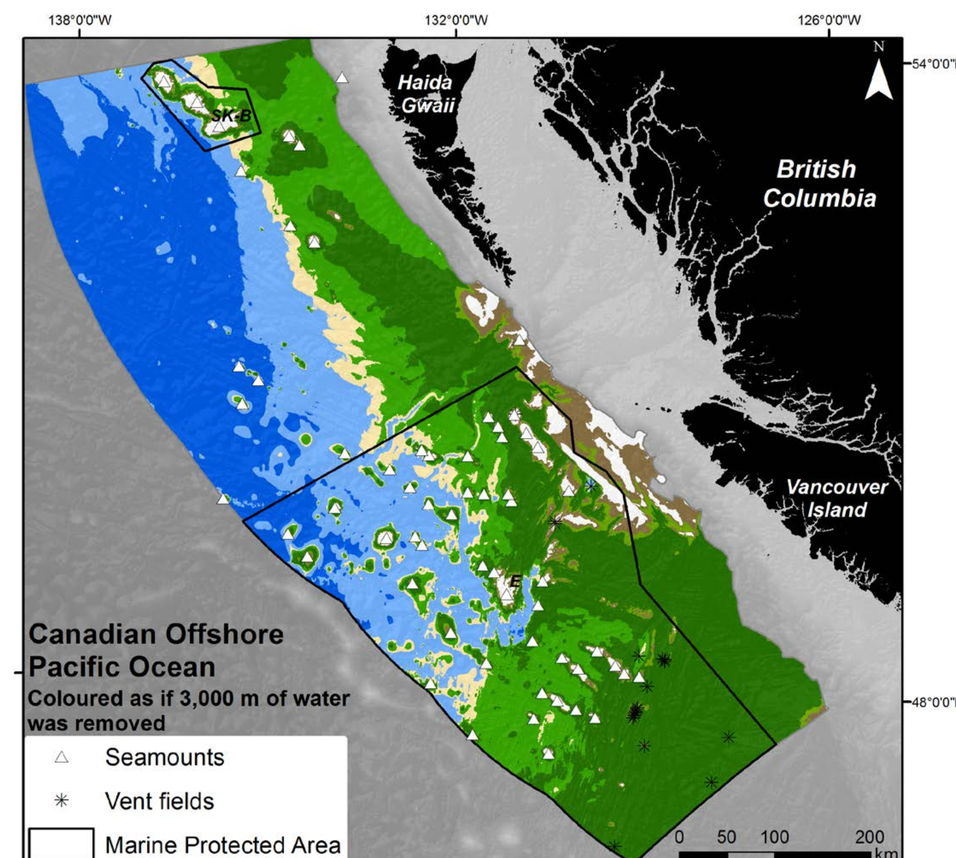
In 2017, Fisheries and Oceans Canada (DFO) proposed a new Pacific MPA[2] to protect over 75% of known Canadian seamounts (Figure 2), which includes all seamounts shallow enough to be directly impacted by human activities. The MPA will also protect all known Canadian hydrothermal vent fields, which are deep-sea hot springs created by the same tectonic activity as seamounts but that support endemic animals (found nowhere else on Earth).

To better protect these deep-sea treasures, we need to understand them. Every summer for the past three years, DFO has led a team of researchers and communicators on an unprecedented seamount campaign.[3] We have discovered and described over forty hidden seamounts. We collected species new to science and filmed never-before-seen animals, places, and behaviors. Surprisingly, we have encountered tropical animals around the seamounts – such as bottlenose dolphins – their shifting distributions attributed to climate change. On Canada's largest seamount, Explorer, we discovered *Spongtopia*[4] – a "Dr Suess" city of towering bugle-like glass sponges meters high (Figure 1). We have found and mapped many other forests made of fragile, long-lived habitat-creating corals and sponges. Like an old-growth forest, if damaged, it will take decades to centuries for these ecosystems to recover.

While our expedition research aims to support science-based decision-making in the development of protection, our imagery – with its broad reach – plays an essential role, showcasing Canadian seamounts and the extraordinary and unique life they support. As *Jacques Cousteau* famously said, "People protect what they love." Alpine environments have not been precluded from this truth despite their general remoteness and historical inaccessibility. Photographs and stories capturing the beauty and importance of mountains have often been enough to inspire awe and shape public opinion, moving people to act. We can only hope for similar success with seamounts as millions of viewers have watched our expedition livestream and highlight reels across Canada and around the world in over 130 countries.[5] Canadians are incredibly fortunate that seamounts are our national heritage and in

The near-shore tectonic activity found in the Canadian Pacific is a globally-rare phenomenon

Figure 2. The hidden underwater topography of the Canadian offshore Pacific (coloured as if 3,000 m of water was removed), its mountain ranges including SGaan Kinghlas-Bowie (SK-B) and Explorer (E) seamounts, and the locations of the existing and proposed seamount Marine Protected Areas (in the north and south, respectively). Credit: C. Du Preez, Fisheries and Oceans Canada.



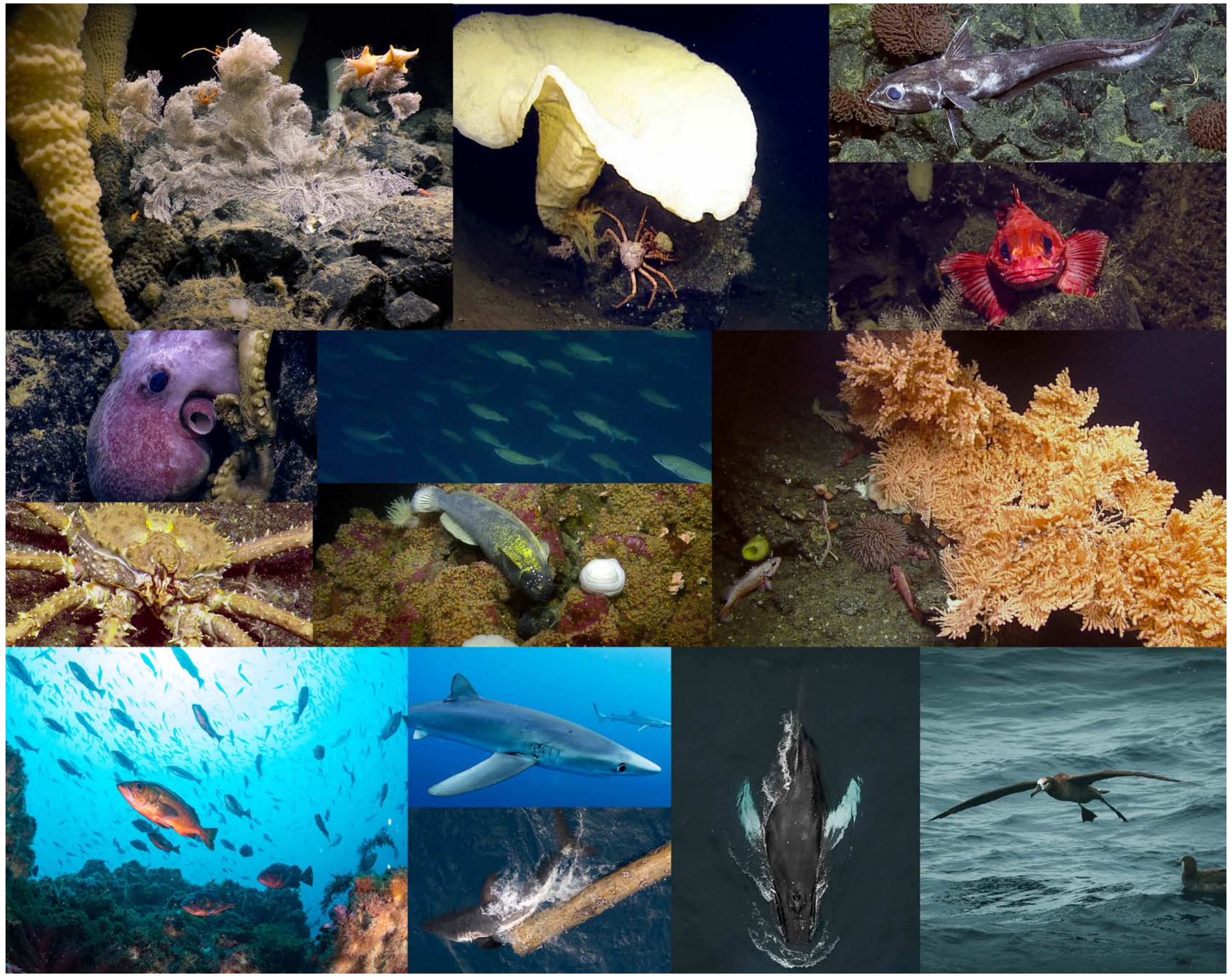


Figure 3. The abundance and diversity of life on and around Canadian mountains in the sea. Starting in the dark and deep flanks (top left) and ascending above the summit to the sunlit sea surface (bottom right), the mosaic shows cold-water corals and glass sponges on pillows of lava, a variety of fishes, octopus, crabs, seaweeds, sharks, whales, and seabirds. Credits: Fisheries and Oceans Canada, S. Du Preez, C. Du Preez, Ocean Exploration Trust, the Northeast Pacific Seamount Expedition partners, Pacific Wild.

our power to understand and protect. Remove the water and these mountains are as much a part of Canada as the Rockies.

