Regional Environmental Change (2025) 25:25
https://doi.org/10.1007/s10113-025-02368-y

ORIGINAL ARTICLE

Climate change vulnerability and adaptation among mountain guides in the Canadian Rockies

Katherine Hanly[1] · Graham McDowell[2]

Received: 14 June 2024 / Accepted: 8 December 2024

Abstract
This study characterizes the vulnerability of mountain guides to climate change in the Canadian Rockies. Using semi-structured interviews ($n=30$) and one focus group ($n=4$ participants) with guides in the region, we assess the extent to which guides have observed climate-related cryospheric changes, evaluate the relevance of these changes to their guiding practices, and examine their responses. Findings demonstrate that all guides observed climate-related changes in the cryosphere of the Canadian Rockies, including glacier recession, the diminishment of snowpacks and alpine ice, changes in waterfall ice conditions, and permafrost degradation. Guides are sensitive to these exposures because they have contributed to an increase in hazards, altered route character and access, and shortened the guiding seasons. Sensitivity varied according to guides' subjective assessment of the change, it's relevance to their guiding practice, and livelihood characteristics. In response, guides have adapted using substitutions, investing more time in research and planning, and adjusting their practices and equipment. However, we found that individual adaptability was determined by social factors (e.g., training, years of experience) that created varied adaptive barriers, leading to differentiated experiences of climate change. We examine the consequences of these impediments and discuss potential strategies for reducing or eliminating them in a mountain guiding context. This study offers insights for the development of interventions aimed at enhancing the resilience of mountain guiding communities in the face of evolving environmental challenges, and provides a benchmark for tracking lived experiences of climate change among mountain guides in the Canadian Rockies.

Keywords Climate change · Vulnerability · Adaptation · Mountain guides · Canadian Rockies

Introduction

Mountain guides play a unique and important role in facilitating connections with high mountain regions by offering expert assistance to individuals or groups engaged in mountain-based activities (e.g., climbing, mountaineering, hiking, skiing). While the profession has always required guides to operate in challenging mountain conditions, today guides are facing increasing pressures associated with the transformative effects of climate change on mountain environments, including glacier recession, alterations in the alpine snowpack, and permafrost degradation (Adler et al. 2022; Hock et al. 2019). Such changes are altering conditions for mountaineering (Hanly et al. 2023; Hanly & McDowell 2024; Purdie & Kerr 2018; Salim et al. 2023), ice climbing (Voorhis et al. 2023), and skiing (Burakowski et al. 2022; Scott et al. 2020; Steiger et al. 2022); have shifted the seasonality of mountain-based activities (Pröbstl-Haider et al. 2020; Salim et al. 2023); and have increased hazards associated with mountain environments (Gruber & Haeberli 2007; Mourey et al. 2022; Purdie et al. 2015; Ravanel et al. 2017; Ravanel & Deline 2011; Temme 2015). In response to these pressures, guides are adapting through substitution strategies (spatial, temporal, activity-based), dedicating more time to trip planning, and cultivating "climatic intelligence"—the ability to adjust climbing techniques and route selection in response to rapidly

Communicated by Wolfgang Cramer

✉ Katherine Hanly
khanly@ucalgary.ca

Graham McDowell
graham@y2y.net

1 Department of Geography, University of Calgary, 2500 University Drive N.W, Calgary, AB T2N 1N4, Canada

2 Yellowstone to Yukon Conservation Initiative (Y2Y), 200-1350 Railway Ave, Canmore, AB T1W 1P6, Canada

Published online: 28 January 2025

changing environmental conditions (e.g., Bourdeau 2014; Mourey et al. 2020; Rushton and Rutty 2023; Salim et al. 2019).

Despite relatively consistent climate-related changes in the cryosphere across high mountain regions, diverse socio-economic, cultural, and political conditions influence guides' adaptation, leading to varied experiences of climatic change. For example, in the European Alps, client's reluctance to adapt their plans in response to adverse conditions can create adaptive barriers for mountain guides. This is particularly true for guides working in destinations that attract one-time visitors, such as international tourists, as they have limited opportunities to climb a specific route during their visit (Mourey et al. 2020; Salim et al. 2019). In the Canadian Rockies, barriers are often shaped by livelihood characteristics which produce diverse vulnerability across guides' career stages (Hanly et al. 2023; Hanly and McDowell 2024). Research regarding how social conditions lead to differentiated experiences of similar climatic changes for mountain guides is growing in European contexts. However, it remains limited in Canada, constraining efforts to understand and address guides' vulnerability to climate change in this region. This is a concerning deficit as mountain guides in Canada have been instrumental in igniting interest in and providing access to high mountain terrain, have cultivated a rich culture around mountain landscapes and mountain pursuits, and have left a lasting legacy of physical infrastructure (e.g., trail systems, alpine huts) and mountain-focused institutions (e.g., Association of Mountain Guides (ACMG)) (Spaar 2010). Today, Canadian mountain guides maintain and grow this legacy by facilitating memorable mountain experiences in ways that embody high standards of safety and professionalism. However, these experiences are increasingly contested by the climate crisis, which poses potentially substantial and consequential challenges for mountain guides in this region.

In response, this study builds on previous Canadian case study work (e.g., Hanly et al. 2023; Hanly and McDowell 2024) by providing the first regional analysis of guides' vulnerability to climate change in the Canadian Rockies, focusing on activities that rely on the mountain cryosphere. Using a contextual vulnerability approach, this study aims to determine causes and consequences of differentiated vulnerability to climate change among mountain guides by identifying climate-related exposures in the region, the implications of these changes for mountain guiding activities, and guides' adaptability to professionally relevant changes. In doing so, the study contributes to a growing body of literature on the human dimensions of cryospheric change in mountain regions (e.g., Carey et al. 2017; Hanly et al. 2023; McDowell et al. 2012, 2021) and provides practical insights that support targeted adaptation strategies capable of addressing differentiated experiences of climate change.

Case study region and context

Situated in western Canada, the Canadian Rockies have been and continue to be homelands for numerous Indigenous Peoples, who have inhabited the region since time immemorial (McDowell et al. 2023). More recently, in recognition of the region's natural beauty and ecological importance, it was designated a UNESCO World Heritage Site. It also contains prominent National Parks including Banff, Jasper, Yoho, and Kootenay. High altitudes in the region experience Subalpine and Alpine climates (Köppen 1936), with cold and snowy winters that support skiing and ice-climbing while cool and dry summers provide favorable conditions for mountaineering activities. Alpine huts, most of which are managed by the Alpine Club of Canada (ACC), are scattered throughout the range and offer shelter and basic provisions to those pursuing such activities. Peaks along the 4800-km-long mountain range vary from 2000 to 3954 m (e.g., Mt Robson) and are primarily composed of sedimentary rock, the loose nature of which can create challenging travel conditions (Gadd 1999). The region also hosts numerous glaciers (e.g., Athabasca Glacier, Peyto Glacier) and icefields (e.g., Columbia Icefield) as well as sporadic and discontinuous permafrost (*ibidi.*). However, climate change is contributing to the rapid retreat and thaw of these components of the mountain cryosphere, altering travel conditions, increasing mountain hazards, and threatening alpine infrastructure (Hanly et al. 2023; Hanly and McDowell 2024) (Fig. 1).

