

**Adapting to climate change:
Canadian skiers' behavioural responses and perceptions of snowmaking**

by

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Author's Declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

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Abstract

Ski tourism is predicated on low temperatures and natural snowfall, with climate change directly impacting the multibillion-dollar ski industry. As the ski industry continues to invest in snowmaking technology in response to warming climatic conditions, concerns regarding the sustainability of snowmaking are amplifying, including high levels of water and energy consumption required to produce snow, as well as associated greenhouse gas (GHG) emissions generated by snowmaking equipment. During the 2023/2024 ski season, Canada experienced a record-warm winter that generated country-wide impacts in the form of late openings, temporal closures, and an early end to the season. The presented thesis is the first to explore skier/snowboarder experiences and behavioural responses immediately following a record-warm winter, and is the first to provide an empirical assessment of Canadian skier perceptions of snowmaking as an environmentally sustainable climate adaptation strategy. Using an online survey administered to active skiers and snowboarders across Canada from March through June 2024, a total of 209 surveys were collected and analyzed. The results reveal that during the 2023/2024 season, skiers have a high tolerance for marginal conditions (e.g., 59% would ski regardless of snow coverage), with most (57%) opting to ski less often (i.e., temporal substitution) versus a spatial (i.e., travelling elsewhere) or activity substitution (i.e., stop skiing). The frequency with which certain conditions were experienced statistically differed by region (e.g., machine-made snow), gender and age (e.g., warm temperatures, thin/bare patches, narrow snow coverage), with women and younger skiers more likely to have experienced these marginal conditions compared to men and older skiers. Older generations were also found to be less accepting of crowding conditions, more tolerant of poor snow conditions, and more in favour of snowmaking as a necessity to maintain ski seasons when compared to younger skiers. Most respondents (80%) are concerned about climate change negatively impacting current and future ski conditions, with a link between reported (i.e., behavioural response in 2023/2024) and projected future behaviours, suggesting a high reliability of using current behaviours following a record-warm season to predict future intentions. Moreover, almost all (90%) of respondents agreed that snowmaking is necessary, and over 80% agree snowmaking capacity must increase in the next five years. The results show the majority of skiers believe snowmaking requires significant water and energy to produce (82% and 80%, respectively), which negatively impacts water resources (36%) and results in significant GHG emissions (28%). Importantly, over one-third of skiers are undecided as to whether or not snowmaking negatively impacts water resources (38%), results in GHG emissions (43%), contributes to climate change (35%), and negatively impacts human health (59%), with women reporting significantly higher uncertainty than men, and older respondents agreeing less to the negative environmental and health impacts of snowmaking than young skiers. Emerging research suggests snowmaking can be compatible with climate action plans, underscoring an important opportunity for mountain destinations engaged in sustainable development to better communicate their adaptation-mitigation efforts to minimize uncertainty.

Keywords: climate change, ski tourism, snowmaking, sustainability, adaptation

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Dedication

I dedicate this thesis to Tito, my loving husband, who has always believed in me even more than I have. Thanks for always standing by my side and supporting me when I have needed you the most. To Chelo and Nana, this is also for you. Remember, it is never too late to learn new things, and may this experience be a reminder to always follow your dreams, like I did.

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Chapter 1

Introduction

1.1 Problem context

Ski tourism is a highly weather-sensitive and climate-dependent industry because it is predicated on natural snowfall and low temperatures (e.g., to preserve the snow base and support snowmaking). In turn, climate change has posed and will continue to pose a direct risk to the multi-billion-dollar ski industry (Steiger et al., 2019), including the mountain destination communities reliant on the industry for their livelihoods (McDowell et al., 2023). Research that explores the impact of climate change on the ski industry has grown substantially in the last decade (Steiger et al., 2019), which unanimously states that in the last decade, despite investments in snowmaking, the industry is facing more variable ski seasons, market contraction (i.e., closure of climatically unviable ski resorts), with increasing snowmaking requirements that have concomitant operating costs and associated sustainability concerns (e.g., water and energy consumption) (e.g., Berard-Chenu et al., 2022; N. Knowles et al., 2023; Steiger, Posch, et al., 2022). Importantly, significant evidence suggests the industry is ill-prepared to adapt to changing ski conditions and emission reduction responsibilities (Knowles, 2019; Scott & Gössling, 2022), with limited research that explores how skiers are (or will) respond to the increasing climate risks and sustainability challenges (Rutty et al., 2021; Steiger et al., 2019).

Most climate change and ski tourism studies have focused on supply-side risks and vulnerabilities related to warming temperatures and decreasing seasonal snow cover (i.e., how climate change will impact ski resort operations), with only 11% of the peer-reviewed studies assessing how demand (i.e., skiers) will respond to changing conditions (Steiger et al. 2019). While limited, demand-side studies reveal that skiers are resilient to marginal conditions, opting to travel further distances to go skiing (i.e., spatial substitution), or to ski more often in a shortened season (i.e., temporal substitution) (e.g., Rutty et al., 2015; Steiger et al., 2020; Unbehaun et al., 2008; Vivian, 2011). As demand shifts in response to those ski resorts that are open and operating, it is anticipated that crowding may increase as skiers concentrate spatially and temporally (Rutty et al., 2015; Scott et al., 2020; Steiger et al., 2020). The potential negative implications of crowding for skier experiences have yet to be explored, including the identification of threshold conditions (i.e., the point at which skiers would no longer be

willing to go to the resort) which are essential to address effective industry and destination-specific climate adaptation needs.

A key climatic adaptation strategy of the ski industry is snowmaking, which has been widely adopted over the last three decades (Abegg et al., 2017; Knowles et al., 2023; Steiger et al., 2019). Increasingly, snowmaking has come under criticism, raising sustainability concerns with respect to the high levels of water and energy consumption required to produce the snow, including associated greenhouse gas (GHG) emissions generated by snowmaking equipment (Aall et al., 2016; Duquette, 2016). For example, the 2022 Beijing Winter Olympic was highly scrutinized in the media, with scathing headlines about the environmental cost of hosting the Games on artificial snow (e.g., De Guzmán, 2022; Orr, 2022; Ungoed-Thomas, 2021). Nevertheless, the ski industry continues to invest in snowmaking (FACTMR, 2023; Scott, Steiger, Rutty, et al., 2020), with many resorts promoting various sustainability features of advanced snowmaking technology, such as enhanced water and energy efficiency that minimizes resource consumption and supports carbon reductions. Although research suggests that snowmaking can be compatible with climate action plans (e.g., pending water source and carbon intensity of electricity grids) (Scott et al. 2022, Knowles et al. 2023), negative media headlines can directly influence tourists' perceptions and the decision on whether or where to travel (e.g., Chemli et al., 2022; Z. Liu & Qi, 2025; Lowe et al., 2006). It remains unclear how skiers perceive snowmaking, including whether skiers perceive it as an unsustainable management strategy or as an essential and sustainable climate adaptation strategy.

In addition to advancing demand-side studies, the proposed research is also novel because it examines the behavioural response of skiers immediately following a record warm winter season. The 2023/2024 ski season was the warmest winter ever registered in Canada since 1948 (ECCC, 2024). According to a report from the Environment and Climate Change Canada Agency (ECCC, 2024), from December 2023 to February 2024, across all of Canada, the average temperature was 5.2 degrees Celsius, above the 1961-1900 average. While studies have surveyed respondents on how they would respond to hypothetical scenario(s) of change, there is much evidence that such climate surveys have a desirability bias (i.e., respondent tendency to answer what they believe to be the 'correct' or 'socially acceptable' answer in a sensitive topic) (Dahlgren & Hansen, 2015; Fisher, 1993). Although there have been efforts to provide more precise and tangible text descriptions of projected climate scenarios at ski resorts (Cocolas et al., 2016; Vivian, 2011; Witting et al., 2021), response bias remains a concern, in addition to uncertainty as to whether or not respondents

accurately understand hypothetical future scenarios of change (Rutty et al., 2021). Collectively, the limitations of existing stated response surveys, and thereby future demand projections, remain uncertain in a climate change and ski context (Steiger et al., 2022). By surveying skiers immediately after experiencing a marginal season that resembles a high emission scenario by mid or end of century (i.e., a climate analogue), this study limits response bias and minimizes the likelihood that respondents misinterpret questions regarding changing climatic conditions.

1.2 Research purpose

The purpose of this survey study is to provide the first empirical assessment that explores skier/snowboarder behavioural responses following a record warm winter, offering insight into future demand patterns due to changing resort conditions, as well as to advance our understanding of the perceptions of snowmaking as an environmentally sustainable climate adaptation strategy. Primary data was collected from 209 active skiers, through an online survey questionnaire distributed through specialized ski groups and networks, including social media groups and non-profit organizations related to the sport.

1.3 Research questions

To achieve the stated research purpose, the following research questions guided the execution of the thesis:

1. How did the record-warm 2023/2024 winter season impact the experience and participation patterns of skiers in Canada?
2. What are skiers' thresholds of acceptability with respect to climate and resort conditions?
3. Are skiers concerned about climate change and future impacts on ski conditions?
4. What are skiers' perceptions of snowmaking as a sustainable adaptation strategy?

1.4 Expected contributions

It is anticipated that the results from this study will make several key contributions. First, the thesis will expand on existing demand-side climate change and ski tourism studies, advancing our understanding of the behavioural responses and potential shifts in demand patterns as a result of warming winter conditions. Although there have been some studies that assess demand patterns based on skiers' responses, this is the first study known to survey skiers immediately following a record-

warm winter, which can help reduce the desirability bias found in previous research using future scenarios. Moreover, this study will improve our understanding of skiers' and snowboarders' acceptance and thresholds for projected future ski conditions (e.g., machine-made snow, narrow snow coverage, bare patches, crowding), offering a stepping stone for future broader research to improve visitor experience. Additionally, this study is the first to assess Canadian skiers' perceptions of snowmaking as an environmentally sustainable adaptation strategy, which is not only the ski industry's most widespread weather management strategy, but investments in the technology are anticipated to continually increase as climate change advances (i.e., ski industry techno-optimism bias). Relatedly, the findings from this study can offer guidance to local ski industry managers, as well as provincial and national ski bodies (e.g., Ontario Snow Resorts Association, Canadian Ski Council), to devise strategies and measures to protect their business model and understand how snowmaking is perceived by their customers or members. By understanding skiers' perceptions of snowmaking, this study can be viewed as an initial point that can contribute to the development and management of communication and stakeholder engagement strategies to support the adaptation and competitiveness of the ski industry.

1.5 Thesis structure

The presented thesis has been organized into six chapters. The introductory chapter (Chapter 1) is followed by a literature review (Chapter 2) that provides an overview of the current state of knowledge on ski tourism and climate change, including observed climate change impacts and the industry's adaptations to climatic variability, as well as demand-side responses to marginal conditions (current and future) and perceptions of snowmaking as an environmentally sustainable response to climatic change. The literature review also highlights key research gaps, including the study of current and future behavioural responses to climate change-associated future risks, the impacts of crowding and the identification of threshold conditions, and skiers' perceptions of snowmaking as a sustainable adaptation strategy, which are addressed by this study. Next, the methods (Chapter 3) for this research are outlined, which include the research design, targeted sample population, survey design and implementation, survey limitations, as well as the process for data analysis. Thereafter, the results (Chapter 4) from the survey are presented, followed by the discussion (Chapter 5) of the main findings as they relate to the growing body of literature on climate change and skiing. Lastly, the thesis concludes (Chapter 6) with a discussion of future research needs and opportunities.

Chapter 2

Literature Review

2.1 Introduction

The sixth assessment report (AR6) from the Intergovernmental Panel for Climate Change (IPCC) estimates a global mean temperature increase between 1.0°C (RCP 1.9) and 5.7°C (RCP 8.5) by the end of the twenty-first century, including declining seasonal snow cover (IPCC, 2023b). Predicated on low temperatures and natural snowfall, the multi-billion-dollar ski industry is at direct risk to climate change, which has received growing research attention since the first publication in the mid-1980s (Steiger et al., 2019).

In a comprehensive review of 119 research papers published between 1986 to 2017, Steiger et al. (2019) notes that 75% of the climate change and ski tourism studies concentrate on five countries: Austria, Australia, Switzerland, the US, and Canada. The research during the pioneering phase (1986-1997) focused almost exclusively on impact and vulnerability assessments, representing approximately 10% of the total publications to date. The second phase (1998-2007) saw the volume of publications double to 20%, expanding the research themes to include tourists' perceptions and responses to future climate conditions, the incorporation of snowmaking as an adaptation strategy, and the first integrated vulnerability assessment. The third phase (2008-2017) was marked by significant growth (70% of publications), leading to the exploration of more diverse research questions through interdisciplinary contributions and increased engagement with industry stakeholders, as well as expanding the geographic coverage. As a whole, there is agreement across the climate change and ski tourism literature that changing snow conditions (e.g., decrease in natural snowfall, precipitation shifting from snow to rain) has and will continue to impact ski seasons length across all markets, resulting in more variable ski season lengths (e.g., disruptions, late start, early end), with decreasing snow reliability and increasing snowmaking requirements (Scott, Steiger, Knowles, et al., 2020; Steiger et al., 2019).

Although less studied, the behavioural response of skiers to climatic conditions reveals that demand is highly resilient (e.g., Austria –(Steiger et al., 2020); Canada –(Rutty, Scott, Johnson, et al., 2015a); US –(Dawson et al., 2011)), though tolerance for successive marginal seasons, crowding (e.g., as the market contracts), and distances willing to travel, remains unclear (Scott, Steiger, Rutty, et al., 2020;

Scott & Gössling, 2022; Steiger et al., 2019). In turn, the future profitability and competitiveness of the ski industry is uncertain (Scott, Steiger, Knowles, et al., 2020).

Following the Introduction chapter, the literature review is structured into six sections. The first section describes the observed changes in climate resources critical for ski tourism (i.e., temperatures, snow coverage), followed by the adaptation responses undertaken by the industry to mitigate or avoid climatic risks, distinguishing technology-driven and business-oriented adaptation strategies. The next section focuses on how those observed and projected changes will impact the supply-side of the ski industry (i.e., operators), including projected impacts on season length and snowmaking needs. Next, demand-side (i.e., tourists') responses are highlighted. The fourth section discusses the sustainability of snowmaking, underscoring key narratives with respect to the environmental impacts of snowmaking, including water and energy use as covered in the media, as well as perceptions of snowmaking in the peer-reviewed literature. Thereafter, risk perception and psychological distance frameworks are introduced, with the final section highlighting existing research gaps and research needs.

2.2 Observed climate change

Climate change is directly, and often negatively, impacting global ski tourism regions, most notably through rising temperatures, shorter winter seasons, and reduced snow cover (Steiger et al., 2019). In turn, the climate change and ski tourism literature widely projects that the ski industry will experience shortened and more variable ski season lengths, increased snowmaking requirements, declining visitation, increased operational costs, the potential of decreasing profits, and even the contraction and loss of ski area markets (Dawson & Scott, 2010; Scott et al., 2015; Steiger & Scott, 2020). As an example, annual financial losses to the US ski industry from climate change are estimated to be \$252 million and over \$5 billion across the last two decades (Scott & Steiger, 2024). By mid-century, annual national losses could range between \$657 million to \$1.3 billion for a low- and high-emission scenario, respectively, with a three- to nine-fold increase by the 2080s (\$733 million to 2.57 billion, respectively). Importantly, these estimates are deemed conservative (e.g., calculation only accounts for lost skier visits/related revenue reductions and increased operational costs linked to snowmaking production), with impacts on the destination economy created by skiers' consumption of goods and services during their ski trips resulting in greater losses. While the study's results cannot be

extrapolated to other markets, it sheds light on the urgency required by the ski industry to continue to respond and adapt to climatic risks.

Globally, rising temperatures are expected to continue throughout the next decades, ranging from 1.3°C to 2.4°C under RCP 2.6 (2041-2060 and 2081-2100) to 1.9°C under RCP 8.5 by mid-century (2041-2060) and 5.7°C by end-of-century (2081-2100) (IPCC, 2023a). Correspondingly, declines in snow depth are projected, with 10-40% under RCP2.6 in the near term (2031-2050) and by the end of 21st century, and 50-90% under the RCP8.5 by the end of century (IPCC, 2019).

In Canada, temperatures are increasing in all regions (e.g., average annual temperature has increased by 1.7°C from 1948 to 2016, doubling the global rate) (ECCC, 2018b). Furthermore, the northern regions of Canada (north of 60° latitude) have experienced an increase of 2.3°C during the same period, tripling the global rate (ECCC, 2018b). Importantly for ski tourism, the greatest warming has occurred during winter season (Bush et al., 2019). Therefore, while annual precipitation has increased in many Canadian regions since 1948, there has been a shift toward less snowfall and more rainfall with observed snowfall in southern Canada reduced as a proportion of total precipitation (Bush et al., 2019). Both snowfall and snow extent have declined as temperatures have risen, with a 5-10% snow cover duration decrease per decade during most winter seasons from 1981 to 2015 (ECCC, 2018a).

Snow cover duration is expected to decline by mid-century across the country given the temperature increases under all emission scenarios. Projections under high emission scenarios exhibit sustained snow loss after 2050. Moreover, seasonal snow accumulation (i.e., the maximum snow water equivalent) has been observed to decrease, with medium confidence, throughout the record period (1981-2015) at a national scale (Bush et al., 2019). Models with a high emission scenario predict significant reductions in seasonal snow accumulation through mid-century in much of southern Canada. In contrast, temperatures in northern Canada are expected to remain sufficiently cold, despite overall warming projections, thus projecting smaller reductions in seasonal snow cover in these regions. Under the medium emission scenario, projections show a loss of 74% - 96% of glacier volume across western Canada's mountains by the end of the 21st century. Also, consecutive snow drought years in western North America are projected to increase in frequency as temperatures rise in the coming decades (IPCC, 2023b).

During 2023/2024, Canada (and the world) experienced a record warm winter, with the national average temperature 5.2°C above the baseline mean (from the 1961-1990 reference period) (ECCC, 2024). Most of Canada experienced temperatures 4° C above the mean baseline, while specific regions, including northern Ontario, central Manitoba around Lake Winnipeg, and the southern border between the previous two provinces, experienced temperatures of 6.5°C or more above the baseline mean. In the case of Nunavut, western Yukon, the east of Newfoundland and Labrador, and most of British Columbia experienced changes above the average baseline of between 1.5°C and 2.5°C, with a small area in the north of Nunavut's region experiencing less than 1.5°C above the average baseline temperature. This represents the warmest winter on record for at least two of the eleven climate regions in Canada (i.e., great Lake/St. Lawrence and Northeastern Forest) since 1948, surpassing the previous record in 2009/2010 by 1.1°C (ECCC, 2024). Canada's temperatures are projected to increase further, ranging between +1.8°C (RCP 2.6 scenario) and +6.3°C (RCP 8.5 scenario) by the end of the century (ECCC, 2018b), compared to the reference period 1986-2005 (Bush et al., 2019).

The impacts of warmer temperatures and changing climate patterns were felt across the Canadian ski industry during the 2023/2024 winter, with delayed opening dates, reduced hill access, exposed terrain, mid-season closures, and early closures in some ski areas. Although snowmaking played a critical role this past season, the higher temperatures made ski areas from coast-to-coast struggle to stay open and provide skiable conditions, as highlighted in the media (e.g., CBC News, 2023; Charlebois, 2024a, 2024b; Greenwood, 2024; Luymes, 2024; Ngan, 2024; Panchadar, 2024).

2.2.1 Ski industry adaptations to weather variability and climatic change

The ski industry has adopted several strategies to cope with climatic variability and change, which is reflective of differing stakeholder motivations (e.g., quality of the ski experience, financial health, environmental sustainability, market growth). As shown in Figure 2-1, adaptation strategies utilized by ski area operators can be classified into two main groups: (1) technology-driven (snowmaking solutions, slope development and operational tactics, cloud seeding, snow farming) and (2) business-oriented (diversification, marketing/price incentives, indoor ski areas, ski conglomerates).

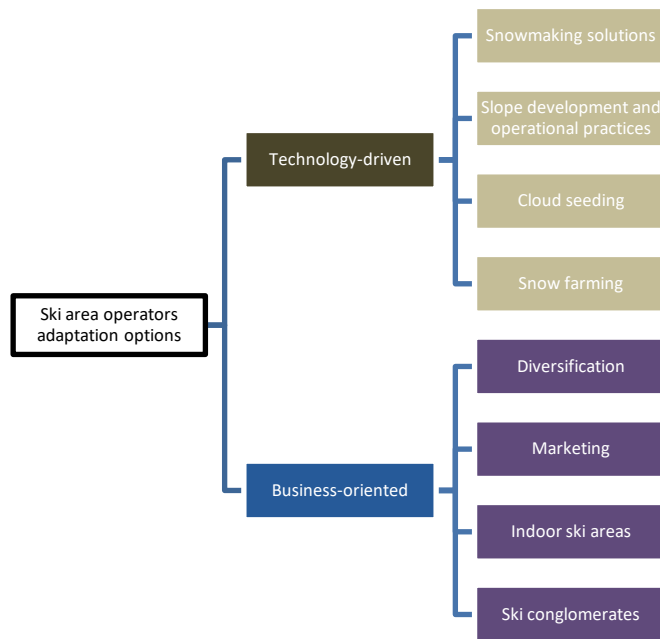


Figure 2-1 Climate adaptation strategies used by ski area operators

Source: Adapted from Scott and Boyle, 2007, p. 1415

2.2.1.1 Technology-driven adaptations

Snowmaking has been the most extensively utilized weather management/climate adaptation strategy employed by the international ski industry (Berard-Chenu et al., 2022; Steiger et al., 2019; Steiger & Scott, 2020). Developed in 1952 and more broadly adopted in the 1980s and 1990s (Steiger et al., 2019), investments in snowmaking technology have been essential for maintaining, but also increasing, ski season length (Scott et al., 2022), as well as to minimize seasonal disruptions due to climatic variability (Hopkins, 2014; Scott et al., 2022; Scott & McBoyle, 2007), and enhance visitor experiences (particularly during marginal conditions) (Steiger et al., 2019).

The process of snowmaking consists of machines pushing water at high pressures through fine nozzles, creating frozen grains that fall to the ground (Blin-Domínguez, 2022; Newby, 2021). The two most standard snow machines to date are fan-assisted, commonly known as snow guns, and the high pressure-based machines, or lances (Blin-Domínguez, 2022). Simply, compressed air is shot through a nozzle that breaks the water into small droplets, whereby the sudden loss of pressure cools the water and forms a snow “seed” that is later impelled into the air together with a fine spray of water droplets. The quality of the snow produced will depend on factors such as air-water mix,

humidity, pressure, temperature and wind speed (Lintzen, 2016 found in Blin-Domínguez, 2022). Snowmaking is currently available on more than 70% of skiable terrain in many regional markets (e.g., Eastern USA, Austria and Italy, China) (Scott et al., 2022). In Canada, this number ranges from 14% in the province of British Columbia to 95% in Ontario (Knowles et al. 2023).

Some scholars have pointed out that resort managers did not initially deem snowmaking as a climate change adaptation measure (e.g., Rice, Cohen, & Scott, 2022; Rutty, Scott, Steiger, et al., 2015), but rather a business decision to maintain profitability and operationality of the ski destinations (Vorkauf et al., 2022), as well as lengthen the ski season and reduce inter-annual weather variability (N. L. B. Knowles, 2019). However, with the combined effect of decreasing natural snow and increasing winter temperatures (IPCC, 2023b), conditions suitable for efficient snowmaking are becoming more limited (Spandre et al., 2019), leading to some scholars and the media to question the sustainability of snowmaking as an adaptation strategy (e.g., Berard-Chenu et al., 2022; de Jong, 2015; Moser & Baulcomb, 2020). Nevertheless, the industry has taken a techno-optimistic approach, believing that advances in snowmaking technology and continued investments in snowmaking infrastructure can eliminate the risks of climate change impacts on their business (Abegg et al., 2017; Rice, Cohen, & Scott, 2022). Over the past decade, the industry has invested over a billion dollars in snowmaking technology, with the global snowmaking system market size valued at US\$129.6 million in 2024, and the ski resorts segment's compound annual growth rate for the next decade estimated to be 6.2% (FACTMR, 2023).

Another adaptation strategy is to strategically develop ski slopes that minimize the quantity of snow required for skiing, such as through slope smoothing (i.e., removal of obstacles such as rocks or bushes) to reduce snow depth requirements, as well as slope contouring to better capture snowmelt to refill water reservoirs for snowmaking (Blin-Domínguez, 2022). Also, planting or preserving tree cover to shade slopes and minimize snowmelt. For resorts with glacial skiing, protection measures such as white polyethylene sheets to minimize ultraviolet radiation and reduce glacier melting (Carver & Tweed, 2021; Clouse, 2022; Jahn, 2005; Scott et al., 2009), as well as adding snow fences at the summit to capture and maintain glacier snow (Efron, 2005; Scott & McBoyle, 2007). Another approach is to develop new or additional skiable terrain, such as infrastructure expansions at higher altitudes where natural snowfall and colder temperatures are more reliable (Dannevig et al., 2021). Expansions can also take advantage of north-facing slopes, which are known to retain snowpack for longer periods (Scott & McBoyle, 2007). For example, the expansion made by the Mont Tremblant

ski area in Quebec, Canada, to develop two ski villages on the north side of the mountain (Versant Nord) (Tremblant Elysium, n.d.).

Cloud seeding has also been utilized by the industry, which is a weather modification technology to generate additional rainfall. Although seeding has mainly been employed in the agricultural sector, some North American (e.g., Telluride, Durango, Vail and Beaver Creek ski resorts in Colorado, USA) and Australian ski areas (e.g., Snowy Mountains) have employed the technology, but there remains little scientific evidence to confirm the efficacy of the technique (French et al., 2018). A prominent example is Vail Ski Resort, which had the longest cloud seeding program in the state of Colorado, lasting 44 years until budget restraints resulted in the resort's decision to pull out the funding for the program since the 2020/21 winter season (Sackett, 2020).

Other adaptation strategies include transferring natural or machine-made snow to snow-insufficient slopes, as well as producing machine-made snow off-site and then transporting and distributing it in the venues (Blin-Domínguez, 2022; Wilkins et al., 2021). Such tactics are readily evident at the Olympic Winter Games, which has long used artificial snow that has been transported to the venues and then distributed for the competitions, as well as artificial freezing of the slopes to ensure conditions are adequate for competition (e.g., on ski jumps and ramps) (Rutty, Scott, Steiger, et al., 2015). Additionally, snow farming – or snow storage – consists of storing winter-accumulated natural or machine-made snow during the summer months for the purposes of preserving the snow during the off-season for reuse at the beginning of the next season (Blin-Domínguez, 2022; Hoogendoorn et al., 2021). Snow farming has mainly been utilized in Scandinavia and German-Alpine regions to guarantee a minimum snow base at the start of the ski season when natural snowfall is more limited (Grünewald & Wolfspurger, 2019).

2.2.1.2 Business-oriented adaptations

Ski resorts have diversified from snow-exclusive to non-snow product offerings, which is particularly important for not only generating revenue during marginal snow seasons, but also year-round revenue (Steiger et al. 2024). Examples include overnight accommodations (e.g., hotels), retail services (e.g., shopping, groceries), indoor entertainment (e.g., pools, spas, wellness centres, fitness centres, tennis and squash courts, games rooms), and non-winter attractions (e.g., golf, fishing, mountain biking, paragliding, hiking, rope courses, zip lining). Although diversification is becoming more common, it is limited to larger resorts (e.g., conglomerates) who can make the significant

financial investments to expand resort development. Other business adaptation strategies include the introduction of different marketing and pricing strategies to secure a satisfactory visitor experience, such as special packages (e.g., combining lift tickets with non-snow products), multi-resort passes, free learning programs, as well as technological options to track crowding and waiting lines (e.g., Epic Pass app from Vail Resorts) (Sachs, 2024). The creation of alternative ski slopes (i.e., indoor ski areas) has been another adaptation approach (Blin-Domínguez, 2022), although its application remains somewhat limited, with notable markets in Dubai (e.g., Ski Dubai ski resort) and northern Europe (e.g., Alpenpark Neuss ski area, Germany; Snow Arena, Lithuania).

Another important ski business model is the emergence of ski resort conglomerates and, whether intentional or unintentional, have proven to become an effective strategy to adapt to climatic variability and change (Blin-Domínguez, 2022). Conglomerates unlock greater access to capital for investments (e.g., to support diversification through non-snow offerings) and to integrated marketing resources, while also minimizing the vulnerability to climatic changes because it spreads the economic risk of ski operations across a network of resorts during seasons with marginal conditions. This business model has been widely adopted in North America, particularly in the USA. For example, companies like Alterra Mountain Company (former Intrawest), Boyne USA Resorts, and Vail Resorts, have been acquiring resorts in different locations and managing multiple ski areas across North America, with recent expansions into Europe and Australia. Table 2-1 highlights some of the largest ski conglomerates in North America. By operating in numerous regions, when poor conditions are experienced in one location, the financial losses can be buffered by those regions that performed well (i.e., spreads the economic risk). The heavy reliance on snowmaking within North American conglomerates is also evident (e.g., N. L. B. Knowles, 2019).

Table 2-1 Regionally and internationally diversified ski conglomerates in North America

Boyne USA Resorts		
Big Ski Resort	Montana	USA
Boyne Mountain	Michigan	USA
Brighton	Utah	USA
Cypress Mountain	British Columbia	Canada
The Highlands	Michigan	USA
Loon Mountain	New Hampshire	USA
Pleasant Mountain	Maine	USA
Sugarloaf	Maine	USA

Summit at Snoqualmie	Washington	USA
Sunday River	Maine	USA

Vail Resort^a

Andermatt-Sedrun-Disentis	Andermatt, Sedrun, Disentis	Switzerland
Attltash	New Hampshire	USA
Beaver Creek	Colorado	USA
Breckenridge	Colorado	USA
Crans-Montana	Valais	Switzerland
Crested Butte	Colorado	USA
Crotched Mountain	New Hampshire	USA
Falls Creek	Victoria	Australia
Heavenly	California	USA
Hotham	Victoria	Australia
Hunter	New York	USA
Keystone Ski Resort	Colorado	USA
Kirkwood Mountain Resort	California	USA
Mount Snow	Vermont	USA
Mount Sunapee	New Hampshire	USA
Northstar Ski Resort	California	USA
Okemo Resort	Vermont	USA
Park City	Utah	USA
Perisher	New South Wales	Australia
Stowe	Vermont	USA
Stevens Pass	Washington	USA
Vail Resort	Colorado	USA
Whistler Blackcomb	British Columbia	Canada
Wildcat Mountain	New Hampshire	USA

Alterra Mountain Company

Arapahoe Basin	Colorado	USA
Big Bear Mountain Resort	California	USA
Blue Mountain Resort	Ontario	Canada
CMH Heli Skiing and Summer Adventures	Alberta	Canada
Crystal Mountain	Washington	USA
Deer Valley Resort	Utah	USA
June Mountain	California	USA

Mammoth Mountain	California	USA
Mike Wiegele Helicopter Skiing	British Columbia	Canada
Palisades Tahoe	California	USA
Shweitzer Ski Resort	Idaho	USA
Snow Valley	California	USA
Snowshoe Mountain	West Virginia	USA
Solitude Mountain Resort	Utah	USA
Steamboat	Colorado	USA
Stratton Mountain Resort	Vermont	USA
Sugarbush Resort	Vermont	USA
Tremblant	Quebec	Canada
Winter Park Resort	Colorado	USA
Pacific Group Resorts		
JayPeak	Vermont	USA
Mountain Washington Alpine Resort	British Columbia	Canada
Powderhorn Mountain Resort	Colorado	USA
Wintergreen Resort	Virginia	USA
Wisp Resort	Maryland	USA

^a Vail Resorts currently operates 42 ski resorts or areas (not all are included).

2.3 Supply-side impacts

2.3.1 Ski season length

Not all ski regions will be impacted equally by climate change, including differing impacts across and within regions, as well as differences based on the timing and magnitude of climate change (Steiger & Scott, 2020) (see Table 2-2). Studies conducted in North America (e.g., Dawson & Scott, 2007; Scott et al., 2008, 2021; Scott, Steiger, Knowles, et al., 2020), Europe (Rice, Cohen, Scott, et al., 2022; e.g., Scott, Steiger, Dannevig, et al., 2020; Steiger, 2011; Steiger & Scott, 2020), Australia (e.g., Hendrikx et al., 2013; Hennessy et al., 2008) and China (Fang et al., 2021) have all noted regional differences in climatic impacts, with low-altitude and low-elevation ski areas more vulnerable to climatic changes compared to high-altitude and high-elevation destinations.

The projected climate change impacts on the North American ski industry have been widely studied. For example, Dawson and Scott (2007) used the SkiSim ski operational model to assess the climate change vulnerability of 18 ski resorts in Vermont, USA. The authors used two economic risk criteria (100-day ski season and the probability of resorts being operative for the Christmas/New Year holiday season) under low (B1) to high-emission (A1Fi) scenarios over three time periods (2010-2039; 2040-2069; 2070-2099). The results project a shorter ski season for all ski areas under low to high-emission scenarios, with differentiated impacts between high- and low-elevation areas. From 2010 to 2029, the average reductions in ski season length ranged from 4% to 14% based on both low and high-emission scenarios. The same range of season length reductions was found between 2040 and 2069 under a low-emission scenario. However, the 2040-2069 period shows a more significant decline under the high-emission scenario. In this period, 72% (or 13) of ski areas experience a projected reduction of 15% or more in their ski season length, with Cochran—the lowest-altitude area—losing up to 26% of its ski season. When looking at ski days, all ski areas are expected to be able to maintain the 100-ski-day threshold in both emission scenarios during the 2010-2039 period. However, by the 2040-2069 period, the lowest altitude ski area can no longer maintain 100 ski days. By the 2070-2099 period under the high-emission scenario, only one additional area fails to meet this threshold.

Scott et al. (2007) explored the projected climate impacts on three ski regions under a low (B2) and high (A1) emissions scenario for the 2020s and 2050s in Quebec (Canada). The results show negligible (0-2%) season length losses under the low emissions scenario in the 2020s, while they range from 13 to 15% under the high emissions scenario. The projected impacts show more noticeable differences in the 2050s. Although changes in ski season remain limited to -4 to -7% in the three regions under the low emissions pathway, the high emissions scenario reveals projected losses exceeding 30% at all locations by mid-century.