Cherisse Du Preez and Tammy Norgard are marine biologists based in B.C. at the Institute of Ocean Sciences (Sidney) and Pacific Biological Station (Nanaimo), research organizations within the Department of Fisheries and Oceans Canada (DFO). Cherisse specializes in studying deep-sea benthic ecology using remotely operated vehicles video surveys and ship-based mutlibeam sonar. Tammy is the Program Head of the Large Offshore Marine Protected Area Program at DFO and has led numerous expeditions to explore, map and document the biodiversity of Canada's west coast, particularly offshore seamounts.

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Submarine Mountains Off Eastern Canada

David J. W. Piper and Georgia Pe-Piper

The Canadian Pisces IV submersible (1973-1986) held a pilot and two scientists, but its maximum depth rating of 2000 m meant that it could be used only on the crests of a few larger seamounts. Here it is being recovered after a dive on Laurentian Fan that included author David Piper.

Offshore from Canada's Atlantic Provinces, in the North Atlantic Ocean (Figure 1), are mountains every bit as majestic and varied as those of the Western Cordillera. They form chains of seamounts, together with larger ridges and plateaus rising one to three thousand metres above the deep ocean floor.[1] They are important sites of marine biodiversity. Their distribution and morphology are known only in general terms, mostly from echo-sounder profiles collected over the past century. Only relatively small areas have been mapped using modern multibeam sounders, which provide bathymetric maps typically gridded at fifty metres. As Roger Revelle famously wrote some 60 years ago, "we still know more about the Moon's backside than about the ocean's bottom."

Few people have directly seen these submarine mountains. The deep ocean is dark, and the lights on manned submersibles or remotely operated vehicles (ROVs), equipped with cameras, normally illuminate only a few metres. In the late twentieth century, manned submersibles were used for close-up investigation of deep-sea mountains, but for safety reasons, ROVs have been preferred this century.[2] A few rock samples have been collected by ROV, but most samples have been recovered by the crude technique of dredging: dragging a chain basket with toothed jaws up steep slopes, in the hope of snagging something important, and not just boulders dropped by icebergs.

The geological origin of these submarine mountains is varied. Orphan Knoll (Figure 1), off northeastern Newfoundland, is a fragment of the North American continent that separated from Canada 100 million years ago, during the stretching of the continental crust prior to the separation of Ireland from Newfoundland by the North Atlantic Ocean. The flat-topped plateau lies at around 1,800 metres below sea level and is about the area of Banff National Park. The precipitous fault-bound northeastern slope is almost 2,000 metres high and eroded by large rockfalls and landslides. The southern and western slopes have a cover of younger

Three seamount chains or clusters lie partly within the seabed in the Atlantic Ocean claimed by Canada under the United Nations Convention on the Law of the Sea

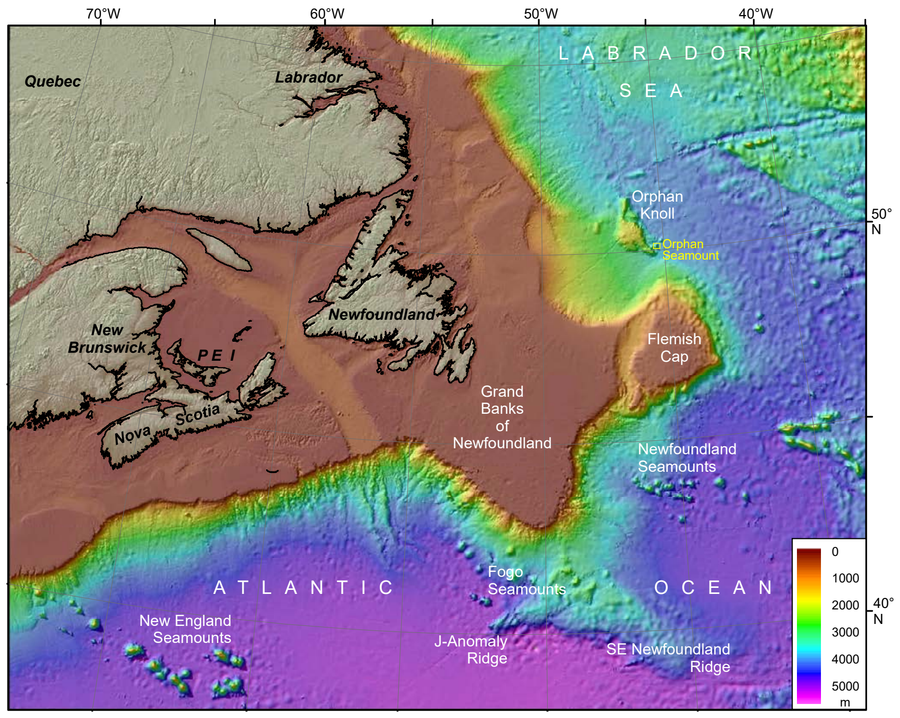
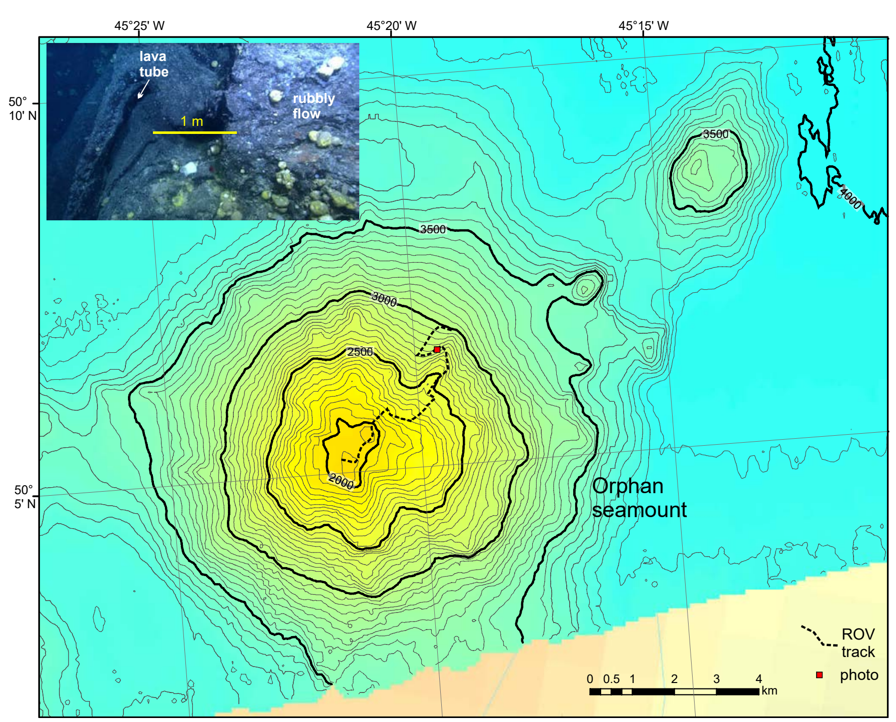


Figure 1. Bathymetric map of the North Atlantic Ocean off eastern Canada. (Source: GEBCO). Based largely on conventional echosounder data.

sediment that has been sculpted by the powerful deep currents that sweep down the western edge of the Labrador Sea. To the south, Flemish Cap is an analogous fragment of continental crust, with a plateau 130 to 1,000 metres deep and steep fault-bound cliffs to the east and south. ROV observations on the 3,000-metre-high southern slope show a series of rock cliffs and terraces, with some granite walls that would be a climber's delight if they were not under the sea.[2]

Three seamount chains or clusters lie partly within the seabed in the Atlantic Ocean claimed by Canada under the United Nations Convention on the Law of the Sea: the New England, Fogo, and Newfoundland seamounts, each including more than a dozen individual volcanic cones (Figure 1). In addition, there are several individual seamounts within Canadian territory, the best known being Orphan Seamount (Figure 2), just southeast of Orphan Knoll, which was investigated by ROV in 2010.[3] Orphan Seamount rises 1,600 metres above the surrounding ocean floor and is cone shaped with an average gradient of about twenty degrees.