Mountain guides have historic and contemporary importance in the socio-economic landscape of the Canadian Rockies. In 1897, the arrival of Swiss mountain guides marked a pivotal moment in Canada's mountain history (Stutfield 1903), sparking widespread interest in mountain exploration and facilitating access to mountain landscapes (Spaar 2010). The subsequent rise in popularity and demand for skilled guides led European guides, Hans Gmoser, Walter Perren, and colleagues, to form the ACMG in 1963 (Martel 2013). The ACMG is the professional organization of mountain guides in Canada that provides training and assessment programs for aspirant guides, including hiking, skiing, rock, and alpine guiding (*The ACMG—Who We Are*, n.d.). Candidates who complete training and assessment program(s) are eligible to become ACMG members under the respective designation(s). The focus of this study is on guides who work in the mountain cryosphere, including ski guides who specialize in ski touring, ski mountaineering, and helicopter/snowcat ski guiding; alpine guides who specialize in alpine, rock, and waterfall ice climbing, and mountain guides who have designations in rock, alpine,

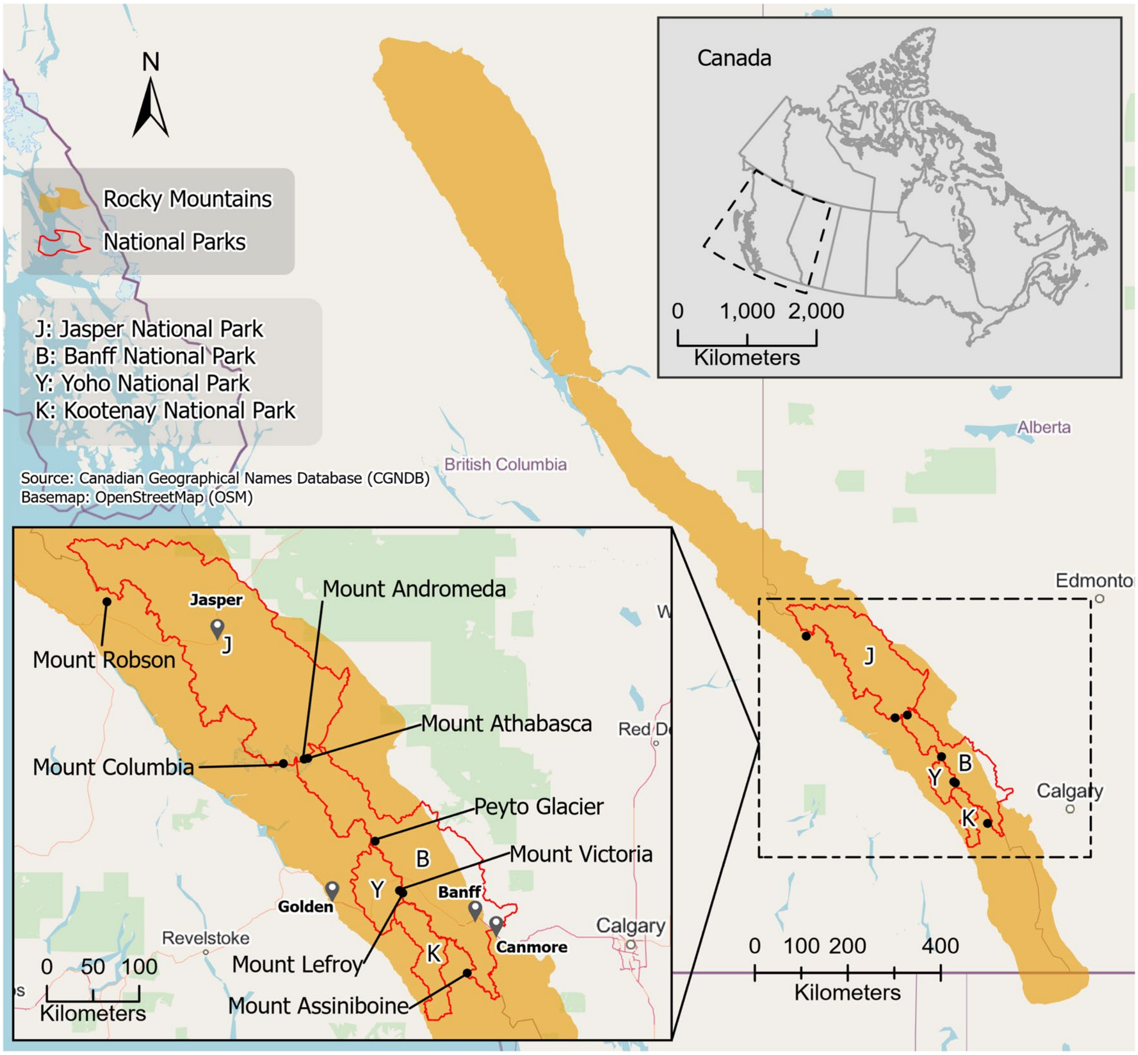

Fig. 1 Map of Canada and the Canadian Rockies, the extent of which are highlighted

and ski guiding (*ibid.*). The number of guides who have passed through this program is growing, increasing by nearly 30% between 2017 and 2022. Most guides work as ski (37%) and mountain (27%) guides; few work exclusively as alpine guides (3%) (Dumba 2021). A notable proportion of these guides establish their homes and livelihoods in the Canadian Rockies evident in the numerous guiding services based in and immediately surrounding the region. These include Yamnuska Guiding Services, one of the oldest and most well-known guiding outfits in Canada; Canadian Mountain Holidays (CMH), the first and largest heli-skiing operation in the world; countless smaller-scale operations including Cloud Nine, Ridgeline Guiding, Arise Mountain Guiding, OnTop Mountaineering, CanRock, and Canadian Rockies Alpine Guides; and the ACC, which has been at the forefront of promoting and employing guides since its establishment in 1906. For such reasons, the Canadian Rockies are recognized as one of the world's preeminent mountain recreation destinations as well as the home of numerous world-renowned mountain guides and mountain guiding organizations.

Research approach

Contextual vulnerability approach

This study uses a contextual vulnerability approach to evaluate guides lived experiences of climate change in the Canadian Rockies. Vulnerability research has undergone conceptual and methodological transformations over the years, producing disciplinary interpretations and critiques that can be classifed into impacts-driven and contextual vulnerability (O'Brien et al. 2007). Impacts-driven approaches conceptualize vulnerability as an outcome of exposure to climatic stimuli and therefore focus on the effects of climate change *on* society (Ford et al. 2010; O'Brien et al. 2007). However, contemporary work on the human dimensions of climate change demonstrates that experiences of climate change are largely determined by social rather than climatic factors. As a result, impacts-driven approaches can obscure the underlying conditions that shape people's lived experiences of climate change (Bassett and Fogelman 2013).