Table 2-2. Projected changes in ski season length

Study Area	Author	Baseline/days	% Season length Change from baseline					
			2010-2039		2040-2069		2070-2099	
			Low emission scenario	High emission scenario	Low emission scenario	High emission scenario	Low emission scenario	High emission scenario
North America								
Vermont, USA	Dawson and Scott 2007	125~173	-12~-4 ^a	-14~-5 ^e	-14~-6 ^a	-26~-12 ^e	-26~-10 ^a	-46~-24 ^e
Quebec, Canada	Scott et al. 2007	152~163	-2~0 ^a	-15~-13 ^f	-7~-4 ^a	-32~-39 ^f	--	--
Northeast USA	Scott et al. 2008	100~172	-21~-6 ^a	-23~-6 ^e	-25~-8 ^a	-38~-14 ^e	-40~-8 ^a	-59~-25 ^e
Ontario, Canada	Scott et al. 2019	106~117	--	--	-12 ^b	-21	--	-75
Ontario, Quebec, Canada/Northeast USA	Scott et al. 2020	70~137	--	--	-86~-9 ^c	-97~-13	-96~-11 ^c	-100~-22
Midwest USA	Scott et al. 2021	56~127	--	--	-70~-12	-85~-16	-80~-14	-98~-32
Europe								
Tyrol, Austria	Steiger 2011	--	-14 ^a	-20 ^g	-32 ^a	-45 ^g	-52 ^a	-85 ^g
Austria	Steiger and Scott 2020	119	-6 ^c	-7 ^h	-10 ^c	-18 ^h	-18 ^c	-49 ^h
Norway	Scott et al. 2020	111~142	--	--	-50~-28 ^c	-64~-27 ^h	-67~-34 ^c	-89~-38 ^h
Sweden	Rice et al. 2022	140~219	-27~-6 ^b	-37~-8 ^h	-32~-8 ^b	-81~-13 ^h	-32~-7 ^b	-99~-27 ^h
Asia								
China	Fang et al. 2021	71~148	-21~-1	-23~-1 ^h	-61~-5	-79~-6 ^h	-80~-5	-97~-10 ^h

Source: Table adapted from Fang et al., 2021

^a Low emission scenario is B1.

^b Low emission scenario is RCP 2.6.

^c Low emission scenario is RCP 4.5.

^d Intermediate emission scenario is RCP 4.5.

^e High emission scenario is A1Fi.

^f High emission scenario is A1.

^g High emission scenario is A1B.

^h High emission scenario is RCP 8.5.

To further understand the impacts in North America, Scott et al. (2008) modelled climate impacts on 14 Northeast USA ski areas under lower (B1) to higher (A1Fi) emission scenarios for the periods of 2010-2039, 2040-2069, and 2070-2099. Results show shortened ski seasons across the region, with losses ranging from less than 10% in Southern Vermont and Western Maine, to 21% in Connecticut under the lower emission scenario (B1) in the 2010-2039 period. By the end of the century, losses in half of the study areas increased to at least 25%. The high emissions scenario shows more severe impacts, with eight ski areas losing over 25% of their ski season in the 2040-2069 period and all ski areas losing at least 25% by 2070-2099, with half losing 45% or more.

In Europe, Steiger (2011) used the analogue approach to assess the sensitivity of the ski tourism industry in Tyrol, Austria, by analyzing the record-warm winter season of 2006/2007, which is representative of the projected average winter season in the 2060s under a high emission scenario (A1B) or the 2080s under a low emission scenario (B1). Similar to the North American studies described above, the resorts most at risk to climate change are small to medium-sized, low-altitude, and have limited snowmaking capacity and coverage, with altitude and capacity the greatest indicators of risk. For example, a large-sized, low-altitude ski area (1,200 masl) with high snowmaking coverage (88%) experienced 4% of season loss compared to 61% loss for another large-size resort at low-altitude (1,100 masl) with lower snowmaking coverage (47%). Additionally, the study shows significant differences in overnight stays at the district level, with low-altitude areas experiencing losses of approximately 10% compared to negligible losses for high altitude resorts, with the latter potentially related to the availability of touristic infrastructure and non-skiing products (e.g., culture and congress tourism) in certain districts (e.g., Innsbruck, Zillertal valley). Moreover, the state of Upper Austria in the East was projected to face the most operational day losses, contrasting with the province of Carinthia in Southern Austria with the least losses. In terms of snow reliability, this study found that while current snowmaking allows for a high baseline period (90% of resorts achieve seasons with more than 100 days and 84% open for the Christmas holiday), the impacts of climate change would be mostly felt on Christmas holidays with a projected decline of -33% (RCP8.5) to -52% (RCP4.5) in the 2050s. The season segments most impacted remain to be the early and late segments. By the end of the century, in the high emission scenario, snow reliability becomes almost unachievable for both the 100-day (11%) and Christmas indicators (5%). The results show that while increased snowmaking capacity can maintain up to 80% of the season length in the 2050s under the high emission scenario for the 100-day indicator and to 66% for the Christmas indicator, it will still be insufficient to maintain reliability in the high emission scenario in the 2080s.

At the national level, the model projected terrain losses of between 6% (2030s) and 16% (2080s) under RCP4.5, and 6% (2030s) to 46% (2080s) under RCP8.5, with regional differences between lower and higher altitude areas, and contrast between areas with different snowmaking availability. The study also found a large concentration of the economic impacts in less tourism-reliant regions.

A decade later, Scott et al. (2019) assessed the impacts of climate change on ski season length and snowmaking requirements for 34 southern Ontario (Canada) ski areas. Applying the SkiSim 2.0 model, the analysis included differential snowmaking capacities at individual levels, updated decision rules, and used “terrain days” to assess capacity changes at a regional market scale for two time periods (2050s and 2080s) and three emission pathways (low - RCP2.6, intermediate - RCP4.5, high - RCP8.5). In all climate change scenarios, inter-annual variability is expected to increase, as well as a decrease in ski season length, which varies by resort size. More specifically, in the 2050s, season losses decrease incrementally between the low (-8% and -11% for large and small ski areas, respectively), intermediate (-11% and -30%, large and small resorts) and high (-18% and -50%, large and small resorts) emission scenarios. In the 2080s, the low emission scenario would lead to almost identical losses to the 2050s. In contrast, the high emission scenario could see season length reductions of up to 90% in small resorts and up to 60% for large resorts, with only three medium ski resorts maintaining a season length of 95-98 ski days. The study also projected the frequency of occurrence of extremely short (<80 days) or long (>120 days) ski seasons. Results show that seasons beyond 120 days would no longer exist under the intermediate emission scenario by mid-century. Most seasons for private and small ski areas would be shorter than 100 days under this scenario (RCP4.5) in the 2050s. Furthermore, the probability of having extremely short seasons (including below 90 days) increases significantly in the high-emission scenario for all ski area sizes. Projections show 86% and 62% of seasons having less than 90 ski days at private and small ski areas, respectively, challenging the viability of many of these areas as early as the 2050s under a high emission scenario. Moreover, the results of this study show pronounced losses in ski days in the early and Christmas/New Year holidays segments, particularly under the high emission scenario. For example, small ski areas would see declines in the probability of being operational during the Christmas/New Year holiday, decreasing from 43% at the baseline to only 5% under RCP2.6 in the 2050s, while intermediate and high emission scenarios show a 0% probability. For large ski resorts, the probability of being operational during the holidays by the 2050s decreases from 94% to 20% (baseline to RCP8.5, respectively) and 66% (RCP2.6).

In a follow up study, Scott et al. (2020) made a number of SkiSim model advancements to examine climate impacts at 171 ski areas in Ontario, Québec, and the Northeastern US markets under low and high-emission scenarios (RCP 4.5 and 8.5, respectively). Performance was improved through the inclusion of more detailed snowmaking practices (e.g., base-layer, emergency snowmaking), critical altitudinal considerations, considerations for system capacity in terms of skiable terrain, as well as analysis based on season segment (e.g., early versus mid-season closures). The study reveals significant regional and state-level differences in ski season length changes, which become more visible in the high emission scenarios in the 2050s (e.g., Vermont and New Hampshire lose 13 and 15% ski days, respectively, while Connecticut (-34%) and Rhode Island (-97%) would experience much greater losses). Furthermore, in the 2080s under low emission scenario, ski season reductions range from -13% in Québec to -18% in Ontario and the US Northeast region, with clear differences at the state level (e.g., Rhode Island shows -97% but Vermont only -11%). The high emission scenario at the end of the century reveals steeper reductions in ski season length, in particular in Ontario (-60%) and the US Northeast region (-45%), where state-level differences persist, showing two distinct impact groups (i.e., Vermont, Maine and New Hampshire $\leq -36\%$ versus $\geq 54\%$ losses for the remainder of the region). The results of this study also highlight that ski areas in Québec and higher-altitude regions (i.e., Vermont, New York, New Hampshire and Maine) are less sensitive to climate impacts. Similar to previous studies, most of the lost ski days materialize in the ‘early’ and ‘late’ season segments (i.e., December and March). Québec shows no mid-season nor holiday season changes under the low-emission scenario in the 2050s and 2080s, while Ontario and the Northeastern US regions show differentiated impacts for all season segments based on emission scenarios and time frames. Skiable terrain-day losses range from 3-4% in Québec, 6-14% in Ontario, and 4-7% in US Northeast in the 2050s. Contrastingly, by the 2080s, the results show distinct differences under RCP4.5 (with losses of 10% or less across the three regions) and RCP8.5 (57% loss in Ontario, 24% loss in the US Northeast region). Following the same pattern as the ski season length, Québec and high-altitude regions do not showcase high skiable terrain-day losses (e.g., Vermont would see a decline of 7%.)

In Norway, SkiSim 2.0 explored the impact of climate change across 110 ski areas in the 2030s, 2050s, and 2080s under low (RCP4.5) and high (RCP8.5) emission scenarios Scott et al. (2020). Given that only half the ski areas had snowmaking capacity at the time of the study, the model was run with a natural snow-only scenario and a snowmaking scenario. When only natural snowfall was

considered, results project a substantial shortening of the ski season as early as the 2030s with regional differences (e.g., regions at greatest risk were at lower altitude and latitudes). Under the high emission scenario, northern Norway is projected to experience a relative decline between 32% and 89% in its season length, compared to -16% to -42% in the southern region. When advanced snowmaking is applied, regional differences appear more pronouncedly in the 2080s under the high emission scenario, with northern Norway having the shortest season again. For example, relying solely on natural snow, the share of snow-reliable areas drops to 45-50% in the 2030s, 32-37% in the 2050s, and 13-30% by the end of the century. In contrast, with snowmaking, 93-96% remain reliable in the 2030s, decreasing to 79-87% in the 2050s, and 61-80% by 2080s. The study underscores that the need to invest in snowmaking infrastructure will continue to rise, but the financial and sustainability implications are not to be disregarded given that most ski areas in Norway do not currently have snowmaking capacity which would require significant capital investment at a time when the number of potential days/hours to generate snow is decreasing.

In the US Midwest, Scott et al. (2021) projects shorter and state-differentiated ski season lengths in 99 ski areas under low (RCP4.5, SSP245), moderate (SSP370), and high (RCP8.5, SSP585) emission scenarios by 2050s and 2080s. Including advanced snowmaking capacity, average regional seasonal losses by mid-century ranged from 21-26% in low- to moderate-emission scenarios, and up to 33% in the high-emission scenario. By the 2080s, the losses increase, spanning from 27-34% (low emission scenario), 49% (moderate emission scenario) and up to 57-62% (high emission scenarios). Moreover, the results showed wide variation in the projected season length losses by the 2050s at the state level (i.e., 12-90% across the Midwest states). The most climate-resilient states (i.e., Minnesota, South Dakota) were those located at higher elevations and more northern latitudes, which supports season lengths over 100-day under low-emission scenarios up to the 2080s, and high emission scenarios by the 2050s. Early and late season segments were the most impacted across the emission scenarios, while other mid-season segments (e.g., Christmas-New Years Holidays) remain resilient for all scenarios in midcentury. By the 2080s, the Christmas-New Year segment is projected to be reduced by up to 66% under high-emission scenarios.

Similarly, Rice et al. (2022) used SkiSim 2.0 to analyze the climate change impacts at 23 ski areas across Sweden, for a low to high-emission scenario (RCP 2.6 to 8.5) in the short (2030s), mid (2050s) and long-term (2080s). The model was run using a natural snow-only scenario and a snowmaking scenario. While 92% of the modelled ski areas have some snowmaking capacity, most do not

currently have capacity over 100% of their skiable terrain. Results showed important regional differences in the average ski season length and projected changes under natural snow conditions. For example, ski season length in Gotaland is projected to decrease 83% by the 2030s under RCP 2.6, whereas Norrland would only exceed a 30% decline under the high emission scenario in the 2080s. The study found these differences correspond with the latitude and altitude of regional ski areas, with Gotaland at a lower latitude (i.e., temperatures are higher versus the rest of Sweden) and also a lower altitude (i.e., 184 m) compared to Norrland and Svealand (584m and 460m, respectively). On the other hand, the results of this study showed that the availability of snowmaking has a positive effect on ski days, increasing the baseline (e.g., Gotaland from 40 to 140 days; Norrland from 181 to 219 days) and reducing the ski length losses (e.g., Gotaland would only exceed a decline of 66% under the high emission scenario in the 2050s and 2080s, and Norrland would have a maximum decline of 27% under RCP8.5 in the 2080s).

Finally, Fang et al. (2021) applied the SkiSim 2.0 model in 116 ski areas in the major ski regions across China, examining four main indicators of climate change impacts: ski season length, operational ski days in ski season segments (i.e., season start, early-season, winter holiday, mid-season, late-season), machine-made snow, and snowmaking needs. The study found that ski seasons in all resorts in China are projected to shorten under all emission scenarios and time frames (see Table 2-2) (e.g., -61 to -5% RCP 4.5; -79 to -6% under RCP 8.5 in the 2050s) with important regional differences that underscore the vulnerability of lower latitude regions compared to northern territories. For example, considering the high emission scenario in the 2080s, the relatively low-latitude areas in eastern and central China (e.g., Shandong, Henan) are projected to have less than 60 ski days, while some resorts in the north, northeast and northwest regions (e.g., Inner Mongolia, Heilongjiang, Jilin, Xinjiang, Qinghai) would have over 100 ski days. In terms of operational ski days, the study found that the majority of lost days in all regions would occur at the season start and late season segments, with the mid-season and winter holiday segments showing less sensitivity. Most of the north, northeast and northwest areas would be operational during the winter holiday period even under the high emission scenario in the 2080s.

2.3.2 Snowmaking needs

Snowmaking production is projected to increase across all ski regions (see Table 2-3). Dawson and Scott (2007) projected increased snowmaking requirements in all 18 ski areas in Vermont under all

emission and time frame scenarios. In the 2010-2039 period, the increase requirements range from 25% to 49% (B1) to 27% to 61% (A1Fi). By 2040-2069, under the high emission scenario, the projections show most areas requiring over 50% more snowmaking and up to over 100% in some cases. In the 2070-2099 period, the needs become more pronounced, with 14 of the 18 ski areas (77%) requiring twice as much machine-made snow than the baseline and low-altitude areas needing more than a 200% increase. Notably, at some ski areas, the temperatures are projected to become too warm to efficiently produce snow during some periods of winter and their ski season lengths are estimated to decline by half. Finally, the study found that all ski areas are prone to experience closures (2010-2039), with only three areas (Cochran, Suicide Si, and Ascutney) falling below 90% probability of being operational during the Christmas/New Year holiday segment in all emission scenarios. Significant changes are projected under the high emission scenario in the 2070-2099 period, where two areas are expected to open for less than 25% of the above-mentioned holiday segment, further denoting contrasts between high and low altitude areas.

Scott et al. (2007) underscored the importance of snowmaking for maintaining ski season length in Quebec, with higher snowmaking requirements in lower latitude ski areas (e.g., Sherbrooke, 25-59%) compared to areas in higher latitudes (e.g., Québec City, 8-24%) by the 2020s. Under the high emissions scenario in the 2050s, all study areas are projected to require twice as much machine-made snow. At the same time, snowmaking costs are expected to increase. Québec City shows very distinct cost increase scenarios in the 2020s (13-22%) and 2050s (31-108%). Sherbrooke shows the highest cost increases in the 2020s (18-53%), but Ste. Agathes-Monts leads in the 2050s (29-142%) due to the shortened ski season in the area and the reduced snowmaking requirements in Sherbrooke. The potential economic impacts were assessed by the 100-ski-day indicator, with results revealing that low latitude ski areas (i.e., Sherbrooke) would be unable to achieve a 100-day season by the 2050s. Similar to other studies', the lost ski days mostly occur at the beginning and end of the ski season (i.e., December and March), with no ski areas projected to lose operational days during the holiday, mid-season and school break segments under both emissions scenarios by 2020s and the low emissions scenario by 2050s.

Table 2-3. Projected increases in snowmaking requirements

Study Area	Author	Baseline snow production (cm)	% Change in Snowmaking requirements					
			2010-2039		2040-2069		2070-2099	
			Low emission scenario	High emission scenario	Low emission scenario	High emission scenario	Low emission scenario	High emission scenario
North America								
Vermont, USA	Dawson and Scott 2007	53~149	+25~+49	+27~+61	+30~+70	+50~+114	+41~+109	+73~+205
Quebec, Canada	Scott et al. 2007	77~132	+8~+25	+24~+59	+18~+44	+116~150	--	--
Northeast USA	Scott et al. 2008	57~225	+11~+46	+0~+42	+3~+39	+12~+86	+12~+65	+3~+155
Ontario, Canada	Scott et al. 2019		--	--	+24~+49	+112~+157		
Ontario, Quebec, Canada/Northeast USA	Scott et al. 2020	31~335	--	--	+64~+179	+88~+256	+82~229	+164~+545
Midwest USA	Scott et al. 2021	76-303	--	--	+56~147	+75~182	+71~+199	+124~+383
Canada	Knowles et al. 2024	46~87	--	--	+50~+119	+60~+140	--	--
Europe								
Tyrol, Austria	Steiger 2011							
Austria	Steiger and Scott 2020	--	+22	+26	+32	+45	+43	+40
Norway	Scott et al. 2020b		27~+65	+31~+104	+37~+104	+51~+140	+48~+168	+146~+340
Sweden	Rice et al. 2022	16~129	+54~+125	+74~+156	+60~+144	+132~+281	+69~+144	+250~+844
Asia								
China	Fang et al. 2021	45~366	8~16	+10~+18	+27~+45	+46~+80	+43~+66	+102~+193

Under a higher emission scenario (A1Fi), Scott et al. (2008) project snowmaking requirements to increase over time across 14 Northeast USA ski areas. In 2010-2039, 25% or higher increases are expected in nine areas, whereas in the 2040-2069 period, 10 ski areas require at least 30% more machine-made snow. In 2070-2099, snowmaking needs are projected to increase by 50 to more than 100% in some areas. However, the warm temperatures make it infeasible to produce snow in five ski areas, thereby leading to declines in snowmaking needs relative to 2040-2069. Additionally, snowmaking costs are expected to surpass the percentage increase in machine-made snow volume due to higher energy demand. To assess the economic impact of the projected shorter seasons and increased snowmaking needs and costs, the study evaluated the 100-ski days (average season below 100 days) and Christmas /New Year holiday (75% probability of ski areas not being operational for the entire holiday season segment) indicators to determine the vulnerability of ski areas. The findings revealed regional differences in the vulnerability to climate change under the two emission scenarios. While some ski areas like Connecticut, western New York, or southeastern New York would reach both risk criteria as early as 2010-2039 under high emission scenario, others like southern Vermont, northeastern New Hampshire and northeastern New York, would be less vulnerable (i.e., do not exceed the economic indicators in either emission or timeframe scenario). Notably, this study found that under the high emission scenario, even with advanced snowmaking, seven ski areas would be lost by 2070-2099 due to climate change.

In Southern Ontario, Scott et al. (2019) note that increased snowmaking production will be required to maintain ski seasons, but with fewer climatically acceptable opportunities to produce snow, as well as increased operating costs. Projections show the greatest need for snowmaking in private and large ski areas, nearly doubling in the 2050s under the low-emission scenario and increasing 112-157% under the high-emission scenario. Small areas will have less increases in snowmaking production (24% to 39% in the 2050s), partly due to their limited snowmaking capacities and locations with fewer opportunities to produce snow under a warmer (RCP8.5) scenario. In the 2050s, the number of suitable snowmaking hours is projected to decline between 22% (RCP2.6) and 39% (RCP8.5) in December, and up to half of the baseline hours under the high emission scenario in the 2080s. Finally, the results revealed two distinct ski futures based on the success or failure to achieve the 2°C Paris Agreement's goals from the international community. Assuming success, the system capacity losses would not exceed 10% in the 2050s and 2080s. Contrastingly, a high emission scenario (RCP8.5) (i.e., failure to achieve the Paris Agreement goal) would trigger system capacity losses ranging from 28% to 73% in the 2050s.

The projections of future snowmaking requirements in Ontario, Quebec and the Northeast of the US (Scott, Steiger, Knowles, et al., 2020) expose increased needs in the late century, especially under the high emission scenario. Increases in snowmaking production range between 308% and 545% in the three regions. Ontario and Québec show higher relative increases than other states, such as Rhode Island or Vermont, related to their current snowmaking capacity and inadequate climatic conditions to produce snow.

Steiger and Scott (2020) modelled the climate impacts on 208 Austrian ski areas using SkiSim 3.0 under moderate (RCP4.5) and high (RCP8.5) emission scenarios in the 2030s, 2050s, and 2080s. The study used season length, snow reliability, and snowmaking volume indicators, as well as two new indicators including terrain days (i.e., available skiing terrain throughout the season, accounting for differences in season length due to snowmaking), and the overall impact of the ski areas' performance at the municipal scale. The study highlighted that 70% of ski areas have snowmaking capacity and when such capacity is considered, the average ski season length increases by 49% compared to relying on natural snow (i.e., natural snow conditions are not considered an adequate indicator of climate change risk for most areas in Austria). Under current snowmaking capacity, shorter ski seasons are projected across all emission scenarios, ranging from -6% (2030s) to -18% (2080s) under RCP4.5, and -7% (2030s) to -49% (2080s) under RCP8.5. However, if snowmaking capacity were to increase, the maximum decline would not surpass -33% in the 2080s under the high emission scenario (see Table 4), showing less sensitivity to climate change.

In Norway, Scott et al. (2020) project that to limit seasonal losses, required snowmaking will need to increase in all emission and timeframe scenarios. However, given that most ski areas do not currently have the required snowmaking capacity, the capital investments required to expand the capacity, paired with the decreasing number of potential days/hours to generate snow, may make ski area managers skeptical about the feasibility of increasing snowmaking as early as the 2030s. The study highlights a significant difference between the snow reliability of ski areas with and without snowmaking. In the reference period, 74% of Norwegian ski areas are snow-reliable without snowmaking, while 98% are reliable with it. Relying solely on natural snow, the share of snow-reliable areas drops to 45-50% in the 2030s, 32-37% in the 2050s, and 13-30% by the end of the century. In contrast, with snowmaking, 93-96% remain reliable in the 2030s, decreasing to 79-87% in the 2050s, and 61-80% by 2080s. The study underscores that the need to invest in snowmaking

infrastructure will continue to rise, but the financial and sustainability implications are not to be disregarded by the industry.

In the US Midwest, a study by Scott et al. (2021) revealed that increased snowmaking capacity will be required across all states under all emission scenarios to maintain continuous ski seasons. The results project a 115-180% increase relative to the baseline by the mid-2050s, and up to 271-355% by the 2080s under high emission scenarios. Moreover, in some states (e.g., Missouri, Indiana, Ohio) increases are projected to be lower due to a high baseline of snowmaking production and increased climatically unfeasible conditions to produce snow. Meanwhile, the northern states of Michigan and Minnesota, where 61% of Midwestern ski areas are located and low baseline requirements are present, are projected to have the highest increases (between 373 and 516%) by the 2080s under high emission scenarios.

Furthermore, snowmaking production is expected to increase to limit season losses in all Swedish ski areas under all emission scenarios (Rice, Cohen, Scott, et al., 2022). Increases required in snow production are estimated between 54-125% (RCP2.6), 67-133% (RCP4.5), and 74-156% (RCP8.5) by the 2030s. Increases become more drastic as time progresses, reaching up to 250-844% under the high emission scenario by the 2080s. Importantly, despite the use of advanced snowmaking and projected increases mentioned above, all ski areas are considered snow reliable during the baseline period, but the ski areas located at low altitudes (i.e., sea level) lose their snow reliability as early as 2030s under the low emission scenario. Those areas in higher altitudes (i.e., Norrland) show more resilience and 65% of resorts are able to maintain snow reliability in the late century under RCP 8.5 scenario.

In China, snowmaking requirements are expected to increase (+27 to +51% RCP 4.5; +46 to +80% RCP 8.5 in the 2050s) (see Table 2-3), as climatic conditions to produce machine-made snow decline (Fang et al., 2021). Moreover, there is high variability between regions which is mainly due to insufficiently cold temperatures to produce snow. The changes are found primarily in the 2050s (-45 to +48% RCP 4.5; -58 to +71% RCP 8.5) and 2080s (-60 to +56% RCP 4.5; -86 to +148% RCP 8.5). Finally, the changes in snowmaking requirements, an indicator that disregards snowmaking limits or temperature thresholds, were similar in all regions and emission scenarios in the 2020s (8 to 16% under RCP 4.5; 10 to 18% under RCP 8.5). In the 2050s, the range varied from 27 to 45% (RCP 4.5)

and from 48 to 80% (RCP 8.5); and for the 2080s, required snow production spanned from 43 to 66% under RCP 4.5 and 102 to 193% under RCP 8.5.

In another recent study, Knowles et al. (2023) explored the environmental sustainability of snowmaking as an adaptation strategy in the Canadian ski market. The study estimated water, energy, and GHG emissions for snowmaking at 136 Canadian ski resorts across four provincial markets (Alberta, British Columbia, Quebec, and Ontario), as well as at a national scale using the SkiSkim2.0 snowmaking model. Based on present electricity emission intensities, three emission scenarios were examined (low – RCP2.6, mid- RCP4.5 and high- RCP8.5) for a baseline (1981-2010) and mid-century (2050) climate scenarios. According to the estimations, average national snowmaking requirements are expected to increase between 55% and 97% by 2050 (based on RCP2.6 and RCP8.5 scenarios). Central ski markets will require less net snow production given the size of snowmaking covered terrain compared to the Western markets. However, Ontario is expected to require the biggest increase under the three projected scenarios (i.e., from 83.5 cm currently to between 156.5 and 200.2 cm by mid-century in the RCP2.6 and RCP8.5, respectively).

2.4 Demand-side responses

Survey-design studies are the dominant method to explore the demand-side response(s) of skiers to climatic variability and change, with ski surveys conducted in Australia (Cocolas et al., 2016; Pickering et al., 2010), Bulgaria (Cholakova & Dogramadjeva, 2019), Canada (Rutty, Scott, Johnson, et al., 2015a, 2015b), the European Alps (Behringer et al., 2000; Steiger et al., 2020; Unbehaun et al., 2008), Germany (Witting et al., 2021), and the US (Dawson et al., 2011, 2013; Dawson & Scott, 2010) (Table 2-4). Collectively, these studies are informed by to Isa-Ahola's (1986) theory of substitutability, whereby skiers can pursue three types of behavioural responses when climatic conditions are undesirable for skiing: (1) spatial substitution (i.e., travel to a different ski resort with favourable conditions), temporal substitution (i.e., go skiing at a different time when conditions are more favourable), or activity substitution (i.e., replace skiing with a different leisure activity. In turn, skier substitution will have direct but differential impacts on the ski industry (e.g., redistribution of skiers, the concentration of demand on fewer days/weeks, and reduction of the number of skiers and skier days). While exact comparisons across geographic studies are constrained due to differences in survey designs and questions asked to respondents, the overall findings suggest that skiers predominantly engage in temporal and spatial substitution (Table 2-4).

Table 2-4 Comparison of survey studies on skiers' behavioural adaptation responses

Author	Country	Sample Size (n=)	Spatial substitution	Temporal substitution	Activity substitution ^a
König (1998)	Australia		63%	31%	6%
Behringer et al. (2000)	Switzerland	1000	49%	32%	4%
Unbehaun et al. (2008) ^b	Austria	540	68%	30%	25%
Pickering et al. (2010)	Australia	351	21%	69%	6%
Vivian (2011)	United States	572	-	40-90%	1-3%
Dawson et al. (2011) ^{b, c}	United States	1167	45% (HIC), 64% (LIC)	47% (HIC), 30% (LIC)	59% (HIC), 40% (LIC)
Dawson et al. (2013)	United States	1167	39%	34%	44%
Rutty et al. (2015a) ^d	Canada	2448	30%	70%	3%
Cholakova & Dogramadjeva (2019) ^b	Bulgaria	126	61%	-	43%
Witting et al. (2021)	Germany	751	18% - 22% (day guests) 21% -26% (overnight guests)	19% - 22% (day guests) 9% (overnight guests)	4% - 22% (day guests) 3% - 30% (overnight guests)

Source: Adapted from Steiger et al. (2019), p. 1358.

Notes:

- a. This included giving up skiing or changing to another snow or non-based activity.
- b. Multiple responses allowed.
- c. HIC: High involvement cluster; LIC: low involvement cluster.
- d. Based on the 'closed today' scenario.

The first published study was by König (1998), who surveyed skiers in Australia and found that 75% would modify their participation in the sport if five consecutive natural snow-deficient winters were to occur, which included 31% who would ski less, 38% would travel to an overseas destination, and 6% who would quit the sport entirely. In a follow-up study, Pickering et al. (2010) found an increase in the percentage of Australian skiers that would alter their behaviour if there were five years with snow-deficient winters (from 75% to 90%), including 69% that would reduce their ski frequency, 15% that would travel overseas to a different location, and 6% who would quit the sport entirely. Behringer et al. (2000) used the same questions in a study in Central Switzerland, finding

that 49% would ski in a resort with more reliable snow (spatial substitution), 32% would ski less often (11% at the same resort and 21% at a different location), and 4% would give up skiing altogether. Of those respondents who stated they would maintain their skiing frequency (58%), 28% would shift to a more snow-reliable resort, while 30% would make no changes.

In a more nuanced study, Unbehaun et al. (2008) added a discrete choice experiment (DCE) to ask skiers in Austria about their behavioural responses to several snow-deficient ski seasons, focusing on destination and travel motivations, as well as personal preferences, attributes and potential of snow-independent alternatives. The participants were offered two hypothetical resort choices with different snow conditions; 68% of respondents chose the option of a more snow-secure destination, indicating that they would pay an extra 10% and drive up to an additional two hours to have a snow-secure winter experience. In contrast, 25% of all socio-demographic groups indicated they would give up skiing. Moreover, nearly 30% would trade off an insufficient winter holiday for a summer holiday. Results in this study showed the main motives driving destination choice were found to be physical activity, spending time with friends, and having the ‘winter experience’, whereas the guaranteed snow conditions, the winter experience, and the size of available ski areas were the most important choice determinants. It is important to note that the DCE was uni-directional (e.g., choosing a more snow-reliable resort, but not more detailed characteristics like price), limiting the ‘real-life’ choices skiers would be realistically faced with.

Rather than exploring behavioural intentions to future hypothetical winters (e.g., five years with insufficient snow), a number of studies have also asked skiers how they have responded to past snow-poor winters to make inferences about future behaviours. For example, Vivian (2011) surveyed 572 skiers in the US Northeast, providing participants with details of the record-warm winter conditions to reduce recall bias among the sample (e.g., “average snowfall at ski resorts in New England is 40% lower than normal). The majority of respondents (87%) indicated they would not alter their usual skiing frequency in seasons that resembled the mentioned winter (i.e., 2001-02), 11% would increase their frequency to compensate the season time reduction, and only 1% would quit skiing for the whole season. Also, between 40% and 92% would wait until their preferred resort opened, depending on the scenario presented (2050s mid-range or worst-case scenario) and the locations of the respondents. Activity substitution was found to be present in only 3% of the responses, while spatial substitution was not explored. Similarly, Dawson et al. (2011, 2013) asked 1167 skiers in the same region whether ‘very little snowfall like the winter of 2001-2002 season’ in the next three out of five

seasons would influence their participation in skiing. While the study sought to evaluate the future reaction of ski tourists, it provided a context to recall past experiences (i.e., very little snowfall like the winter of 2001-2002 season) to help mitigate misinterpretations, a limitation recognized in previous studies. The study found that 51% of skiers had made substitutions in previous seasons with marginal snow, with 60% of skiers having skied within the region, 67% outside of it, and 38% having reduced the frequency of the activity. However, when asked what they thought they would do in future scenarios with similar conditions to those of the 2001-2002 season, similar substitution results were recorded (46% indicated they would engage in substitution of some kind versus 51% who effectively did it), but a reduction of 21% (within the region) and 28% (outside of the region) was found compared to spatial substitution (i.e., 39% responded they would change to a different ski destination) (Dawson et al., 2013). Given that little difference was found between past and future behavioural intentions, the use of statements within surveys that reference previous snow deficient condition may have reduced misinterpretations and improved the reliability of responses. The study also found that the involvement level of the skiers influenced activity substitution, with 30% of respondents from the low involvement cluster stating they would ski less, compared to 47% from the high involvement cluster (Dawson et al., 2011).

While a detailed survey narrative may help participants better visualize future climate scenarios, this approach could bias tourists to respond based on a single extreme season, when climate projections suggest that a record-warm winter will likely become the new climate normal. In turn, Rutty et al. (2015a) surveyed 2429 skiers in Ontario (Canada) and asked skiers how they would respond in three scenarios: if the ski resort was closed today, if it opened at mid-season, or if it was permanently closed. The study used questions referring the weather variability instead of climate change (i.e., ‘if you could not ski at this resort (today) due to lack of snow, what would you do?’), also aiming to avoid the negative emotional connections associated with the topic. As can be seen in Table 2-4, spatial substitution rises as the time of the closure increases (30% today, 48% mid-season, 61% permanent), while temporal substitution presents the opposite behaviour (70%, 50%, 36%, respectively). Similar to previous survey studies (Behringer et al. 2000, Pickering et al. 2010, Konig 1998), only a small portion of the sample (3%) indicated they would give up skiing (i.e., activity substitution), which is significantly lower compared to Unbehaun et al. (2008) and Dawson et al. (2013) (25-44%) (Table 2-4). In a follow-up study, Rutty et al. (2015b) also found that willingness to travel increased depending on the length of the skip trip (e.g., 53% would travel 2 hours one-way,

60% up to four hours for a weekend trip, and 62% over 6 hours for a holiday), with no statistically significant differences in travel distance thresholds based on socio-demographics nor skill level (e.g., beginner vs experience skiers). These findings resemble those in Unbehauen et al.'s (2008) choice experiment, even extending the range of hours ski tourists would travel.