Figure 2. Contoured multibeam bathymetric map of Orphan Seamount.[3] Inset shows basalt lava near the base of the seamount



Of the seamount chains, the Fogo Seamounts are the best known.[4] More than forty conical seamounts are recognised, the highest more than 1,000 metres above the regional sea floor. The Fogo Seamounts range in age from 150 to 125 million years, and are partly buried by younger sediment on the continental slope. Some related volcanoes on the Grand Banks were drilled by exploratory petroleum wells in the 1970s. Some of the Fogo Seamounts have flat eroded tops, at present depths of 3,000 to 4,500 metres, suggesting that they originally formed volcanic islands, and were eroded off at sea level, before gradually subsiding to their present depth.

The Newfoundland Seamounts are younger, about 100 million years old, but higher, rising up to 2,000 metres above the regional sea floor. They form a more linear chain in comparison to the scattered Fogo Seamounts (Figure 1). The New England Seamounts also form a linear chain and range in age from 88 to 123 million years. The largest rise 3,000 metres above the ocean floor, and their flanks were investigated by a scientific drill ship in 1975, as well as by manned submersible. All of our seamounts have subsided several kilometres, together with the surrounding ocean floor, due to cooling of the underlying crust and mantle since their formation.

The J-anomaly Ridge and the SE Newfoundland Ridge (Figure 1), extending southwest and southeast from the southern tip of the Grand Banks, are also of volcanic origin. Both originally formed about 130 million years ago, as the Grand Banks were rifting away from Spain and Portugal, allowing the Atlantic Ocean to start propagating northward. The J-anomaly ridge formed by unusually voluminous volcanism at the northeastern tip of the oceanic spreading ridge of the central Atlantic Ocean between Nova Scotia and Morocco. The SE Newfoundland Ridge formed by coalescing volcanoes along the Newfoundland-Azores-Gibraltar Fracture Zone that marked the termination of the central Atlantic Ocean at that time.

More generally, the origins of the plateaus, escarpments, volcanic ridges and seamounts are all linked to the progressive opening of the North Atlantic Ocean between eastern Canada and western Europe. This rifting apart of the continents started about 160 million years ago, but was completed only about 100 million years later, when continental rifting gave way to oceanic spreading between Greenland and both northeastern Canada and northwestern Europe. The rifting was intimately linked to convection and heat distribution in the Earth's mantle, which softened the crust and produced basaltic magma by partially melting the upper mantle. The details of these processes and the role played by the magma that built the seamounts and volcanic ridges are a matter of continuing debate.[5]

Author David Piper with a damaged coring device used to recover samples from the deep sea bed. Aboard CSS Hudson in 1985.

David J.W. Piper is an Emeritus Scientist with the Geological Survey of Canada (Atlantic). His first research cruise to the Newfoundland Seamounts was in 1974, and he has been fascinated with the underwater mountains offshore eastern Canada ever since.

Georgia Pe-Piper is Professor Emerita of Geology at Saint Mary's University in Halifax. She has worked over the last 40 years on the geochemistry and origin of ancient volcanic rocks offshore.

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A dredge haul from one of the Newfoundland Seamounts coming aboard the CSS Hudson in 1973.

Geological Origins of Canada's Cordilleran Mountain System

Looking west across the Nakina mountain range of north-central British Columbia toward the snow-covered Coast Ranges of B.C. and the Alaskan pan-handle in distance. Rocks in the foreground being examined by Dante Canil (geology professor, Univ. of Victoria). Photo: S.T. Johnston.

Stephen Johnston

The Cordilleran Mountain System, extending the length of the west margin of the North American continent, consists of numerous separate and distinct mountain ranges, is host to much of the continent's mineral and energy natural resources, is the source of much of our freshwater the last bastion of all of our sub-arctic glaciers, and constitutes one of the continents last great wilderness regions. But why the Cordillera exists at all remains a difficult question to answer. It is understood that plate tectonics plays a key role in the formation of mountains. Typically, one continent crashes into another resulting in a thickened, mountainous welt of buoyant continental crust. The ongoing collision of India with the south margin of Asia giving rise to the Himalayan mountains and the Tibetan plateau is a modern example of this process. So what collision gave rise to the Cordillera?

Continents collide when oceanic plates separating them subduct (sinking down into the Earth's mantle) resulting in ocean closure. In the case of India and Asia, the Indian continent was attached to an oceanic plate that subducted beneath Asia, pulling the Indian continent into and beneath Asia. During collision, the Asian continental crust slid up and over the Indian continental crust, giving rise to a mountain system (the Himalaya) that advanced over and helped push down the incoming Indian plate. As a result, the mountains of the Himalaya consist of (from south to north, and highly simplified) crust and sediment scraped from and pushed back over the leading edge of the Indian continent; a belt of basalts and oceanic rocks referred to as a suture (the Indus Tsang-Po suture), which is a remnant of the ocean that formerly separated the two continents, and, north of the suture, deformed Asian crust (Figure 1). The bulk of the Indian continental crust south of the mountains lies buried by kilometres of sediment eroded from the high-standing mountains, forming what we refer to as a syn-collisional foreland basin south of the mountain system.

Applying this 'template' to the Cordillera, it appears that our mountain system resulted from the closure of an ocean basin that separated a North American continent that extended west to the current Alberta-B.C. border, from a slender 'Cordilleran' continent to the west. In this model, the Himalaya are represented by the Rocky Mountains, India by the North American continent, and Asia by a Cordilleran continent that underpins BC and Yukon (Figure 2). The Rockies consist of North American crust pushed back to the east over itself, implying that, like India, North America was attached to an oceanic plate that subducted to the west.

This model makes three testable predictions: (1) North American crust east of the Rockies should be buried beneath kilometres of 'syn-collisional' sediments that were derived from mountains during collision; (2) there should be a 'suture' to the west of the Rockies that marks the site of the closed ocean; and (3) the Cordilleran continental crust to the west of the suture should be different and distinguishable from North American crust to the east. Only one of these predictions is fully borne out. North American crust east of the Rockies is characterized by an immense stack of Late Cretaceous sedimentary strata. Near the mountain front, these clastic (sandstone and mudstone) sedimentary sequences and interbedded coal layers are more than four kilometres thick (Figure 2). They thin to the east, are 'syn-collisional,' and define a large 'foreland basin' similar to the one that is forming south of the Himalaya today. But traversing west through the Rockies looking for a suture of basalts and oceanic deposits has proved fruitless. Because there is no discernable suture, it is debatable whether or not there is a 'Cordilleran' continental domain west of the Rockies that is stratigraphically and geologically distinguishable from truly 'North American' crust to the east (Figure 2). And while paleontological and paleomagnetic data suggest that most of B.C. and Yukon lay 2,000 to 3,000 kilometres south of North America as recently as seventy million years ago, most Cordilleran researchers argue that there is no suture, that 'bona fide' North American crust extends west to or near to the current west coast, and that there was no continental collision.

If there was no continental collision, then why do we have a Cordilleran mountain system at all? Perhaps the answer lies with another mountain system to the south: the Andes. This mountain system, including the Altiplano plateau, is the second-highest mountain system on Earth, next only to the Himalaya/Tibetan plateau. And yet, the Andean (west) margin of South America is characterized by the subduction of an oceanic plate (the Nazca) beneath the continent. There is no 'continental collision' suggesting that mountain systems can be generated by subduction. And yet subduction, because it consists of the gravitational sinking of the oceanic plate, usually results in extension, subsidence, basin development and inundation of the adjacent continental plate – the exact opposite of mountains. So why subduction should give rise to mountain systems at some points in Earth history (the Cordillera in the Cretaceous, and the Andes today) while generally having the opposite effect, remains a major unresolved question in understanding plate tectonics, the workings of the solid Earth, and the deep time evolution of the Earth System.