Contextual approaches conceptualize vulnerability as a pre-existing condition *of* society and seek to understand experiences of climate change by examining the relationship between exposure, sensitivity, and adaptive capacity (Smit and Wandel 2006). Exposure refers to the nature and magnitude of climate-related stresses, sensitivity refers the relevance of these stresses for the system, and adaptive capacity refers to the capability of a system to respond in a manner that reduces harm or capitalizes on new opportunities (Adger 2006). This approach reveals how socio-economic, cultural, and political factors interact across time and space to shape diverse experiences of climate change (Ribot 2010), and therefore provides a more nuanced theoretical foundation for understanding the human–environment dynamics shaping guides' experiences of climate change in the Canadian Rockies.

Methodology

To assess guides' vulnerability, this study used semi-structured interviews and a focus group to explore their exposure, sensitivity, and adaptive responses to climate-related change in the Canadian Rockies, consistent with prior work focused on the nexus of climate change and mountain guiding (e.g., Hanly et al. 2023; Mourey et al. 2020; Purdie and Kerr 2018; Salim et al. 2019; Voorhis et al. 2023). Study participants were ACMG guides working in the Canadian Rockies. These individuals were identified through the ACMG website; those that agreed to participate were asked to take part in an interview lasting between 45 min and an hour. The interviews were conducted using a questionnaire that focused on demographics, observations, experiences, and responses to climatic change in the the Canadian Rockies, as well as guides' perceptions about the outlook for the moutain guiding industry in the region. Following the questionnaire, a period of open discussion with individual respondents aimed to explore in greater detail the specific topics mentioned during the interview. With consent, audio from all interviews was digitally recorded, transcribed, and imported into NVivo (version 14.24.1), a software designed to organize, analyze, and identify insights in qualitative data.

Interviews ($n=30$) were conducted between March 13 and June 11, 2023. Most participants were male (90%), a gender bias that is consistent with the Canadian guiding community (Reimer 2019). The average age was 50 years old, which exceeds the Canadian average (*ibid.*). Almost all (90%) had a full certificate in at least one guiding stream, with the majority being mountain guides (69%), followed by ski (21%) and alpine guides (10%). Apprentice guides, guides who have finished the initial phase of training and worked under the supervision of a certified guide, composed 10% of the sample population and were all apprentice alpine guides. The sample skews toward mountain guides and those who are fully certified. This is because early-career guides were more likely to decline participation, citing a lack of confidence in their observations due to their limited career experience (achieving full mountain guide certification requires substantial time and expertise, which early-career guides may not yet have attained). Furthermore, the majority of guides (67%) held multiple roles, often working as independent contractors, affiliated with a larger guiding organization, and/or in positions outside guiding, such as serving as Mountain Rescue Specialists for the federal government. In contrast, 33% worked exclusively in one of these capacities.

Summary statistics were calculated for responses to structured questions to provide insights into the extent of changes in the mountain cryosphere, when these were observed (i.e., spring, summer, fall, winter months), and the frequency with which individuals experienced and responded to these changes. Open-answer responses and content from post-questionnaire discussions were examined using content analysis (Payne and Payne 2004). Guide's responses were deductively coded according to their exposure, sensitivity, and the adaptations they used (Table 1). These data was analyzed qualitatively, by grouping similar codes to form themes and identify patterns or trends, providing greater insight into guide's vulnerability to climate change.

Following the completion of structured interviews, a focus group was conducted on October 1, 2023. The focus group included four guides from the interview sample who were selected based on their expertise, experience, and willingness to participate. The focus group participants ($n=4$) were on average 57 years old (range 52–70) and all identified as male. All participants were mountain guides and had spent on average, 33 years guiding in the Canadian Rockies. Within the participant group, two guides worked exclusively for larger guiding operations, one owned a guiding company, and another worked for both a larger guiding operation and their own company concurrently. The composition of the focus group was on average, older, more experienced, and had more training than the ACMG community (Reimer 2019). Although the underrepresentation of early-career guides is a notable limitation in our research protocol and results, the bias toward more experienced guides offers a unique advantage. This bias allows for longer-term insights

Table 1 Table of deductive codes used to guide qualitative analysis, informed by contextual vulnerability theory (Adger 2006)

Theme	NVivo codes	Description
Exposure	Glacier retreat and/or down wasting	Withdrawal of a glacier's terminus and thinning due to melting and reduced accumulation
	Alpine ice loss	Reduction in semi-permanent ice formed by pressure sintering or recrystallization of snow
	Changes in snowpack	Variation in the amount, timing, extent, and duration of snow accumulation and melt in mountainous regions
	Changes in waterfall ice	Variation in the formation, its timing, duration of ice, and quality (i.e., brittle, plastic, wet)
	Permafrost thaw	Subsurface thermal phenomenon observable via its manifestations (e.g., rockfall, landslides)
Sensitivity	Change in objective hazards	Alterations in risk posed by the physical environment (e.g., rockfall, avalanche) that can cause injury or damage to people, equipment, or infrastructure
	Alterations in guiding season	Change in the timing or duration of a period when guided activities (i.e., mountaineering, backcountry skiing, waterfall ice climbing) are offered
	Modification of route character	Change in the fundamental characteristics or qualities of a previously established route, such as terrain type, difficulty level, and exposure to hazards
	Change in access	Modification in guide's ability to enter and/or use terrain due to environmental, regulatory, and/or infrastructure changes
Adaptation	Substitution behavior	Adaptation strategy that occurs when the original plan becomes unfeasible and guides must adapt by altering when, where, or how they travel through terrain
	Increased time spent planning	Increased duration and effort dedicated to preparing for excursions due to the unpredictability of weather, shifting terrain conditions, and the need for enhanced safety measures
	Modification to technical guiding practices	Changes made to established guiding protocols or procedures to improve efficiency, effectiveness, or adaptability
	Equipment modification	Alterations in the gear brought while guiding clients to improve efficiency, effectiveness, or adaptability
Adaptive capacity	Differentiating characteristics	Industry level characteristics that influence guide's degree of exposure-sensitivity and their ability to adapt to climate change (e.g., specialization, experience, employment model)
	Barriers to adaptation	Institutional or social constraints that can be addressed to reduce vulnerability to climate change
	Limitations of adaptation	Thresholds beyond which adaptation becomes extremely limited or impossible, resulting in vulnerabilities that can have an effect on guide's identity, well-being, and livelihoods
	Vulnerability	Opportunities to overcome barriers to adaptation

into observed cryospheric changes that less experienced guides may not yet be able to provide. This gathering aimed to validate and build upon insights derived from individual interviews, and to identify priority concerns within the mountain guiding community. This involved 3 h of discussion organized around observations, experiences, and responses to climate change as well as conversations about the future of guiding in the region, which focused on strategies for overcoming adaptive barriers. Insights from the focus group were triangulated with interview data to corroborate results, elaborate understanding of study themes, and identify further insights not captured in the interview process.

Results

Guides' observations of climate change in the Canadian Rockies

Guide's observations of change throughout their careers (22-year average) indicate climate change has dramatically influenced the mountain cryosphere of the Canadian Rockies, through glacier recession and down wasting, the diminishment of snowpacks and alpine ice, changes in waterfall ice conditions, and permafrost degradation. Significant glacier retreat and down wasting was reported by all of guides, all of whom noted increases in glacial forefields and rising firn lines. The majority also observed heightened rockfall frequency (97%), a shift in glacier slope gradients (97%), alterations in crevasse patterns (90%)—including unpredictability, disappearance, and increased density— the emergence of new lakes (87%), increased moraine instabilities (74%), and an increase in debris on glacier surfaces (74%). In addition, all guides reported a reduction of alpine ice throughout their careers, including an increase in rockfall frequency (97%), the progressive thinning of alpine ice (87%), and increased exposure of underlying rock (83%) as well as ice (68%). All guides reported that changes in both glaciers and alpine ice are most apparent between June and August.