Cocolas et al. (2016) surveyed 231 skiers in Australia, incorporated a push-pull framework with three descriptive scenarios of worsening snow cover conditions to evaluate the probability of substitution in the three alternatives presented: 'reduced snow cover with a mostly functional resort', 'minimal snow cover and minimal operating conditions', and 'no snow cover season'. It is to be noted that Likert scales were used to answer the questions, which were framed in a negative perspective (i.e., 'the scenario would not affect...'). Similarly to Rutt et al.'s (2015a) approach, the term climate change was purposefully excluded to avoid biases. While no percentages were specified in the study, the findings revealed that spatial substitution was preferred over activity substitution, with the substituting behaviours positively correlated to worsened snow cover conditions scenarios. It is important to note that temporal substitution was not included as an option for respondents (i.e., temporal substitution is therefore unknown). In turn, two distinct and significant categories were found, leisure-specific tourists and experience-driven tourists, with the former more likely to spatially substitute given the value placed on participation in the sport and the latter having a higher resilience to poor snow conditions.

Cholakova & Dogramadjeva (2019) surveyed skiers in Bulgaria ($n = 216$) and asked how they would respond to marginal conditions due to climate change, with only a 3% difference between spatial (46%) and activity substitution (43%) behaviours. The majority (76%) of skiers who consider themselves experts would travel to a destination outside of Bulgaria, while only 33% of beginner-level skiers would travel outside the country. When asked about climate change adaptation measures that they would prefer their resort to take, only 9% chose to increase snowmaking capacity (with the greatest support from frequent skiers), with the majority (69%) indicating they want Bulgaria to convert their ski resorts to an all-year destination, followed by diversifying winter products (60%), constructing more pistes and lifts (21%), and offering more summer options (20%).

Steiger et al. (2020) conducted an online survey with 1957 skiers in Austria, including a choice experiment to simulate real-life decisions and evaluate the most relevant resort characteristics during snow-poor winter seasons. The study found snow conditions are the highest-ranked and most

important factor in destination choice (an average of 48% of the total evaluation relies on this factor), which is similar to findings in the USA (Vivian, 2011). However, 39% do not rank “snow conditions” in their top 3 attributes, and 64% of respondents rank other factors first (e.g., price/performance ratio, uncrowded slopes, no wait times at ski lifts, size of ski area), which suggests that poor snow conditions could be compensated through other means. Price performance and crowding were also very important factors, with 30% of respondents prioritizing them above snow conditions. These findings are similar to those of Unbehaun et al. (2008) where price was ranked as one of the most important factors, and long waiting times (i.e., crowding) were not acceptable (Unbehaun et al., 2008). Interestingly, factors directly associated with snow reliability and potential closure of slopes were not often chosen (i.e., altitude, snowmaking capacity). Results showed that if there was mostly machine-made snow, 19% of skiers would not go skiing. This finding compares to previous studies reflecting that artificial snow is considered a necessity, but not a preferred condition (e.g., Unbehaun et al., 2008). Additionally, the study found that a reduction of half the capacity of the resorts would result in 30% of respondents opting to stay home. Survey results show that if there are spatial substitution options, total demand would remain stable, with an increase in demand for climatically reliable slopes and a corresponding drop in demand for those resorts with reduced snow reliability. If all destinations are affected (i.e., no substitution options), demand is projected to drop 12% (assuming artificial snow provides a good skiing experience). In contrast, if snow reliability is low and artificial snow does not create a positive experience, demand would drop 64%. Furthermore, activity substitution (e.g., non-snow-based activities) cannot compensate for marginal snow conditions and declining snow reliability in diversified destinations.

Lastly, with a focus on differentiating between daytrip and overnight tourists, Witting et al. (2021) surveyed 751 skiers in Germany and found that the former place more importance on snow conditions and thereby more likely to engage in behavioural substitution (Table 2-4). For example, of the day-trippers, 18-22% were categorized as ‘destination switchers’ (i.e., spatial substitution) who place more importance on snow conditions, 19-22% as ‘time switchers’ (i.e., temporal substitution) who are sensitive to both snow and weather conditions, 15%-22% as ‘activity switchers’ (i.e., activity substitution) who place more importance on weather conditions that are not necessarily related to snow conditions (e.g., sunshine duration), 4%-5% as ‘stop winter sport’ (i.e., activity substitution), and 37%-38% were denominated ‘business as usual’ who continue their activities regardless of poor weather or snow conditions. In comparison, 21%-23% of overnight guests were categorized as

‘destination switchers’, 9% as ‘time switchers’, 27%-30% as ‘activity switchers’, 3% as ‘stop winter sports’, and 35%-37% as ‘business as usual’ skiers. The study showed day-trippers place more importance on non-snow requirements (e.g., train accessibility, good food) compared to overnight tourists who prefer to have snowmaking infrastructure. The results support that changes in tourist’s responses are influenced by personal determinants (e.g., lifestyles, sociodemographic characteristics), and not solely by weather and climatic conditions (e.g., sunshine, precipitation), nor the type of snow conditions (e.g., artificial snowmaking, deficient snow depth, landscapes with low natural snow cover).

In addition to how skiers will behaviourally respond to climatic changes, survey results have found that skiers not only have high levels of climate change awareness but also perceive climate change to be an important risk to their sport (see Table 2-5). In Central Switzerland, 83% of 1000 skiers surveyed across five resorts indicated that climate change would threaten ski tourism, with almost 50% estimating the impacts would occur between 2000 and 2030 (Behringer et al., 2000). In Vienna, Austria, 73% of the 540 surveyed skiers who participated in a discrete choice experiment indicated being aware of climate change and its impacts, with over 70% having experienced snow-insufficient ski seasons in the past winters (Unbehaun et al., 2008). In Australia, 79% of the 351 skiers surveyed thought that climate change would negatively impact the ski industry, with 59% estimating that the risks would materialize before 2030 (Pickering et al., 2010). At Pamporovo resort in southern Bulgaria, 126 skiers were asked if they considered climate change to be a threat at the global, regional, and resort level, with risk perceptions correspondingly decreasing at each geographical scale (e.g., a mean of 4.4 on a five-point Likert scale at the global scale versus 3.8 at the local/Pamporovo scale) (Cholakova & Dogramadjeva, 2019). The findings support literature that describes climate change to be perceived as a distant phenomenon (Trobe & Liberman, 2010) and is therefore unsurprising that the most frequent behavioural adaptation stated by tourists in six out of the eight survey-based studies is spatial (i.e., would travel to a different resort) with skiers opting to continue their support despite perceived and/or real climate risks (i.e., low activity substitution) (Table 2-4).

Table 2-5 Climate change concerns among skiers

Study	Location	Climate change concerns for ski conditions (%)
Behringer et al. (2000)	Switzerland (<i>n</i> = 1000)	83 ^a
Cholakova and Dogramadjeva (2019)	Bulgaria (<i>n</i> = 126)	3.8 ^b
Unbehaun et al. (2008)	Austria (<i>n</i> = 540)	73 ^c
Pickering et al. (2010)	Australia (<i>n</i> = 351)	79 ^d
Hoogendoorn et al. (2021)	Africa (<i>n</i> = 170)	64 ^e

^a Do you perceive climate change to be a threat for ski tourism?

^b Climate change represents a serious threat to snow sports in Pampovoro (value presented as a mean, not percentage).

^c No phrasing found in the study

^d Do you believe that global warming could threaten skiing in Australia?

^e Climate Change will impact tourism in Afriski (ski resort)?

2.5 Snowmaking and environmental sustainability

Given the projections that snowmaking capacity will need to increase across all ski regions in the future (see Table 2-3), it is argued that snowmaking contradicts mitigation goals while simultaneously straining water resources that are projected to become increasingly constrained due to climate change (IPCC, 2022). In turn, snowmaking has brought negative media attention within the context of climate change (see Table 2-6), with headlines questioning the long-term sustainability of artificial snow in a warmer world (e.g., “Snowmaking stretches ski season. But is it sustainable?”, Cox, 2022; “The complicated ethics of creating fake snow”, Reimers, 2022). The media has also highlighted the double-edged sword, stating that snowmaking is not only necessary for the industry in the face of climate change, but it is also maladaptive (e.g., Paddison, 2024; Ressler, n.d.).

Maladaptation is defined by the IPCC (2023b) as

“actions that may lead to increased risk of adverse climate-related outcomes, including via increased greenhouse gas (GHG) emissions, increased or shifted vulnerability to climate change, more inequitable outcomes, or diminished welfare, now or in the future” (2023b, p. 2915).

Not all media attention is negative, with some outlets noting improvements in snowmaking technologies (e.g., “Greener snowmaking is helping ski resorts tackle climate change” Root, 2024), but nevertheless drawing attention to the need for energy-efficiency, including the importance of transitioning to renewable energy sources (e.g., “Artificial snowmaking: Sustainability must become a priority” Ralls, 2023). In addition to the media drawing attention to the water and energy needs of snowmaking, headlines have also identified human health concerns related to additives used for snowmaking (e.g., Snowmax), which has been posed as risky to the surrounding ski communities (e.g., “Artificial snow 'could make you sick': report" The Local, 2015).

Table 2-6 Example media headlines on the sustainability of snowmaking

Headline	Media Outlet	Author
Vermont Snowmaking gets bigger, stronger and greener	AP News	Associated Press
Artificial snow could make you sick	The Local	The Local (2015)
Artificial snow: A slippery slope	American Chemical Society	Dingle, Adrian (2019)
Is Artificial snowmaking detrimental to the environment?	China Daily	Xinhua (2022)
A sustainable solution for artificial snowmaking	Innovation Origins	Suntinger, Hildegard (2022)
Ski resorts aim for more efficient snowmaking amid drought	AP News	Peipert, Thomas (2022)
Virtually all of the Beijing snow is fake – a resource-intensive, ‘dangerous’ trend as climate warms	CNN	Van Dam, Derek (Van Dam, 2022)
Snowmaking stretches ski season. But is it sustainable?	MSU Denver RED	Cox, Mark (2022)
The complicated ethics of creating fake snow	Deseret News	Reimers, Frederick (2022)
Artificial snowmaking: Sustainability must become a priority	Earth.com	Ralls, Eric (2023)
New artificial snowmaking technology could offer a lifeline to struggling ski resorts	CNN	Paddison, Laura (2024)
Greener snowmaking is helping ski resorts tackle climate change	The Guardian	Root, Tik (2024)
Snowmaking in the Time of Drought	The Sustainable Play Reader	Rassler, Brad (n.d.)

Researchers have similarly claimed that snowmaking uses substantial amounts of water, but often without empirical evidence (e.g., Gerbaux et al., 2020; Wilson et al., 2018). An exception is Moser and Baulcomb (2020), who state that the Davos Ski Resort (Switzerland) uses up to 14 million m³ of water each winter season, exceeding the annual water use of the capital city (Bern). In the same region, it has been estimated that the Parsenn and Jakobshorn ski areas use approximately 600,000 m³ of water for snowmaking, which is linked to a 50% reduction in water levels in Lake Davos during the winter season and corresponds to 33% of the annual drinking water of the area (de Jong, 2015). In Kitzbühel (Austria), it has been estimated that water demand for snowmaking has increased four-fold between 2004 and 2010 to reach more than 2 million m³ (de Jong, 2015). Knowles et al. (2023) estimate national water use for snowmaking in Canada to be 43.4 million m³, which is expected to increase in the future, though improvements in snowmaking technology and expansions in snowmaking-covered terrain will influence the quantity used. As a continent, François et al. (2023) estimate the median annual water requirement for snowmaking across Europe to be 103 million m³, which assumes 50% of ski slopes are covered by machine-made snow, which is projected to increase between 8-25% at +2°C warming scenario and increase 14-42% under a +4°C scenario.

To assess sustainability, it is important to differentiate between water consumption versus water use, with the former defined as “the portion of water use that is *not* returned to the original water source after being withdrawn” (Reig, 2013, p. 1). To assess consumption, an experimental study by Grünewald & Wolfsperger (2019) estimated that total water losses from snowmaking was within the range of $7 \pm 35\%$, with little evidence of evaporation and sublimation that would cause the transfer of water resources between watersheds (i.e., water use, not consumption). In terms of water use for sustainability, a critical consideration is the source of water that is being drawn from for snowmaking (Scott et al., 2022). Water sources may include lakes, rivers, and streams, as well as groundwater (e.g., from municipalities’ wells) and at reservoirs built specifically for snowmaking. The sources can be within the ski operator’s land, but other times, operators may extract from adjacent or distant land, where water rights must be acquired and redirected. Using groundwater for snowmaking has been considered maladaptive as it creates a situation of water scarcity for future generations, shifting climate risks to other users and ecosystems (Scott et al., 2022). Furthermore, in locations where there are few withdrawal regulations, policies and/or limited monitoring, there is a higher potential to adversely affect vulnerable populations or ecosystems. In 2014, St. Johann Ski Resort (Austria) tripled the amount of water that had been authorized, withdrawing (42,000 m³ of water instead of the

14,000 m³ allowed by the local authorities (ORF, 2014). According to the resort's management team, more water was required due to a combination of snowmaking capacity expansions and marginal climatic conditions (ORF, 2014). That same year, Kleine Scheidegg-Männlichen (Switzerland) was accused by Pro Natura, a nature protection association, of illegally withdrawing water from streams through permanent installations (Guggenbühler, 2014).

Concerns that snowmaking can negatively impact water quality have also been raised. For example, Kangas et al. (2012) found that snowmaking contributed to an increase in nitrogen and phosphorus levels in lakes in Finland, which can lead to eutrophication (i.e., the potential excessive growth of algae and other cyanobacterial organisms). Rixen et al. (2003) argue that because machine-made snow melts slower than natural snow, the delayed spring runoff not only impacts biodiversity, but can also change plant species composition due to the fertilizing effect of increased water input on ski slopes. Moser & Baulcomb (2020) also point out that the nitrates can sometimes be used to produce artificial snow to lower the melting point (e.g., competition events such as World Cups and Olympics), which has been found to negatively impact the vegetation and water ecology in the European Alps (Rixen et al., 2008 retrieved from Moser & Baulcomb, 2020). The environmental and human health-related impacts of using salts and snow additives are controversial¹ with additives forbidden in several countries (e.g., Germany, Austria) (Wintersport Arena, n.d.). In a review paper by de Jong (2015), the general lack of higher altitude hydrological data in scientific publications is underscored, noting that despite the salience of identifying and treating water pollution sources driven by the ski industry, no empirical studies are available to adequately assess water quality degradation driven by snowmaking.

In addition to water resources, snowmaking has also been negatively linked to high energy consumption, which is contradictory to global climate mitigation goals. For example, snowmaking electricity use in Davos, one of the largest ski resorts in Switzerland, was estimated to be approximately 1.7 million kWh in 2006/2007, or roughly 25% of Davos' cableways total energy consumption, and around 250 times the per capita annual Swiss energy consumption (Moser & Baulcomb, 2020). Authors have also indicated that the continued investment in snowmaking technology locks in regional dependencies on non-renewable energy (Berard-Chenu et al., 2022),

¹ The additives are products with ice nucleation activity (INA) to enhance ice crystal formation, facilitating the production of machine-made snow, which can include dangerous types of bacteria (e.g., phytopathogenic or dead bacteria) (Lagriffoul et al., 2010).

preventing the industry from shifting toward alternative and more sustainable development paths that minimize the risk of maladaptation (Abegg et al., 2017). In Canada, it has been estimated that snowmaking currently uses 478,000 MWh annually, resulting in snowmaking-related emissions of 130,000 tonnes of CO₂e per year, with the authors noting that emissions will decline sharply in the future as provincial electricity grids decarbonization under current policy targets (N. Knowles et al., 2023). Nonetheless, provincial differences will persist, with Alberta's fossil fuel-reliant electricity grid remaining responsible for approximately 96-97% of national snowmaking emissions in the current policy scenario, or approximately 10 times higher emissions per skier visits compared to the British Columbia, Ontario, and Quebec (i.e., 7370 gCO₂e, 554 gCO₂e, 520 gCO₂e, 17 gCO₂e, respectively). Francois et al. (2023) estimated the total annual electricity requirement for snowmaking in 12 European countries at 309 ± 103 GWh (assuming 50% snow coverage), which is projected to increase 18- 24% on average in a +2°C and +4°C climate warming scenarios. In turn, the annual carbon footprint of snowmaking in these European ski markets was estimated to be 78 ± 26 kt CO₂eq, increasing to 93 ± 31 CO₂eq (+2°C warming scenario) and 97 ± 32 CO₂eq (+4°C warming scenario). Importantly, considerable footprint differences were found across each of the European countries, which, similar to the Canadian study, was largely dependent on the carbon intensity associated with electricity source, which is expected to decline in the future as a result of decarbonization-related policy changes.

To better assess whether or not snowmaking ought to be considered a maladaptive climate change strategy, Scott et al. (2022) applied a five criteria adaptation framework developed by Barnett and O'Neill's (2010) that includes: (1) GHG emissions increase, (2) high opportunity costs (environmental, social, or economic) in comparison with other alternatives, (3) disproportionate impact on vulnerable populations, (4) reduced adaptation incentives by the creation of dependencies; and (5) path dependency reinforcement through sizeable infrastructural investments. The study found that the degree to which snowmaking can be considered successful or maladaptive ultimately depends on the local socio-ecological context, including the differences in technological and operational conditions that play a significant role in the adaptation outcomes. For example, in regions where there is low water stress and the electric grids are renewable (e.g., hydroelectric), snowmaking can be successful. In contrast, regions with high water stress and high carbon-intensity electricity grids (e.g., fossil fuel), snowmaking can be maladaptive. Moreover, given that the framework includes five criteria, it is inappropriate to straightforwardly deem snowmaking as either maladaptive or

sustainable, but rather recognize that snowmaking is on an adaptation continuum, depending on how each criterion is assessed. Importantly, a layer of complexity is added due to the different perspectives of multiple stakeholder groups who may prioritize the criteria differently, with the opportunity costs and impacts subjectively evaluated based on stakeholder perceptions.

2.5.1 Snowmaking perceptions

To date, research exploring perceptions of snowmaking as a climate adaptation strategy has predominantly focused on ski industry stakeholders (e.g., ski resort managers or area operators, industry associations, NGOs, businesses) (i.e., supply-side), with very few studies exploring tourists' (i.e., demand-side) perspectives. The first study to explore snowmaking perceptions was conducted by Hopkins (2014) in New Zealand, who interviewed ski industry representatives ($n = 33$), including ski field operators, peripheral business operators (e.g., ski hire, apparel, ski tour guides), community stakeholders (e.g., leaders with council positions, residents), and skiers. The findings revealed diverse perspectives, with industry participants indicating that snowmaking was not just a short-term business strategy, but rather a long-term climate change adaptation strategy. In terms of the skiers, some viewed snowmaking as a successful strategy that improved snow quality, while others highlighted environmental and social concerns that were not raised by industry nor community stakeholders (e.g., water usage, energy consumption and the implications for carbon emissions, ethical issues of resource allocation). These findings are supported by Cholakova and Dogramadjeva (2019), whose study found that 39% of skiers in Bulgaria ($n = 126$) were uncertain about the environmental, social, and economic impacts of snowmaking, with 25% indicating negative feelings about machine-made snow.

Moser and Baulcomb (2020) conducted interviews with a diverse group of Swiss stakeholders ($n=31$), including academics, ski industry businesses, the Farmer's Association, NGOs, government officials, and a National Winter-Sports Organization. The study concluded that snowmaking was associated with three main concerns, including high water usage, high electricity consumption, and biodiversity degradation, with consensus across participants that snowmaking strategies must be place-specific. In turn, industry representatives could be categorized as *Conservative Ecologists* (22% of the study variance; perceived snowmaking as an inappropriate strategy that leads to vegetation loss, changing biodiversity, and soil erosion), *Universalists* (19% of the study variance; supported the consideration of social, economic, and environmental dimensions within the development of long-

term, site-specific sustainability strategies), or *Winter Industry Preservers* (17% of the study variance; preserving status-quo is a non-negotiable priority with a strong focus on economic development).

Hoogendoorn et al. (2021) similarly explored climate change awareness and perceptions of snowmaking as an adaptation strategy in Lesotho (Africa), which included interviews with Afriski ski resort managers ($n = 4$). The managers perceived snowmaking as a necessary climate strategy, with plan to further invest in snowmaking technology to expand their capacity (i.e., add more ski trails) despite climatic changes. However, concerns over water scarcity was identified as a potential limitation for the ski industry in the region. Similarly, Wilkins et al. (2021) conducted interviews with eight Utah ski resort managers who also deemed snowmaking as a necessary business strategy to maintain adequate conditions (i.e., quality and quantity of snow) to keep attracting visitors to the resort. Concerns about water availability and temperatures to produce snow were raised as barriers to snowmaking in future warmer scenarios.

Rice, Cohen, & Scott (2022) interviewed nine ski resort managers in Sweden, concluding that managers do not perceive snowmaking as a climate change adaptation strategy, but rather a necessary business strategy to maintain ski demand, which aligns with the findings of Blin-Dominguez (2022) who used semi-structured interviews with three ski resort managers and the Minister of Environment, Agriculture and Sustainability in Andorra. All interviewees perceived snowmaking as a necessary adaptation for the industry, with high confidence that the technological evolutions would counteract future impacts of climate change in the region. Water use was not perceived to be problematic by ski managers, noting the use of recycled water from reservoirs. In contrast, the government official highlighted potential future water access limitations. The future economic feasibility of snowmaking was mentioned to be a concern, as managers projected increases in the electricity price due to warmer temperatures. Furthermore, emissions were highlighted as a concern by the government interviewee, and actions to achieve carbon neutrality from operations were indicated by the other participants.

2.6 Risk perceptions and psychological distance

Research has shown that direct personal experience of an event, which would equal being psychologically *close* spatially, temporally, socially and hypothetically (i.e., the perceived confidence of a future event occurring), can have a positive influence on the acceptance of climate change (McDonald et al., 2015; Milfont et al., 2014; van der Linden, 2014). Previous studies have revealed

correlations between people's perceptions and personal experience of relatively minor climatic events (e.g., weather or temperature anomalies) that can be attributed to climate change and thereby an increased climate change risk perception, including worry about climate change and belief in the anthropogenic causes of the phenomenon (Akerlof et al., 2013; Donner & Mcdaniels, 2013; McDonald et al., 2015; Taylor et al., 2014; Weber, 2006). Relatedly, research has found that as the temporal dimension of the 'psychological distance' increases, the mental portrayals of risks associated with climate change become less concrete and more abstract (Spence et al., 2012; van der Linden, 2017). Future risks are mentally construed differently than present risks (Trope & Liberman, 2010; van der Linden, 2017). In this way, as the impacts of climate change are framed mentally closer to the person, the risks are perceived psychologically closer, thus increasing the concern levels. Furthermore, previous literature has persistently underscored that females tend to have higher risk perceptions than males (Davidson & Freudenburg, 1996; Hitchcock, 2001; Horne et al., 2021; D. Liu et al., 2018; Lujala et al., 2015; Slovic, 1999), including those related to environmental and climate change issues (van der Linden, 2015). Moreover, women have been characterized as more concerned about human health, due to their close relationship with birth and life (Slovic, 1999). Additionally, some studies have concluded that younger individuals have higher risk perceptions than older individuals as it relates to environmental issues and climate change (Champ et al., 2013; Schneiderbauer et al., 2021; Sherpa, 2014).

2.7 Research gaps and opportunities

Climate change is happening and already impacting the ski industry, influencing behavioural substitution among skiers. Spatial substitution is expected, with demand shifts that would benefit ski destinations with better operational conditions and higher snow reliability (Dawson & Scott, 2010; Rutty, Scott, Johnson, et al., 2015a; Scott, Steiger, Knowles, et al., 2020). While research on the demand-side response of skiers to climate change is increasing, there are notable geographic gaps in the literature (Steiger et al., 2019), including not only Africa and South America (Steiger, Knowles, et al., 2022), but also western Canada. Also, no known studies have gathered survey data immediately following a record-warm winter to understand how skiers responded to marginal snow conditions, instead studies have relied on self-declaration of future behaviours. Considerable evidence from the tourism literature has shown that self-declarations on a survey differ from actual behaviours (e.g., Dahlgren & Hansen, 2015; Gössling et al., 2012; Juvan & Dolnicar, 2016; Nieto-

García et al., 2024). On the other hand, different studies have projected an increase in crowding as demand patterns shift to fewer operational resorts. Yet, no studies were found to have examined how tourists will respond to this new condition, considering that a couple of studies have already identified crowding as not acceptable for tourists (Steiger et al., 2020; Unbehaun et al., 2008).

Moreover, although snowmaking has been the dominant adaptation strategy in response to climatic variability and is projected to increase in the future, only a handful of studies have asked skiers about their perceptions of snowmaking. Importantly, these studies are limited to Bulgaria, New Zealand, and Lesotho, where snowmaking is far less prevalent than in Canada (N. Knowles et al., 2023). Studies have also overlooked skiers' perceptions of snowmaking in the context of climate change, including perceived energy consumption and associated GHG emissions. Given that stakeholders will evaluate the opportunity costs and impacts of snowmaking differently (Scott et al. 2022), skier perceptions of the sustainability of snowmaking is an important gap in the literature that requires research consideration.

Chapter 3

Research Methods

3.1 Introduction

This chapter outlines the research method utilized to assess skiers' and snowboarders' responses to climatic conditions, and perceptions of snowmaking as a sustainable adaptation strategy. It offers an overview of the research design, participants, recruitment, questionnaire design, data collection process, data analysis, and research limitations involved in this study.

3.2 Research design

This empirical study utilized a survey design to assess skiers' and snowboarders' responses to changes in ski conditions, their participation patterns and acceptability thresholds, as well as perceptions of snowmaking as a sustainable adaptation strategy. The survey design builds on previous studies that have also examined skiers behavioural responses to changing climate conditions (e.g., Dawson et al., 2013; Rutty, Scott, Johnson, et al., 2015a; Steiger et al., 2020; Unbehaun et al., 2008; Vivian, 2011). A structured online questionnaire with open and close-ended questions was administered using Qualtrics (an online survey platform) through different sampling methods. Questionnaire surveys are an appropriate and effective method to capture primary data from a large sample population (Green, 2017) in order to objectively gain broad insights into individual's opinions, perceptions, and behavioural changes from large sample groups (Creswell & Creswell, 2018). Moreover, online questionnaires are cost-effective and time-efficient (Regmi et al., 2016), especially when trying to reach a geographically distributed sample (i.e., across Canada) (Regmi et al., 2016).

However, online survey design also presents some disadvantages and limitations, such as the lack of flexibility and depth in the participant's perspectives that qualitative methods (e.g., interviews) can provide (Hopkins & Maclean, 2014). Moreover, the research results depend directly on the quality of the survey instrument, which is fundamental in determining the validity and reliability of the findings (Creswell & Creswell, 2018). Additionally, self-reported evaluations can potentially be influenced by social desirability bias, a phenomenon whereby answers reflect what the respondent believes to be the "correct" answer (Fisher, 1993). In survey-designed studies, participants are required to respond to their current conditions or are requested to reply to survey questions based on how a past or imagined

future self might react (Markowitz & Bailenson, 2021), not necessarily reflecting actual behaviours (Dahlgren & Hansen, 2015; Nieto-García et al., 2024). Finally, low response rates can be a disadvantage when using this research design, therefore defining a strategy to ensure an adequate response rate is essential (Creswell & Creswell, 2018).

3.3 Sample

3.3.1 Study site

The ski tourism industry in Canada includes 240 ski operational areas across the country (Canadian Ski Council, 2023) employing over 35,000 people (Canadian Ski Council, 2019). The industry generates an estimated economic impact of over CAD\$4 billion (CSC, 2023). Skier visits for the 2022/2023 season reached 21 million, including domestic (19.17 MM) and international visitors (1.8 MM). Four major regional markets (i.e., Quebec (QC), Ontario (ON), Alberta (AB), and British Columbia (BC) comprise 96% of Canada's skier visits and skiable terrain (Canadian Ski Council, 2023). The diverse areas offer a variety of skiing experience across the geographies given the socio-ecological contexts in which they operate, resulting in various climate impacts and distinct applicable climate adaptations (N. Knowles, 2023).

According to the Canadian Ski Council (2023), there are slightly more male than female skiers nationally (56% and 44%, respectively). The largest group of skiers and snowboarders is represented by those aged 35-49 (24%), followed by those between 50-64 (22%) (Table 3-1). The 2022/2023 national age average for Canadian skiers is 42.9 years, with a declining population of skiers and snowboarders aged 18-34, as well as those under 17 years old (Canadian Ski Council, 2023). Nationally, 13% of skiers self-identify as beginners, 43% as intermediate, and 41% as experts, with most respondents (60%) indicating having 11 or more years of skiing or snowboarding, followed by those with less than six years in the sport (21%), and 6-10 years of participation (19%). Finally, in the last available report with ticket type profiles, the Canadian Ski Council found that during the 2018 season, 57% used some sort of lift ticket (i.e., single-day tickets (41%), multi-day tickets (8%), half-day or hourly tickets (4%), and night tickets (4%)), while 33% of skiers used season-pass holders at the ski area. Another 7% of skiers used a frequency card, with a few skiers (4%) stating other type of lift. Notably, 45% of skiers they personally own a season pass at any ski area, reflecting the mobility of skiers across territories. Moreover, the statistics reflect that those who regularly ski and participate

every season, which account for more than half the skiers (55%), tend to be season-pass holders (73%).

Table 3-1 Canadian ski market demographic information

Variable	Subcategory	National average (%)
Gender^a	Female	56
	Male	44
Age	18-24 years old	20 ^a
	25-34 years old	16 ^a
	34-49 years old	24
	50-64 years old	22
	65+ years old	11 ^a
Self-rated experience	Beginner	13 ^b
	Intermediate	43 ^b
	Expert	41 ^b
Years in the sport	Less than 6 years	21% ^b
	6-10 years	19% ^b
	11+ years	60% ^b

Sources: (Canadian Ski Council, 2018, 2019, 2023)

^a Information for the 2022/2023 year was not available. The average of snowboarders and skiers for the 2018/2019 stats report was utilized as a reference.

^b The values used for this variable were from the 2017/2018 Consumer profile satisfaction survey, as no updated information was available during the study.

3.3.2 Population

A total of 209 adult participants (i.e., 18 years or older) completed the survey questionnaire. The sample population consisted of self-identified skiers and snowboarders who had skied in Canada during the 2023/2024 winter season.

Participants for the study were recruited online using a convenience and snowball sampling method. While random sampling was not possible for this study due to time and economic constraints, the dissemination of the survey through specialized groups and organizations was considered appropriate to represent the population targeted for the study. Online surveys were shared through active skier and snowboarder networks from non-profit organizations related to the sport. The organizations who accepted to disseminate the survey to their members included Protect Our Winters (POW) Canada, which is a not-for-profit organization that unites over 34,000 skiers from across Canada to advocate for policy solutions to climate change (*Protect Our Winters Canada*, 2024), and Beaver Valley Destination Stewardship, a volunteer nonprofit organization dedicated to conserving Beaver Valley (ON) through sustainable tourism practices. Additionally, the personal Facebook account of the researcher was used to share the survey link in three private and public skier and snowboarders' specialized Facebook groups (Toronto and area ski and snowboarding, Vancouver Snowboard Club, Barrie Snowboarding & Skiing Buy/Sell/Trade) after permission was granted by the groups' administrators or content moderators. Through the snowball sampling approach, the administrator of the group Women in Skiing/WIS/Le ski au féminin (a chapter from CSIA) contacted the researcher, with permission requested (and subsequently granted) to publish the survey link on their Facebook page. The WIS administrator also offered to share the survey link on the national Facebook group of the Canadian Skier Instructors Alliance (CSIA) to give access to the broader sample. After permission was granted, the survey was also published on this channel. Altogether, these Facebook groups included approximately 15,000 members. It must nevertheless be noted that in social media groups, it is difficult to assess the number of active and engaged members, which could lead to lower potential participants reached. While other relevant Facebook groups were approached (e.g., Whistler Blackcomb Skier and Snowboarders, Banff Shredders – Banff ski and board buddies, Banff/lake Louise Ski/Snowboard buddies, Ski & Snowboard Canada gear for sale), no response was received. Overlapping between the social media groups may exist, with individuals being part of multiple groups. However, it is assumed that no duplication of answers was received.

The researcher recognizes that the sampling method has some limitations. First, the members of POW Canada and Beaver Valley may not accurately reflect the entire population, as this sample has a higher level of engagement with sustainability and climate change topics. Also, the respondents from the Canadian Ski Instructor's Alliance could potentially be a biased sample in terms of experience. Despite these potential biases, responses are still considered valid and must be analyzed with caution.

3.4 Survey design

3.4.1 Questionnaire design

The survey instrument used for this research was built on previous studies conducted by Rutty et al. (2015a) and Steiger et al. (2020), which explored skiers' adaptation behaviours and ratings of ski resorts conditions, adding novel sections of snowmaking perceptions in the context of environmental concerns pointed in the literature. A 28-item survey questionnaire was meticulously planned to address key design considerations such as length, question order, phrasing, and layout. The questionnaire assessed respondents' 1) climatic experiences during the 2023/2024 ski season, 2) thresholds of acceptability, 3) perceptions of snowmaking as a sustainable climatic adaptation, 4) future behavioural responses, and 5) demographics. The final version of the questionnaire can be found in Appendix A.

The questionnaire started with the consent form, followed by a question about the last year the participants' skied or snowboarded in Canada, which was used as a screening question (i.e., if the respondent had not gone skiing or snowboarding during the 2023/2024 season, they were automatically directed to the end of the survey). Next, respondents were asked to identify the province(s) where they skied/snowboarded in 2023/2024.

The following section captured the participants' behaviours during the last ski season (i.e., 2023/2024) using a multiple-choice question that provided context on Canada's record warm conditions. Using a display logic, respondents who answered they had either skied or snowboarded about the same or more than most seasons, were asked a follow-up question to further understand their response to the climatic conditions. The response options included 1) waiting for their preferred resort to open and increasing their skiing frequency to compensate for a shorter season, 2) travelling within or 3) outside their province, or 4) travelling internationally to ski at different resorts. Participants were also given an opportunity to provide an open-text answer if those options did not reflect their behaviour during the season.