If there was no continental collision, then why do we have a Cordilleran mountain system at all?

Stephen is the Chair of the Department of Earth and Atmospheric Sciences at the University of Alberta. His research concerns the origins and tectonic significance of mountain belts, both ancient and still forming, of western and Arctic North America, South America, Melanesia, China, southern Africa and Europe.

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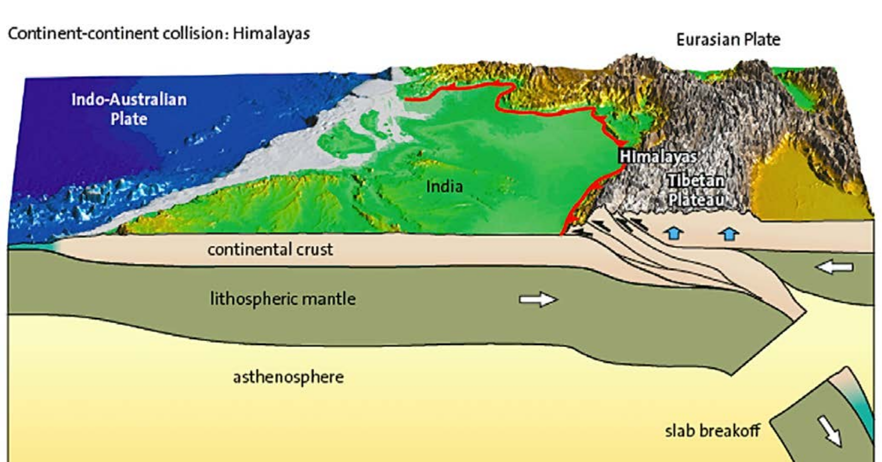

Figure 1. A simplified block model through the Himalaya (after Frisch et al., 2011) viewed looking east (south to left) showing the Himalaya as a product of collision of India with Asia after closure of an ocean that formerly separated the two continents by subduction of the oceanic lithosphere (depicted here as breaking off and sinking into the mantle).

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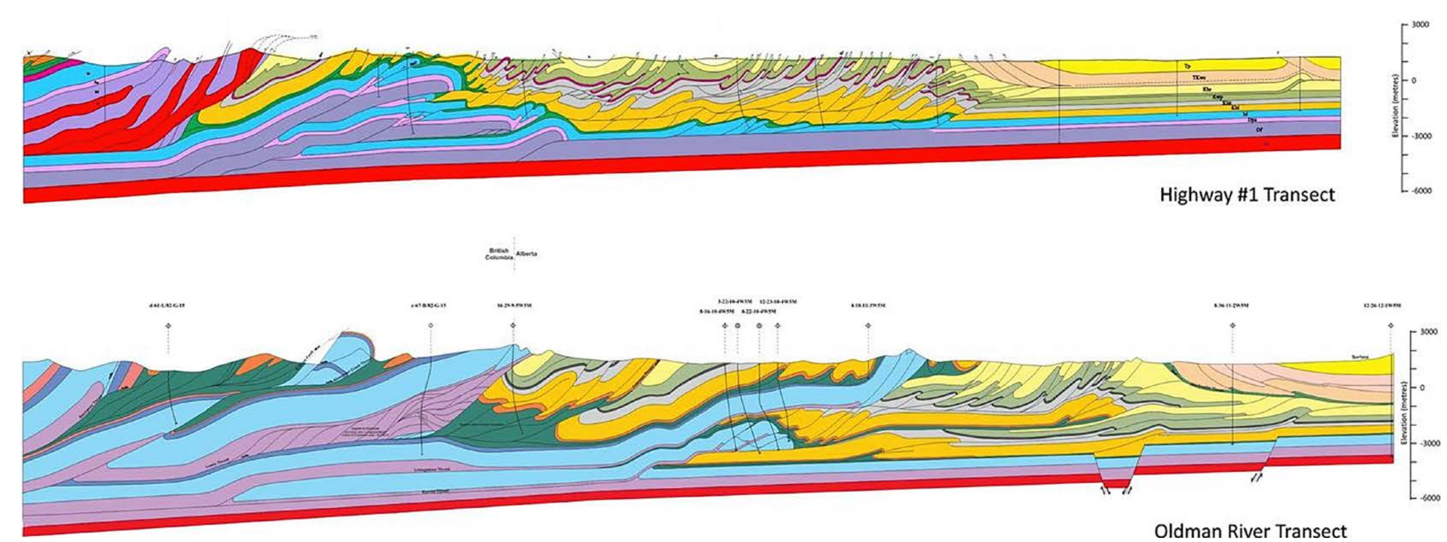

Figure 2. Two cross-sections of the Rocky Mountains (after MacKay, 2015) viewed looking north (west to the left). North American Precambrian basement (in red) is continuous at depth. Overlying Precambrian to Cretaceous sedimentary strata has been faulted, stacked up and pushed eastward. Deformation can be interpreted to have resulted from collision of North America beneath a Cordilleran continent subsequent to closure of an ocean basin separating the two (like the Indian continent colliding with Asia) or as a product of interaction with oceanic lithosphere subducting beneath the west margin of Noth America.

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Dark Frontiers: Exploring Western Canada's Underground

The Crystal Tube, Raspberry Rising. Photo: C. Stenner 2018

John Pollack, Christian Stenner, and Chas Yonge

Modern mountaineers can view mountains and routes in broad daylight, but cave exploration remains a journey into unknown territory. The underground is hidden, and even finding a cave can be a challenge. Searching for new cave systems may require as much effort as exploring them. The western mountain ranges and forests abound with shallow cave entrances and sink holes, but most of these features are plugged with frost-shattered rock and till, and don't "go." It may require years of work to find a route into the "main drain."

Invariably a major cave will expand gradually as each expedition pushes further into new territory.

Once a major cave is found, multiple exploratory trips determine the ultimate depth or length of the passages. Western caves require technical climbing ability – from the top down – as well as specialized exposure gear to deal with the low temperatures. There is also a firm ethic to survey new discoveries and publish maps. Invariably a major cave will expand gradually as each expedition pushes further into new territory. Exploration of some caves – such as the twenty-one-kilometre-long Castleguard Cave – continues after fifty years.

While caving for sport remains a popular pastime in the 1,800 +/- catalogued western caves, Canada has a small and dedicated cadre of "project cavers" who focus on exploration. This tradition dates to 1965, when Dr. Derek Ford's geography students at McMaster University began to explore the karst of the NWT, BC, and Alberta.[1] Ford's team triggered a "golden age of discovery" that continues today. Since then, a handful of caving organizations have formed, and the carbide lamps and cotton coveralls of the 1960s have been replaced with modern exposure suits and high-output headlights. Yet the conditions underground remain unchanged; they range from the uncomfortable to the appalling, with flooded passages, exposed climbs, loose rock, and constrictions. And invariably, the caves get deeper, longer and more difficult.

Recent Discoveries and Records

The pace of discovery has picked up in the last decade. Highlights include Bisaro Anima, currently the deepest cave in Canada at 674 metres, with a depth potential of 900 metres. Discovered in 2012, the cave is amongst fourteen caves and over 150 sinkholes and entrances found on the Bisaro Plateau in southeastern BC.[2] The multi-year project continues with a current length of 6,599 meters, now the seventh longest cave in Canada.[3] Bisaro is notable for its mid-winter, underground camps of up to 8 days duration, and the use of cave diving to push its lower flooded passages.