Guides also identified year-round change in the mountain snowpack. Most guides (90%) stated that the rate of seasonal snow melt has increased between April and June, decreasing snow cover throughout July and August. Fewer guides (59%) observed change between November and March. Changes include a decrease in snow depth (47%) and an increase in variability (26%), throughout the winter (e.g., longer snow droughts, more intense snowfalls, more rain on snow events) and between winters (e.g., increased variability in deep and shallow snow years).

Comparatively few guides (25%) identified change in waterfall ice, which is a common feature of the region between late October and early March. Guides reported that some features no longer reliably form (15%) and climbing conditions are increasingly variable (10%), including more frequent fluctuations in ice thickness and quality (i.e., plastic, brittle, wet). Guides attributed these changes to observed increases in temperature, decreasing the number of days with temperatures below freezing. Alterations in formation and variability of conditions were also believed to be related to decreases in summer/fall precipitation, which can reduce the amount of water available for ice formation.

Permafrost thaw is a subsurface phenomenon, observed through its surface effects such as rockfall and landslides. About a third of guides (30%) explicitly stated observing phenomenon consistent with permafrost thaw, all of which were reported in July and August. The most common observations include increases in rockfall frequency, encounters with unstable slopes, and the presence of water in unexpected locations. Given limits of direct observation of permafrost and the confounding effects of glacier retreat, alpine ice loss, and changes in the snowpack, the results presented here could underrepresent the extent of permafrost thaw in the Canadian Rockies and its attendant impacts on guiding activities.

Guides' sensitivity climate change in the Canadian Rockies

All guides experienced sensitivity to climate-related change in the mountain cryosphere. However, the degree of sensitivity they experienced to each exposure (i.e., glaciers, alpine ice, snow, waterfall ice, permafrost) varied according to guide's subjective assessment of how significantly each had changed, its relevance to their guiding practice, and livelihood characteristics, notably the activities they guide (i.e., mountaineering, backcountry skiing, and waterfall ice climbing) (Fig. 2).

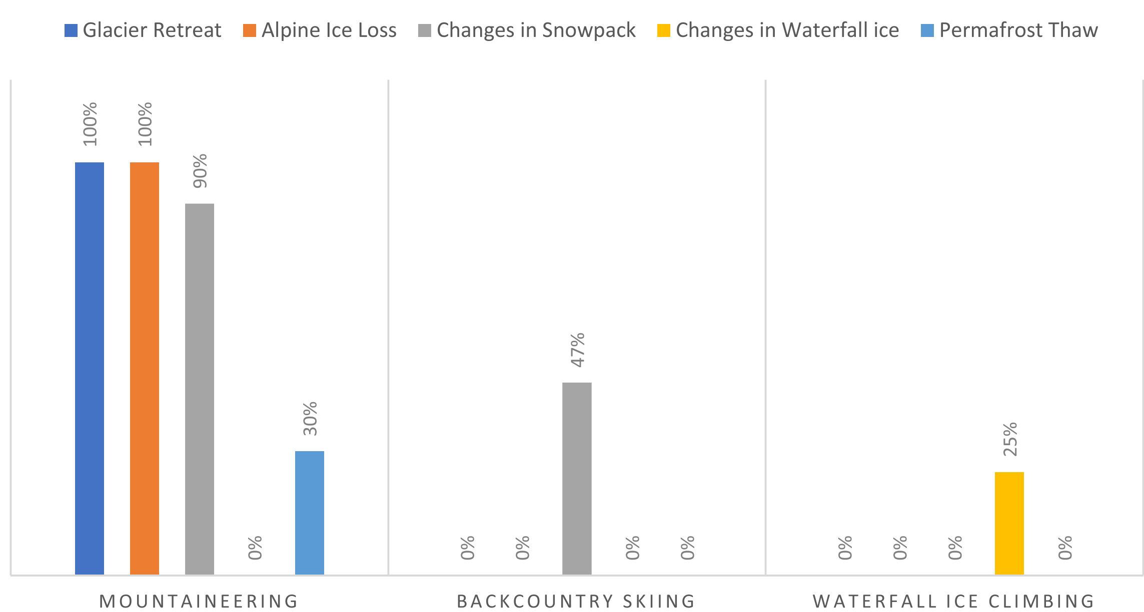

Fig. 2 Percentage of guides who stated that their observations of climate-related exposures were of relevance to mountaineering, skiing, and ice climbing activities

Mountaineering

All guides offering mountaineering services, which include general mountaineering and ski mountaineering, reported being affected by glacier retreat and alpine ice changes. Mountain snowpack changes impacted 90% of guides, and permafrost thaw affected 30%. Guides are sensitive to these cryospheric changes because they have increased objective hazards, altered route character, changed access, and constricted the guiding season.

The most frequently reported intensification of objective hazards included increases in diurnal and seasonal rockfall frequency, changes in crevasse patterns, and alterations in slope gradients. Guides reported that glacier and alpine ice loss exposed underlying debris-laden terrain, creating new rockfall zones on slopes. Furthermore, where the terrain was stabilized by permafrost, some guides reported that the loss of overlying ice can initiate thaw processes further amplifying rockfall and creating slope instabilities (e.g., retreat of the Upper Victoria Glacier at Abbot Pass, Banff National Park). Glacier down wasting was reported to increase crevassing on glaciers with steep underlying terrain. This can intensify fall hazards, which are amplified by delays in, and rapid melt of, seasonal snow accumulation (i.e., weak snow bridges). Increases in glacier slope gradients can also exert greater stress on the snowpack, increasing the likelihood of avalanches throughout the guiding season. Changes in hazards were felt most acutely by guides while mountaineering in July and August and to a lesser extent while ski mountaineering in January (start of season) and May (end of season).

Moreover, since many mountaineering routes (e.g., Skyladder on Mt Andromeda, Jasper National Park) were originally established on glacier or alpine ice, the loss of these mediums can alter the route's character. Guides are increasingly climbing on newly exposed rock instead of ice, which raises route technicality and limits options for secure protection. This shift enhances dependence on seasonal snow, transforming alpine ice routes into snow climbs (e.g., Mt. Lefroy, Banff National Park), which require distinct climbing techniques. Similar changes were reported to affect ski mountaineering; however, the impact appears to be less significant. This is because ski mountaineering, which relies on seasonal snow, occurs in late winter and early spring when snow coverage is typically more abundant, preserving the original character of routes.