To assess climatic experiences, the survey instrument included a 5-point Likert scale question ranging from Never (1) to Always (5), whereby participants were asked to indicate how frequently they had experienced 14 winter and ski resort conditions, including natural snowfall, machine-made snow, thin batches on the slope, reduced hill access, crowding on the slope, and other conditions. Additionally, the instrument asked participants to rate those conditions on a 5-point Likert scale from

Unacceptable (1) to Ideal (5). After these two sections, the questionnaire explored participants' behavioural responses under future unacceptable conditions, providing similar answer options of those presented by Rutty et al. (2015a).

At the core of the survey instrument is a 5-point Likert scale question that asked participants to indicate their level of agreement with respect to snowmaking, from Disagree Strongly (1) to Agree Strongly (5), with statements referring to the necessity of snowmaking to maintain ski seasons, the need of increasing snowmaking's capacity in future years (i.e., 5 and 10 years), as well as the sustainability of this strategy in terms of water usage and water resource impacts, environmental pollution, energy consumption, and health impacts. The statements were informed by previous studies evaluating the concerns about snowmaking and Barnett and O'Neill's (2010) adaptation framework adapted by Scott et al. (2020).

The survey also explored skiers' thresholds of acceptability on snow coverage, crowding, and wait times. The question on snow coverage asked participants to indicate at what point (i.e., a percentage) they would find the snow conditions (natural and machine-made) on a ski slope to be UNACCEPTABLE for skiing (i.e., when they would not go skiing). Participants were then asked what the likelihood was of their resort having that percentage of snow coverage using a multiple-choice question with the response options being 1) improbable (unlikely to occur), 2) remote (unlikely, although possible), 3) occasional (likely to occur occasionally during ski seasons), 4) probable (not surprised, will occur in a given time), and 5) frequent (likely to occur, to be expected). Similarly, participants were asked to determine at what point they thought they would find the ski slope to be too crowded to go skiing and to choose from five options on a multiple-choice question with the response options being $\leq 10\%$ more people than usual, 25% more people than usual, 50% more people than usual, 75% more people than usual, and 80% more people than usual. Similar to the aforementioned snow cover question, this section also asked participants to indicate the likelihood of the chosen crowding scenario occurring using the same multiple-choice options as the snow cover question. Participants were asked to evaluate the difficulty or ease of visualizing percentages in snow coverage and crowding scenarios on a five-point Likert scale with the response options being extremely difficult, somewhat difficult, neither easy nor difficult, somewhat easy and extremely easy. Finally, the survey asked participants to indicate the maximum time they would be willing to wait in line for a chairlift during peak season, as well as the likelihood of the chosen wait time to happen at

their preferred ski resort, using a multiple-choice option that included five minutes or less, between six and 10 min, between 11 and 15 minutes, between 16 and 20 minutes, and more than 21 minutes.

Next, the questionnaire explored respondents' climate change concern levels. A 5-point Likert scale question asked respondents to rate their level of concern from Not at all Concerned (1) to Extremely Concerned (5) regarding changes in temperature and precipitation negatively impacting current and future (i.e., in 5 and 10 years) ski conditions. The term climate change was purposefully avoided in this question to minimize potential biases, similar to Rutty et al. (2015a) and Cocolas et al.'s (2016) approaches. Participants were then asked to indicate their preferred adaptation strategy during periods with limited natural snowfall (i.e., what resort operators should focus on), including close some trails/slopes to concentrate snowmaking on select trails/slopes (i.e., full snow coverage on select trails/slopes), open all slopes, but with narrow and/or thin snow coverage on each slope (e.g., bare terrain patches and/or no snow along the edges of the slope), or increase lift ticket price to support full snowmaking coverage across the entire resort (i.e., all slopes open with full snow coverage). Those who indicated they would prefer their resort to increase lift ticket prices were then prompted to select from five options of price increase percentage they would be willing to accept.

Finally, a set of questions was asked to understand the respondent's profile and demographics, including the distance they typically travel and the maximum distance they would be willing to travel to ski, their skill profile, frequency, and times of skiing during a season, type of lift ticket they purchase, years of experience, age and gender identification.

3.4.2 Pre-testing

A pre-test of the survey was conducted on 185 people before the distribution of the survey. The pre-test included ten of the researcher's friends and family for the full instrument and 175 outdoor enthusiasts (i.e., fishers, hunters, boating and power sports fans) at the Toronto Sportsmen's Show (March 14-17th, 2024) for the sustainability of snowmaking questions. The pre-test provided an opportunity to identify potential improvement areas for the questions, format, and instructions. As a result of the pre-test feedback, slight changes to the ski resort conditions were made to make the statements clearer and to add relevant options (e.g., reduced hill access: not all slopes and chairlifts open) in the winter conditions experience and rating questions. Also, an indication of Canadian ski resorts was added to guarantee the correct framing of responses by participants (i.e., only providing their responses based on Canadian ski resorts and no other countries' experiences). This pre-test

confirmed that questions were understood and provided a sense of time required for the survey completion.

The survey received ethics clearance (ORE #46070) through the Office of Research Ethics at the University of Waterloo in March 2024.

3.5 Survey implementation

The survey was launched online on March 27th, 2024, and remained open until June 28, 2024 (approximately 3 months). As previously noted, a link to the online survey was distributed to members of Protect Our Winters (POW) Canada through an Instagram story and through their monthly online newsletter. During the same period, the survey was posted in the authorized Facebook groups (Toronto and area ski and snowboarding, Vancouver Snowboard Club, Barrie Snowboarding & Skiing Buy/Sell/Trade). The researcher made two reposts in each authorized group; the first repost was made one week after the original post and the second repost was made three weeks after the original post. On April 15th, 2024, Beaver Valley Destination Stewardship agreed to disseminate the survey through their Instagram and LinkedIn web pages and networks. Additionally, through the reach out of Beaver Valley Destination Stewardship's, Beaver Valley Ski Club and Osler Ski Club both circulated the survey to their members. During the month of May, the administrator of the national Canadian Ski Instructors Alliance contacted the researcher and published the survey in their social media group in the third week of June.

Participants were provided with a link to the online survey and a QR code as an alternative distribution method. The introduction of the survey in Qualtrics included relevant details about the study's purpose and objectives, as well as the voluntary and anonymous nature of the research (see Appendix A). A total of 247 surveys were retrieved, 213 of whom indicated they had skied during the 2023/2024 season. Four respondents did not give consent to participate and closed their browser, therefore they were cleared from the data being analyzed, resulting in a total of 209 valid responses for the data analysis.

3.6 Data analysis

Following the online data collection, survey responses were input into the Statistical Package for the Social Sciences (SPSS) (Version 29.0.2) for analysis. Multiple statistical tests were utilized to explore and analyze the data collected. Frequencies were used to analyze responses in each question.

Additionally, Chi-square goodness of fit tests, Kruskal-Wallis tests, Mann Whitney test, and Spearman's rho tests were used to examine differences in the distributions of answers, relationships, and correlations between the variables. All statistical analyses used a 95% confidence level ($p = 0.05$) to determine statistical significance of results. The selection of non-parametric test to analyze the data set was based on the non-normal distribution of the data, the type of data collected (e.g., nominal data and ordinal scales) (La Morte, 2017), as well as the moderate sample sizes (Harpe, 2015). Scatterplots, histograms, and statistical tests such as Kolmogorov-Smirnov (Harpe, 2015) were utilized to verify the distribution of the data set for each analysis conducted. The interpretation of the Spearman's correlation coefficient used the psychology model proposed by Dansey and Reidy (retrieved in Akoglu, 2018) (see Table 3-2). Microsoft Excel was also used to graph experience with conditions, conditions' ratings and snowmaking and sustainability perceptions.

Table 3-2 Interpretation of the Spearman's Rho Correlation Coefficients

Correlation Coefficient		Interpretation (Dansey & Reidy)
+1	-1	Perfect
+0.9	-0.9	Strong
+0.8	-0.8	Strong
+0.7	-0.7	Strong
+0.6	-0.6	Moderate
+0.5	-0.5	Moderate
+0.4	-0.4	Moderate
+0.3	-0.3	Weak
+0.2	-0.2	Weak
+0.1	-0.1	Weak
s	0	Zero

Source: Adapted from (Harpe, 2015, p. 92)

3.7 Research challenges and limitations

This study has several known limitations. First, the small sample size could represent challenges with respect to representation of the broader Canadian ski population and results should therefore be

interpreted with caution. Engagement from members of POW and Beaver Valley Destination Stewardship was limited. To boost response rates, a request was made to POW to share the link for a second time on their email listserv as well as repost the link on their social media (vs. one-time sharing as an Instagram story), as well as a follow up with Beaver Valley Destination Stewardship to resend emails to the members of Beaver Valley Ski Club and Osler Ski Club, which both circulated the survey to their members on their email listserv. Also, due to the late inclusion of the Canadian Ski Instructor Alliance (i.e., 11 weeks after the survey launched), limited access may have reduced responses from this group. Moreover, the recruitment through Facebook was not deemed effective or successful, with various non-responsive administrators. In one case, the researcher was able to post on the group, however, the post was later removed by the administrators. No feedback was provided on why this occurred. With the objective to increase the sample size, the researcher also contacted The Blue Mountains Resort to request permission to survey in-situ, with no positive response. In a similar way, the researcher reached out to the organizers and managers of the World Ski and Snowboard Festival which took place in Whistler, British Columbia in April, 2024, but approval was not granted for in-situ data collection at the event.

In turn, the composition of the sample is likely to be biased given that POW, WIS, CSIA and Beaver Valley's Destination Stewardship all have high levels of ski experience and are likely to be a climate-change aware population given the environmental advocacy of their respective organizations. Moreover, the use of online surveys has limitations compared to in-person surveys, such that online questionnaires are completed without the assistance of the researcher that could result in interpretation errors with no opportunity to ask follow-up questions (Green, 2017), although the pre-testing aimed to minimize misinterpretations and support question clarity. Online surveys distributed through mailing lists and social media platforms can make it difficult to identify the population that could have accessed and responded to the survey (Andrade, 2020), with possible researcher bias with respect to the selection of a social media group (i.e., limited to what the researcher was able to find). In this study, this limitation was partially addressed by distributing the survey to known membership lists as well as social media channels. However, given the small proportion of members who responded, results must be regarded as tentative (Andrade, 2020) as they could potentially be contaminated by nonresponse bias, with those who didn't respond differing from those who did (De Veaux et al., 2022).

In terms of the statistical analysis, this study used non-parametric tests, which are known to have lower statistical power compared to parametric equivalents (De Veaux et al., 2022), as non-parametric tests can lead to some loss of information (Webb, 2023). However, after thoroughly revising the assumptions required for the tests (e.g., sample distributions, sample sizes, type of question and data), it is considered that the results are still valid, although future research could attempt to normalize the data to gain more robustness of statistical analysis.

Chapter 4

Results

4.1 Introduction

This chapter outlines the results from the online skier and snowboarders' survey. The chapter is divided into six main sections. The first section comprises information about skier and snowboarder profiles, including socio-demographic characteristics, experience and skill levels, preferred skiing locations and habits, and their typical and maximum travel distances. The second section focuses on the behavioural responses of skiers during the 2023/2024 season, followed by the climatic and resort conditions experienced during the season. Next, respondents' thresholds of acceptability, including the ratings of ski resort conditions, snow coverage, crowding, and wait time limits, as well as perceived likelihoods of such thresholds being exceeded. The fifth section focuses on climate change concerns and future ski behaviours, including preferred adaptation strategies. Finally, the perceptions of snowmaking as a sustainable adaptation strategy will be explored, including the relationship between perceptions and climate change concerns.

4.2 Respondent profile

A total of 209 skiers and snowboarders who last skied during the 2023/2024 season agreed to participate in the study. Of the respondents, 55% are men, 44% are women, and the remaining 1% identified themselves as non-binary and/or did not disclose their gender.² In terms of age, most respondents are between 35 and 49 years old (31%), followed by 50 to 64 years old (25%), 25 to 34 years old (19%), 65 years or older (17%), and 18 to 24 years old (8%). Furthermore, most participants (86%) indicated they have been skiing or snowboarding for 11 years or more, followed by six to ten years (8%), and a few respondents indicated four to five years (3%), two to three years (2%), and for one year or less (1%). The provinces where participants typically ski included British Columbia (48%), Ontario (43%), Quebec (30%), Alberta (23%), the Atlantic provinces (3%; New Brunswick, Newfoundland and Labrador, Nova Scotia), Manitoba (1%), and Saskatchewan (<1%).

² Only 183 responses were recorded on the question to identify gender out of the original 236 participants who started the survey and the 209 that selected to have skied during the 2023/2024 season.

No respondent selected Prince Edward Island. It is important to note that respondents had the option to select multiple provinces, with 64% of respondents selecting one province, 24% selecting 2 provinces, and 12% selecting three or more. To analyze differences between ski regions, respondents who selected that they typically ski in western Canada (i.e., Alberta and British Columbia) ($n = 76$ or 36 %) and central Canada (i.e., Ontario and Quebec) ($n = 87$ or 42%) were segmented and compared, with those respondents who indicated they had skied in both regions ($n = 41$ or 20%) or in neither of the regions ($n = 5$ or 2%) excluded from the regional comparisons.

The profile of respondents in this study was compared to the national skier/snowboarder profile developed by the Canadian Ski Council (CSC) through their annual ‘stats and facts’ report (Canadian Ski Council, 2023) and the latest available National Consumer Profile Satisfaction Survey report (Canadian Ski Council, 2018). The gender profile from this study is identical to that of the national average (56% male, 44% female). Moreover, from an age perspective, both in this study and at the national level, the largest groups of skiers are aged 35-49 (31% vs 24%) and 50-64 (25% vs 22%), with a slight over-representation of both age groups in this study compared to the national average (Table 4-1). Compared to the national average, this study has an over-representation of skiers that self-identify as experts (69% vs 41%) and underrepresents the beginner and intermediate skill-levels (2% vs 13% and 29% vs 43%, respectively), with most respondents (86%) indicating having 11 or more years of skiing or snowboarding in comparison to the national average³ (60%). Finally, this study showed a high overrepresentation of season-pass holders compared to the national average⁴ (75% vs 33%), and consequently, an underrepresentation of lift-ticket holders (i.e., multi-day, single-day, special), which denotes a highly committed sample of skiers. The accurate representation of gender and main age groups is contrasted by skill level and consumer profiles’ differences, both characteristics that must be considered for the analysis.

³ This average considers the 2018 season as a base.

⁴ IDEM.

Table 4-1. Demographic and skill characteristics of sample (*n* = 209).

Variable	Subcategory	This study (%)	National averageⁱ (%)
Gender^a	Male	56	56
	Female	44	44
Age	18-24 years old	8	20 ^b
	25-34 years old	19	16 ^b
	34-49 years old	31	24
	50-64 years old	25	22
	65+ years old	17	11 ^b
Self-rated experience	Beginner	2	13 ^c
	Intermediate	29	43 ^c
	Expert	69	41 ^c
Years in the sport	Less than 6 years	6%	19%
	6-10 years	8%	19%
	11+ years	86%	60%

ⁱCanadian Ski Council (2024, 2018)

^a In this study, 1% of the sample identified as non-binary or did not disclose their gender. To compare with the national average, only females and males were considered.

^b Information for the 2022-2023 year was not available. The average of snowboarders and skiers for the 2019 stats report was utilized as a reference.

^c The values used for this variable were from the 2017/2018 Consumer profile satisfaction survey, as no updated information was available at the time of this study.

In terms of skill level, the majority of survey respondents indicated they feel most comfortable on expert (black diamond) trails (69%), followed by intermediate (red) trails (29%), and beginner (blue) trails (2%). When asked about the type of lift ticket they typically purchase, of the 184 responses, the majority (75%) stated they buy a season pass, followed by 9% who buy multi-day passes, 9% purchase special lift tickets (e.g., weekday and/or evening passes), 6% selected one-day passes, and the final 1% indicated they buy two-day passes. In terms of the frequency of skiing, the largest group (43%) ski three or more times per week, followed by those who ski one to two times per week (35%), three times per month (11%), twice a month (7%), less than once per month (2%), and once per month (1%). A multiple-choice question that asked respondents to indicate when they typically go skiing/snowboarding found that 90% of participants ski during the day, compared to 25% who ski at night. Furthermore, 74% indicate they ski on the weekends, while 60% go on weekdays, and 26% go on weeknights. The majority of respondents (58%) stated that they ski during the winter holidays (i.e., Christmas and New Year), and 45% during school break (e.g. March break), with 10% of

participants providing open-text responses with alternative options that included “non-holiday ski week/vacations,” “Family Day weekend,” “whenever the snow is good!,” “anytime a lift is running,” and one respondent specified to be “retired and live at a ski resort.”

Almost half of the respondents indicated that they typically travel ≤ 49 km to go skiing (48%), followed by 50-99km (20%), 100-200 km (19%), 500km or more (7%), and 201-499 km (6%). However, respondents indicated they are willing to travel further to go skiing, with the majority indicating a maximum of 500 km or more (53%), followed by 100-200 km (22%), 201-499 km (10%), 50-99 km (10%), and ≤ 49 km (5%) (Figure 4-1).

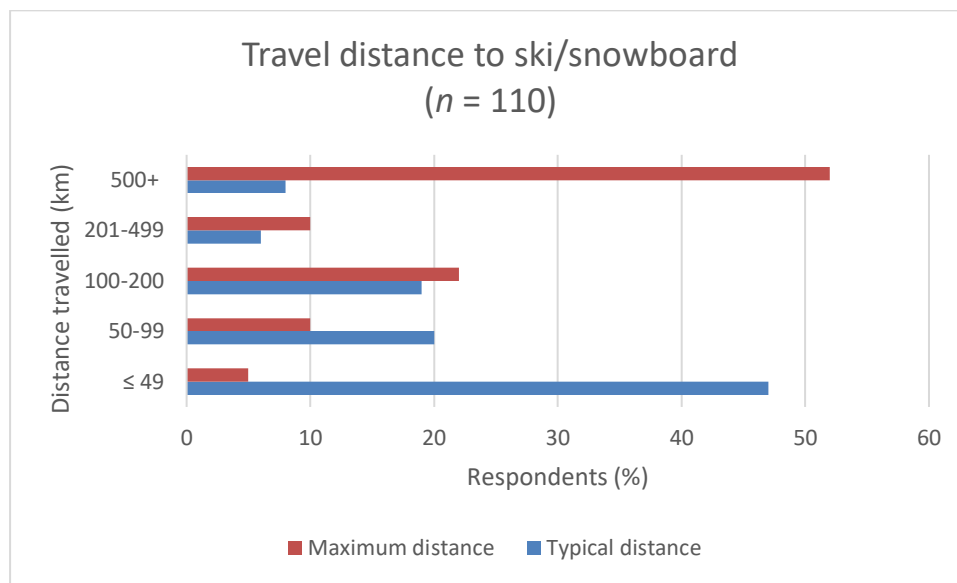


Figure 4-1 Typical and maximum travel distance among survey respondents

4.3 Impact of record warm 2023/2024 winter season on ski frequency

During the record warm 2023/2024 winter season, the majority (57%) of respondents ($n = 209$) skied less than most seasons due to the temporary closure of ski resorts, followed by those who skied about the same (33%), and those who skied more than most seasons (9%)⁵ (Table 4-2). Moreover, of those 68 respondents who stated they skied about the same amount as most seasons, 40% indicated in an

⁵ Only 1% of the participants who last skied in the 2023/2024 season indicated that the 2023/2024 season was their first time skiing in Canada and therefore skied more than most seasons.

open-text answer there had been no closures at their ski resorts. The open-text answers also included: open resorts with fewer runs open, skiing in poor conditions, and shifting to backcountry skiing. Additionally, 34% waited for their resort to open and increased the frequency of their skiing to compensate for a shorter season. In comparison, 26% travelled to different resorts (13% travelled within their province, 10% outside of their province, and 3% internationally). Of the 18 respondents who stated they skied more, 44% indicated through open-text answers that there were no closures at their preferred resorts, 28% waited for their resort to open, and 28% travelled to different resorts (11% within province, 11% internationally, and 6% outside of the province).

Table 4-2 Skiers' behavioural responses during the 2023/2024 season

Ski frequency	Responses (%)	Substitution behaviour
I skied less than most seasons	57%	Not asked
I skied about the same as most seasons ²	33%	40% No substitution (no closures) 34% Temporal substitution 26% Spatial substitution
I skied more than most seasons ^{*1,2}	9%	44% No substitution (no closures) 28% Temporal substitution 28% Spatial substitution
First time skiing in Canada	1%	

*. Statistically significant ($p \leq 0.05$)

¹ Gender

² Age

A Mann-Whitney U test was conducted to assess whether respondents who typically ski in the western (Alberta, BC) versus central (Ontario, Quebec) Canada differed in their frequency of skiing as a result of poor snow conditions in the 2023/2024 season. No statistically significant difference was found between the regional groups ($U = 467$, $z = -1.25$, $p = .213$). Thereafter, a Mann-Whitney U test was conducted to explore whether men and women skiers differed in their frequency of skiing as a result of poor snow conditions in the 2023/2024 season. The results indicate men were statistically likely to ski more than most seasons compared to women (Men: *Mean Rank* = 92.54, $n = 98$; Women: *Mean Rank* = 75.92, $n = 72$), $U = 2,838$, $z = -2.48$, $p = .013$, two-tailed. Next, a Kruskal-Wallis revealed statistically significant differences between age groups and their ski frequency in response to poor snow conditions in the 2023/2024 season ($n = 171$, $H = 15.65$, $df = 4$, $p = .004$). Post-hoc pairwise comparisons using Dunn's method for multiple tests found that the older age groups (50-64, 65+) were statistically higher (i.e., reported to ski more frequently) compared to the younger

age groups. Specifically, the mean rank of ski frequency of respondents 18-24 years old versus 50-64 years old ($p = .006$) and 65+ years ($p = .001$), as well as 25-34 year olds and 35-49 year olds versus 65+ ($p = .005$ and $p = .029$, respectively). Finally, a Spearman's correlation test found no statistically significant association between the maximum distance respondents are willing to travel and their ski frequency in response to poor snow conditions ($\rho(173) = -.004, p = .960$).

4.4 Winter conditions experienced during the 2023/2024 ski season

On a 5-point Likert scale from Never (1) to Always (5), respondents were asked to indicate how frequently they experienced 14 winter conditions during the 2023/2024 season at the resort they typically ski/snowboard at in Canada. As shown in Table 4-3, machine-made snow was experienced the most ($Mdn = 4, M = 3.55, SD = 1.2$), followed by groomed snow or packed powder ($Mdn = 4, M = 3.49, SD = 1.0$), ice conditions on the slope ($Mdn = 3, M = 2.92, SD = 1.0$), reduced hill access (i.e., not all slopes and chairlifts open) ($Mdn = 3, M = 2.86, SD = 1.2$), and warm temperatures ($Mdn = 2, M = 2.64, SD = 0.9$). In contrast, long wait times at the chairlifts were the least experienced winter condition during the 2023/2024 ski season ($Mdn = 2, M = 2.02, SD = 1.0$), followed by rain ($Mdn = 2, M = 2.05, SD = 0.7$), the presence of fog and reduced visibility ($Mdn = 2, M = 2.11, SD = 0.8$), natural snowfall ($Mdn = 2, M = 2.14, SD = 0.7$), and crowded slopes ($Mdn = 2, M = 2.28, SD = 1.0$). An additional 29 respondents selected "other," and four open-ended answers were recorded, which included: "dangerous, hard to predict avalanches," "children complaining about cold toes and fingers," and accidents or skier injuries.

Table 4-3 Winter conditions experienced by skiers during 2023/2024 ski season

Conditions	<i>n</i>	Never (1)	Sometimes (2)	About half the time (3)	Most of the time (4)	Always (5)	Mean	SD	Mdn
Machine made snow ^{*1}	198	8%	15%	12%	47%	19%	3.55	1.2	4
Groomed snow/packed powder	196	0%	23%	18%	45%	14%	3.49	1.0	4
Ice conditions on ski trails/slopes ^{*1}	198	5%	37%	25%	28%	5%	2.92	1.0	3
Reduced hill access (i.e., not all slopes and chairlifts open) ^{*2}	197	10%	37%	23%	19%	11%	2.86	1.2	3
Warm temperatures ^{*2, 3}	197	2%	51%	27%	18%	2%	2.64	0.9	2
Thin/bare patches on the slope ^{*2, 3}	197	8%	54%	15%	16%	6%	2.58	1.1	2
Narrow snow coverage ^{*2, 3}	198	12%	49%	20%	14%	5%	2.51	1.0	2
Wet snow	195	6%	60%	20%	13%	2%	2.45	0.8	2
Crowded chalet restaurants	194	26%	40%	13%	16%	5%	2.31	1.1	2
Crowded slopes ^{*2}	197	22%	45%	20%	10%	3%	2.28	1.0	2
Natural snowfall (powder conditions) ^{*1}	197	12%	69%	14%	4%	2%	2.14	0.7	2
Fog/reduced visibility ^{*1}	194	17%	63%	13%	6%	1%	2.11	0.8	2
Rain	196	15%	70%	11%	4%	1%	2.05	0.7	2
Long wait times at the chairlift ^{*2}	196	34%	43%	14%	7%	3%	2.02	1.0	2
Other	29	45%	14%	21%	10%	10%	2.28	1.4	2

*. Statistically significant ($p \leq 0.05$)

¹ Region

² Gender

³ Age

A Mann-Whitney *U* test was conducted to assess whether the 14 ski conditions experienced during the 2023/2024 season differed between those who typically ski in western versus central Canada, with statistically significant differences found in four conditions (Table 4-4). Skiers in the western provinces

indicated they experienced natural snowfall ($z = -3.70, p = <.001$) and fog/reduced visibility ($z = -3.84, p = <.001$) more frequently than those skiing in Central provinces, while the latter group indicated they had experienced machine-made snow ($z = -7.71, p = <.001$) and ice conditions on the ski slopes ($z = -3.20, p = .001$) more frequently than those skiing in the West (Table 4-5).

Table 4-4 Regional differences in frequency of experienced conditions between respondents skiing in western versus central provinces

Ski/resort condition experienced	Mann-Whitney U	Wilcoxon W	Z	Asymp. Sig (2-tailed)
Natural snowfall*	2065.5	5468.5	-3,70	<0,001*
Machine-made snow*	898	3383	-7,71	<0,001*
Fog/reduced visibility*	1909.5	5230.5	-3,84	<0,001*
Ice conditions on the slope*	2077	4562	-3,20	0,001*
Thin or bare patches of ice	2429	5915	-1,91	0,056
Warm temperatures	2529	5014	-1,39	0,166
Reduced hill access	2514	4999	-1,37	0,170
Rain	2618	5033	-0,96	0,338
Long wait times at chairlifts	2638	5123	-0,91	0,363
Crowded chalet restaurants	2618.5	5858.5	-0,41	0,683
Crowded slopes	2776.5	6179.5	-0,37	0,714
Narrow snow coverage	2818	5303	-0,34	0,734
Groomed snow/packed powder	2782.5	5267.5	-0,21	0,836
Wet snow	2826	5241	-0,16	0,875

*. Statistically significant ($p \leq 0.05$).

Table 4-5 Mean ranks of differences for winter conditions experienced in western versus central ski regions

Experienced condition	Ski Region	N	Mean Rank	Sum of Ranks
Natural snowfall	Western	70	87.99	6159.5
	Central	82	66.69	5468.5
Groomed snow/packed powder	West	70	75.25	5267.5
	Central	81	76.65	6208.5

Experienced condition	Ski Region	N	Mean Rank	Sum of Ranks
Ice conditions on ski trails/slopes	West	70	65.17	4562
	Central	83	86.98	7219
Machine-made snow	West	70	48.33	3383
	Central	83	101.18	8398
Wet snow	West	69	75.96	5241
	Central	83	76.95	6387
Rain	West	69	72.94	5033
	Central	82	78.57	6443
Warm temperatures	West	70	71.63	5014
	Central	82	80.66	6614
Fog/reduced visibility	West	69	88.33	6094.5
	Central	81	64.57	5230.5
Thin/bare patches	West	70	83.8	5866
	Central	83	71.27	5915
Narrow snow coverage	West	70	75.76	5303
	Central	83	78.05	6478
Reduced hill access	West	70	71.41	4999
	Central	82	80.84	6629
Crowded slopes	West	70	77.84	5448.5
	Central	82	75.36	6179.5
Long wait times chairlifts	West	70	73.19	5123
	Central	82	79.33	6505
Crowded chalets	West	68	75.99	5167.5
	Central	80	73.23	5858.5

A Mann-Whitney U test was conducted on the data to assess if women and men skiers/snowboarders differed in terms of the 14 ski conditions they experienced during the 2023/2024 season. The results showed statistical differences between the groups in six conditions (Table 4-6). Women were statistically more likely than men to report that they had experienced warm temperatures ($z = -2.20, p = .028$); thin or bare patches on the slopes ($z = -3.10, p = .002$); narrow snow coverage (i.e., exposed terrain along the sides of the slopes) ($z = -2.23, p = .026$); reduced hill access (i.e., not all the slopes open) ($z = -4.02, p = <.001$); crowded slopes ($z = -2.01, p = .044$); and long wait times at the chairlifts ($z = -2.34, p = .019$). While no significant differences between the two groups were found in the other eight conditions (i.e., $p >.05$), *Mean Ranks* suggested that women were also more likely to experience ice conditions on the slopes, as well as wet snow, rain, and crowded chalets (Table 4-7).

Kruskal-Wallis tests showed there were statistical differences across the five age groups with respect to experience with warm temperatures ($H = 18.53, df = 4, p = <.001$), thin/bare patches on the slope ($H = 14.87, df = 4, p = .005$), and narrow snow coverage ($H = 14.23, df = 4, p = .007$) (Table 4-8). Post-hoc pairwise comparisons using Dunn's method for multiple tests indicated that 18-24 year old respondents were statistically more likely to state they had experienced warm temperatures compared to 65+ year olds ($p = <.001$), 50-64 years old ($p = <.001$), and those 35-49 years old ($p = .002$). For thin/bare patches on the slope, the results indicated 18-24-year-old respondents as well as 35-49 year olds were statistically more likely to experience thin/bare patches on the slope more frequently than 65+ year olds ($p = .002$ and $p = .036$, respectively). Also, mean ranks showed that 18-24-year-old respondents were statistically more likely to experience thin/bare patches than 50-64 year olds ($p = .002$). Finally, pairwise comparisons indicated that the youngest respondents (18-24 years old) were statistically more likely to indicate experience with narrow snow coverage on the slope than 25-34 year olds ($p = .011$), 35-49 years olds ($p = .003$), 50-64 year olds ($p = <.001$) and 65+ years olds ($p = <.001$) (see Table 4-9 for Mean Ranks).

Table 4-6 Mean ranks of differences between men and women regarding winter conditions experienced

Condition	Mann-Whitney U	Wilcoxon W	Z^a	p-value (2-tailed)
Natural snowfall	3129,000	5904,000	-1,65	0,100
Groomed snow/packed powder	3192,500	5893,500	-1,17	0,243
Ice conditions on ski trails/slopes	3016,500	7769,500	-1,87	0,061
Machine-made snow	3524,000	8277,000	-0,22	0,829

Condition	Mann-Whitney <i>U</i>	Wilcoxon <i>W</i>	<i>Z</i> ^a	p-value (2-tailed)
Wet snow	3082,500	7835,500	-1,65	0,100
Rain	3061,500	7717,500	-1,90	0,058
Warm temperatures	2906,000	7562,000	-2,20	0,028*
Fog/reduced visibility	3280,500	7840,500	-0,86	0,387
Thin/bare patches on the slope	2675,500	7428,500	-3,10	0,002*
Narrow snow coverage	2921,500	7674,500	-2,23	0,026*
Reduced hill access	2319,000	6975,000	-4,02	0,000*
Crowded slopes	2946,500	7602,500	-2,01	0,044*
Long wait times at chairlifts	2810,000	7466,000	-2,34	0,019*
Crowded chalet restaurants	2991,500	7647,500	-1,56	0,119

*. Statistically significant ($p \leq 0.05$).

^aCorrected for ties.