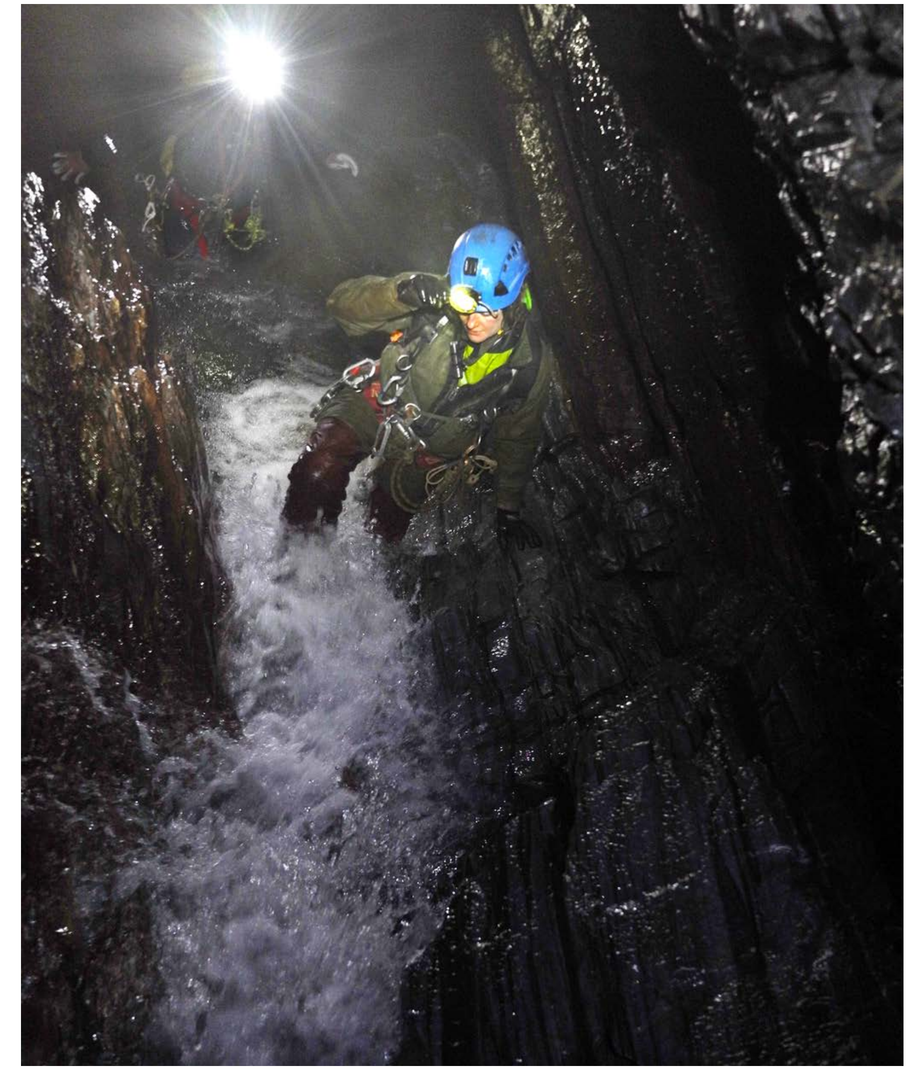
Within Glacier National Park, BC, Raspberry Rising is the longest marble cave in Canada, recently explored to 5,504 metres in length and 219 metres depth. The cave contains incredibly diverse and unique cave formations making it the most decorated example in the country.[4] Unlike most caves that are formed in limestone, Raspberry Rising's folded marble "stripe karst" has sparked the wider exploration of marble outcrops in the Rockies. Exploration of another "stripe karst" cave – White Rabbit – began in 2009, and currently it has 5,350 metres of passages 459-metres deep. The latter cave may connect to other, adjacent caves, with depth potentials of 600-840 metres.[5]

In 2019, a connection was made between two large caves – the Arch/Treasure system (12,080 metres) and Resonance Cave (4,596 metres) – on Vancouver Island via a twenty-six-metre dig through a sediment-filled passage. The resulting ARGO system is now the second longest in Canada at 17,101 metres in length and 400 metres in depth.[6]

An unexpected 2018 find in Wells Gray Provincial Park was a large vertical shaft located during a helicopter caribou survey. An immense 102 x 60-metre pit has formed in marble, swallows a small river, and is one of the largest cave entrances in Canada. The huge passage was explored to a depth of eighty metres, and it continues downward from there, promising perhaps the most spectacular river caving yet seen in Canada.[7]

A Cave Diving Renaissance

Water often fills cave passages and halts exploration – temporarily. Modern Canadian cave diving with open-circuit SCUBA began in the mid-1980s on northern Vancouver Island and in Canada's longest underwater cave, the 6,563-metre Three Island Cave (Ottawa River, Ontario). The introduction of closed-circuit rebreathers revolutionized this extreme exploration method, and significantly increased the range of trained cave divers. The downside of cave diving is large loads of gear, particularly in remote alpine locations. In 2018, one team took more than a week to



Above: Kathleen Graham negotiates a streamway in Raspberry Rising. Photo: J. Habiak 2018

Left: Colin Massey with hammocks at Camp 0.5 in Bisaro Anima cave, 200 m deep. Photo: J. Lavigne 2018

undertake a short solo dive by Kathleen Graham at the bottom of Bisaro Anima, which established the cave as Canada's deepest.[8]

Unquestionably, the most significant cave diving effort was made by Martin Groves, who, in 2009-2010, pushed Boon's Blunder in Castleguard Cave for 845 metres to reach a large, continuing air-filled passage. The breakthrough promises a

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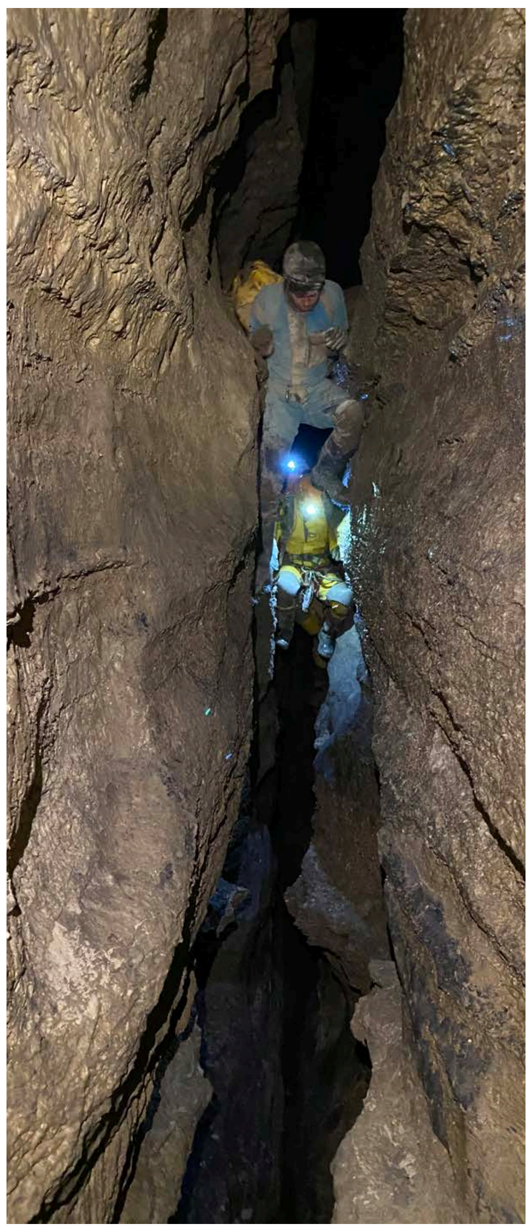

Above: Tammera Kostya, Alyssa Horn, and Chris Coxson at an ice pingo in Castleguard Cave Photo: C. Stenner 2012

Right: Cavers negotiate the Second Fissure, Castleguard Cave. Photo: C. Stenner 2020

Cave exploration is commonly allied with science, notably karst geomorphology, cave biology, and paleontological research.

major extension in Canada's longest cave, but efforts to return have been stymied by ice blockages in the low crawls near the cave entrance.[9]

Other examples include the spectacular find Wet Dream, a 1,710-metre-long underwater cave on northern Vancouver Island. This system was first dived in 2012 and mapped between 2015-17.[10] It lies in the same region as Reappearing River, a large 1,604-metre underground river system that had been pushed hard in 1990 by open-circuit cave divers, and extended by a large team in 2019 to a depth of seventy-seven metres.[11]

A notable 2018 effort, by Jason Richards, was Canada's deepest cave dive at Hole in the Wall Cave NW of Tumbler Ridge, BC, where he reached ninety-four metres in a short, steeply-descending passage.[12]