Glacier retreat and down wasting has also affected access, increasing the distance to glacier toes and changing the terrain that guides and their clients must travel through. Crevasses and bergschrunds are opening increasingly early in the season and growing in width and length (e.g., North summit of Victoria via the Vic-Collier col), moraines are increasingly unstable (e.g., Mt Athabasca glacier forefield), and new supra- and proglacial streams and lakes are emerging (e.g., Peyto Glacier, Banff National Park). Such changes have rendered an expanding number of routes and summits inaccessible earlier in the year. Again, impacts were most acutely felt while mountaineering in July and August. Ski mountaineering was less impacted, in part, due to the cooler temperatures associated with winter which can improve travel conditions (i.e., more snow coverage) and stabilize the terrain.

The cumulative effect of these changes is a constriction of guides' mountaineering and ski mountaineering seasons. Glacier and alpine ice loss has reduced and altered the medium upon which routes are climbed/skied, increasing these activities reliance on seasonal snow. However, seasonal snow accumulation is increasingly delayed and melting increasingly early in the year. This has advanced the mountaineering season, causing it to commence and conclude earlier in the year before the seasonal snow melts away. For ski mountaineering, delayed snow accumulation postpones the start of the season, as greater snowfall is needed to cover ice loss and bridge crevasses, while accelerated melt shortens its duration.

Backcountry skiing

Backcountry skiing, skiing in remote, ungroomed areas, remains unaffected by glacier retreat, alpine ice loss, and permafrost thaw, but snowpack changes have impacted 47% of guides' ability to offer this service. Impacts include an increase in objective hazards, alterations in route character, and reductions in access and length of the guiding season—all of which were most pronounced early (i.e., November) and late (i.e., April) in the ski season.

With regard to hazards, decreases in snow accumulation can result in insufficient burial of natural hazards (e.g., logs, rocks), increasing risk of injury. Some guides hypothesized that avalanche hazard has also changed due to increases in seasonal variability, particularly related to warming, which has contributed to greater snowpack stratification. However, there was no consensus on whether warming-related changes have increased avalanche hazard, particularly as decreases in snow depth are often associated with decreases in avalanche hazard. Changes in route characteristics for backcountry skiing had both positive and negative impacts. Decreased snow accumulation created new terrain features like drops, pillows, and gullies, but also reduced ski quality and increased poorly buried hazards. Furthermore, insufficient snow accumulation in valley bottoms can limit access to higher elevation terrain.

The cumulative impact of these changes is a restriction of the backcountry ski season. Warmer temperatures delay snow accumulation which can restrict access to ski terrain and exacerbate hazards, postponing the start of the season while accelerated snow melt can end the season prematurely.

However, guides emphasized uncertainty in this observation due to the highly variable nature of the snowpack.

Waterfall ice climbing

Guides reported that glacier retreat, alpine ice loss, and permafrost thaw have not affected waterfall ice climbing, the sport of ascending frozen waterfalls or ice formations. However, 25% of the guides indicated that changes in waterfall ice conditions have influenced their ability to provide waterfall ice climbing services, with the predominant impact being a reduction in the length of the guiding season. The increasing variability of waterfall ice quality (i.e., brittle, wet), along with fluctuations in ice thickness has also reduced the number of days during which waterfall ice is suitable for guiding. While such alterations are most often felt early (i.e., October) and late (i.e., April) in the season, several guides stated that this variability is increasingly prevalent mid-season. Despite these changes, the biggest impact to guides' ability to offer waterfall ice climbing services has been the increase in popularity of the activity. Guides reported that congestion in popular climbing areas can increase hazards (i.e., icefall) and reduce accessibility (i.e., routes only have so much space for climbers), both of which can negatively impact their operations.

Guides' adaptation and vulnerability to climate change in the Canadian Rockies

All guides described adapting to climate-related change in the mountain cryosphere with the goal of finding favorable climbing conditions and/or reducing exposure to objective hazards. All reported responses involve some form of substitution behavior. Temporal and spatial substitutions were employed by all guides, whereas activity-based substitutions were common but not ubiquitous (83%). Increased time on route/trip planning in the context of less predictable conditions emerged as a widespread adaptation (83%), particularly for lesser-known or remote areas where up-to-date information is scarce.

Guides also adapted by changing their technical guiding practices (60%). Changes included shifts from short roping to belaying where terrain had become more technical, increasing the use of ropes on glaciers due to increased crevassing, and modifying their approach to terrain, considering both acute and long-term conditions to assess if the traditional route remains the best ascent option. Equipment modifications were adopted by about a quarter of the participants (27%) and included a shift in preference from mountaineering axes to ice tools and decreased use of snow pickets due to less snow and more exposed glacier ice, more frequent use of short ice screws that are more suitable for thin ice, and more often carrying warmer weather gear (e.g., lighter sleeping bag, less clothing) due to higher average temperatures. It is important to note that both these strategies are likely confounded by external variables, such as the evolution of mountain gear, guiding standards, and the skill of clients.

Although the guiding community's efforts to address cryospheric change are well-documented, individual adaptability is dictated by a number of social factors, leading to differentiated experiences of climate change among guides. Guide's training emerged as a key determinant of adaptive capacity, with those trained as mountain guides employing adaptation strategies more than other specializations (Fig. 3). This appears to be related to both years of

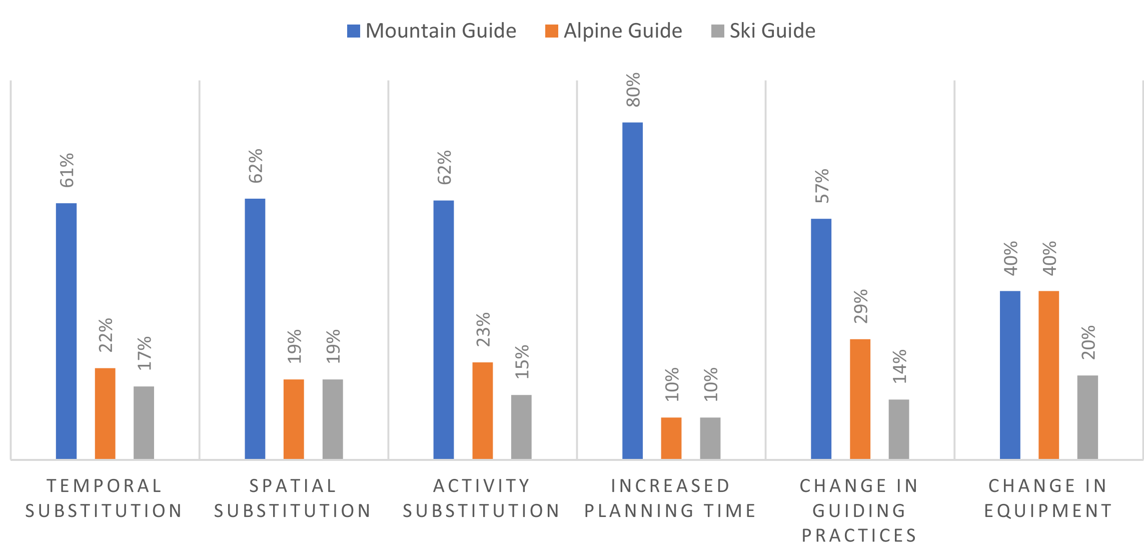

Fig. 3 Proportion of guides who reported that they frequently used each adaptation strategy, according to their guiding stream

experience as well as the broader activity repertoire of those holding mountain guide certifications. On average, mountain guides had more years of experience (26 years) than alpine (8 years) and ski guides (18 years), and this has enabled mountain guides to ski and climb numerous routes across the Canadian Rockies in a range of conditions. Exposure to these new circumstances appears to facilitate adaptation in their practices. Furthermore, all mountain guides frequently lead mountaineering activities, mainly in spring and summer when climate change impacts are greatest. This requires continuous adjustment to unpredictable conditions, which over time enables them to refine their decision-making practices and build their adaptive expertise. In contrast, only 25% of ski guides often lead ski mountaineering, mostly in late winter and early spring, when climate change effects are less pronounced and require less adaptation.