Table 4-7 Mean ranks of winter conditions experienced by gender in the 2023/2024 season

Conditions	Gender	<i>n</i>	Mean Rank	Sum of Ranks
Snowfall	Man	96	89.91	8631.00
	Woman	74	79.78	5904.00
Groomed snow/packed powder	Man	97	89.09	8641.50
	Woman	73	80.73	5893.50
Ice conditions	Man	97	80.10	7769.50
	Woman	74	93.74	6936.50
Machine made snow	Man	97	85.33	8277.00
	Woman	74	86.88	6429.00
Wet snow	Man	97	80.78	7835.50
	Woman	73	91.77	6699.50
Rain	Man	96	80.39	7717.50
	Woman	74	92.13	6817.50
Warm temperatures	Man	96	78.77	7562.00
	Woman	74	94.23	6973.00
Fog/reduced visibility	Man	95	82.53	7840.50
	Woman	74	88.17	6524.50

Conditions	Gender	<i>n</i>	Mean Rank	Sum of Ranks
Thin/bare patches	Man	97	76.58	7428.50
	Woman	74	98.34	7277.50
Narrow snow coverage	Man	97	79.12	7674.50
	Woman	74	95.02	7031.50
Reduced hill access	Man	96	72.66	6975.00
	Woman	74	102.16	7560.00
Crowded slopes	Man	96	79.19	7602.50
	Woman	74	93.68	6932.50
Long wait times for chairlifts	Man	96	77.77	7466.00
	Woman	73	94.51	6899.00
Crowded chalets	Man	96	79.66	7647.50
	Woman	72	90.95	6548.50

Table 4-8 Mean ranks of differences in the experience of winter conditions across the five age groups

Winter Condition	Kruskal-Wallis <i>H</i>	df	p-value (2-tailed)
Natural snowfall	7.703	4	0.103
Groomed snow/packed powder	9.469	4	0.050
Ice conditions on ski trails/ slopes	7.722	4	0.102
Machine-made snow	3.100	4	0.541
Wet snow	5.599	4	0.231
Rain	6.672	4	0.154
Warm temperatures	18.534	4	0.001*
Fog/reduced visibility	2.046	4	0.727
Thin/bare patches on the slope	14.873	4	0.005*
Narrow snow coverage	14.231	4	0.007*
Reduced hill access	6.383	4	0.172
Crowded slopes	0.531	4	0.97
Long wait times at chairlifts	2.236	4	0.692
Crowded chalet restaurants	0.891	4	0.926

*Statistically significant ($p \leq 0.05$)

Table 4-9 Mean ranks of winter conditions experienced by age group during 2023/2024 season

Winter Condition	Age	<i>n</i>	Mean Rank
Natural Snowfall	18-24	12	75.29
	25-34	32	82.06
	35-49	55	84.11
	50-64	44	82.27
	65+	28	104.66
Groomed snow/packed powder	18-24	13	71.92
	25-34	32	83.58
	35-49	55	75.06
	50-64	44	95.83
	65+	27	101.91
Ice conditions	18-24	13	99.35
	25-34	32	95.72
	35-49	55	93.35
	50-64	44	76.08
	65+	28	72.91
Machine made snow	18-24	13	92.27
	25-34	32	73.80
	35-49	55	87.50
	50-64	44	91.15
	65+	28	89.07
Wet snow	18-24	13	106.54
	25-34	31	87.69
	35-49	55	88.11
	50-64	44	84.14
	65+	28	73.38
Rain	18-24	13	74.65
	25-34	32	74.98
	35-49	55	95.75
	50-64	44	86.35
	65+	27	84.07
Warm temperatures	18-24	13	127.85
	25-34	32	96.53
	35-49	55	85.18
	50-64	44	78.82

Winter Condition	Age	<i>n</i>	Mean Rank
	65+	27	66.74
Fog/reduced visibility	18-24	13	88.00
	25-34	32	92.31
	35-49	54	87.31
	50-64	44	79.09
	65+	27	83.04
Thin/bare patches	18-24	13	118.85
	25-34	32	91.97
	35-49	55	93.66
	50-64	44	73.63
	65+	28	71.39
Narrow snow coverage	18-24	13	129.27
	25-34	32	90.55
	35-49	55	86.41
	50-64	44	77.28
	65+	28	76.68
Reduced hill access	18-24	13	109.46
	25-34	32	83.34
	35-49	55	91.62
	50-64	44	82.11
	65+	27	72.74
Crowded slopes	18-24	13	86.88
	25-34	32	85.73
	35-49	55	88.05
	50-64	44	81.86
	65+	27	88.46
Long wait times chairlifts	18-24	13	90.19
	25-34	32	89.27
	35-49	55	90.04
	50-64	43	77.83
	65+	27	81.76
Crowded chalets	18-24	13	77.92
	25-34	31	85.82
	35-49	55	88.08
	50-64	42	85.92
	65+	28	79.95

4.5 Thresholds of acceptability

4.5.1 Rating of ski resort conditions

On a 5-point Likert scale from Unacceptable (1) to Ideal (5), respondents were asked to rate the same 14 winter conditions listed in the previous question. As shown in Table 4-10, groomed snow/packed powder was considered the most acceptable condition with a mean score of 4.03 ($SD = 0.9$), followed by natural snowfall ($M = 3.93$, $SD = 1.3$), machine-made snow ($M = 3.44$, $SD = 0.9$), wet snow ($M = 2.79$, $SD = 0.9$), and warm temperatures ($M = 2.71$, $SD = 0.9$). Contrastingly, rain was the least accepted condition ($M = 1.89$, $SD = 0.9$), followed by long wait times at the chairlift ($M = 2.16$, $SD = 0.9$), crowded slopes ($M = 2.20$, $SD = 0.8$), thin/bare patches on the slope ($M = 2.25$, $SD = 0.9$), and narrow snow coverage (i.e., exposed terrain along the sides of the slope) ($M = 2.35$, $SD = 0.8$). Although an open-text space was provided, no additional conditions were stated by the 12 respondents who chose “other.”

Table 4-10 Rating of ski resort conditions

Conditions	<i>n</i>	Un acceptable (1)	Slightly unacceptable (2)	Neutral (3)	Acceptable (4)	Ideal (5)	Mean	SD	Mdn
Groomed snow/packed powder	178	0%	8%	12%	47%	33%	4,0	0.9	4
Natural snowfall (powder conditions)* ^{2, 3}	181	4%	15%	15%	15%	50%	3,9	1.3	5
Machine made snow* ¹	177	3%	13%	25%	53%	5%	3,4	0.9	4
Wet snow	177	5%	32%	42%	19%	1%	2,8	0.9	3
Warm temperatures	179	8%	35%	35%	20%	2%	2,7	0.9	3
Ice conditions on ski trails/slopes* ²	179	11%	42%	30%	16%	1%	2,5	0.9	2
Crowded chalet restaurants * ³	173	10%	38%	43%	8%	1%	2,5	0.8	3
Fog/reduced visibility* ¹	178	13%	40%	32%	14%	1%	2,5	0.9	2
Reduced hill access	177	8%	53%	27%	12%	0%	2,4	0.8	2
Narrow snow coverage	177	11%	54%	23%	12%	0%	2,4	0.8	2
Thin/bare patches on the slope	177	16%	55%	18%	11%	1%	2,3	0.9	2
Crowded slopes * ³	176	19%	48%	26%	7%	0%	2,2	0.8	2
Long wait times at the chairlift * ³	174	24%	44%	25%	6%	1%	2,2	0.9	2
Rain	178	40%	37%	19%	4%	1%	1,9	0.9	2
Other ^a	12	17%	0%	67%	8%	8%	2,9	1.1	3

*Statistically significant ($p \leq 0.05$)

¹ Region

² Gender

³ Age

^a Of those 12 responses, only one alternative condition was provided, indicating the respondent did not go to lodges. The other open-text responses included increased skier injuries, busy chairlifts but without long wait times.

A Mann-Whitney U test assessed whether there were geographical differences in the rating of conditions between skiers typically skiing in the western versus central provinces, with the latter statistically more likely to rate machine-made snow ($z = -4.12, p = <.001$) higher than those in the west, while the opposite was true for fog/reduced visibility ($z = -2.10, p = .04$) (Table 4-11).

Table 4-11 Regional differences in rating of conditions between skiers who typically ski in western versus central provinces

Ski/resort condition rated	Mann-Whitney U	Wilcoxon W	Z	Asymp. Sig (2- tailed)
Machine-made snow*	1455.5	3285.5	-4.118	<0.001*
Fog/reduced visibility*	1887	4890	-2.09	0.037
Thin or bare patches of ice	1909	4835	-1.943	0.052
Wet snow	1905.5	4831.5	-1.9	0.057
Natural snowfall	2141	5301	-1.371	0.17
Narrow snow coverage	2080	5083	-1.254	0.21
Warm temperatures	2139	5220	-1.073	0.283
Reduced hill access	2114	5195	-1.055	0.291
Groomed snow/packed powder	2182	4135	-0.798	0.425
Rain	2231.5	5312.5	-0.495	0.62
Crowded chalet restaurants	2153	3923	-0.286	0.775
Long wait times at chairlifts	2242	4072	-0.176	0.861
Ice conditions on the slope	2343	4234	-0.162	0.871
Crowded slopes	2292.5	4122.5	-0.081	0.935

*Statistically significant ($p \leq 0.05$)

A Mann-Whitney U test explored whether the rating of ski conditions differed significantly between men and women, revealing that women were statistically more likely to rate natural snowfall higher (i.e., ideal) ($z = -2.20, p = .028$) and ice conditions on the slope lower (i.e., unacceptable) ($z = -2.69, p = .007$). While not statistically different, the rating of warm temperatures ($N = 178$, Women: *Mean Rank* = 96.86, $n = 80$; Men: *Mean Rank* = 83.49, $n = 98$), $U = 3,331.00, z = -1.82$ (corrected for ties), $p = .069$, two-tailed, suggests that women are more accepting of warmer temperatures than men (i.e., closer to ideal) (Table 4-12). *Mean Ranks* also suggest that women are more accepting of groomed snow, wet snow, rain, fog, reduced hill access, and crowded chalets, whereas men are more accepting of machine-made snow, thin patches on the slope, narrow snow coverage, crowded slopes and long wait times at the chairlift (Table 4-13).

Table 4-12 Mann-Whitney test of differences in rating of ski resort conditions by gender

Resort Conditions	Mann-Whitney <i>U</i>	Wilcoxon <i>W</i>	<i>Z</i>	p-value (2-tailed)
Groomed snow/packed powder	3279.000	7839.000	-0.650	0.516
Natural snowfall (powder conditions) *	2899.000	7555.000	-2.203	0.028*
Machine made snow	3319.000	6020.000	-0.398	0.691
Wet snow	3329.000	7794.000	-0.350	0.726
Warm temperatures	2929.500	7489.500	-1.959	0.050
Ice conditions on ski trails/slopes*	2714.500	5489.500	-2.687	0.007*
Crowded chalet restaurants	3028.500	7399.500	-0.974	0.330
Fog/reduced visibility	3165.000	7630.000	-1.058	0.290
Reduced hill access	3286.500	7751.500	-0.514	0.607
Narrow snow coverage	3328.000	6029.000	-0.365	0.715
Thin/bare patches on the slope	3277.500	5978.500	-0.548	0.584
Crowded slopes	3204.000	5905.000	-0.667	0.505
Long wait times at the chairlift	3221.000	5777.000	-0.283	0.777
Rain	3296.500	7761.500	-0.617	0.538

*Statistically significant ($p \leq 0.05$)

Table 4-13 Mean ranks of differences by gender in rating of ski resort conditions in the 2023/2024 season

Ski conditions	Gender identity	<i>n</i>	Mean Rank	Sum of Ranks
Natural snowfall*	Man	96	78.70	7555.00
	Woman	74	94.32	6980.00
Groomed snow/packed powder	Man	95	82.52	7839.00
	Woman	73	87.08	6357.00
Ice on slope *	Man	95	93.43	8875.50
	Woman	74	74.18	5489.50
Machine made snow	Man	94	85.19	8008.00
	Woman	73	82.47	6020.00
Wet snow	Man	94	82.91	7794.00
	Woman	73	85.40	6234.00
Rain	Man	94	82.57	7761.50
	Woman	74	86.95	6434.50
Warm temperatures	Man	95	78.84	7489.50
	Woman	74	92.91	6875.50
Fog/reduced visibility	Man	94	81.17	7630.00

Ski conditions	Gender identity	<i>n</i>	Mean Rank	Sum of Ranks
Thin/bare patches	Woman	74	88.73	6566.00
	Man	94	85.63	8049.50
	Woman	73	81.90	5978.50
Narrow snow coverage	Man	94	85.10	7999.00
	Woman	73	82.59	6029.00
Reduced hill access	Man	94	82.46	7751.50
	Woman	73	85.98	6276.50
Crowded slopes	Man	93	85.55	7956.00
	Woman	73	80.89	5905.00
Long wait times chairlifts	Man	93	83.37	7753.00
	Woman	71	81.37	5777.00
Crowded chalet restaurants	Man	93	79.56	7399.50
	Woman	71	86.35	6130.50

*. Statistically significant ($p \leq 0.05$)

Next, a Kruskal-Wallis test was completed to explore whether age groups differed in their ranking of the 14 ski resort conditions. The findings revealed statistically significant difference in the rating of four ski resort conditions, including natural snowfall ($H = 10.48$, $N = 171$, $df = 4$, $p = .033$), crowded slopes ($H = 11.64$, $N = 167$, $df = 4$, $p = .020$), crowded chalet restaurants ($H = 13.67$, $N = 165$, $df = 4$, $p = .008$), and long wait times for the chairlift ($H = 12.41$, $N = 165$, $df = 4$, $p = .015$) (Table 4-14).

Table 4-14 Test to evaluate statistical differences in rated ski conditions by age group

Winter Condition	Kruskal-Wallis <i>H</i>	df	p-value (2-tailed)
Natural snowfall*	10.48184	4	0.033*
Groomed snow/packed powder	2.158449	4	0.707
Ice conditions on ski trails/slopes	5.894417	4	0.207
Machine-made snow	4.004912	4	0.405
Wet snow	5.25094	4	0.263
Rain	3.19707	4	0.525
Warm temperatures	3.127621	4	0.537
Fog/reduced visibility	8.438413	4	0.077
Thin/bare patches on the slope	8.256305	4	0.083
Narrow snow coverage	1.062695	4	0.900

Winter Condition	Kruskal-Wallis <i>H</i>	df	p-value (2-tailed)
Reduced hill access	3.907072	4	0.419
Crowded slopes*	11.64011	4	0.020*
Long wait times at chairlifts*	12.41392	4	0.015*
Crowded chalet restaurants*	13.66587	4	0.008*

*. Statistically significant ($p \leq 0.05$)

Post-hoc pairwise comparisons using Dunn's method for multiple tests showed that the mean rank rating of natural snowfall from respondents aged 50-64 years old were significantly lower (i.e., unacceptable) compared to skiers between 35-49 years old ($p = .004$) and 25-34 years old ($p = .007$), respectively. However, there was no significant difference between the mean ranks of other age groups.

For crowded slopes, the mean rank ratings were significantly lower (i.e., unacceptable) for older versus younger skiers, with three groups rating crowded slopes significantly lower than the 18 to 24 year old group: the 65+ years old ($p = .005$), 50-64 years old ($p = .008$), and 35-49 years old ($p = .003$). Following the same trend, results showed that for crowded chalet restaurants, the mean rank ratings were significantly lower (i.e., unacceptable) for older generations, with the group of 65 or more years old having significantly lower ratings than the 18 to 24 years old group, $p = .004$, and the 25 to 34 years old group, $p = .007$. Also, respondents in the group of 50 to 64 years old rated significantly lower this condition than the group of 18 to 24 years old, $p = .013$ and the 25 to 34 years old group, $p = .025$. Finally, respondents in the group of 35 to 49 years old also rated crowded chalet restaurants significantly lower than respondents in the 18 to 24 year-old group, $p = .025$. Consistently, results showed that the mean rank rating of long wait times at chairlifts was significantly rated lower by older than younger respondents, with significantly lower results from respondents in all age groups than in the group of 18 to 24 year-old respondents: the group of 65 or older than, $p = .002$, the group of 50 to 64 year-olds, $p = .002$, the group of 35 to 49 years, $p = .001$, and the 25 to 34 year-olds, $p = .025$. In all crowding-related conditions, results were consistent to show that older generations of skiers are less accepting of crowding than younger skiers (Table 4-15).

Table 4-15 Mean ranks of rated ski conditions by age group

Ranks	Age	N	Mean Rank
Rating of condition Snowfall	18-24	12	85.71
	25-34	32	96.72
	35-49	54	94.79
	50-64	44	67.92
	65+	29	85.36
Rating of condition groomed snow/packed powder	18-24	12	74.58
	25-34	32	94.08
	35-49	54	84.16
	50-64	44	81.76
	65+	27	85.83
Rating of condition ice on slope	18-24	12	68.67
	25-34	32	96.09
	35-49	54	85.81
	50-64	44	76.45
	65+	28	94.21
Rating of machine-made snow	18-24	12	77.42
	25-34	32	79.72
	35-49	54	78.52
	50-64	44	91.66
	65+	26	93.96
Rating of wet snow	18-24	12	67.50
	25-34	32	85.56
	35-49	54	91.88
	50-64	43	75.42
	65+	27	90.50
Rating of rain	18-24	12	86.50
	25-34	32	77.56
	35-49	54	91.60
	50-64	43	78.43
	65+	28	90.21
Rating of warm temperatures	18-24	12	77.00
	25-34	32	92.67
	35-49	54	87.94
	50-64	44	76.72

Ranks	Age	N	Mean Rank
	65+	28	90.05
Rating of fog/reduced visibility	18-24	12	96.04
	25-34	32	99.08
	35-49	54	88.49
	50-64	44	70.95
	65+	27	79.31
Rating of thin/bare patches	18-24	12	93.88
	25-34	31	97.40
	35-49	54	78.43
	50-64	44	74.00
	65+	27	94.78
Rating of narrow snow coverage	18-24	12	87.42
	25-34	32	88.38
	35-49	53	79.66
	50-64	44	84.82
	65+	27	87.59
Rating of reduced hill access	18-24	12	93.38
	25-34	32	88.36
	35-49	53	77.49
	50-64	43	80.98
	65+	28	94.96
Rating of crowded slopes	18-24	12	119.54
	25-34	32	94.25
	35-49	53	76.85
	50-64	43	80.50
	65+	27	75.67
Rating of long wait times chairlifts	18-24	11	125.23
	25-34	32	89.81
	35-49	53	77.59
	50-64	42	78.87
	65+	27	74.76
Rating of crowded chalet restaurants	18-24	11	113.23
	25-34	32	99.11
	35-49	53	80.32
	50-64	42	75.79
	65+	27	68.07

4.5.2 Snow coverage thresholds

Respondents were asked at what point they would find the snow conditions to be unacceptable for ski/snowboarding, with most (41%) indicating that if $\leq 65\%$ of slope is covered in snow, they will not go skiing. However, the majority (59%) indicated that so long as the resort is open, they will go skiing (i.e., regardless of how little the slope is covered in natural or machine-made snow) (Table 4-16). The results showed no statistical significance in snow cover thresholds between respondents who typically ski in western versus central provinces ($U = 2,133$; $z = -.87$; $p = .384$), nor any statistical significance between men and women ($U = 3,051$; $z = -1.90$; $p = .057$), with weak and non-statistically significant correlations between respondents' snow cover thresholds and winter conditions experienced in the 2023/2024 season, including narrow snow coverage, reduced hill access, thin or bare patches on the slopes, and warm temperatures. However, a Kruskal-Wallis test identified statistically significant differences across the five age groups ($H = 14.738$; $df = 4$, $p = .005$), with respondents aged 25-34 years old revealing significantly lower mean ranks (i.e., lower tolerance for poor snow conditions) compared to respondents aged 65 years or older ($p = <.001$). Similarly, respondents aged 35-49 and 50-64 also had statistically significant lower mean ranks compared to the group of 65 or older ($p = <.001$ and $p = .021$, respectively).

Table 4-16 Snow coverage thresholds for skiers and snowboarders during 2023/2024 season

Percentage of snow coverage	Frequency	Valid Percent	Cumulative Percent
$\leq 90\%$ of the slope is covered in snow	6	3.4	3.4
$\leq 85\%$ of the slope is covered in snow	4	2.3	5.6
$\leq 80\%$ of the slope is covered in snow	8	4.5	10.2
$\leq 75\%$ of slope is covered in snow	21	11.9	22
$\leq 70\%$ of slope is covered in snow	12	6.8	28.8
$\leq 65\%$ of slope is covered in snow	21	11.9	40.7
If the resort is open, I will go skiing/snowboarding	105	59.3	100

Based on the snow cover threshold respondents identified as being unacceptable, participants were then asked what they believed the likelihood was that their Canadian ski resort would experience such conditions (e.g., if respondents identified $\leq 65\%$ of the slope covered in snow as unacceptable, a follow up question asked what the likelihood was of their Canadian resort having $\leq 65\%$ of the slope covered)

(Figure 4-2). Of those 21 participants whose threshold was $\leq 65\%$, most (38%) thought the likelihood was occasional, followed by probable (33%), frequent (19%), and the remaining respondents were split between improbable (5%) and remote (5%). Moreover, of those 12 participants who chose $\leq 70\%$ snow coverage as their threshold, half of the respondents indicated they thought it was probable to occur, while the other half split equally between remote (17%), occasional (17%), and frequent (17%). Furthermore, of those 21 participants who responded their threshold was $\leq 75\%$ snow coverage, an equal number of participants indicated the likelihood was occasional (35%) or probable (35%), followed by frequent (24%), and a minority who thought it was improbable (6%). Of the eight respondents who indicated their threshold was $\leq 80\%$, half of the respondents indicated they considered the likelihood of occurrence to be probable, followed by frequent (38%), and remote (13%). In the case of the $\leq 85\%$ snow coverage threshold, answers were split between probable (75%) and frequent (25%) among the four respondents. Finally, in the case of the six respondents who selected $\leq 90\%$ snow coverage as their threshold, each of the options of remote (i.e., unlikely although possible), probable (i.e., not surprised, will occur in a given time) and frequent (i.e., likely to occur, to be expected) were chosen by a third of respondents. It is important to note that the 105 respondents who stated they would ski so long as their resort was open (i.e., all snow coverage is acceptable) were not asked about the likelihood of resorts' closures.

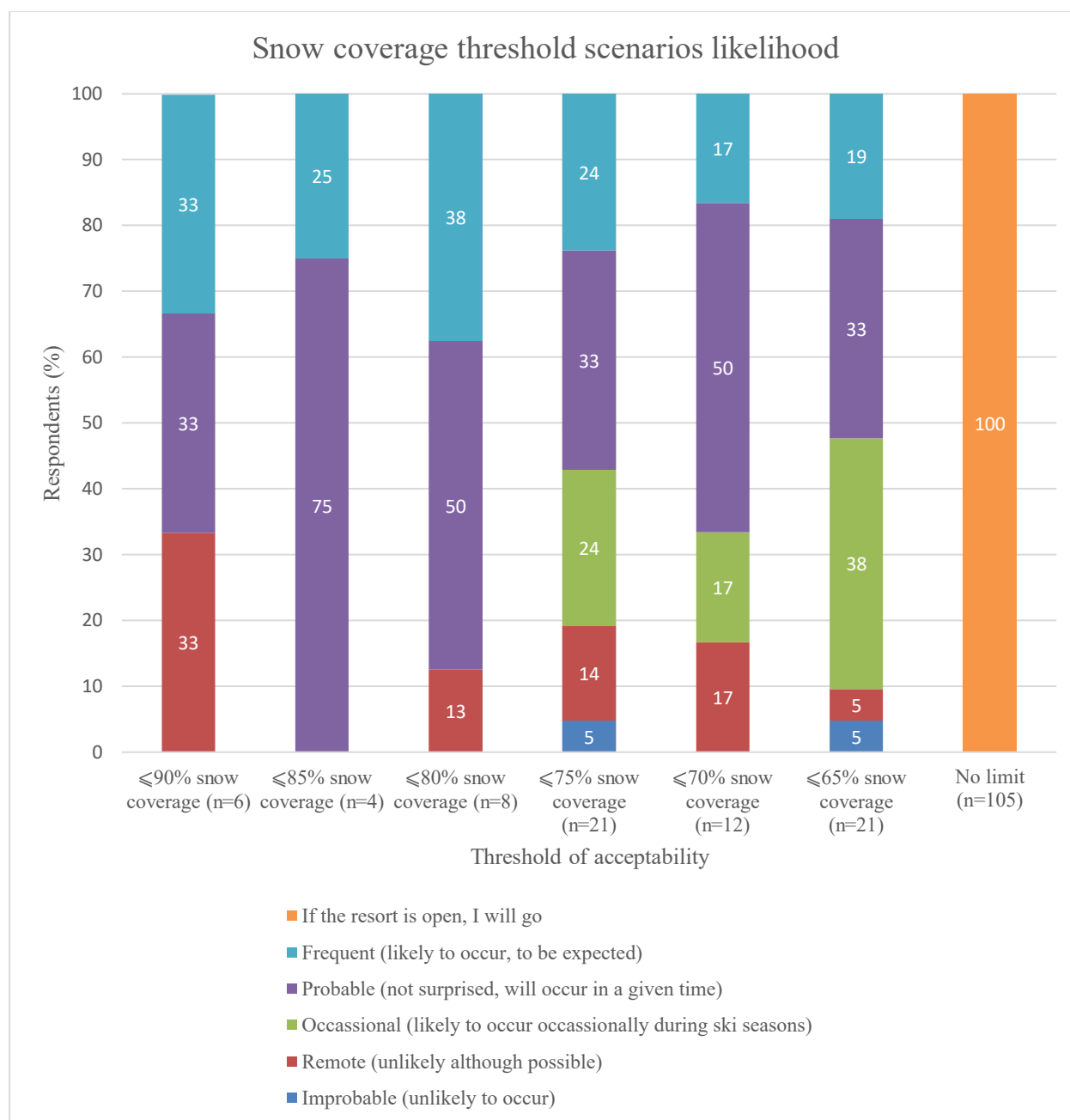


Figure 4-2 Respondents' perceived likelihood that their ski resort would have unacceptable snow coverage

In a follow up question, respondents were asked if it was easy or difficult to visualize the percentage change in snow cover that they would deem unacceptable for skiing. The majority (55%) stating that the question was easy to visualize/answer, while a third of the respondents (33%) indicated it was difficult, suggesting that thresholds could be misinterpreted when presented as a percentage of snow cover. A Spearman's Rho correlation analysis was conducted to examine the relationship between the respondents'

thresholds for snow coverage and their visualization assessment based on percentages (i.e., how easy, or difficult, was for respondents to visualize the snow coverage percentage). Results showed a weak but statistically significant positive correlation ($\rho(186) = .24, p = <.001$) indicating that as visualization becomes easier for respondents, the threshold increases (i.e., willingness to accept less snow coverage).

Table 4-17 Summary of perceived likelihood of occurrence of snow, crowding and wait time scenarios

Conditions	Improbable (Unlikely to Occur)		Remote (Unlikely, although possible)		Occasional (Likely to occur occasionally during ski seasons)		Probable (Not surprised, will occur in a given time)		Frequent (Likely to occur, to be expected)		Mean	SD	Mdn
	Counts	%	Counts	%	Counts	%	Counts	%	Counts	%			
Insufficient snow covering the slope	2	3	9	13	15	21	29	40	17	24	3.69	1.06	4
Ski slope too crowded	14	8	34	20	74	43	36	21	15	9	3.02	1.04	3
Wait time for chair lift too long	19	11	32	19	52	30	43	25	26	15	3.15	1.21	3

4.5.3 Crowding and wait time thresholds

Participants were asked at what point they would find the ski slope to be too crowded to go skiing/snowboarding. The majority (68%) of 173 respondents indicated that 50% more people than usual would be too crowded to go skiing, with an additional 32 respondents (19%) stating 75% more people than usual would be too crowded, and a further 24 respondents (14%) stating over 80% more people than usual would be too crowded to go skiing (Table 4-18). The results showed no statistically significant differences in terms of crowding threshold between skiers who typically ski in western versus central provinces ($U = 2,017; z = -.71; p = .478$), nor between men and women ($U = 3,299; z = -.60; p = .547$), nor across the five age groups ($H = 3.162; df = 4 p = .531$). There were also very weak and non-statistically significant correlations between crowding thresholds and crowding conditions experienced in the 2023/2024 season (e.g., crowded slopes, crowded chalet restaurants, long wait times at chairlifts) (Error! Reference source not found.) ($\rho(167) = .14, p = .073$).

Table 4-18 Crowding threshold

Threshold of acceptance	Frequency	Valid Percent	Cumulative Percent
≤ 10% more people than usual	4	2.3	2.3
25% more people than usual	40	23.1	25.4
50% more people than usual	73	42.2	67.6
75% more people than usual	32	18.5	86.1
> 80% more people than usual	24	13.9	100

Based on the crowding threshold respondents identified as being unacceptable, participants were then asked what they believed was the likelihood that their Canadian ski resort would experience such crowding (e.g., if respondents identified 50% more people than usual, the follow up question asked what they believed the likelihood that their resort would experience 50% more people). Results showed that of those 24 respondents who indicated that 80% more people than usual would be too crowded to ski, the perceived likelihood that this level of crowding would occur was occasional (42%), followed by improbable (21%), with respondents split equally between remote, probable and frequent (13% each) (Figure 4-3). Similarly, most of the 32 respondents considered 75% more people than usual likely to occur occasionally (41%), followed by remote (34%), improbable (9%) or frequent (9%), and a minority perceived it as probable (6%). In the case of those 73 respondents who would accept a 50% increase of skiers on the slope, the largest group (43%) thought the scenario could occasionally occur, followed by probably (29%), remotely (16%), frequently (7%), and an improbable likelihood (6%). Consistent with the previous crowding scenarios, of those 40 respondents who selected 25% more people as their threshold, almost half (48%) thought the likelihood of occurrence to be occasional, followed by probable and remote (20% each), and a minority who perceive it as frequent (8%) or improbable (5%). Finally, having 10% or fewer more people than usual was found to be probable by half of the four respondents, while the other half was split between occasional and frequent likelihood.

Similar to the previous question about snow cover, respondents were also asked whether it was difficult to visualize crowding, with more than half of respondents (57%) indicated it was easy to visualize and 21% found it difficult to visualize.

A Spearman's Rho correlation analysis was conducted to examine the relationship between the respondents' thresholds for crowding and their visualization assessment based on percentages (i.e., how

easy, or difficult, was for respondents to visualize the additional percentage of skiers). Results showed no correlation ($\rho(182) = .01, p = .885$).

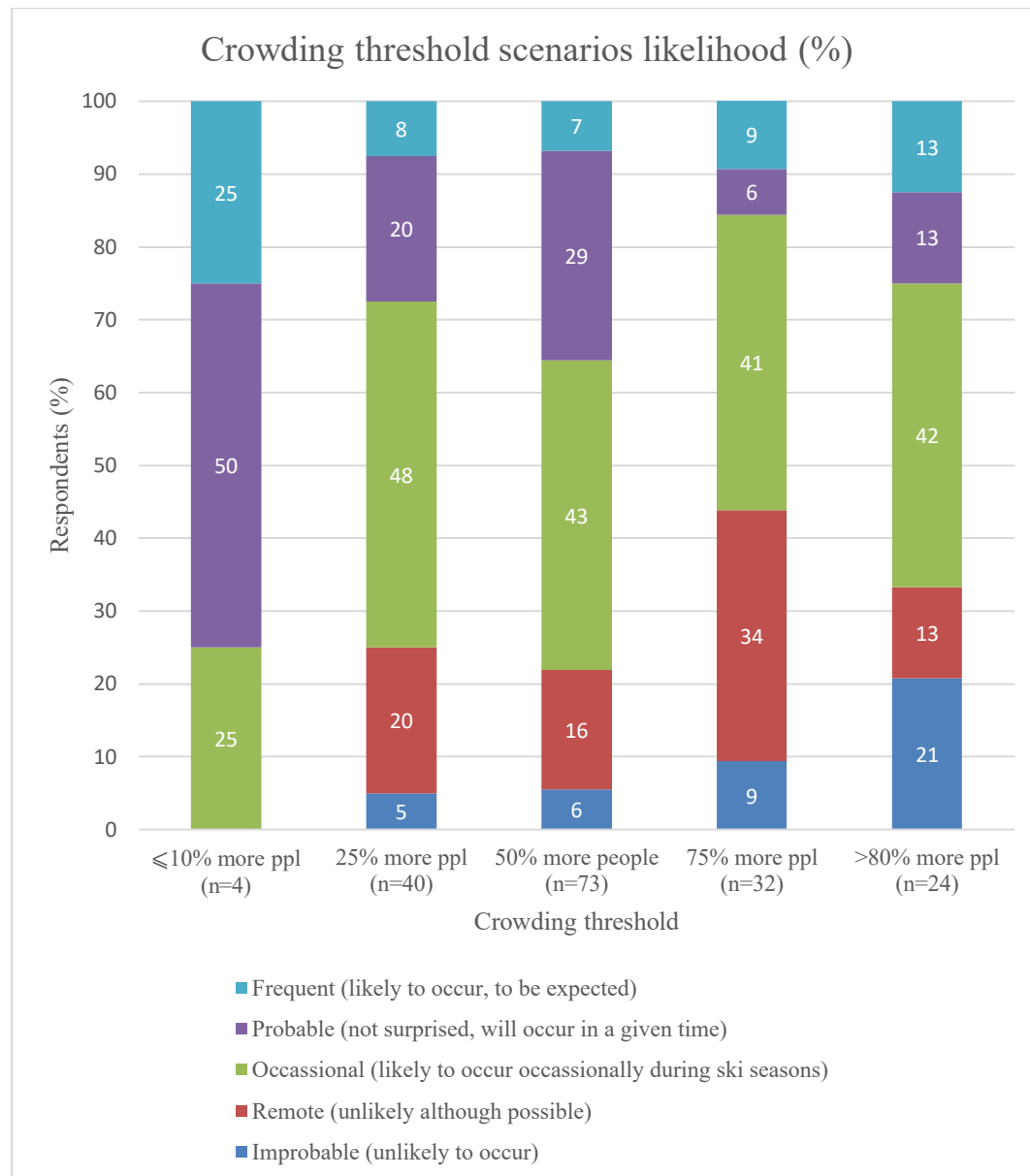


Figure 4-3 Respondents' perceived likelihood that their ski resort would have unacceptable crowding

Respondents were also asked their maximum wait time for a chair lift, with the majority (74%) indicated they would wait in line for for a maximum of 11-15 minutes, followed by 16-20 minutes (16%), 21 minutes or more (11%) (Table 4-19). The results of a Mann-Whitney U test showed men were statistically more likely to wait longer in line for a chairlift than women ($U = 2,387; z = -3.56; p = <.001$), along with weak positive and statistically significant correlations between crowding and wait time

thresholds ($\rho(168) = .19, p = .013$) (i.e., respondents who have a higher tolerance for crowding at the slope also have a higher tolerance for waiting for a chairlift). However, there are no significant differences between skiers who typically ski in western versus central Canada ($U = 1,929; z = -1.41; p = .158$), or across the five age groups ($H = 5.43; df = 4; p = .246$), nor statistically significant correlations found based on winter conditions experienced in the 2023/2024 season ($\rho(167) = .14, p = .073$).

Table 4-19 Wait time threshold (in minutes)

Threshold of acceptance	Frequency	Valid Percent	Cumulative Percent
≤ 5 min	0	8.1	9.9
6-10 min	58	33.7	43.6
11-15 min	52	30.2	73.8
16-20 min	27	15.7	89.5
+21 min	18	10.5	100.0

Based on the wait time threshold respondents identified as being their maximum, participants were then asked what they believed the likelihood was that their Canadian ski resort would experience such chair lift queues (e.g., if respondents identified 21+ minutes, then the follow up question asked what they believed the likelihood that they would have to wait 21+ minutes for a chair lift at their resort). Results showed that of those 17 who selected five minutes or less as their threshold, most deemed that likelihood to be remote (29%), followed by improbable and frequent (24% each), occasional (18%), and probable (6%). Of those 58 respondents whose threshold was between six and 10 minutes, the likelihood this would occur was thought to be occasional (38%), followed by probable (29%), improbable (17%), remote (10%), and a minority who stated frequent (5%). Of the 52 respondents that identified 11-15 minutes as their maximum wait time, most thought the likelihood this would occur was occasional (29%), probable (27%), remote (23%), frequent (15%), or improbable (6%). Of the 27 respondents who identified 16-20 minutes as their maximum wait time, most believed this would happen occasionally (30%), followed by remote (26%), probable (22%), frequent (19%), and one respondent who deemed it improbable (4%). Finally, for those who indicated 21+ minutes as the maximum they would be willing to wait for a chairlift, most indicated the likelihood would be frequent (33%), followed by probable (28%), occasional (22%), remote (11%), and one respondent considered waiting more than 21 minutes as improbable (7%) (Figure 4-4).