Cave Science

Cave exploration is commonly allied with science, notably karst geomorphology, cave biology, and paleontological research. The late Chas Yonge, an early collaborator on this essay, pioneered the measurement of fluid inclusions in speleothems (cave formations),[13] methods that have formed the basis for modern cave paleoclimate research. Recent data from speleothems collected from Grotte Valerie in the NWT show a record going back 1.4 million years.[14] Ice caves (caves in rock which contain perennial ice) are sensitive indicators of present-day climatic conditions, as well as archives of past climates. Recent observations have shown that that ice caves in northwestern Canada are losing their perennial ice accumulations at an accelerated rate.[15] Other impacts are also being observed. The ice loss from glaciers and snowfields exposes new terrain, and is responsible for the Wells Gray find. And after nearly fifty years of relative stability, surface meltwater percolating underground and then freezing has made Castleguard Cave, Canada's most famous and longest, inaccessible several times in the last decade.[16] There are other remarkable collaborations resulting from cave exploration. Recently unique extremophile bacteria, with potential as novel treatments against multi-drug resistant infections, have been found in western Canadian caves.[17] Also, dedicated bat biologists have teamed up with cavers to seek solutions for White Nose Syndrome, a disease that has devastated eastern bat populations.[18]

The exploration of Canada's western caves remains a tough and rewarding game pursued by specialized explorers, and it is adding to our knowledge of our geography, climate, and biology. This article mentions a few of the more prominent projects, and there are many others. Canadian cave exploration has carried across three generations, and more discoveries are likely. It is entirely possible that the golden age of discovery will continue for another fifty years.

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Christian Stenner has been a caver for sixteen years, completing expeditions in North America as a member of the Alberta Speleological Society. He is a Fellow of the Royal Canadian Geographical Society and a Fellow International of the Explorers Club. He also serves as Alberta provincial coordinator for the Alberta/British Columbia Cave Rescue Service.

Charles (Chas) Yonge was a legendary Canadian rock climber and creator of bold routes, a strong expeditionary caver, cave scientist and author, who passed away this February during the writing of this essay.

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Above: The great unnamed river cave (people circled) on Upper Ovis Creek, Wells Gray Provincial Park. Photo: J. Pollack 2018

Below: Cave diver in Wet Dream Cave, northern Vancouver Island. Photo: E. Wolpin 2018

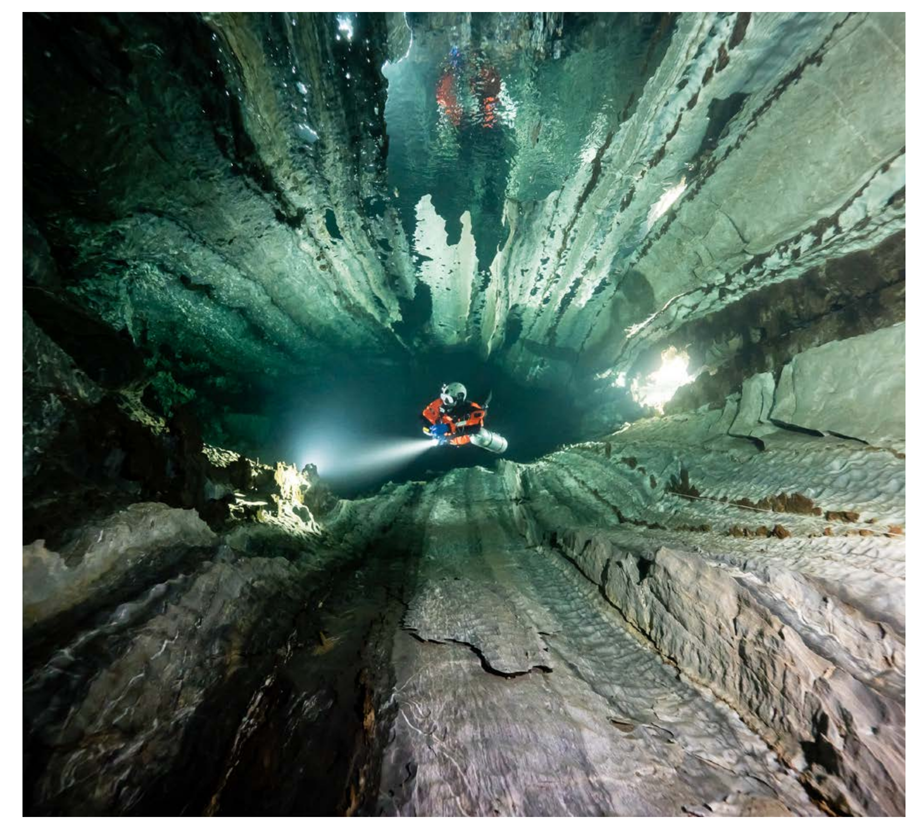

Figure 1. Mount Logan, Yukon (in the background, seen here from the north). The mountain's upper regions have warmed ~1.6 times faster than the global average since the 1970s. Photo: Zac Robinson.

Elevation Dependant Warming in Canada's Saint Elias Mountains

Scott Williamson

The atmosphere in many of the high-elevation mountains on Earth is warming faster than the global average, a phenomenon referred to as Elevation Dependent Warming (EDW).[1] There is growing evidence that EDW is a global phenomenon, supported by both observations and climate modeling studies, and it appears that many of the highest mountain ranges are warming more rapidly than the surrounding lowlands.

Many of the highest mountain ranges are warming more rapidly than the surrounding lowlands.

Mountains are distributed unequally around the globe, with the majority of the highest mountain ranges in the middle latitudes. Until recently it was unknown if EDW was occurring at high latitudes (> 60 N) because there is insufficient monitoring in these remote areas. This gap in our understanding includes the vast Saint Elias Mountains of the Yukon Territory, including Mount Logan (5,959 metres), Canada's highest peak (Figure 1).

To understand how the atmosphere changes the higher you go up a mountain, and the further away you are from the Equator, it is necessary to examine the composition of the troposphere, the lowest layer of the atmosphere. The troposphere contains approximately three-quarters of the atmosphere's mass, and the vast majority of its water vapour. The troposphere is approximately seventeen kilometres thick at the Equator, but only about nine kilometres thick at the poles. This height difference is determined by both the centripetal forces caused by the Earth's spin and differences in air temperature.

Mountain air gets "thinner" the higher you go. This really means that the air is less dense, and that the mass of gasses and water vapour pressing down on the surface is reduced compared to air at sea level. Water vapour decreases with air pressure, but unlike oxygen and other atmospheric gasses, water vapour decreases exponentially with temperature. So, by 3,000 metres, it is cold enough that most water vapour has been removed from the air. From the perspective of the Earth's climate, water vapour is important in regulating temperature because it is a powerful greenhouse gas. At altitudes above 3,000 metres, most of the aerosols in the atmosphere, such as sea salts and black carbon, have settled out. And most of the sunlight-driven convective clouds are found below the summits of high mountain peaks.

We designed an experiment to discover if EDW was present in the highest mountain range in Canada.[2] Several sources of observational data were integrated to construct a detailed understanding of the factors that influence temperature in the Saint Elias Mountains (Figure 2), including meteorological (weather) station measurements to validate downscaled air temperature data. We also investigated the possible drivers of EDW by comparing reanalysis temperature trends with vertical profiles of temperature and water vapour pressure from radiosonde balloons, long term climate information from high-elevation ice cores extracted from the St. Elias Icefield, and satellite measurements of high-elevation albedo (or how intensely sunlight is reflected by the snow).

For the years 1979 to 2016, we found a warming rate of 0.028°C per annum between 5,500 and 6,000 metres and this warming was approximately 1.5 times greater than the warming rate at 2,000 to 2,500 meters (Figure 3). The warming rate at the highest elevations was approximately 1.5°C per annum times greater than the global average warming rate over a similar time period (1970-2015). Warming trends in the St. Elias region appears to be driven by recent warming of the free troposphere. The satellite data showed no evidence for an enhanced snow albedo feedback; declining trends in sulfate aerosols deposited in high elevation ice cores suggested only a modest increase in radiative forcing at these elevations; however, water vapour at the elevation of Mount Logan's summit suggests that a long-wave radiation vapour feedback is contributing to the observed EDW. Therefore, the most compelling explanation for EDW in the Saint Elias is the increase in tropospheric water vapour. Warming rates at high elevation are extremely sensitive to small changes in water vapour when the absolute concentration is extremely low, which is the case in the Saint Elias Mountains at high elevation.