Guide's training influenced their ability to moderate exposure-sensitivities by creating adaptive barriers related to institutional frameworks that govern land access, employment, and access to financial, human, and technical resources. For example, Parks Canada's restructuring of permit applications in 2021 created a situation that is reported by 67% of guides operating in Canada's national parks as a barrier to adaptation. Historically, the ACMG had a group blanket permit under which guides could operate across most areas within national parks, barring those already subject to public closures and restrictions. The revised system requires guides to individually apply to Parks Canada. This process involves submitting detailed information for all planned trips that season (e.g., route, date, time, guests, and stops), approximately 6 months ahead of time to each field unit governing a national park. In the context of climate change, which has already shortened the guiding season and reduced route options, this system has further constrained substitution adaptation strategies. Guides are now limited in their selection and implementation of adaptations to predefined routes on dates outlined in permits. This finding is particularly consequential for mountain and alpine guides, as 95% of them rely on substitution strategies to continue delivering their services in a changing climate. For this same group of guides, 63% adapt by spending additional time on trip planning—a strategy that is more burdensome due to the new time-intensive requirements of the permit system. In contrast, only 40% of ski guides utilize substitution strategies and increased time on trip planning to maintain their services. While the overall burden of this new system appears to be greatest for mountain and alpine guides, all guides indicate that it has increased their vulnerability to climate change by reducing their flexibility when guiding in dynamic mountain environments.

Several Parks Canada's regulations regarding access have also made some adaptations more difficult. Recognizing the need for regulations in response to concerns like overcrowding at popular sites, 53% of guides feel that the existing regulations governing access do not consider the specific dynamics of guides. Of note, in 2023, Parks Canada implemented an annual summer closure on Moraine Lake road to private vehicles. The agency now offers a shuttle service starting at the Lake Louise Park and Ride area between 6:30 AM and 7:30 PM. However, this new system constrains temporal substitution for summer activities such as mountaineering. This is because the shuttle timeframe does not align with mountaineering realities that require descending snow and ice faces before intense solar heating, a phenomenon exacerbated by climate change. Guiding operations have addressed this barrier by applying for commercial vehicle permits, purchasing e-bikes, and using the services provided by private companies (e.g., Radventures). However, small to medium-scale operations and independent guides often face barriers in accessing financial, human, and technical resources required to employ these adaptations, reducing their ability to moderate exposure-sensitivities. This has particularly consequential impacts for medium and small-scale alpine guiding operations as their specialized training can limit their adaptability and therefore employment opportunities, reducing access to resources such as financial capital. For example, many mountain guides (73%) work as ski guides for larger companies (e.g., Canadian Mountain Holidays) during the winter and provide mountaineering services via their own independent businesses in the summer. This diversified employment model reduces vulnerability by offering more consistent employment opportunities during the winter months, when the effects of climate change are felt less acutely.

These results reveal that environmental changes are not the only factor shaping the vulnerability of mountain guides in the Canadian Rockies. Social factors that increase exposure-sensitivity (e.g., guide's training) and reduce adaptive capacity (e.g., institutional barriers) also have a strong bearing on lived experiences of climate change, with variability among these factors leading to differentiated experiences of climate change within the guiding community (e.g., those primarily working in national parks).

Discussion

Guides' observations of climate-related changes in the mountain cryosphere are consistent with prior studies focused on the Canadian Rockies (Hanly et al. 2023; Hanly and McDowell 2024; Rushton and Rutty 2023), as well as other mountaineering regions globally (e.g., Mourey et al. 2020; Salim et al. 2019). As such, our findings contribute to the understanding that cryospheric degradation is a significant factor influencing guides' vulnerability to climate change. Moreover, they advance the emergent discourse that emphasizes physical environmental changes alone do not fully account for vulnerability; social, political, and economic dimensions also play critical roles. As an example, akin to the findings of Mourey and colleagues (2020), our study revealed that guides' adaptive capacity is linked to the scope of activities they provide. Guides who exclusively or predominantly offer mountaineering services (e.g., alpine guides) exhibit lower adaptive capacity relative to those whose services are more diversified (e.g., mountain guides). This is a novel finding in the Canadian context and is important because it underscores the necessity of addressing barriers to diversification, such as access to resources, in enhancing guide's adaptive capacity.

One way to reduce or overcome barriers to resource access is by building social capital. Collaborative relationships can facilitate the mobilization and use of existing resources, making them more accessible (Burch 2010). For example, ACMG partnerships with accelerators or incubators, such as Startup Canada, ECO Canada, and Mitacs, can provide funding, mentorship, research collaborations, and networking opportunities to support innovation in service offerings, technology integration, and/or skill development. Such collaborations could be integrated into guide's training curriculum and/or professional development opportunities, supporting the expansion of their professional competencies. In the Rockies region, guides have independently leveraged this model to offer photography workshops and indoor skill sessions (e.g., Tech Tip Tuesday). These examples demonstrate how partnerships can facilitate diversification beyond traditional guide training to generate alternative revenue streams and reduce climate-related impacts on livelihoods. The ACMG's adoption of a similar model could create structured pathways for guides to access the resources needed for guides to diversify their business operations and increase their adaptive capacity.

We also found that guides' vulnerability is tied to specific geographies, like national parks, where landscape-specific factors such as governance create unique barriers to adaptation. These findings align with Salim et al. (2019), who found that tourism flows in specific mountain areas, such as Chamonix, where international tourists are less flexible, can hinder guides' ability to adapt. Addressing location-specific barriers is essential for creating adaptive strategies that tackle the unique challenges guides face in places like Moraine Lake in Banff National Park.

Positive amendments to access challenges at Moraine Lake represent a process model the ACMG could formalize via institutional learning procedures to ratify its role in advocating for the integration of guides' experiential insights into future land management policy and adaptation strategies. In this example, the absence of an alpine start program during the inaugural summer of Parks Canada's shuttle service (2023) was attributed to an overnight (8PM–6AM) wildlife closure along Whitehorn Drive, the road accessing the shuttle's pick-up and drop-off point. This created barriers to adaptation for mountain and alpine guides which prompted ACMG guides as well as other key stakeholders (e.g., Alpine Club of Canada) to engage in consultation with Parks Canada. Consultation involved a review of the existing shuttle service, the feasibility of an alpine start that respects wildlife closures, and how the two could be integrated for ease of usership and affordability. Parks Canada determined that starting in spring 2024, two alpine start shuttles (50 seats per shuttle) will run from the Lake Louise Lakeshore to Moraine Lake at 4AM and 5AM, thereby avoiding Whitehorn drive during evening closures. This policy change both maintains Parks Canada's mandate to uphold ecological integrity and reduces adaptive barriers for mountain and alpine guides. This approach demonstrates the efficacy of iterative policy refinement in addressing the unique needs of each guiding stream via the integration of guides' experiential knowledge with scientific expertise. Formalizing this process through institutional learning mechanisms can ensure that the perspectives and expertise of guides are integrated into policy development from the outset, thereby reducing emergent adaptive barriers. Based on findings presented here, it is possible that more experienced guides could have particularly valuable contributions in such initiatives. Consistent with findings from Mount Washington Valley, New Hampshire (Voorhis et al. 2023), we found that experienced guides exhibit higher adaptive capacity. As such, their input could enhance policy refinement and support targeted strategies to reduce adaptation barriers in this community.