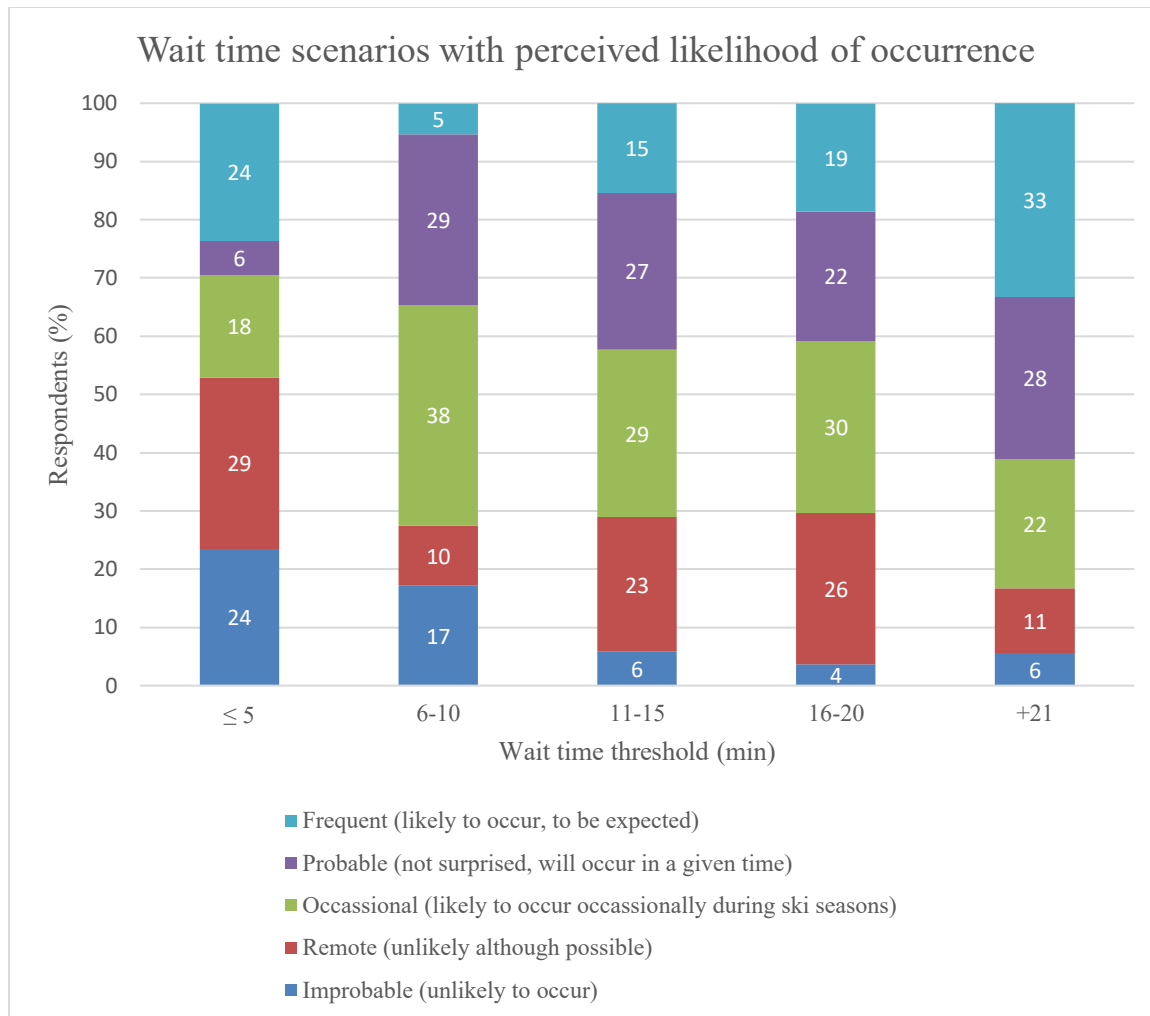


Figure 4-4 Respondents' perceived likelihood that their resort would have chairlift wait times that exceed the maximum willingness to wait

4.6 Climate change and future ski behaviour

4.6.1 Level of concern with climate change impacting ski conditions

Respondents were asked to rate their level of concern regarding climate change negatively impacting current and future ski conditions in terms of temperature and precipitation (rain, snow). A 5-point Likert scale was used, with one being “not at all concerned,” two “slightly concerned,” three “somewhat concerned,” four “very concerned,” and five “extremely concerned.” As shown in Figure 4-5, most respondents are extremely concerned (47%), followed by very concerned (33%), somewhat concerned (11%), slightly concerned (6%), and not at all concerned (3%). The level of concern increases in future years, such that current climate change concerns had a median of 4 and a mean score of 4.15 ($SD = 1.0$),

whereas concerns five years from now increased the median to 5 and a mean score of 4.29 ($SD=1.1$), and ten years from now had a median score of 5 and mean of 4.42 ($SD = 1.0$) (Table 4-20).

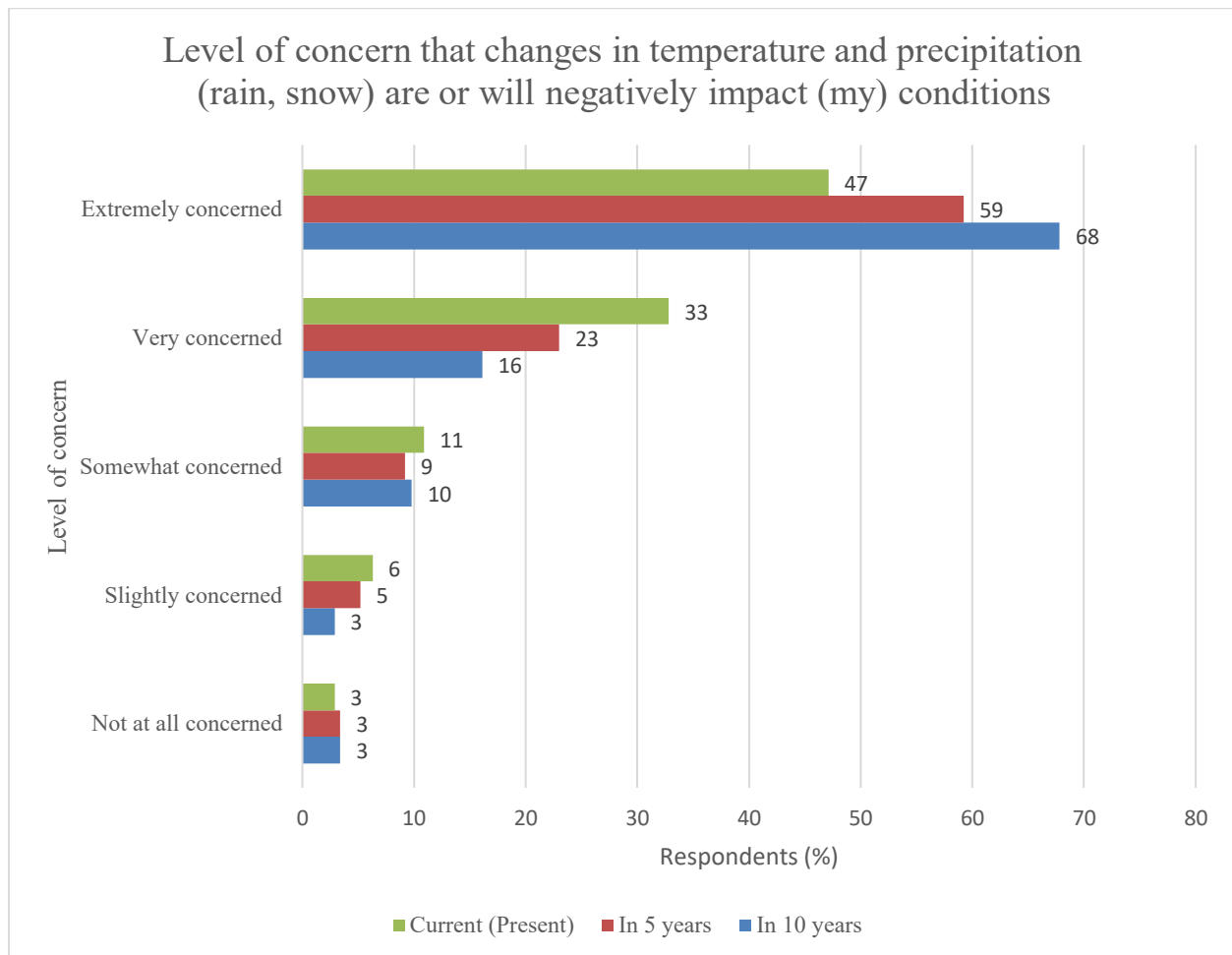


Figure 4-5 Skiers' level of concern that changes in temperature and precipitation (rain, snow) will negatively impact ski conditions

Table 4-20 Levels of concern with climate change impacting current and future ski conditions

	Mean	SD	Mdn
I am concerned that changes in temperature and precipitation (rain, snow) are negatively impacting my CURRENT ski conditions	4.15	1.0	4
I am concerned that changes in temperature and precipitation (rain, snow) will negatively impact ski conditions in 5 years	4.29	1.1	5
I am concerned that changes in temperature and precipitation (rain, snow) will negatively impact ski conditions in 10 years	4.42	1.0	5

A Spearman's Rho correlation analysis revealed that there is a strong and significant positive correlation between concern about climate change negatively impacting current ski conditions and concern about future conditions, both in five years ($\rho(172) = .81, p < .001$), and in ten years ($\rho(172) = .70, p < .001$). Moreover, a stronger and statistically positive correlation is found between concern in five years and concern in ten years ($\rho(172) = .87, p < .001$), which suggests that skiers who are currently concerned that changes in temperature and precipitation are already impacting ski conditions are also very likely to be concerned with conditions in the future. A Mann-Whitney U test assessed whether there were differences in concern levels between those respondents who typically ski in the west and those who ski in central Canada, with the latter statistically more likely to be concerned about temperature and rain impacting current ski conditions compared to western skiers ($U = 1,818; z = -2.01; p = .044$), while concerns about the next five and ten years were not significantly different between the two regional groups ($p = .211$ and $p = .334$, respectively). Also, a Mann-Whitney U test explored whether levels of concern differed by gender, and although the *Mean Rank* suggest that women are slightly more concerned about current conditions, there were no statistical differences (Women: *Mean Rank* = 87.64, $n = 74$; Men: *Mean Rank* = 84.75, $n = 97$), $U = 3,467.50, z = -.409$ (corrected for ties), $p = .682$, two-tailed. Similarly, for future conditions, although *Mean Ranks* are higher for women, no statistically significant differences were found in the five-year ($N = 171$, Women: *Mean Rank* = 91.75, $n = 74$; Men: *Mean Rank* = 81.61, $n = 97$), $U = 3,163.50, z = -1.506$ (corrected for ties), $p = .132$, two-tailed, nor 10-year scenario ($N = 171$, Women: *Mean Rank* = 92.47, $n = 74$; Men: *Mean Rank* = 81.07, $n = 97$), $U = 3,110.50, z = -1.805$ (corrected for ties), $p = .071$, two-tailed.

Spearman's Rho correlation analysis revealed a number of statistically significant relationships between conditions experienced during the 2023/2024 season (see Table 4-3) and levels of climate change concerns, including two negative (natural snowfall and groomed snow/packed powder) and eleven positive (ice conditions, machine-made snow, wet snow, rain, warm temperatures, thin/bare patches, narrow snow coverage, reduced hill access, crowded slopes, long wait times on chairlifts, and crowded chalets) correlations (see Table 4-21). For example, there are weak negative correlations between experience with natural snowfall conditions in the 2023/2024 season and concerns about changes in temperature and precipitation negatively impacting current conditions ($\rho(172) = -.23, p = .002$) and future conditions in both the five-year scenario ($\rho(172) = -.27, p < .001$) and ten-year scenario ($\rho(172) = -.30, p < .001$). Similarly, there are weak negative correlations between experience with groomed snow/packed powder and concern about current conditions ($\rho(172) = -.22, p = .003$), conditions in five years ($\rho(172) = -.21, p = .005$), and in ten years ($\rho(172) = -.17, p = .028$). These results indicate that as experience with natural snowfall and groomed snow/packed powder increases, the concern about climate change impacting ski conditions both current and, in the future, tends to decrease.

In contrast, experience with ice conditions on the slope shows a weak positive and significant correlation with concerns about temperature and precipitation changes impacting ski conditions in the three different time scenarios, including current ($\rho(173) = .28, p < .001$) and future scenarios (i.e., 5 and 10 years) ($\rho(173) = .24, p = .002$; $\rho(173) = .27, p < .001$). These results suggest that greater experience with ice on the slopes is related to higher levels of concern about climate changes. Moreover, experience with machine-made snow revealed a weak but statistically significant positive correlation with concern about changes in temperature and precipitation negatively impacting current conditions ($\rho(173) = .17, p = .029$) and future conditions in five years ($\rho(173) = .20, p = .007$), and in 10 years ($\rho(173) = .20, p = .009$). In the case of wet snow, a weak positive association was found with changes negatively impacting current conditions ($\rho(171) = .20, p = .019$) and conditions in the five-year scenario ($\rho(171) = .16, p = .042$). A weak but statistically significant positive association was also found between experience with rain and concerns for current conditions ($\rho(172) = .16, p = .032$), and future scenarios in five years ($\rho(172) = .18, p = .019$) and ten years ($\rho(172) = .19, p = .012$). Additionally, a weak and statistically positive correlation was found between experience with thin or bare patches on the slopes during the 2023/2024 ski season and levels of concern in current ($\rho(173) = .35, p < .001$) and in five and ten years, respectively ($\rho(173) = .34, p < .001$; $\rho(173) = .33, p < .001$). Similarly, experience with narrow snow coverage shows a weak statistically positive correlation with concern for current conditions ($\rho(173) = .32, p < .001$), five years ($\rho(173) = .30, p < .001$), and ten years ($\rho(173) = .25, p < .001$). Experience with reduced hill access also shows a weak and significantly positive correlation with concern about current conditions ($\rho(172) = .23, p = .002$), and conditions in five years ($\rho(172) = .32, p < .001$), and ten years ($\rho(172) = .31, p < .001$).

Experience with crowding showed significant associations with climate change concerns. For example, experience with crowded slopes reveal a weak and statistically positive association with concerns current conditions ($\rho(172) = .19, p = .002$) and conditions in five years ($\rho(172) = .20, p = .010$). Similarly, experience with crowded chalets shows a weak and statistically positive association with concerns for current conditions ($\rho(170) = .20, p = .010$) and in five years ($\rho(170) = .16, p = .038$). While weak, stronger correlations were found between experience with long wait times on chairlifts and concerns for the three timeframes ($\rho(171) = .21, p = .005$; $\rho(171) = .25, p = .001$; $\rho(171) = .17, p = .028$, respectively).

Finally, the strongest correlation was found with experience with warm temperatures, which showed a moderate and statistically significant positive correlation with climate change concerns impacting current ski conditions ($\rho(172) = .41, p < .001$), as well as conditions in five years ($\rho(172) = .49, p < .001$), and in 10 years ($\rho(172) = .46, p < .001$).

Table 4-21 Correlation between experience with winter conditions and climate change concerns

		Concern current conditions	Concern 5 years	Concern 10 years
Warm temperatures	Correlation Coefficient	.411**	.488**	.459**
	Sig. (2-tailed)	0.000	0.000	0.000
	N	172	172	172
Thin/bare patches	Correlation Coefficient	.346**	.344**	.327**
	Sig. (2-tailed)	0.000	0.000	0.000
	N	173	173	173
Narrow snow coverage	Correlation Coefficient	.317**	.296**	.249**
	Sig. (2-tailed)	0.000	0.000	0.001
	N	173	173	173
Reduced hill access	Correlation Coefficient	.233**	.322**	.306**
	Sig. (2-tailed)	0.002	0.000	0.000
	N	172	172	172
Ice conditions	Correlation Coefficient	.282**	.239**	.269**
	Sig. (2-tailed)	0.000	0.002	0.000
	N	173	173	173
Natural Snowfall	Correlation Coefficient	-.233**	-.271**	-.297**
	Sig. (2-tailed)	0.002	0.000	0.000
	N	172	172	172
Groomed snow/packed powder	Correlation Coefficient	-.224**	-.212**	-.168*
	Sig. (2-tailed)	0.003	0.005	0.028
	N	172	172	172
Long wait times chairlifts	Correlation Coefficient	.213**	.248**	.168*
	Sig. (2-tailed)	0.005	0.001	0.028
	N	171	171	171
Wet snow	Correlation Coefficient	.180*	.156*	0.092
	Sig. (2-tailed)	0.019	0.042	0.232
	N	171	171	171
Machine made snow	Correlation Coefficient	.166*	.203**	.198**
	Sig. (2-tailed)	0.029	0.007	0.009
	N	173	173	173
Rain	Correlation Coefficient	.163*	.179*	.191*
	Sig. (2-tailed)	0.032	0.019	0.012
	N	172	172	172

Crowded chalets	Correlation Coefficient	.197*	.160*	0.074
	Sig. (2-tailed)	0.010	0.038	0.334
	N	170	170	170
Crowded slopes	Correlation Coefficient	.191*	.197**	0.148
	Sig. (2-tailed)	0.012	0.010	0.053
	N	172	172	172
Fog/reduced visibility	Correlation Coefficient	0.103	.151*	0.126
	Sig. (2-tailed)	0.180	0.049	0.100
	N	171	171	171

*Statistically significant correlation ($p \leq 0.05$)

**Statistically significant correlation ($p \leq 0.001$)

4.6.2 Substitution behaviours

When asked what respondents would do if their preferred Canadian ski resort had unacceptable conditions in the future, the majority (56%) indicated they would ski less, of which 31% would opt to wait until their resort had acceptable conditions (i.e., temporal substitution) and the other 25% would travel to other ski resorts (i.e., spatial substitution). Thereafter, 40% of the respondents anticipate that they will ski or snowboard about the same, of which 25% would wait for their resort to have acceptable conditions and increase their frequency during the shortened season (i.e., temporal substitution), while the other 15% would travel to ski resorts in search of acceptable ski conditions (i.e., spatial substitution). Less than 3% of respondents indicated they would stop skiing (i.e., activity substitution). Open-ended answers from the remaining 2% included statements that resorts are consistently opened and rarely have unacceptable conditions (Figure 4-6).

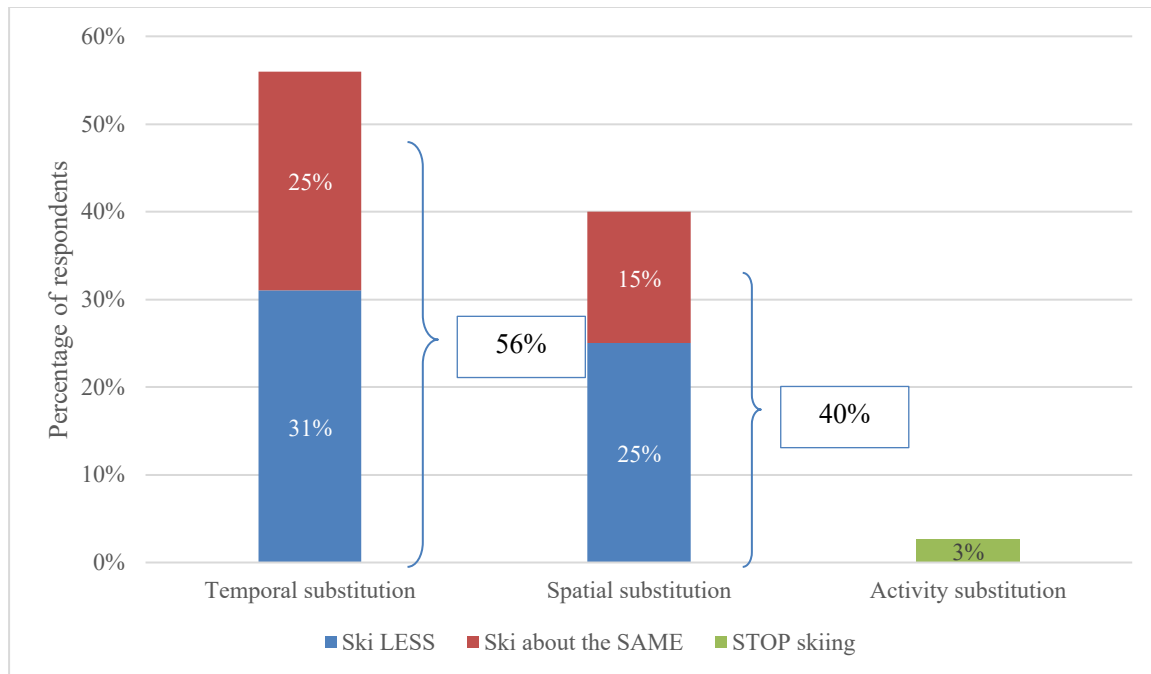


Figure 4-6 Skier substitution if their preferred ski resort had unacceptable conditions in the future

A pair-wise comparison explored how respondents behaved during the record warm 2023/2024 versus how they said they would respond in the future to marginal conditions ($n = 172$) (Table 4-22). Of those 104 respondents who indicated they skied less during the 2023/2024 season, the majority (67%) indicated they would behave the same in the future by skiing less (39% would wait for the conditions at their resort to improve, while 29% would travel elsewhere), with 28% indicating they would ski the same in the future (despite not doing so in 2023/2024), of whom 21% would wait for their resort to open and 7% would travel elsewhere. Of the 61 respondents who indicated they skied the same amount in 2023/2024 despite marginal conditions, the majority (57%) indicated they would behave the same in the future (of whom 33% would wait for their resort to open and 25% would travel elsewhere), with 38% indicating they would ski less (18% would wait and 20% would travel). The greatest difference between current behaviour and stated future behaviour was found for those 15 respondents who stated they skied more during the 2023/2024 season, with almost half (47%) stating they would ski less in the future if their resort had unacceptable conditions.

Table 4-22 Skiers' behavioural responses during 2023/2024 season compared to their projected future behaviours

Behavioural response 2023/2024 season	Future behaviours under unacceptable conditions			
	I would ski LESS	I would ski about the SAME	I would STOP skiing	Other
Skied LESS (<i>n</i> = 104)	67%	28%	4%	1%
Skied about the SAME (<i>n</i> = 61)	38%	57%	0%	5%
Skied MORE (<i>n</i> = 15)	47%	53%	0%	0%

Table 4-23 highlights the differences in how respondents indicated they would respond in the future to unacceptable conditions versus how they did respond to record warm conditions in the 2023/2024 winter season, revealing small net changes. A Pearson's Chi-square test of contingencies was conducted to explore if projected behaviour was related to real behaviour (i.e., if the behavioural response during the 2023/2024 season was associated with behavioural intentions in the future should resorts have unacceptable conditions), revealing a significant association, $X^2(2) = 15.8, p = <.001$. The behavioural response in 2023/2024 accounts for 54.7% variation in the stated future behaviour, suggesting that we can use current substitution behaviours to project how skiers may respond to marginal conditions in the future (i.e., future behaviour is dependent on past behaviour).

Table 4-23 Comparison of intended versus real behaviour

Behaviour	2023/2024 (<i>n</i> = 209)	Projected (<i>n</i> = 182)	Net change
Ski LESS	57%	56%	-1
Ski about the SAME	34%	40%	-6
Ski MORE	8%	n/a	n/a
STOP skiing	n/a	3%	n/a

A Kruskal-Wallis test was completed to evaluate if the projected behavioural response varied across the five age groups in the study, but no statistically significant differences were found in the distribution of future behaviour responses across the five age groups ($H = 3.383, p = .496$). Similarly, a Mann-Whitney U test revealed no statistically significant differences between respondents who typically ski in the west versus central Canada ($U = 2,265; z = -1.03; p = .301$), nor between men and women ($z = -1.072$,

$p = .284$), nor was any relationship found between future behaviours and experience with marginal conditions in 2023/2024 ski season. There was also no statistically significant associations or correlations found between future behaviour and concern for climate change during any of the three temporal periods (current, 5 years, 10 years). A Spearman's Rho correlation test was conducted to assess the relationship between future behavioural responses and the likelihood of respondent's resorts having unacceptable snow coverage, with a moderate and statistically significant positive correlation between the likelihood of having 75% of slope covered in snow and respondents' future behaviour under unacceptable conditions ($\rho(21) = .49, p = .023$).

4.6.3 Snowmaking options

During periods with limited natural snowfall, respondents were asked what they would prefer their chosen ski resort to do in terms of snowmaking coverage. The majority of respondents (83%) indicated they would prefer their ski resort to close some trails to concentrate snowmaking on select slopes (i.e., reduce the number of open trails to enable full snow coverage on open trails). In contrast, 12% of respondents indicated they would prefer their resort to have all slopes open, with narrow or thin snow coverage on each slope. The fewest number of respondents (5%) indicated they would prefer their resort to increase lift ticket prices to support full snowmaking coverage across the entire resort. Of those nine respondents, seven would be willing to pay 10% or more for their lift ticket in order to support more snowmaking coverage. No statistically significant differences in terms of preferred snowmaking options were found by ski region, gender, nor by age groups ($p > .050$).

4.7 Perceptions of snowmaking as an adaptation strategy

The survey asked respondents to indicate their level of agreement for eight snowmaking statements on a 5-point Likert scale from “disagree strongly” (1) to “agree strongly” (5). As shown in Table 4-24, the three statements that received the highest level of agreement included the need to increase snowmaking capacity in the next 10 years ($M = 4.40, SD = 0.9$), that snowmaking is necessary for ski resorts to maintain ski seasons ($M = 4.39, SD = 0.9$), and the need to increase snowmaking capacity in the next five years ($M = 4.29, SD = 0.9$). In contrast, the statements with the lowest level of agreement (i.e., respondents disagreed with the statement) included the perception that additives in snowmaking negatively impact human health ($M = 2.86, SD = 1.0$), that producing machine-made snow contributes to climate change ($M = 2.93, SD = 1.2$), and that snowmaking generates significant GHG emissions ($M = 3.05, SD = 1.1$).

Table 4-24 Means of agreement with snowmaking perceptions

Snowmaking statements	<i>n</i>	Mean (1-5)	SD	Mdn
Snowmaking capacity will need to increase in the next 10 years ^{*1}	173	4.40	0.9	5
Snowmaking is necessary for ski resorts to maintain ski seasons ^{*1,3}	177	4.39	0.9	5
Snowmaking capacity will need to increase in the next 5 years ^{*1}	175	4.29	0.9	5
Snowmaking requires significant energy (electricity) to produce	176	4.10	0.8	4
Snowmaking requires significant water to produce	176	4.09	0.9	4
Snowmaking negatively impacts the environment ^{*2, 3}	175	3.29	1.1	3
Snowmaking negatively impacts water resources ^{*2, 3}	176	3.20	1.2	3
Snowmaking results in significant greenhouse gas (GHG) emissions ^{*2, 3}	176	3.05	1.1	3
Snowmaking contributes to climate change ^{*2, 3}	176	2.93	1.2	3
Additives in snowmaking negatively impact human health ^{*2, 3}	175	2.86	1.0	3

*. Statistically significant ($p \leq 0.50$)

¹ Region.

² Gender.

³ Age.

Figure 4-7 highlights the level of agreement for all snowmaking statements. Almost all respondents (90%) agree that snowmaking is necessary for ski resorts to maintain ski seasons (57% of whom agree strongly), followed by the need for snowmaking capacity to increase in the next five and 10 years (82% and 84%, respectively). In terms of the environmental perceptions of snowmaking, the majority agree that snowmaking requires significant water and energy (82% and 80%, respectively), with 39% agreeing that snowmaking negatively impacts the environment. However, when asked specifically about snowmaking negatively impacting water resources, most (38%) were unsure or undecided, while 36% agreed (18% of whom agreed strongly), and 26% disagreed (7% of whom disagreed strongly). There was also high uncertainty with respect to snowmaking in the context of climate change (e.g., 35% were unsure), in addition to 43% who are unsure or undecided on whether snowmaking results in significant GHG emissions. The majority (59%) are also unsure or undecided whether snowmaking additives' negatively impact on human health.

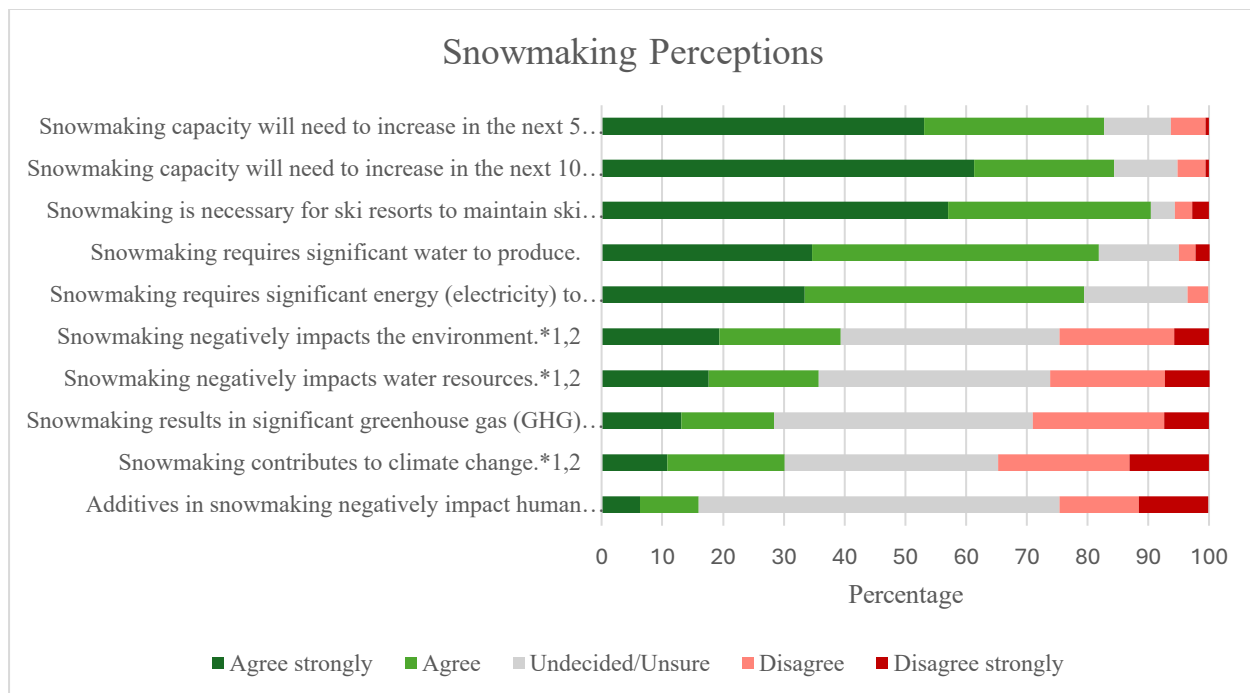


Figure 4-7 Perceptions of snowmaking as an adaptation strategy

*. Statistically significant ($p \leq 0.05$)

¹Age

²Gender

A Spearman's Rho correlation analysis showed that there is a weak positive correlation between the agreement that snowmaking is necessary to maintain ski seasons and the agreement that snowmaking capacity will need to increase in the future, both in the next five years, $\rho(175) = .24, p = .002$, and ten years, $\rho(173) = .26, p = <.001$. Although some outliers were found in both future scenarios, these results suggest that individuals who see snowmaking as a necessity to maintain current seasons are also more likely to agree that the capacity will need to be increased in the future. Furthermore, a very strong and statistically positive correlation was found between the agreement that snowmaking capacity will need to increase in the next five years and that it will have to increase in the next ten years, $\rho(173) = .85, p = <.001$.

There is also a weak but significantly positive association between the agreement that snowmaking capacity will need to increase in the next five years and concern about precipitation negatively impacting current conditions ($\rho(173) = .30, p = <.001$), conditions in five years ($\rho(173) = .34, p = <.001$) and in ten years ($\rho(173) = .39, p = <.001$). Results also revealed weak and significant positive associations between agreement that snowmaking capacity will need to increase in the next 10 years and concern for current conditions ($\rho(171) = .31, p = <.001$), and conditions in five years ($\rho(171) = .39, p = <.001$).

The association was moderate and significantly positive when evaluating the 10 year concerns (ρ (171) = .44, p = <.001). These findings suggest that as the concern about climate change impacting ski conditions increases, so does the perception that snowmaking capacity will need to be expanded in the next five and ten years.

A Mann-Whitney U test evaluated whether respondents who typically ski in western and central Canada differed in their perceptions of the sustainability of snowmaking (Table 4-25). The results showed that those skiers typically skiing in central Canada are statistically more in agreement that snowmaking is necessary (z = -5.09 ; p = <0.001), and that snowmaking capacity will need to increase in five (z = -2.90 ; p = .004) and ten years (z = -3.42 ; p = .001) compared to those skiing in western Canada (Table 4-26).