So, the thin air in the Saint Elias is now warmer and moister than it has been in the recent past. And although the air at the summit of Mount Logan still reaches -50°C even in summer, it is warming more rapidly than the lower slopes.

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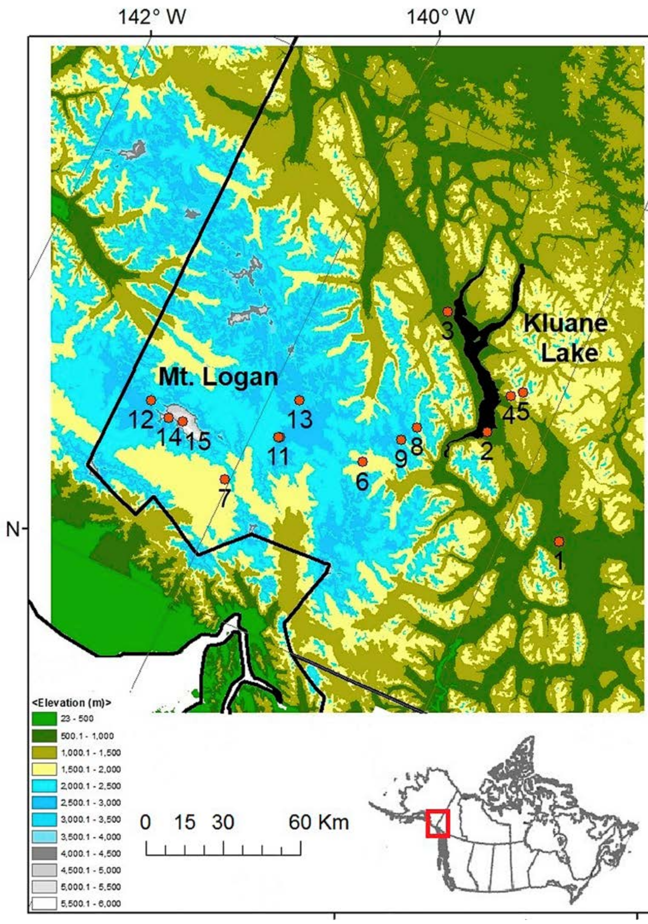
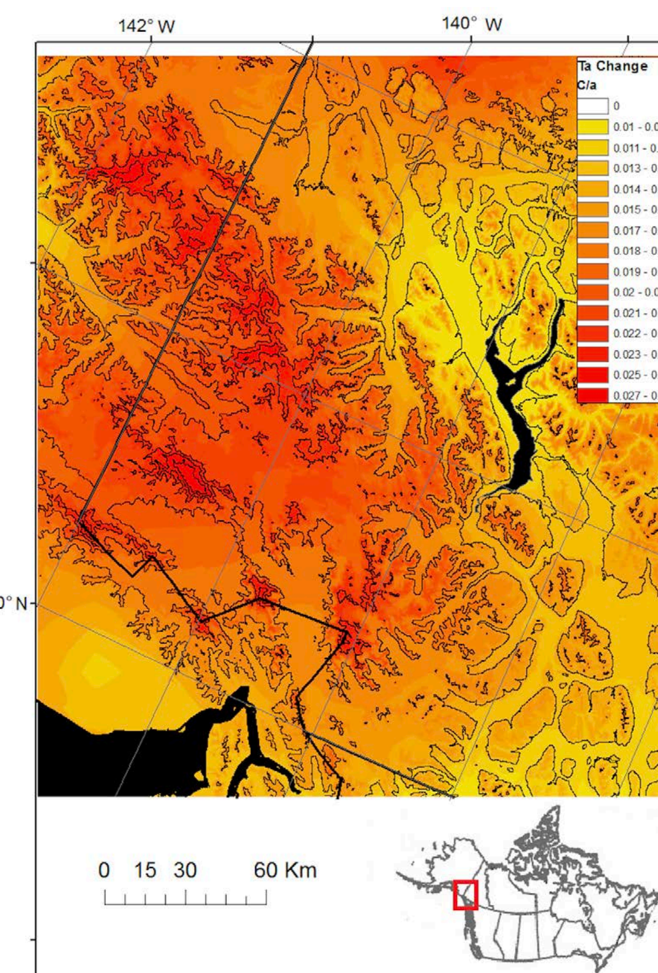


Top: Figure 2. The St. Elias Mountains in southwest Yukon. The numbered red dots are meteorological stations and the colours indicate 500 m elevation bands, from sea level to the top of Mt. Logan (5959 m), and into the Kluane Lake (Lhù'ààn Mân) region east of Kluane National Park.



Right: Figure 3. The spatial distribution of surface warming rates (°C per year) between 1979 and 2016 in the southwest Yukon. Warming rates above 3000 m (red shades) are statistically significant at the $p < 0.05$ level.

Observations and Modelling of Glacier Mass Changes in Western Canada

The lower Athabasca Glacier, Jasper National Park. Photo: Kurt Morosson

Valentina Radić

The retreat of mountain glaciers worldwide is a key indicator of modern climate change, with mass loss from glaciers contributing to sea level rise and to river flows during dry and warm parts of the year. In western Canada, maintenance of low flows by glacier meltwater is essential for maintaining biodiversity, hydro-power generation, agricultural irrigation, and water supply for major cities and small towns. The coming decades will see rapid and unprecedented changes to glaciers in western Canada. However, current projections are unable to resolve with certainty how individual river basins will be impacted by the loss of glacier ice in their headwaters.

The western provinces of British Columbia and Alberta together contain more than 15,000 mountain glaciers

Glaciers are one of Canada's important natural resources, serving as frozen reservoirs of water that supplement runoff in late spring, summer, and early autumn during periods of low river flow. The western provinces of British Columbia and Alberta together contain more than 15,000 mountain glaciers, totalling roughly 29,000 square-kilometres of glaciation (Figure 1). Estimates based on remote sensing indicate that glaciers in B.C. and Alberta have lost about eleven percent and twenty-five percent of their area, respectively, over the period of 1985-2005. The thinning rate of these glaciers, however, has not been constant in recent times. The earliest estimate based on remote sensing methods reveals a thinning rate of about 78 (±19) centimetres a year between 1985-1999, while the most recent study reports a slowing during 2000-2009, followed by an increase for 2009-2018. The largest increase (by twenty percent) in the rate of ice thinning relative to 1985-1999 is reported for the Coast Mountains of B.C. (sub-regions 3-5 in Figure 1). This volume is comparable to the loss of one large Himalayan glacier annually! It is still unknown what has driven the variable rate in glacier mass loss over the last four decades: whether it is the natural climate variability known to affect glacier mass balance along the west coast of North America, stochastic variability, or whether these recent changes are related to anthropogenic climate change.

Over the last decade, glacier models of different complexity have simulated future mass changes on global and regional scales in response to climate scenarios from Global Climate Models (GCMs). But despite differences in their structure and calibration, all the models agree that glaciers in western Canada and United States (without Alaska) will lose more than fifty percent of their current mass by the end of the century (Figure 2). A model, developed by coupling physics-based ice dynamics with a surface mass balance model, has projected the fate of glaciers in western Canada in response to the climate scenarios from an ensemble of Global Change Models. The results indicate that, by 2100, the volume of glacier ice will shrink by seventy percent (± ten percent) relative to 2005. According to these simulations, few glaciers will remain in the interior of western Canada and the Rockies (sub-regions 6-10 in Figure 1), but maritime glaciers, in particular those in northwestern B.C. (sub-regions 1-2 in Figure 1), will survive, but in a diminished state. The model also projects the maximum rate of ice volume loss, corresponding to peak contribution of meltwater to streams and rivers, to occur around 2020-2040. The resulting decrease in late summer streamflow, as glaciers keep diminishing from the watersheds, will have large implications for aquatic ecosystems, agriculture, forestry, alpine tourism, and water quality.