Despite these opportunities, there are limits to guides' adaptations. Climate change unfolds over decades and centuries, while mountain guides adaptation decisions are a response to the immediate manifestations of a changing environment. These mismatching temporal scales can lead to a focus on short-term priorities and solutions, rather than long-term adaptation needs (Biesbroek et al. 2013). For instance, guides' strategies for adapting to the loss of snow and ice with spatial or activity substitution are sufficient to maintain their services within current environmental conditions. However, projections indicate that even with efforts to limit global warming to 1.5 °C above pre-industrial levels, extensive deglaciation in the mountains of Western Canadian is expected by 2100 (Rounce et al. 2023). This process of deglaciation represents a threshold beyond which adaptation becomes extremely limited or impossible, resulting in vulnerabilities (Adger et al. 2013; Barnett et al. 2016) that can have an effect on guide's identity, well-being, and livelihoods (Adger et al. 2022). These impacts foreshadow a future in which guides may need to re-imagine the provision of their services, analogous to the experiences of some European guides who have reduced their mountaineering services in favor of climbing schools, mountain biking, or via ferrata (e.g., Salim et al. 2019).

Conclusion

Our results revealed that guides have observed and adapted to significant climate-related change in the mountain cryosphere of the Canadian Rockies. Such changes have resulted in increases in objective hazards, alterations to route characteristics, and restrictions in when and where guides can operate. Experiences of these changes are mediated by social factors that shape sensitivity (i.e., guides' subjective assessment of the change, it's relevance to their guiding practice, and livelihood characteristics) and adaptive capacity (i.e., guide's training, years of experience, repertoire of services). Consequently, variations in the distribution of these factors resulted in diverse experiences of climate change, with some guides being more vulnerable than others. Notably, our findings indicate that guides whose work is primarily situated within national parks may face greater vulnerability compared to their counterparts operating outside these protected areas. Therefore, there is a need to better understand the institutional frameworks governing Canada's national parks and the challenges they present to guide's adaptive efforts. Given trajectories of climate change in the Canadian Rockies, transdisciplinary efforts involving Parks Canada, the ACMG, mountain guides, and human dimensions of climate change researchers will be needed to identify pathways that effectively balance the needs of multiple users of rapidly changing mountain environments.

Acknowledgements We thank the interviewees and the Association of Canadian Mountain Guides for sharing their valuable time and insights and Ian Jackson for his expert review of this paper. We also thank Jiaao Guo for his support in creating Fig. 1.

Data availability Data is available upon request.

Declarations

Ethical approval The study was conducted in accordance with and approved by the Conjoint Faculties Research Ethics Board (CFREB) at the University of Calgary (REB22-0472).

Consent to participate Informed consent was obtained from all subjects involved in the study.

Consent to publish All authors provide consent to publish.

Competing interests The authors declare no competing interests.

References

Adger WN (2006) Vulnerability. Glob Environ Chang 16(3):268–281. https://doi.org/10.1016/j.gloenvcha.2006.02.006

Adger WN, Barnett J, Brown K, Marshall N, O'Brien K (2013) Cultural dimensions of climate change impacts and adaptation. Nat Clim Chang 3(2):112–117. https://doi.org/10.1038/nclimate1666

Adger WN, Barnett J, Heath S, Jarillo S (2022) Climate change affects multiple dimensions of well-being through impacts, information and policy responses. Nat Hum Behav 6(11):1465–1473. https://doi.org/10.1038/s41562-022-01467-8

Adler C, Wester P, Bhatt I, Huggel C, Insarov MD et al (2022) Cross-chapter paper 5: mountains. In: Pörtner H-O, Roberts DC, Tignor M, Poloczanska ES, Mintenbeck K, Alegría A, Craig M, Langsdorf S, Löschke S, Möller V, Okem A, Rama B (Eds.), Climate change 2022: impacts, adaptation and vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (pp 2273–2318). Cambridge University Press. https://doi.org/10.1017/9781009325844.022

Barnett J, Tschakert P, Head L, Adger WN (2016) A science of loss. Nat Clim Chang 6(11):976–978. https://doi.org/10.1038/nclimate3140

Bassett TJ, Fogelman C (2013) Déjà vu or something new? The adaptation concept in the climate change literature. Geoforum 48:42–53. https://doi.org/10.1016/j.geoforum.2013.04.010

Biesbroek GR, Klostermann JEM, Termeer CJAM, Kabat P (2013) On the nature of barriers to climate change adaptation. Reg Environ Change 13(5):1119–1129. https://doi.org/10.1007/s10113-013-0421-y

Bourdeau P (2014) Effet du changement climatique sur l'alpinisme et nouvelles interactions avec la gestion des espaces protégés en haute montagne: Le cas du parc national des Écrins. PACTE. Retrieved March 2021, from http://oai.eauetbiodiversite.fr/entrepotsOAI/PNE/BOURDEAU_chang_clim_alpinisme_2014_13127.pdf

Burakowski E, Contosta A, Grogan D, Nelson S, Garlick S et al (2022) Future of winter in Northeastern North America: climate indicators portray warming and snow loss that will impact ecosystems and communities. Northeastern Naturalist. Retrieved from https://scholars.unh.edu/faculty_pubs/1394

Burch S (2010) Transforming barriers into enablers of action on climate change: insights from three municipal case studies in British Columbia, Canada. Global Environ Change 20(2):287–297. https://doi.org/10.1016/j.gloenvcha.2009.11.009

Carey M, Molden OC, Rasmussen MB, Jackson M, Nolin AW et al (2017) Impacts of glacier recession and declining meltwater on mountain societies. Ann Am Assoc Geogr 107(2):350–359. https://doi.org/10.1080/24694452.2016.1243039

Dumba K (2021) Executive director's annual report to the membership. Association of Canadian Mountain Guides. (p 17)

Ford JD, Keskitalo ECH, Smith T, Pearce T, Berrang-Ford L et al (2010) Case study and analogue methodologies in climate change vulnerability research: climate change vulnerability research. Wiley Interdiscip Rev: Clim Change 1(3):374–392. https://doi.org/10.1002/wcc.48

Gadd B (1999) Handbook of the Canadian Rockies: geology, plants, animals, history, and recreation from Waterton/Glacier to the Yukon (2nd ed.). Corax Press

Gruber S, Haeberli W (2007) Permafrost in steep bedrock slopes and its temperature-related destabilization following climate change. J Geophys Res: Earth Surf 112(F2). https://doi.org/10.1029/2006JF000547