Table 4-25 Differences in snowmaking perceptions between western and central skiers

Snowmaking perceptions	Mann-Whitney U	Wilcoxon W	Z	Asymp. Sig. (2-tailed)
Level of agreement snowmaking is necessary to maintain ski seasons	1272,500	3102,500	-5,090	<0,001**
Level of agreement snowmaking capacity will have to increase in next 10 years	1509,000	3279,000	-3,420	0,001**
Level of agreement snowmaking capacity will need to increase in next 5 years	1639,500	3409,500	-2,900	0,004**
Level of agreement snowmaking requires significant energy	1900,000	3730,000	-1,786	0,074
Level of agreement snowmaking requires significant water to produce	2074,500	3904,500	-0,968	0,333
Level of agreement snowmaking contributes to CC	2096,000	5022,000	-0,832	0,406
Level of agreement snowmaking results in significant GHG emissions	2118,000	5044,000	-0,741	0,459
Level of agreement snowmaking negatively impacts water resources	2176,000	5102,000	-0,473	0,636
Level of agreement snowmaking negatively impacts the environment	2190,000	5040,000	-0,275	0,784
Level of agreement snowmaking additives negatively impact human health	2210,000	5136,000	-0,159	0,873

*. Statistically significant ($p \leq 0.05$)

**. Statistically significant ($p \leq 0.01$)

Table 4-26 Mean ranks of differences between western and central Canada skiers in snowmaking perceptions

Snowmaking perceptions	Ski Region	<i>N</i>	Mean Rank	Sum of Ranks
Level of agreement snowmaking is necessary to maintain ski seasons	Western	60	51.71	3102.50
	Central	77	82.47	6350.50
Level of agreement snowmaking capacity will need to increase in next 5 years	West only	59	57.79	3409.50
	Central only	76	75.93	5770.50
Level of agreement snowmaking capacity will have to increase in next 10 years	West only	59	55.58	3279.00
	Central only	74	76.11	5632.00
Level of agreement snowmaking negatively impacts the environment	West only	60	69.00	4140.00
	Central only	75	67.20	5040.00
Level of agreement snowmaking additives negatively impact human health	West only	59	68.54	4044.00
	Central only	76	67.58	5136.00
Level of agreement snowmaking requires significant water to produce	West only	60	65.08	3904.50
	Central only	76	71.20	5411.50
Level of agreement snowmaking negatively impacts water resources	West only	60	70.23	4214.00
	Central only	76	67.13	5102.00
Level of agreement snowmaking requires significant energy	West only	60	62.17	3730.00
	Central only	76	73.50	5586.00
Level of agreement snowmaking results in significant GHG emissions	West only	60	71.20	4272.00
	Central only	76	66.37	5044.00
Level of agreement snowmaking contributes to CC	West only	60	71.57	4294.00
	Central only	76	66.08	5022.00

A Mann-Whitney *U* test was conducted to explore whether or not women and men agree on snowmaking (Table 4-27). Women were statistically more likely than men to agree that snowmaking negatively impacts the environment ($z = -2.08, p = .038$) and water resources ($z = -2.86, p = .004$), and that snowmaking additives negatively impact human health ($z = -3.57, p = <.001$). Furthermore, women were statistically more likely to agree that snowmaking results in significant greenhouse gas (GHG) emissions ($z = -2.86, p = .004$) and that it contributes to climate change ($z = -3.67, p = <.001$). However, in both cases, despite mean ranks suggesting women agree more with snowmaking contributing to emissions and climate change (Table 4-28), percentages also suggest there is a higher level of uncertainty among women than men when determining the role of snowmaking in climate change.

Table 4-27 Differences in snowmaking perceptions by gender

Snowmaking statement	Mann-Whitney <i>U</i>	Wilcoxon <i>W</i>	<i>Z</i>	Asymp. Sig. (2-tailed)
Snowmaking requires significant energy (electricity) to produce	3584.500	8337.500	-0.015	0.988
Snowmaking requires significant water to produce	3579.000	8332.000	-0.034	0.973
Snowmaking negatively impacts the environment*	2914.000	7570.000	-2.077	0.038*
Snowmaking negatively impacts water resources*	2705.500	7458.500	-2.861	0.004*
Snowmaking results in significant greenhouse gas (GHG) emissions. *	2717.000	7470.000	-2.857	0.004*
Snowmaking contributes to climate change*	2451.500	7204.500	-3.665	<0.001**
Additives in snowmaking negatively impact human health*	2542.500	7198.500	-3.567	<0.001**

*. Statistically significant ($p \leq 0.05$)

**. Statistically significant ($p \leq 0.01$)

Table 4-28 Mean ranks of snowmaking perceptions by gender

Snowmaking statement		<i>n</i>	Mean Rank	Sum of Ranks
Level of agreement snowmaking negatively impacts the environment*	Man	96	78.85	7570.00
	Woman	74	94.12	6965.00
Level of agreement snowmaking additives negatively impact human health**	Man	96	74.98	7198.50
	Woman	74	99.14	7336.50
Level of agreement snowmaking requires significant water to produce	Man	97	85.90	8332.00
	Woman	74	86.14	6374.00
Level of agreement snowmaking negatively impacts water resources	Man	97	76.89	7458.50
	Woman	74	97.94	7247.50
Level of agreement snowmaking requires significant energy	Man	97	85.95	8337.50
	Woman	74	86.06	6368.50
Level of agreement snowmaking results in significant GHG emissions*	Man	97	77.01	7470.00
	Woman	74	97.78	7236.00

Level of agreement snowmaking contributes to CC**	Man	97	74.27	7204.50
	Woman	74	101.37	7501.50

*. Statistically significant ($p \leq 0.05$)

**. Statistically significant ($p \leq 0.01$)

Additionally, a Kruskal-Wallis test was conducted to identify differences in agreement levels across the five age groups, revealing statistically significant differences regarding the need for snowmaking to maintain ski seasons ($H = 17.54$, $N = 172$, $df = 4$, $p = .002$), negative impacts on the environment ($H = 15.81$, $N = 171$, $df = 4$, $p = .003$), snowmaking additives negatively impacting human health ($H = 10.10$, $N = 171$, $df = 4$, $p = .039$) and water resources ($H = 21.47$, $N = 172$, $df = 4$, $p = <.001$), as well as snowmaking contributing to significant GHG emissions ($H = 18.38$, $N = 172$, $df = 4$, $p = .001$) and climate change ($H = 26.53$, $N = 172$, $df = 4$, $p = <.001$) (Table 4-24 and Figure 4-7). In turn, post-hoc pairwise comparisons using Dunn's method for multiple tests was conducted for the conditions where significant differences were found. The results indicates that the mean rank agreement with snowmaking being necessary to maintain ski seasons is significantly higher among 25 to 34 year old respondents than among 50 to 64 year old respondents, $p = .013$; among 35 to 49 year old respondents than among 18 to 24 year old respondents, $p = .043$ and 50 to 64 year olds, $p = .008$. It was also found to be significantly higher among 50 to 64 year old respondents than among 18 to 24 year old respondents, $p = <.001$, and among those 65 years old or more than of 18 to 24 year old, $p = .005$. These results suggest that older respondents agree more strongly that snowmaking is a necessity for ski resorts to maintain their ski season.

Contrastingly, older respondents (65+ years old) were statistically more likely to disagree that snowmaking negatively impacts the environment compared to younger respondents, including the 18-24 age group ($p = .007$), the 25-34 age group ($p = .010$), and the 35-49 age group ($p = .010$). Similarly, the 50- to 64-year-old group were statistically more likely to disagree that snowmaking negatively impacts the environment compared to the 18- to 24-year old group ($p = .012$), the 25 to 34 year old group ($p = .017$), and the 35 to 49 year old group ($p = .015$), with the same age trend found regarding snowmaking negatively impacting water resources (Table 4-29). Also, respondents aged 50 to 64 years old are statistically more likely to disagree that snowmaking negatively impacts water resources than 18 to 24 year olds ($p = .012$), as are the 35 to 49 year olds versus the 18 to 24 years olds ($p = .021$).

Table 4-29 Pairwise comparisons of agreement in snowmaking's negative impacts on water resources by age groups

Sample 1-	Sample 2	Test Statistic	SE	Std. Test Statistic	<i>p-value</i>
65+	50-64	26.800	11.605	2.309	.021*
65+	35-49	30.734	11.144	2.758	.006*
65+	25-34	45.795	12.422	3.687	<.001**
65+	18-24	64.876	16.111	4.027	<.001**
50-64	18-24	38.076	15.153	2.513	.012*
35-49	18-24	34.142	14.804	2.306	.021*

*. Statistically significant ($p \leq 0.05$)

**. Statistically significant ($p \leq 0.01$)

Post-hoc pairwise comparisons using Dunn's method for multiple tests were also used to examine the differences in the level of agreement about snowmaking additives negatively impacting human health across the age groups. The results showed that the mean rank agreement was significantly lower among the group of 65+ year olds compared to those aged 25-34 ($p = .045$) and compared to the 35-39 year old group, $p = .008$. Mean ranks in this category were also significantly lower in the 50-64-year-olds compared to the 35-49-year-olds ($p = .021$) (Table 4-30).

Table 4-30 Pairwise comparisons of agreement in additives' negative impacts to human health by age group

Sample 1-	Sample 2	Test Statistic	Std. Error	Std. Test Statistic	<i>p-value</i>
65+	50-64	6.450	10.677	.604	.546
65+	18-24	19.320	14.757	1.309	.190
65+	25-34	22.855	11.378	2.009	.045*
65+	35-49	27.117	10.208	2.657	.008*
50-64	18-24	12.870	13.917	.925	.355
50-64	25-34	16.405	10.265	1.598	.110
50-64	35-49	20.667	8.950	2.309	.021*
18-24	25-34	-3.535	14.461	-.244	.807

18-24	35-49	-7.797	13.560	-.575	.565
25-34	35-49	-4.262	9.776	-.436	.663

*. Statistically significant ($p \leq 0.05$)

The results also revealed significant differences with respect to snowmaking contributing to GHG emissions, with respondents aged 65+ years old more likely to disagree with the statement compared to younger groups (18 to 24 years, $p = .001$; 25 to 34 years, $p = .004$; 35 to 49 years, $p = .004$). The same age trend held between the groups aged 50 to 64 years old and 35 to 49 years old compared to 18 to 24 years old ($p = .006$ and $p = .044$, respectively). The results also revealed that the mean rank agreement with snowmaking contributing to climate change was significantly lower in the oldest respondents (i.e., 65 years or older) than in the age categories of 18 to 24 ($p = <.001$), 25 to 34 ($p = <.001$), and 35 to 49 ($p = <.001$). Also, the mean rank of the 50- to 64-year-old respondents was significantly lower than the one for the 18 to 24 age group ($p = .021$), the 25 to 34 age group ($p = .003$), and the 35 to 49 age group ($p = .021$). Collectively, these results suggest older respondents agree less with snowmaking generating GHG emissions and contributing to climate change and generating emissions.

Additionally, a Spearman's Rho correlation analysis was conducted to examine the relationship between respondents agreement that snowmaking is a necessity to maintain ski seasons and their experience with machine-made snow, thin/bare patches on the slope, narrow snow coverage and reduced hill access during the 2023/2024 season (Table 4-31). The results revealed a moderate and statistically positive association between the experience with machine made snow, $\rho(175) = .40$, $p = <.001$, which indicates that skiers who have experienced more machine-made snow tend to agree more with the need for snowmaking to maintain ski seasons. In turn, the results showed a weak and statistically negative association between experience with thin/bare patches and agreement on the necessity of snowmaking, $\rho(175) = -.22$, $p = .004$, suggesting that as people experienced more thin/bare patches of snow on the slopes, their agreement with snowmaking being a necessity to maintain ski seasons tended to decrease. No statistically significant association were found for narrow snow coverage and reduced hill access.

Table 4-31 Relationship between experienced conditions and agreement on snowmaking as necessary

Experienced condition		Level of agreement snowmaking is necessary to maintain ski seasons
Machine made snow	Correlation Coefficient	.401*
	Sig. (2-tailed)	<.001
	<i>n</i>	175
Thin/bare patches	Correlation Coefficient	-.218*
	Sig. (2-tailed)	0.004
	<i>n</i>	175
Narrow snow coverage	Correlation Coefficient	-0.055
	Sig. (2-tailed)	0.466
	<i>n</i>	175
Reduced hill access	Correlation Coefficient	-0.07
	Sig. (2-tailed)	0.357
	<i>n</i>	174

*. Statistically significant ($p \leq 0.05$)

Similarly, results from Spearman's rho correlation analysis showed a weak to moderate and statistically positive association between experience with machine-made snow and the agreement of the need to increase snowmaking capacity in the next five years $\rho (172) = .37, p = <.001$, and in the next ten years $\rho (170) = .41, p = <.001$ (i.e., the more experience individuals have with machine-made snow, the more likely they are to agree that snowmaking capacity needs to increase in the future). Additionally, a weak and statistically significant association was found between experience with reduced hill access and the agreement that snowmaking capacity will need to increase in the next 10 years, $\rho (172) = .17, p = .024$. No other associations were found between experience with thin/bare patches or narrow snow coverage and the agreement that snowmaking capacity needs to increase in the future (i.e., in five or ten years). There were also no statistically significant associations found between the agreement that snowmaking capacity will need to increase in the next five and 10 years and the likelihood of resorts having unacceptable snow coverage.

A Spearman's Rho correlation analysis revealed a weak but significant positive association between respondents' agreement that changes in temperature and precipitation are negatively impacting ski

conditions in all three time-frames (i.e., current, next 5 years, next 10 years) and that snowmaking requires significant water to produce, that snowmaking negatively impacts water resources, and that snowmaking negatively impacts the environment (Table 4-32). Noticeably, while still significant, the relationships between both water-specific snowmaking statements and concern for current ski conditions and ski conditions in 10 years are weaker than for the five-year scenario. Collectively, these relationships suggest skiers who are more likely to agree that snowmaking negatively impacts the environment are also more likely to agree that they are concerned about changes in temperature and precipitation negatively impacting ski conditions in the present and future.

Table 4-32 Relationships between environment and water-related agreement levels and climate change concerns for current and future ski conditions

		Concern for current conditions	Concern 5 years	Concern 10 years
Level of agreement snowmaking negatively impacts the environment	Correlation Coefficient	.226**	.218**	.211**
	Sig. (2-tailed)	0.003	0.004	0.005
	<i>n</i>	173	173	173
Level of agreement snowmaking requires significant water to produce	Correlation Coefficient	0.131	.191*	.188*
	Sig. (2-tailed)	0.084	0.012	0.013
	<i>n</i>	174	174	174
Level of agreement snowmaking negatively impacts water resources	Correlation Coefficient	.214**	.245**	.216**
	Sig. (2-tailed)	0.005	0.001	0.004
	<i>n</i>	174	174	174

*. Statistically significant ($p \leq 0.05$)

**. Statistically significant ($p \leq 0.01$)

A Spearman's Rho correlation analysis revealed a weak and statistically positive correlation between agreement that snowmaking contributes to climate change and concern that changes in temperature and precipitation are negatively impacting ski conditions for all three temporal periods (current, 5 years, 10 years) and agreement that snowmaking contributes to climate change, $\rho(174) = .30, p = <.001$ (current), $\rho(174) = .31, p = <.001$ (five years), and $\rho(174) = .29, p = <.001$ (ten years). (Error! Reference source not found.). Relatedly, the results revealed a weak and statistically positive correlation between respondents' agreement that snowmaking generates significant GHG emissions and their concerns for current and future (in 5 and 10 years, respectively) ski conditions ($\rho(174) = .31, p = <.001$; $\rho(174) = .28, p = <.001$; $\rho(174) = .26, p = <.001$). These findings suggest that as individuals

increase their agreement with snowmaking being a contributor to climate change and GHG emissions, concern about changes in temperature and precipitation negatively impacting ski conditions also increases.

Table 4-33 Relationships between agreement on snowmaking contribution to climate change and GHG emissions and concerns for current and future ski conditions

		Concern current conditions	Concern 5 years	Concern 10 years
Level of agreement snowmaking contributes to CC	Correlation Coefficient	.299**	.307**	.289**
	Sig. (2-tailed)	0.000	0.000	0.000
	<i>n</i>	174	174	174
Level of agreement snowmaking results in significant GHG emissions	Correlation Coefficient	.305**	.276**	.256**
	Sig. (2-tailed)	0.000	0.000	0.001
	<i>n</i>	174	174	174

*. Statistically significant ($p \leq 0.05$)

**. Statistically significant ($p \leq 0.01$)

4.8 Chapter summary

This chapter presented the quantitative results derived from the online survey distributed through three social media groups, and social media channels from Protect Our Winters Canada, Beaver Valley Destination Stewardship, and the Canadian Ski Instructors Association. The analysis included behavioural responses of skiers during the 2023/2024 season, which found a general decrease in ski frequency in response to temporary resort closures. The climatic and resort conditions experienced during the season were also analyzed, noting machine-made snow and groomed/pack snow were among the most frequently experienced conditions, with long wait times, rain and natural snowfall being the three least experienced conditions. Also, respondents' thresholds of acceptability, including the ratings of ski resort conditions, snow coverage, crowding, and chairlift wait times were examined, along with perceived likelihoods that individual thresholds would be exceeded. The results highlight that the majority of skiers have high levels of acceptance for marginal snow conditions and crowding. Statistically significant differences were found by age and gender in several experienced conditions, as well as their level of acceptance (i.e., thresholds) for various ski conditions. Climate change concerns and future ski behaviours, including preferred snowmaking options were analyzed, noting high levels of concerns and similar future behaviours as the responses during the 2023/2024, with temporal substitution as the most

prevalent choice in the face of future unacceptable conditions. The majority of respondents stated a preference for the closure of some trails to concentrate snowmaking on select fully snow-covered slopes. Finally, the perceptions of snowmaking as an adaptation strategy was examined, including the relationship between perceptions and climate change concerns. The findings highlight high agreement with the need for snowmaking to maintain ski seasons, as well the need to increase its capacity in the future, along with high uncertainty with respect to the environmental and climate impacts of snowmaking, including statistically significant differences by gender and age.

Chapter 5

Discussion

5.1 Introduction

This research has explored the behavioural responses of skiers and snowboarders during the record-warm winter season of 2023/2024, their thresholds of acceptability, climate change concerns, and perceptions about snowmaking as an adaptation strategy in the ski industry. The following chapter discusses the main findings, including the implications of the research results as they relate to the growing body of literature on climate change and skiing.

5.2 Participation patterns

The record-warm winter of 2023/2024 impacted the participation pattern of skiers. The majority (57%) of the respondents in this study indicated they skied less due to the temporary closures of ski resorts, which is similar to the US Northeast whereby 53% of skiers ceased participation for part of a season when they experienced record-warm conditions (Dawson & Scott, 2010). However, compared to a Canadian study conducted almost two decades ago (Scott & Jones, 2005), one-third (34%) of skiers in Ontario and Quebec indicated they would ski less in the future under marginal conditions (i.e., a difference of over 20%), which may indicate that the risk of marginal conditions (or climate change) is no longer perceived as a distant threat, but now actively experienced by skiers (i.e., increasing exposure to marginal conditions, partial closures, seasonal interruptions).

Media noted that the Canadian industry from coast to coast struggled with late openings, as well as multiple closures mid-season and an early end to season (e.g., Greenwood, 2024; Luymes, 2024), which was also the case in Ontario during the record warm season of 2011/2012 (Rutty et al., 2017). Several studies agree that ski seasons are more likely to be impacted during the early and late season segments (e.g., Fang et al., 2021; Scott, Steiger, Knowles, et al., 2020), including the Christmas/New Year Holidays which is an important economic period for the industry (i.e., high skier visits) (Scott et al., 2019; Scott, Steiger, Rutty, et al., 2020). Importantly, despite record warm and marginal conditions in 2023/2024, 42% of respondents continued to either ski about the same as they normally do or more than most seasons, with a large percentage within those groups indicating that they did not experience any closures at their preferred ski resorts. Nonetheless, even those who continued skiing experienced marginal conditions, including poor snow conditions, limited open runs, and delayed openings, indicating

that while resorts may have been operating, they were doing so at partial capacity. Delays and closures are often dependent on the size and location of the resorts, with smaller and lower elevation and/or lower latitude resorts at greatest risk (e.g., Dawson & Scott, 2007; Rice, Cohen, & Scott, 2022; Scott, Steiger, Rutty, et al., 2020; Steiger, 2011). As such, it is likely that those survey respondents who did not experience closures skied or snowboarded in more snow reliable regions (e.g., 48% of the respondents typically ski in BC, 30% in Quebec, and 23% in Alberta), or in ski areas where more machine-made snow was produced (e.g., 43% indicating they typically ski Ontario where 95% of ski terrain has snowmaking) (N. Knowles et al., 2023). Alternatively, respondents might not have been able to accurately state the extent of the closures due to a possible recall bias (Wattanacharoensil & La-ornual, 2019), though this seems unlikely given the short time proximity between the ski season (i.e., December-March) and the survey (i.e., April-June).

Most studies have found a much higher percentage of spatial substitution compared to this study, but activity substitution (i.e., stop skiing) is similar (<5%) (see Table 2-4). Nonetheless, compared to the ‘if your ski resort was closed today’ scenario from Rutty et al.’s (2015a), the results from this study also show a higher percentage of temporal substitution (70% in Rutty et al.’s vs 13% as a proportion of the whole sample in this study), and consequently, a lower percentage of spatial substitution projection (30% vs 11%), which may suggest that when skiers effectively experience marginal conditions, such as in 2023/2024 versus a hypothetical scenario, they remain resilient, but more likely to engage in temporal versus spatial substitution. This change in behavioural patterns also reflects the extent to which climate change risk perceptions may be shaping new responses. This study found that skiers in Canada are highly or extremely concerned about climate change impacting the sport, which increases over time (i.e., from 80% currently, to 82% in 5 years and 84% in 10 years) and is consistent with existing ski studies (Behringer et al., 2000; Cholakova & Dogramadjeva, 2019; Hoogendoorn et al., 2021; Pickering et al., 2010). Furthermore, as marginal conditions extend and the whole ski system is impacted by climate change, spatial substitution becomes less viable (Steiger et al., 2020), and skiers’ potential to shift from one ski area to another is reduced (Scott, Steiger, Rutty, et al., 2020). This was likely the case in the 2023/2024 season, whereby marginal conditions were experienced across the country, so temporal substitution was a more suitable alternative as skiers navigated the impacts of climate change. In fact, research has highlighted spatial substitution’s bigger financial and environmental implications, especially when skiers engage in international travel (or in long-distance flights, such as substituting skiing in Ontario for British Columbia), increasing personal travel costs, as well as travel distances and associated GHG emissions (Steiger et al., 2019) compared to skiing ‘close to home.’

This study revealed that 96% of skiers would modify their participation in the sport (i.e., engage in temporal or spatial substitution) if they deemed the winter conditions to be unacceptable, which is 21% higher compared to the first exploratory study in Australia (König, 1998) almost 30 years ago. Notably, in terms of modification, König's study found that only 31% would ski less, which is much lower than skiers in this study (57%), suggesting that conditions may have increasingly worsened, forcing skiers to change their participation patterns, but also showcasing the high resiliency of skiers, who ultimately find avenues to continue participating in the sport. At the same time, results highlighted the impact that the framing of future scenarios has on climate change concerns. Two key conditions converged in this study, which could have impacted this higher percentage of substitution projected compared to previous studies. On the one hand, the framing of this study positioned the temporal distance as more proximate to the participants, compared to “between 2000 and 2030” (Behringer et al., 2000) (other time frames used were not explicitly stated in the study), or “before 2030”, “before 2060”, “between 2060 and 2100” (Pickering et al., 2010), which at the time of those studies, reflected time horizons of up to 30 years and up to 90 years in the future, respectively. On the other hand, the conditions and impacts projected by climate change models (ECCC, 2024; Steiger et al., 2019) were being experienced at the time of surveying, suggesting that future behaviours would be based on a more vivid representation of what unacceptable conditions could look like, as opposed to hypothetical, and psychologically distant scenarios. The increase in concern levels when assessing a perceived closer future can be linked to research that has found that as the temporal dimension of the ‘psychological distance’ increases, the mental portrayals of risks associated with climate change become less concrete and more abstract (van der Linden, 2017). Future risks are mentally construed differently than present risks (Trope & Liberman, 2010; van der Linden, 2017). In this way, as the framing or experience brings the impacts mentally closer to the person (i.e., presents the impacts of climate change in a shorter time frame or occurring already), the more psychologically closer the risks can be perceived, thus increasing the concern levels reported by respondents in this study. Contrastingly, the studies in Bulgaria and Africa (Cholakova & Dogramadjeva, 2019 and ; Hoogendoorn et al., 2021, respectively) showed that as impacts were framed more locally, skiers' risk perceptions decreased. While this spatial dimension was not assessed in this study, future research could explore both temporal and spatial distance in more depth to better understand how skiers position the impacts of climate change when using a more complex construct and it may influence their participation patterns in turn.

Furthermore, the small net changes and the moderately strong link between actual and projected skiing behaviour suggest responses from the record warm 2023/2024 season can provide important insights to project future intentions in response to changing winter conditions (i.e., current behaviour accounts for 55% of the variance in stated future behaviour). This finding supports previous research from Dawson

and Scott (2010) in the US Northeast that found limited variability between adaptation responses of ski tourists during a past analogue warm winter season and their stated behaviour for future seasons. However, Rutty et al. (2017) found skier visits in Ontario declined by 10% during a record warm winter (representative of high-emissions, mid-century scenario) vs. 3% who said they would stop skiing if their resort was closed under the ‘today’ or ‘until mid-season’ scenarios. Interestingly, as the first study to survey skiers immediately after a record-warm winter, thus minimizing gaps between real versus hypothetical scenarios (Steiger et al., 2019), the findings only explain 55% of the variance, suggesting that other factors are likely influencing future intentions, such as pricing and crowding (Rutty, Scott, Johnson, et al., 2015a; Steiger et al., 2020), requiring further research to examine key motivations and decision-making factors that influence when, how frequently, and where people ski when conditions are marginal. Importantly, this study did not offer respondents the option of projecting to ski more in the future, despite unacceptable conditions. This overlook should be addressed in future research, as 9% of respondents stated that they had skied more during the 2023/2024 season. While few previous studies have asked respondents if they would ski more often (Dawson et al., 2011, 2013), this remains a possibility for highly committed skiers (such as the respondents captured in this study).

5.3 Ski conditions: Experience vs thresholds

The winter season of 2023/2024 aligned with climate projections in the literature, showing reduced natural snowfall paired with warmer temperatures (Bush et al., 2019) and increased snow production Table 2-3. Natural snowfall, although experienced the least, was the most desirable condition. On the other hand, respondents identified machine-made snow as the most experienced winter condition and highly acceptable, with 90% indicating that snowmaking is necessary for resorts to maintain the ski season. Snowmaking is the most widely utilized strategy by the ski industry to both maintain and extend ski seasons (Scott et al., 2022), which proved to be critical in 2023/2024 to enable operators to open at partial capacity despite minimal natural snowfall and preserve the economic viability of ski resorts (e.g., Scott & Steiger, 2024; Steiger et al., 2019; Steiger & Scott, 2020). With snowmaking coverage currently spanning from 14% in British Columbia to 95% in Ontario (N. Knowles et al., 2023), this adaptation strategy allowed to secure skiable conditions for visitors (Abegg et al., 2017; Rice, Cohen, & Scott, 2022; Wilkins et al., 2021),

However, it is important to note that while machine-made snow was rated as the third most acceptable condition in this study, it was not necessarily widely identified as ideal (5%) but mostly as acceptable (53%). These findings are in agreement with previous research that had underlined the high preference from skiers for natural snow conditions (Steiger et al., 2020). In contrast, machine-made snow has been deemed as a necessary but not a preferred condition or even a positive attribute of ski resorts (Unbehaun

et al., 2008). As an example, Steiger et al. (2020) found that almost 20% of ski tourists in Austria would not book a skiing holiday if there was predominantly machine-made snow. The fact that 76% of respondents experienced machine-made snow between most of the time and always, and it was considered acceptable, might be an indicator of a shift in acceptance from skiers. As marginal conditions become more frequent, and so does machine-made snow (i.e., machine-made snow is becoming the norm), this study supports previous research that shows that skiers are getting used to less desirable conditions (Witting et al., 2021) and that they view snowmaking as a way to counteract the impacts of climate change (Blin-Domínguez, 2022).

At the same time, there was wide agreement on the need to expand snowmaking capacity in future (i.e., 82% of respondents stated the capacity would need to increase in the next five years and 84% in the next 10 years), which aligns with ski industry leaders who have expressed their intentions to further invest in improved snowmaking capacity (Abegg et al., 2017; Hopkins, 2014; N. Knowles et al., 2023; N. L. B. Knowles, 2019; Steiger et al., 2019). Snowmaking's global capacity is expected to grow at a compound annual rate of 6.2% from 2024 to 2034 in the ski resorts segment (FACTMR, 2023). The techno-optimism bias permeates the risk perceptions of industry leaders and skiers alike, who believe that future snowmaking technological developments will be able to solve the challenges associated with snow-deficient and warmer winters (Hopkins & Maclean, 2014). This study also found a statistically significant relationship between skiers who view snowmaking as a current necessity and strongly agree that snowmaking capacity will need to increase in the next five and ten years. These views are likely to inform skiers' expectations and thereby continue to extend their acceptance and willingness to ski in machine-made snow, even if it is not the ideal condition.

A clear majority (83%) of skiers favour the concentration of snowmaking on select slopes (i.e., reduced hill access) to enable full snow coverage on open trails during periods of limited natural snowfall. This preference conflicts with the 61% that indicated reduced hill access is unacceptable. Having fewer slopes available could amplify some concerns raised in the literature about crowding, further diminishing visitor experiences (Rutty, Scott, Johnson, et al., 2015a; Scott & Steiger, 2024). The literature has already highlighted the importance of crowding in skier decision-making, with respondents indicating an unwillingness to ski in destinations with long waiting times (Unbehaun et al., 2008) and crowded ski slopes (Steiger et al., 2020). However, crowding was among the least experienced conditions during 2023/2024, with less than 14% of respondents stating that slopes were crowded and/or wait times at chair lifts were long 'most of the time' or 'always.' These findings contradict previous estimations of increased crowding driven by shifting demand patterns due to the transfer of skiers from low-elevation and/or highly impacted ski areas from snow-insufficient winters (Scott, Steiger, Rutty, et al., 2020; Scott &

Steiger, 2024; Steiger et al., 2019). Notably, participation patterns in this study revealed not only fewer skiers on the hills but also a higher temporal than spatial substitution.

Although crowding was one of the least ideal conditions, the majority of respondents (i.e., both those who typically ski in western and central Canada), indicated a willingness to accept up to 50% more skiers and/or wait times that exceed 15 minutes for a chairlift, before deeming conditions unacceptable. Despite this finding being in line with skiers in Australia who similarly identified 15 to 20 minutes as the maximum they would be willing to wait for a chairlift (Unbehaun et al., 2008), this study shows an important contradiction between crowding ratings and thresholds (i.e., respondents rated crowding conditions poorly yet they indicated high threshold, with willingness to accept up to 50% more people on the slopes). The lack of experience with crowding, or perhaps a misunderstanding of the survey question phrasing regarding percentage of unacceptable crowding (despite 57% indicating they found it easy to visualize crowding using percentages) might have resulted in the perception that crowding is a temporally distant issue (i.e., psychologically distant, reducing risk concerns) (Taylor et al., 2014; Weber, 2006), with skiers unsure about when the effects of crowding may become a new normal at Canadian ski resorts. The findings suggest that crowding is not currently problematic or perceived as a serious immediate risk for skiers, with no statistically significant association found between experience with crowded slopes and long wait times at chairlifts and crowding thresholds. This finding is in contradiction with most studies that have explored the risks and negative perceptions of crowding for the visitor experience (e.g., N. L. B. Knowles, 2019; Rutty, Scott, Johnson, et al., 2015a; Scott, Steiger, Rutty, et al., 2020; Steiger et al., 2020) and the industry's actions to prevent crowding. For example, Vail Resorts Vail Resorts launched 'My Epic' app in 2023 to help skiers avoid crowding in support of improving visitor experience. The digital initiative is a customer-centric innovation that includes real-time data on wait times at lifts to help skiers improve planning, thus preventing overcrowding, a top concern for their customers (LaConte, 2023). According to Vail, this innovation has resulted in shorter wait times around the slopes (i.e., lift lines longer than 10 minutes have occurred only three percent of the time this season) (McKee, 2025), which is 1-5 minutes below what this study found to be the threshold for the majority of skiers. Using smartphone technology to address crowding concerns could be the start of a trend that other large ski groups with stronger presence in Canada, such as Alterra (e.g., The Blue Mountain in Ontario or Mount Tremblant in Quebec), could implement to similarly avoid crowding with real-time tracking of wait times or geolocation of skiers, as well as possibly create opportunities for regional markets as a whole (e.g., if one resort is deemed over-crowded, a skier could then look to go to another resort).

Another condition that was largely unacceptable to skiers was to expand snowmaking to all slopes, but with narrower coverage and potential thin or bare patches on the edges of slopes (i.e., only 12% of

respondents indicated this as acceptable). Interestingly, despite identifying poor snow coverage as unacceptable, the majority (59%) indicated they would nevertheless ski if their resort were open, regardless of how little snow the slope has, with an additional 41% who indicated they would continue skiing so long as more than 65% of the slope was covered in snow. When reviewing the frequency with which this sample experienced narrow snow coverage and thin/bare patches on the slope, around half the respondents (49% and 54%, respectively) indicated they had experienced the conditions ‘sometimes,’ while almost 40% stated to have experienced it half of the time or more in both conditions (39% and 37%, respectively). These findings reinforce prior research that has suggested that skiers may already be getting used to, and accepting of, narrow snow-strips surrounded by brown, snowless areas (Witting et al., 2021). As new generations of skiers enter the sport, a key component to the long-term sustainability of the sport (Canadian Ski Council, 2023), climatic conditions will continue to warm with young skiers anticipated to experience conditions that differ from those of generations who are retiring from the sport. Exposure to these increasing marginal conditions might alter the way they engage with substitution and respond to adaptation strategies.

The increased acceptability of marginal conditions and high tolerance to reduced snow coverage and crowding could be explained through the lens of shifting baseline syndrome (SBS) (Pauly, 1995), which has also been referred to as “environmental generational amnesia” (Kahn & Kellert, 2002; Soga & Gaston, 2018). SBS describes the gradual adjustment of environmentally acceptable conditions resulting from the absence of experience, and/or historical memory or knowledge of conditions (Soga & Gaston, 2018). Applied to skiing, this phenomenon offers insight into how intergenerational shifts, in particular when new skiers join the sport, contribute to the normalization of marginal conditions, such as reduced hill access with increased crowding, increased reliance on machine-made snow, and bare patches of terrain on the slopes. In other words, what skiers deem as unacceptable now, may be acceptable in the future as the conditions become ‘normal’ for new ski generations and particularly if the other alternative is to stop skiing due to poor snow coverage.