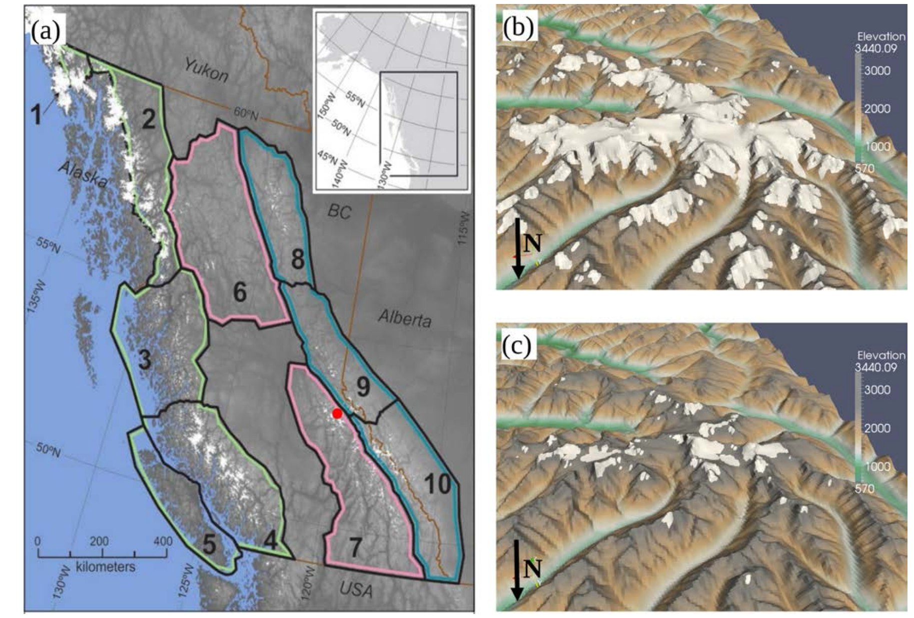


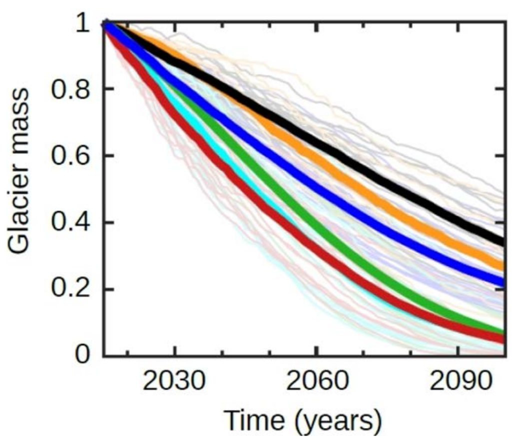
Figure 1. From Clarke et al. (2015): (a) Glacierized sub-regions in Western Canada used in the modelling study: Coast (1- St Elias, 2 - Northern Coast, 3 - Central Coast, 4 - Southern Coast, 5 - Vancouver Island; Interior (6 - Northern Interior, 7 - Southern Interior), and Rockies (8 - Northern Rockies, 9 - Central Rockies, 10 - Southern Rockies). Glacier extent from 2005 is indicated in white. Red dot in region 7 indicates the area in Caribou Mountain Range, for which the modelled glacier extent is shown for (b) year 2020 and (c) year 2100, in response to climate scenario from a global climate model.

Despite the recent substantial progress in large-scale measurements and modelling of glacier mass changes, large uncertainties remain in the projections of glacier mass loss. The global climate signal needs to be translated into a local one (a process known as "down-scaling") in order to resolve processes that drive the mass gain (e.g. snowfall) and mass loss (e.g. surface melting) at a scale of individual glaciers in the region. All current models rely on relatively simple statistical downscaling methods that have limited applicability since

The results indicate that, by 2100, the volume of glacier ice will shrink by seventy percent (± ten percent) relative to 2005

Left: Eyebrow Peak, Purcell Mountains, 2015. Photo: Zac Robinson

Top: The Shackleton Glacier, Rocky Mountains, 2010. Photo: Zac Robinson



Middle: Figure 2. From Hock et al. (2015): Projected time series of glacier mass 2015–2100 for Western Canada and United Stated (without Alaska) based on six glacier models, each one using RCP8.5 emission scenario (the most extreme scenario in terms of future emissions of greenhouse gases) and an ensemble of Global Climate Models (GCMs). Glacier mass is normalized to mass in 2015. Thick lines show multi-GCM means for each glacier model (each glacier model has different color) and thin lines mark the results from individual GCMs.

Bottom: Figure 3. Automated weather station with glacio-meteorological sensors that measure all components of surface energy balance, installed at Nordic glacier in the Rockies in summer 2014. Photo: Noel Fitzpatrick

they require observations from weather stations installed at glacier surfaces. Fewer than one percent of glaciers worldwide, including only a handful of glaciers in western Canada, have these necessary measurements (an example of a weather station installed at a glacier surface is shown in Figure 3). The lack of meteorological observations at glaciers also presents an impediment for a development of physics-based models of glacier melt to be successfully applied on regional and global scales. These models attempt to account for all components of surface energy balance (e.g. incoming solar radiation, longwave radiation, and turbulent heat fluxes), which contribute to the energy available for melt. The poorly constrained parameters in empirical models based on observational data can lead to large uncertainties in the projections of glacier mass loss and their contribution to streamflow, especially at local scales. Resolving the uncertainties and providing more accurate estimates about the future of glacier-fed water resources will be relevant to local policymakers and user communities, and improvements in all these areas of modelling and observations are needed.

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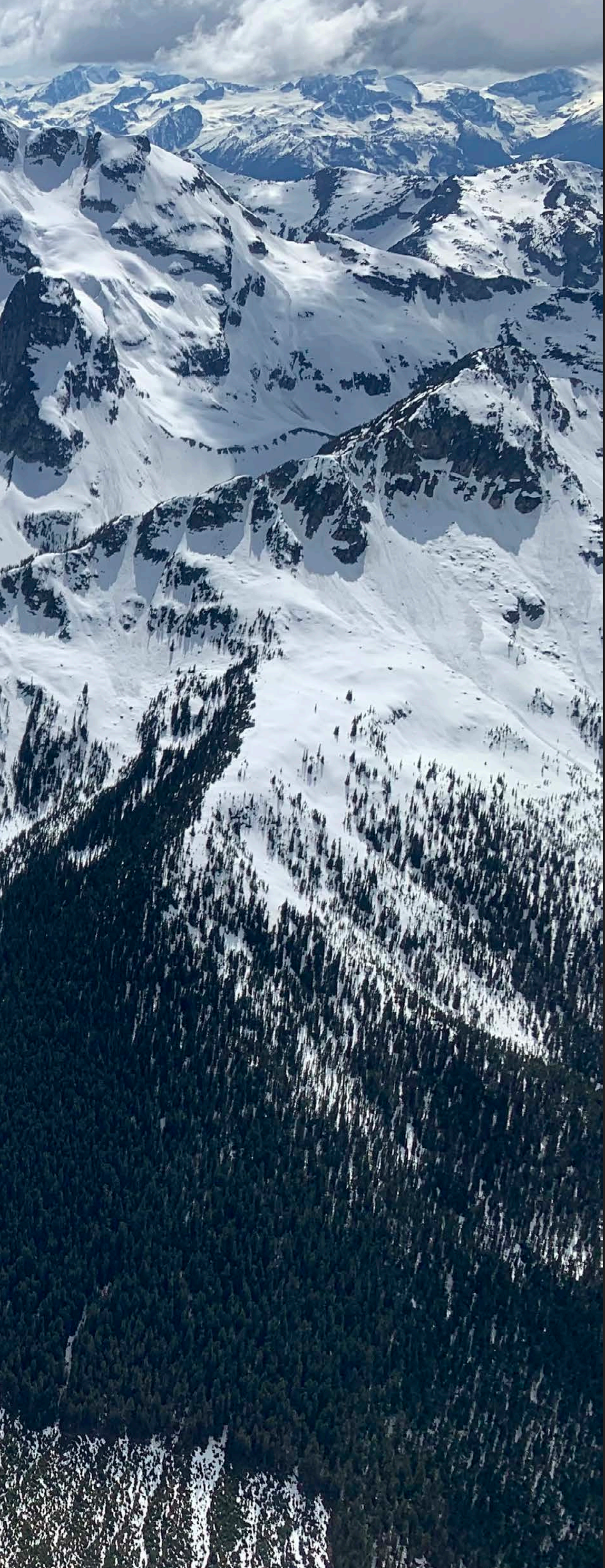
Participants and staff at the ACC's 2019 Westfall General Mountaineering Camp in the Selkirk Mountains. Photo: Zac Robinson



The State of the Mountains Report

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

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