Hanly K, McDowell G, Tricker J (2023) Climbing through climate change in the Canadian Rockies: guides' experiences of route transformation on Mt. Athabasca. Tourism Hospitality 4(4):4. https://doi.org/10.3390/tourhosp4040033

Hanly K, McDowell G (2024) The evolution of "riskscapes": 100 years of climate change and mountaineering activity in the Lake Louise area of the Canadian Rockies. Clim Change 177(49). https://doi.org/10.1007/s10584-024-03698-2

Hock R, Rasul G, Adler C, Cáceres B, Gruber S et al (2019) High mountain areas. In: IPCC special report on the ocean and cryosphere in a changing climate (pp 131–202). Cambridge University Press. https://www.ipcc.ch/srocc/chapter/chapter-2/

Köppen W (1936) Das geographische System der Klimate. Gebrüder Borntraeger

Martel L (2013) Seizing the sharp end: 50 years of the ACMG. Alpine Club of Canada

McDowell G, Ford JD, Lehner B, Berrang-Ford L, Sherpa A (2012) Climate-related hydrological change and human vulnerability in remote mountain regions: a case study from Khumbu, Nepal. Reg Environ Change 13(2):299–310. https://doi.org/10.1007/S10113-012-0333-2

McDowell G, Koppes M, Harris L, Chan KMA, Price MF et al (2021) Lived experiences of 'peak water' in the high mountains of Nepal and Peru. Clim Dev: 1–14. https://doi.org/10.1080/17565529.2021.1913085

McDowell G, Stevens M, Marshall S, et al (2023) Canadian mountain assessment: walking together to enhance understanding of mountains in Canada. University of Calgary Press

Mourey J, Perrin-Malterre C, Ravanel L (2020) Strategies used by French Alpine guides to adapt to the effects of climate change. J Outdoor Recreat Tour 29:100278. https://doi.org/10.1016/j.jort.2020.100278

Mourey J, Lacroix P, Duvillard P-A, Marsy G, Marcer M et al (2022) Multi-method monitoring of rockfall activity along the classic route up Mont Blanc (4809 m a.s.l.) to encourage adaptation by mountaineers. Nat Hazards Earth Syst Sci:. https://doi.org/10.5194/nhess-2021-128

O'Brien K, Eriksen S, Nygaard LP, Schjolden A (2007) Why different interpretations of vulnerability matter in climate change discourses. Clim Policy 7(1):73–88. https://doi.org/10.1080/14693062.2007.9685639

Payne G, Payne J (2004) Key concepts in social research. SAGE Publications, Ltd. https://doi.org/10.4135/9781849209397

Pröbstl-Haider U, Hödl C, Ginner K, Borgwardt F (2020) Climate change: impacts on outdoor activities in the summer and shoulder seasons. J Outdoor Recreat Tour 34:100344. https://doi.org/10.1016/j.jort.2020.100344

Purdie H, Kerr T (2018) Aoraki Mount Cook: environmental change on an iconic mountaineering route. Mt Res Dev 38(4):364. https://doi.org/10.1659/MRD-JOURNAL-D-18-00042.1

Purdie H, Gomez C, Espiner S (2015) Glacier recession and the changing rockfall hazard: implications for glacier tourism. NZ Geogr 71(3):189–202. https://doi.org/10.1111/nzg.12091

Ravanel L, Deline P (2011) Climate influence on rockfalls in high-Alpine steep rockwalls: the north side of the Aiguilles de Chamonix (Mont Blanc massif) since the end of the 'Little Ice Age.' Holocene 21(2):357–365. https://doi.org/10.1177/0959683610374887

Ravanel L, Magnin F, Deline P (2017) Impacts of the 2003 and 2015 summer heatwaves on permafrost-affected rock-walls in the Mont Blanc massif. Sci Total Environ 609:132–143. https://doi.org/10.1016/j.scitotenv.2017.07.055

Reimer R (2019) Diversity, inclusion, and mental health in the avalanche and guiding industry in Canada (pp 1–8). Lotus Mountain Consulting Inc. Retrieved from https://cdn.ymaws.com/www.avalancheassociation.ca/resource/resmgr/about_us/190512_execsummary_diversity.pdf

Ribot J (2010) Vulnerability does not fall from the sky: toward multiscale, pro-poor climate policy. In: Mearns R, Norton A (eds) Social dimensions of climate change: equity and vulnerability in a warming world. The World Bank, pp 47–74

Rounce DR, Hock R, Maussion F, Hugonnet R, Kochtitzky W et al (2023) Global glacier change in the 21st century: every increase in temperature matters. Science 379(6627):78–83. https://doi.org/10.1126/science.abo1324

Rushton B, Rutty M (2023) Gaining insight from the most challenging expedition: climate change from the perspective of Canadian mountain guides. Curr Issue Tour 26:1–13. https://doi.org/10.1080/13683500.2023.2185506

Salim E, Mourey J, Crépeau A-S, Ravanel L (2023) Climbing the Alps in a warming world: perspective of climate change impacts on high mountain areas influences alpinists' behavioural adaptations. J Outdoor Recreat Tour 44:100662. https://doi.org/10.1016/j.jort.2023.100662

Salim E, Mourey J, Ravanel L, Picco P, Gauchon C (2019) Mountain guides facing the effects of climate change. What perceptions and adaptation strategies at the foot of Mont Blanc? Rev Géogr Alp 107(4). https://doi.org/10.4000/rga.5865

Scott D, Steiger R, Rutty M, Pons M, Johnson P (2020) Climate change and ski tourism sustainability: an integrated model of the adaptive dynamics between ski area operations and skier demand. Sustainability 12(24):24. https://doi.org/10.3390/su122410617

Smit B, Wandel J (2006) Adaptation, adaptive capacity and vulnerability. Glob Environ Chang 16(3):282–292. https://doi.org/10.1016/j.gloenvcha.2006.03.00

Spaar I (2010) Swiss guides: shaping mountain culture in Western Canada (p 58). Consulate General of Switzerland in Vancouver. https://www.tourismgolden.com/sites/default/files/Swiss%20Mountain%20Guide.pdf

Steiger R, Knowles N, Pöll K, Rutty M (2022) Impacts of climate change on mountain tourism: a review. J Sustain Tour: 1–34. https://doi.org/10.1080/09669582.2022.2112204

Stutfield H (1903) Chapter 2: Ascent of Lefroy and Victoria: and the Waputehk Icefield. In: Climbs & exploration in the Canadian Rockies (pp 45–72). Rocky Mountain Books

Temme AJ (2015) Using climber's guidebooks to assess rock fall patterns over large spatial and decadal temporal scales: an example from the Swiss Alps. Geogr Ann Ser B 97(4):793–807. https://doi.org/10.1111/geoa.12116

The ACMG (n.d.) Who we are. Retrieved April 8, 2022, from https://www.acmg.ca/03public/about/who.aspx#tp31_4

Voorhis J, McDowell G, Burakowski E, Luneau T (2023) The implications of warmer winters for ice climbing: a case study of the Mount Washington Valley, New Hampshire, USA. Front Hum Dyn 5:1097414. https://doi.org/10.3389/fhumd.2023.1097414