The high involvement of this study’s sample may be influencing the willingness to accept marginal snow coverage conditions. The sample was recruited through organizations that have members who are highly committed to the sport (i.e., Canadian Ski Instructors Alliance, Protect Our Winter), with significant experience skiing (i.e., expert-skill level, 11+ years skiing). Additionally, the high involvement is further supported by a profile of skier who purchases season passes (75%), and ski three or more times a week (43%). In turn, this study supports Rutty et al. (2015) and Behringer et al.’s (2000) findings that expert-level skiers are less likely to change their skiing behaviour as their commitment to the sport is higher; while beginners, an underrepresented group in this study, are more likely to stop

skiing (Rutty, Scott, Johnson, et al., 2015a). In contrast, several other studies (Cholakova & Dogramadjeva, 2019; Cocolas et al., 2016; Dawson et al., 2013) show that highly engaged and skilled skiers are less willing to accept poor snow conditions, and, consequently, more prone to engage in spatial substitution behaviours (i.e., travel to find optimal conditions), thus suggesting lower thresholds than what we unveiled in this study. It is important to remember that this study showed more temporal substitution, which aligns with the higher thresholds.

In contrast with the lower perceptions that crowding is likely to occur in the future, the majority indicated that the likelihood of having unacceptable snow cover was probable. Nonetheless, results also showed that those respondents who selected higher thresholds (i.e., willing to accept more marginal snow conditions) perceived the scenarios as less likely to occur, portraying a higher psychological distance with this condition. The psychological distance might be influenced by an optimistic bias that leads people to underestimate the probability of personally experiencing the impacts of climate change (van der Linden, 2017) in the future, in this case, through snow-poor winter seasons. Contradictorily, this study found that skiers in Canada are highly or extremely and increasingly concerned about climate change impacting the sport. Nevertheless, further larger-scale research with a bigger sample size would be required to determine how likely are the risks of having limited snow coverage perceived on a broader sample and how the optimism bias might change over time as the impacts and their mental representations become more concrete and as skiers experience the conditions more frequently. It is also important to note that future research should include the perceived likelihood of resort closures. In this study, only those who indicated a threshold were asked to predict the probability of that threshold being met. Understanding how skiers perceive the risk of their ski resorts being unable to open for a season, could shed light on how distant they perceive climate change impacting their activity, and how that could force activity substitution in the future.

On the other hand, rain was rated as the most unacceptable winter condition, aligning with research from Knowles et al. (2024), where elite alpine skiing and snowboarder athletes rated rain poorly. However, during the 2023/2024 season, rain events were experienced ‘sometimes’ by 70% of respondents, while a mere 5% stated rain happened ‘most of time’ or ‘always.’ Albeit, climate projections anticipate an increased number of rain events and reduced snowfall as global temperatures rise (Bush et al., 2019). It is interesting to note that previous research underscores the important role rain plays in skiers’ and snowboarders’ travel planning and decision-making, highlighting that rain and freezing rain are the greatest deterrents (Rutty & Andrey, 2014). This result shows great coincidence with the fact that skiers might have a higher tolerance for insufficient snow cover than they would for rain, a condition ski operators cannot manage.

5.4 Region, gender and age-based differences

The frequency with which certain conditions were experienced differed by skiers who typically ski in western versus central Canada (e.g., machine-made snow, natural snowfall), as well as by gender and age (e.g., warm temperatures, thin/bare patches, narrow snow coverage). Results reflected the higher prevalence of natural snowfall in higher altitude resorts (e.g., British Columbia), with skiers in central Canada exposed to more machine-made, which aligns with heavy reliance on snowmaking infrastructure in Ontario and Quebec (N. Knowles et al., 2023). Correspondingly, skiers in central Canada rated machine-made snow more favorably and consider it more necessary, with stronger agreement in the need to increase snowmaking capacity in the future compared to respondents who typically ski in western Canada. Once again, SBS could help explain the regional differences found, such that skiers at smaller and lower altitude resorts in central Canada are exhibiting an increased tolerance for worsening environmental conditions, coupled with changes in the expectations of what the desired state would be (Soga & Gaston, 2018). In other words, skiers in central regions are likely becoming more used to snowmaking and have normalized this strategy after decades of experiencing it, with the possibility that skiers in western Canada may follow a similar trajectory such that as skiing experiences shift in a warming world (e.g., as new skiers enter the sport), new base lines will be established in western provinces too (i.e., machine-made snow will become more acceptable and the need for increased snowmaking capacity will increase).

To date, no other studies have explored gender- nor age-based differences in the experience or rating of winter or ski conditions. Women and younger skiers were more likely to have experienced the marginal conditions compared to men and older skiers. Additionally, women rated natural snowfall higher than men, whereas older skiers rated this condition as more unacceptable than younger skiers. Although conditions might have been objectively the same (i.e., the physical resources would not have differed in place), it is interesting that women perceived certain conditions directly related to climate impacts to occur more frequently. These results underline individual differences in how people may perceive the same stimulus or condition, depending on affect (i.e., people's feelings, positive or negative, in regards to a specific concept, stimuli, or ideas) and emotions (e.g., fear) (Keller et al., 2012). Simply put, similar situations, such as amount of natural snowfall, will be appraised differently emotionally by each person (Smith & Kirby, 2009). In this sense, women's perception of more frequent narrow snow coverage or thin/bare patches on the slopes may be related, for example, to the increased perception of risk. Much literature has found that women in sports tend to have comparatively higher perceptions of risk, with a lower estimation of ability and reduced risk taking as a result (e.g., Demirhan, 2005; Short et al., 2004). Also, these findings could suggest women have higher expectations for what they consider ideal skiing

conditions, independently of where they ski, and their thresholds might be on the verge of being exceeded as they also perceived experiencing marginal conditions more frequently. Risk perception studies have noted that women tend to have higher risk perceptions than men (Davidson & Freudenburg, 1996; Hitchcock, 2001; Slovic, 1999), which could have negative implications for the ski industry as women often play decisive roles in destination decision-making planning and information collection processes (Mottiar & Quinn, 2004). Consequently, women often influence when and where couples and families go skiing (i.e., potentially shifting demand patterns). Moreover, the literature notes that personal experience with climatic events (e.g., warmer temperatures) can increase risk perception (Weber, 2010). Women already participate less in the sport (e.g., 44% vs 56% in Canada), and younger skiers are critical to maintaining a stable market (Steiger et al., 2019).

This study also found that older generations are comparatively more tolerant of poor snow conditions and are more in favour of snowmaking as a necessity. The higher tolerances are likely a reflection of the high involvement of the age bracket, with decades of commitment to the sport and thereby high levels of self-declared skill in the sport (i.e., higher estimation of ability which reduces perceived risks associated with crowding and poor snow conditions) (Demirhan, 2005). Conversely, older generations are less accepting of crowding conditions, which may also be explained with SBS, such that older generations likely remember what resorts once use to be versus younger generations who have grown up with skiers on the slope as the market contracts and skiers concentrate at fewer resorts. Reports from the Canadian Ski Council have highlighted that the average age of skiers has been moving upward consistently over time (Canadian Ski Council, 2018, 2019, 2023), underscoring the challenges of an aging customer base and the need to ensure the growth of the younger skier market (Canadian Ski Council, 2023). As climatic conditions continue to become warmer and wetter (ECCC, 2024), it will be important for future research to examine gender and generational responses to better understand whether and how personal experience with marginal conditions alters ski behaviours, including the timing, location, and frequency of participation in the sport. Also, understanding new generations' expectations and beliefs related to climate change concerns becomes fundamental for the industry to determine how to address those concerns and secure the participation of young skiers in the long term. Moreover, Witting et al. (2021) found that personal determinants, including sociodemographic characteristics and lifestyles, influence tourists' responses beyond weather and climatic conditions or changes, snow conditions, and availability of machine-made snow. In the context of this research, these personal determinants could also be important in understanding the responses of skiers during 2023/2024 and their projections for future winters.

5.5 Skiers' perceptions of snowmaking

As one of the few studies to explore skiers' understanding of snowmaking, including perceived impacts on the environment, human health, and climate change, the results underscore key uncertainties and concerns. First, significant uncertainty was uncovered, such that 59% were unsure if additives are used in the production of snowmaking that could negatively impact health. While in some countries (e.g., Austria, Italy and Switzerland) additives are not allowed in the production of machine-made snow due to environmental and health concerns, there was no literature found to support the restrictions of additives in Canada. However, a study conducted by the French Agency for Environmental and Occupational Health Safety (Lagriffoul et al., 2010), concluded risks for workers who are involved in the snowmaking process were negligible to none if safety measures were followed. Moreover, according to the French study, the bacteria⁶ used for the additives such as Snowmax, which is utilized in some Canadian ski areas, did not represent a danger for humans, beyond potential allergies in highly sensitive individuals. The high level of uncertainty speaks to the scarce information the public has available on how machine-made snow is produced. Moreover, almost half (43%) of respondents were unsure whether snowmaking results in significant GHG emissions, with over one-third (>35%) unsure whether snowmaking negatively impacts water resources, contributes to climate change, or negatively impacts the environment. Respondents were at both ends of the agree-disagree continuum, indicating an important lack of consensus, with women reporting a significantly higher level of uncertainty than men. This finding is consistent with previous literature that underscores that females tend to have higher risk perceptions than males (Hitchcock, 2001; Slovic, 1999), including those related to environmental and climate change issues (van der Linden, 2015). Moreover, women have been characterized as more concerned about human health, due to their close relationship with birth and life (Slovic, 1999). Moreover, there is less agreement among older versus younger respondents on the negative environmental and human health impacts of snowmaking, with a disconnect between concern about climate change, negative perceptions of snowmaking impacts, and yet a large agreement with the need for snowmaking in the present and future.

Interestingly, the perception that significant water and energy are required for snowmaking production was not contested in this study, with no regional differences found between skiers in western and central Canada. The consensus regarding energy and water intensity for snowmaking showcases a long-standing narrative that has been mainstreamed by media and academics alike about the substantial requirements of these resources to make machine-made snow possible (e.g., François et al., 2023; Knowles et al., 2024; Vorkauf et al., 2022 and Table 2-6). Water and energy have been at the core of the snowmaking

⁶ For this study, the biological or chemical hazards identified were based on ice nucleation additives using active bacterium *Pseudomonas syringae*, e.g., Snowmax.

sustainability debate, and at the forefront of developments from snowmaking equipment manufacturers, who advertise their technologies as increasingly energy and water efficient to address financial and environmental concerns (e.g., SMI, Technoalpine, HKD, Ratnik Industries).

Arguably, the relationship between an intensive use of energy and GHG emissions, which have been demonstrated to drive climate change, should be more straightforward. However, the use of renewable energy plays an important role in driving down emissions. Knowles et al. (2023) highlighted the dependency of snowmaking on water and energy sources, with the results noting that while snowmaking is expected to increase between 55-97% in Canada by mid-century in a low- and high-emissions scenario (with water and energy consumption to increase accordingly), future emissions associated with snowmaking will decline under current climate policy targets as electricity grids decarbonize. It was beyond the scope of this study to examine respondents' perspectives and understandings of the energy matrix utilized to produce machine-made snow (e.g., hydroelectric, natural gas, coal). Interestingly, there were no significant differences between the perceptions of either energy use nor emission contributions when comparing skiers who typically go to western (Alberta or British Columbia) or central (Ontario or Quebec) ski areas, suggesting there is a nation-wide lack of understanding from skiers with respect to the role of energy matrices and the sustainability of snowmaking. Nevertheless, future research should consider examining public perceptions because as climate change progresses and new snowmaking capacity is introduced in the market, new conflicts and regulations might become a reality at local scales. Nonetheless, Knowles et al.'s (2023) study exposes how snowmaking can effectively support mitigation at the broader tourism sector scale (e.g., if a group of 65 decided to take a round trip flight from Montreal to Vancouver for a ski trip near Whistler, their total carbon emissions would be similar to Québec's entire snowmaking production). As it relates to this study, the majority of respondents indicated they typically ski in British Columbia (48%), Ontario (43%) and Quebec (30%), with only 23% of respondents stated Alberta, where emissions per skier are 10 times higher than in the other three provinces. Thereby, for this sample set, although respondents were largely uncertain, snowmaking could be considered a sustainable adaptation strategy.

The ski industry has largely advocated that snowmaking practices are sustainable, noting the active engagement of ski operators in climate action and environmental stewardship (e.g., the Sustainable Slopes program and Climate Challenge endorsed by Ski Canada and the National Ski Areas Association) (National Ski Areas Association, n.d.). Snowmaking companies have also claimed that machine-made snow can provide environmental benefits through the protection of ski-run vegetation as snowpack is insulated (Rixen et al., 2003), and snowmaking professionals in ski resorts argue about the nonconsumptive character of snowmaking, stating that the water used for snowmaking is mainly recycled

at the water reservoirs, with small water losses (Reimers, 2022). Leading resorts, including The Blue Mountain (Ontario), Mount Tremblant (Quebec), and Vail Resorts (Whistler, BC) also use their websites and Environmental and Social Responsibility Reports to highlight information about initiatives that support their sustainability strategies, including energy efficiency-oriented snowmaking investments (Blue Mountain Resort, 2024; Vail Resorts, 2024), the communication of snowmaking's water use and sources in an attempt to increase transparency (Mount Tremblant, 2025), and commitments to ecosystems' conservation and protection (Mount Tremblant, 2025; Vail Resorts, 2024).

Despite the industry's efforts to ensure a positive framing of snowmaking and their active role in climate action, the fact that skiers who are climate advocates (i.e., considering that this sample included a group of respondents from Protect Our Winters, a climate advocacy group) have such a high level of uncertainty about the environmental sustainability of snowmaking, raises questions about the communication strategies being used to engage with skiers, as well as perceptions of the broader public and the implications this could have for the ski industry (e.g., the broader public is likely less informed about snowmaking than self-proclaimed climate advocate skiers). Consequently, with no loyalty to the sport, non-skiers, who could potentially influence political decisions about the future of ski areas and resources, could be influenced by media outlets, which have become highly powerful in shaping perceptions of climate change issues (Lowe et al., 2006), and which have in the past framed snowmaking both as a maladaptation (e.g., Cox, 2022; Dingle, 2019; Reimers, 2022; Sackett, 2019; Van Dam, 2022; Xinhua, 2022) with negative environmental and health consequences, and more recently, as the only way to 'save' the ski industry from a warming future (e.g., Paddison, 2024; Suntinger, 2022), emphasizing the need to prioritize sustainability in an era of climate change (Ralls, 2023). The conflicting landscape leaves both skiers and the broader public to navigate a complex sustainability debate. As time progresses, increased pressure to strengthen regulations for access to water, a basic resource for ski areas, could have negative repercussions for operators, either increasing costs or forcing closures. While this study highlights the high acceptance of snowmaking and the need to increase its capacity in the future, skiers also remain highly uncertain and/or err on the side of snowmaking being highly water and energy-intensive, despite industry efforts to communicate sustainable snowmaking practices.

Moreover, while skiers denote high levels of concern over climate change impacting their sport, in this study there is further support to previous research that has found that increased knowledge about climate change and its impacts may lead to increased generalized concern, but is not necessarily transferred into a personal sense of risk (van der Linden, 2015, 2017). This study also brings to surface the great opportunity the industry has to engage with the skiing community and other stakeholders to showcase the positive impacts of snowmaking in the environmental and social dimensions of sustainability, while

building resilience and adaptive capacity of the ski-tourism system. To this extent, ski area managers need to take action to strengthen communication and transparency to build trust and prevent misinformation. Annual sustainability reports with detailed information about snowmaking impacts (e.g., energy/water use and sources, efficiency gains) coupled with real-time environmental dashboards shared in different digital platforms (e.g., websites, apps, in-situ displays, social media) could raise awareness in this area. A tailored communication approach that highlights the environmental benefits of skiing locally could also be beneficial (e.g., net zero skiing by staying in Ontario or Canada, as opposed to traveling internationally to the Alps). Moreover, enhancing engagement with skiers, local communities, government authorities, media and advocacy groups, while strengthening sector-wide and academia-industry collaborations (Steiger et al., 2019) will contribute to collectively advance sustainability and adapt to climate change and the challenges ahead.

Chapter 6

Conclusion and future research

6.1 Introduction

Canada experienced a record-warm winter season in 2023/2024 (ECCC, 2024), marking it as the warmest ski season ever registered in Canada since 1948 (ECCC, 2024). Ski tourism studies have consistently projected that climate change will lead to shorter and more variable ski season lengths, with increasing ski area closures and snowmaking requirements, with concomitant operating costs and sustainability concerns (e.g., due to increasing energy and water requirements to produce snow) (N. Knowles et al., 2023; Scott et al., 2022). Moreover, marginal ski resort conditions (e.g., narrow snow coverage, bare/thin patches on the slopes) and demand shifts are anticipated, which could lead to increased crowding as skiers concentrate spatially and temporally at climatically viable resorts (Rutty et al., 2015; Scott et al., 2020). To date, the tourism literature has largely focused on supply-side impacts of climate change, with far less research that explores how demand will respond to changing climatic conditions (Rutty et al., 2021), including how skiers have or will respond as threshold conditions are reached (i.e., the point at which skiers would no longer be willing to go to the resort) (Steiger et al., 2020). It is also unclear how snowmaking, the most widely utilized adaptation strategy in response to climatic variability, is perceived by skiers, both in terms of its necessity and whether or not it is deemed environmentally (un)sustainable. Furthermore, demand-side studies have predominantly relied on surveys that use hypothetical future scenarios that can not only introduce a desirability bias (Fisher, 1993), but also lead to respondent uncertainty despite efforts to provide more precise and tangible text descriptions of projected climate scenarios at ski resorts (Cocolas et al., 2016; Vivian, 2011; Witting et al., 2021).

As the impacts of climate change are increasingly being experienced, record warming events often go unstudied, representing a missed opportunity to gain insight into climate impacts that are expected to occur more often in the future (Scott, 2024). The presented study is novel, surveying skiers immediately after experiencing a record-warm season that resembles a high emission scenario by mid- or late-century (i.e., a climate analogue), which not only limits desirability bias, but also minimizes respondent misinterpretations regarding future scenarios. The findings from the research add to the body of literature that aims to understand skier/snowboarder behavioural responses to climate change, offering insight into temporal and spatial demand patterns, as well as advancing our understanding of the perceptions of snowmaking as a climate adaptation strategy. To achieve this aim, the research was guided by four research questions that reveal how the record-warm 2023/2024 winter season impacted the experience

and participation patterns of skiers/snowboarders in Canada (i.e., Research Question 1), skiers' thresholds of acceptability regarding climate and resort conditions (i.e., Research Question 2), skiers' concern about climate change and future impacts on ski conditions (i.e., Research Question 3), and finally, the perceptions of snowmaking as a sustainable adaptation strategy (i.e., Research Question 4).

6.2 Main findings

This study revealed that the record-warm winter of 2023/2024 impacted the number of skiers who engaged in the sport (i.e., 57% reported to have skied less), with greater temporal versus spatial substitution patterns that contrast with previous studies (Behringer et al., 2000; Dawson et al., 2011; Ruddy, Scott, Johnson, et al., 2015a; Unbehauen et al., 2008). Noteworthy, this study found an important link between reported (or actual response in 2023/2024) and projected future ski behaviours, suggesting the reliability of using past behaviours to predict future intentions. In this study, actual behaviour accounted for 55% of the variance in projected future behaviour, with a very small gap between stated behaviour and intentions under future unacceptable scenarios. The results revealed that 96% of skiers would modify their participation patterns if ski conditions were unacceptable in the future, a fifth more than the first behavioural response study conducted almost three decades ago (König, 1998). Most respondents indicated they waited for better conditions (i.e., temporal substitution), but this finding must be analyzed in the context of the large number of season pass-holders in this study, which may restrict some of the spatial movement as skiers have paid for the season in advance and want to get the most economic value out of their pass. Nevertheless, the projected behaviours stated in this study suggest there is an important opportunity for the ski industry to secure season passholders and seize loyalty in preparation for similar future ski conditions that are projected to become standard in the future (IPCC, 2023), thereby increasing the chances that skiers will wait for their resort to open versus travelling elsewhere (i.e., spatial substitution).

Furthermore, an important group (42%) continued to ski as usual in 2023/2024 (i.e., skied the same or more than most seasons), with 17% of the total proportion of respondents (40% of those who skied about the same and 44% of those who skied more) indicating that they did not experience any resort closures, while those who did ski recognized that conditions were not necessarily ideal. Although results need to be analyzed with caution (e.g., over reporting may have occurred despite the efforts to minimize social desirability and recall bias through timing and type of questions), the findings speak to the high resilience and adaptive capacity of skiers, but at the same time, they uncover that the risk of marginal conditions is now actively being experienced by skiers (i.e., insufficient natural snow, partial closures, and seasonal interruptions) and no longer a distant future. Notably, the record-warm skiing experience aligned with climate projections (i.e., reduced natural snowfall and warmer temperatures over the coming decades)

(Bush et al., 2019) and increased snowmaking requirements stated in the literature (e.g., Dawson & Scott, 2007; Rice, Cohen, Scott, et al., 2022; Scott, Steiger, Knowles, et al., 2020; Steiger, 2011). Respondents indicated a high prevalence and acceptance of machine-made snow, although it was not necessarily considered ideal, underlining skiers' preference for natural snowfall and suggesting skiers might be increasing their acceptance levels as they get more used to machine-made snow as the new normal.

The presented study also provided new insights into skiers' and snowboarders' thresholds of acceptability with respect to climatic and resort conditions. Poor snow coverage was deemed unacceptable, yet a clear majority (59%) would ski regardless of snow conditions (i.e., they would go so long as the resort was open), with an additional 41% of respondents selecting the lowest available snow coverage threshold (i.e., 65% slope coverage). Collectively, this finding underscores once again that skiers are highly resilient and adaptable to marginal conditions. In terms of the perceived likelihood that marginal conditions will occur in the future, results show that those willing to accept more marginal conditions on the slope are slightly more inclined to perceive the future climate scenarios as probable. However, respondents who selected the highest thresholds (i.e., the most tolerant to marginal conditions) perceived the climate scenarios as less likely to occur. In other words, skiers seem to distance themselves psychologically more from insufficient snow cover. At the same time, despite the key role of crowding in decision-making (Steiger et al., 2020; Unbehaun et al., 2008), and its negative rating in both this and previous studies (Steiger et al., 2020; Unbehaun et al., 2008), crowding was not only rarely experienced, but the perceived likelihood of experiencing crowding on the slopes was less immediate compared to the snow coverage scenarios. Nonetheless, the study revealed that the majority of respondents would be willing to accept up to 50% more skiers on the slope and wait up to 11 to 20 minutes for a chair lift before considering it unacceptable. While these findings are consistent with studies conducted in the European context (Steiger et al., 2020; Unbehaun et al., 2008), they reveal the context-specific character of skiing with marked differences between small, medium and large-sized resorts, as well as altitude and lift networks, and raises the question of what that 50% would look like in the different regions and times of skiing. For example, ski resorts in the Alps (somewhat similar to those in British Columbia or Alberta) span multiple mountains and provide skiers with a variety of runs and wider slopes that distribute skiers, reducing the risk of crowding. Whereas resorts in Ontario are much smaller, with a limited number of runs and fewer lifts that offer fewer options to avoid crowding.

Interestingly, this study provided evidence of regional differences in the experience and rating of conditions, as well as the perceived need for snowmaking in the present and in the future. Moreover, it underscored that women and men perceive and rate conditions differently and highlighted age-based differences, mainly in the rating of crowding-related conditions. Personal determinants, including

sociodemographic characteristics and lifestyles, influence tourists' responses beyond weather and climatic conditions or changes, snow conditions, and availability of machine-made snow (Witting et al., 2021). In the context of this research, these personal determinants could also be important in understanding the responses of skiers during 2023/2024 and their perceived likelihood that marginal conditions would occur in future winters. The experienced conditions where the differences were significant between men and women are related to expected consequences of climate change, such as warm temperatures, thin patches on the slopes, narrow snow coverage, reduced hill access, crowded slopes and long wait times at chairlifts. Older generations appeared to be less accepting of increased numbers of skiers on the slopes and wait times at chairlifts (i.e., crowding) suggesting there could be changing baselines for ski conditions as younger generations experience resorts differently than older generations once did. Given that young skiers were underrepresented in this study compared to the national average, the industry might have an opportunity to target and retain this younger audience who seem more willing to navigate future crowding conditions as climate-related shifts develop. Understanding gender and age-based differences might become crucial in the future to ensure participation and engagement in the sport, in particular for women, who indicated experiencing more marginal conditions, and young skiers, a key segment for the sustainability of the sport (Canadian Ski Council, 2023)

The majority of skiers (80%) in this study are highly or extremely concerned about climate change negatively impacting their current and future ski conditions, with concern increasing over time (i.e., present, 5-years, 10-years). While the sample in this study can be considered highly climate-change-aware (e.g., members of sustainability and climate advocacy groups), the concern is similar to previous studies (e.g., Behringer et al., 2000; Pickering et al., 2010; Unbehaun et al., 2008), reinforcing the importance and concern that climate change risk represents for skiers. Importantly, given that skiers experienced a record-warm winter, the psychological distance is reduced, which can positively influence the acceptance of climate change (McDonald et al., 2015). In this regard, the results showed a moderate and significant positive correlation between the previous experience of skiers with warm temperatures and their concerns about climate change impacting their conditions in the present and future. Additionally, the study showcased wide agreement on both the need for snowmaking to maintain ski seasons and the necessity to expand snowmaking capacity in the coming years, aligning with the industry's intentions to invest further in this adaptation strategy (N. Knowles et al., 2023). A majority of skiers (83%) would prefer resort operators to concentrate snowmaking on select slopes to enable full snow coverage (i.e., reduced hill access) versus snowmaking on all slopes but with narrower snow coverage and potential thin/bare patches on the edges, which also aligns with the low acceptability ratings

skiers assigned to those conditions (i.e., median of 2 with 5 being ideal for narrow snow coverage and thin/bare patches in both cases).

Through an examination of skiers' perceptions of snowmaking as a sustainable adaptation strategy, this study revealed that almost all respondents (90%) agreed that snowmaking is not only necessary for ski operations now, but skiers also agreed snowmaking capacity will need to increase in the next five and 10 years (>82% of respondents). However, there are high levels of uncertainty regarding whether or not snowmaking negatively impacts the environment (36%), water resources (38%), or human health (59%), with respondents also unsure whether snowmaking is a significant source of emissions (43%) or a contributor to climate change (35%). Nevertheless, a notable proportion of the respondents perceive snowmaking to negatively impact the environment (39%), water resources (36%), contribute to CC (30%), and consistent with risk perception theory, women showed significantly higher levels of perceived risk than men (Slovic, 1999). Despite the reported concerns and uncertainty, as well as the high levels of concern about climate change impacting ski conditions, respondents want ski resorts to continue producing snow to ensure they can continue skiing when climatic conditions are marginal.

6.3 Future research

The presented study surveyed Canadian skiers following the end of the warmest winter recorded since 1948, which is novel because their stated behavioural responses are based on recent experience and not on hypothetical future warming conditions. While the sample provides key insights into how skiers respond to marginal conditions, it was relatively small ($n = 209$), and not representative of the Canadian ski market as a whole. This study showcased the high adaptability and tolerance of skiers to marginal conditions, as well as the high acceptance of snowmaking, but given the overrepresentation of expert skiers with over 11 years in the sport, it remains unclear whether the beginner and intermediate skill level, including those new to the sport, will respond and perceive conditions and risks similarly. Importantly, novice skiers' experiences with snow conditions may determine if they continue in the sport, which would have important implications for market stability and growth. Also, understanding new generations' expectations and beliefs related to climate change impact on skiing is fundamental for the industry to best address those concerns (e.g., whether or not to concentrate snowmaking on select hills or spread or disperse crowds across multiple hills but with more narrow slopes) and secure the participation of young skiers in the long term. In the same vein, the over-representation of season pass holders may be masking the sensitivity of the broader market to marginal conditions, such that season pass holders who have already paid for the season are likely wanting to get the most out of their pass (i.e., economic efficiency), with day-pass and/or international skiers potentially more sensitive to poor resort conditions resulting in differing substitution patterns.

In turn, future surveys should examine the range of skill levels (i.e., beginner, intermediate, advanced), years of experience in the sport, particularly those new to the sport (e.g., <5 years), as well as all types of pass holders (e.g., day pass, multi-pass, international skiers). A more representative survey could also reveal additional age- and gender-based differences, as well as shed new insight on varying climatic and resort thresholds and corresponding behavioural responses (e.g., temporal and spatial substitution patterns). Future studies with a mixed methods approach could use SBS as a framework to assess how different generations perceive and accept various ski conditions. For the industry's long-term sustainability, it will be important to understand how future generations will engage with the sport in the decades to come (e.g., as new skiers join the sport in the next 10, 20 or 30 years). What is deemed unacceptable now in 2024 may not deter novices if they grow into the sport having experienced present day marginal conditions from the outset. From a gender perspective, risk perception theories could provide deeper insights into why women perceive marginal conditions more frequently and the association with risk, at both individual and family levels, providing pathways for industry to tailor communication to this group to increase their engagement and participation. It is also possible that socio-economic factors (e.g., income, occupation, education) could influence preferences and responses, such as willingness to pay more for snowmaking coverage or to travel longer distances (e.g., ski holiday) in response to warming conditions. It also remains unclear what those who stated they would ski regardless of snow coverage (i.e., 59% who stated no threshold) perceive to be the likelihood of closures in their preferred ski resorts, including what their behavioral responses would be under a closure scenario. Relatedly, the 41% of respondents who selected higher thresholds (i.e., willing to accept more marginal snow conditions) perceived climate impacts as less likely to occur (i.e., higher psychological distance), suggesting that future research could further explore how optimism bias may (or may not) shift over time as marginal conditions become more common (e.g., a survey following multiple marginal seasons in a row) or other heuristics or mental models that influence risk perception (e.g., affect, availability) (van der Linden, 2017).

A future survey could also incorporate open-ended questions (or qualitative interviews or focus groups) to elicit deeper insights into skiers' experiences, thresholds, concerns, and future behavioural responses to warming conditions (e.g., emotions, attitudes, motivations). For example, future research could explore both temporal and spatial distance (i.e., believing the impact is, or will be, elsewhere geographically) in more depth to better understand how skiers position the impacts of climate change when using a more complex construct, and how this may influence their participation patterns in turn. At the same time, future research could explore whether or not behavioural responses vary by geographic markets (e.g., Europe, US, Australia), as well as based on the size of the resort (e.g., small, medium, large, public/private). Research has shown that climatic preferences and thresholds vary by country of origin,

with the needs of Canadians not necessarily the same as those of skiers in other markets. Moreover, the size of the resort could influence behaviour as larger resorts, including those in world-renowned mountain ranges (e.g., Rockies, Alps), have a significantly larger non-climatically dependent draw (e.g., landscape aesthetic, accommodations, shopping, spas, indoor pools), which could make demand less sensitive to marginal conditions given that there are other recreational opportunities on site. Larger resorts also tend to have greater snowmaking infrastructure compared to smaller resorts, which not only minimizes the impact of warming conditions, but could draw demand away from small resorts (i.e., spatial substitution).

Skiers' perceptions of snowmaking as a sustainable adaptation strategy is an important but understudied area of research with opportunities to explore the topic in more detail. Given that the sustainability and impacts of snowmaking are highly location-specific depending on not only the source of water used as input, but also the type of electricity grid (e.g., François et al., 2023; N. Knowles et al., 2023), future research could be more explicit in examining skier's perceptions of sustainable snowmaking for the resort they frequent most (versus industry snowmaking as a whole) and with a region-based approach (i.e., differentiating between ski markets). More broadly, future research could incorporate other dimensions of risk perception (i.e., cognitive, experiential and socio-cultural factors) (van der Linden, 2015, 2017) and measure not only concern but also worry, and support to climate change adaptation and mitigation strategies.

For example, it would be interesting to survey not only skiers, but the general public, regarding their knowledge on water sources used for snowmaking (e.g., where do they think the water is coming from? How would the sources of water change their perceptions and their support for increased snowmaking capacity?). Similarly, as water becomes scarcer in the future due to climate change, it remains an important avenue for future research to understand how skiers (and the public) perceive water allocation for snowmaking. Similarly for emissions, it is unclear whether skiers are aware of the electricity used by their resorts (and whether or not they understand the associated emissions from the energy source), as well as whether or not (and to what degree), skiers would change their behaviours based on their carbon footprint for various resort options. For example, would they be willing to reduce long-haul travel to minimize their footprint if snowmaking allows for acceptable skiing experiences at a smaller local resort? In addition to skiers, more research is needed that explores the perceptions of the general public toward snowmaking, including the communities near ski areas. Given that media headlines target audiences well beyond skiers, broad public opinion could place pressure on the ski industry to behave a certain way (e.g., influence policies around water allocation) or possibly deter people from joining the sport in the future, which would both hinder the industry's long-term viability.

This study used a negative phrasing of statements related to the sustainability of snowmaking. The statements mimicked how the media and literature have framed the issues. However, there is evidence that framing has an impact on how people respond to issues, in particular those related to climate change (Nerlich et al., 2010; Pelletier & Sharp, 2008). Therefore, future research could explore conducting experimental research with both positive and negative framings to identify potential biases and differentiated responses.

Lastly, behavioural responses to climate change will continue to evolve in response to marginal ski conditions. Longitudinal studies incorporating the shifting baseline syndrome framework would be beneficial to track changes in perception and experience as climate change advances. Relatedly, given the synchronic evolution of impacts and adaptations that will take place in tandem from both the supply- and demand-side of the ski industry, more integrated assessments are urgently needed to further support ski tourism and the socioeconomic and environmental systems attached to it. To develop adequate and sustainable adaptation strategies, more collaboration between the academy and the industry stakeholders is required to further advance the understanding of future competitive conditions and adaptive capacities of the multiple stakeholders (Steiger et al., 2019).

6.4 Final thoughts

Climate change poses a direct threat to the multi-billion dollar ski tourism industry (Steiger et al., 2019), with global temperatures expected to rise and natural snowfall to decline (IPCC, 2023b), resulting in more variable ski seasons (interruptions, shortened) and increasing snowmaking requirements (including water and energy resources). Skiers' behavioural responses to marginal ski conditions is vital to understand if the industry is to adequately respond to shifting demand and minimize the risk of exceeding skiers unacceptable thresholds (e.g., crowding, slope conditions). Skiers' willingness to accept conditions such as crowding, insufficient snow coverage, and increased machine-made snow will influence substitution behaviours (i.e., when and where skiers will pursue the sport), ultimately shaping the future of the ski industry. Although this study underscores skiers' high adaptability and tolerance to marginal conditions (e.g., 42% skied the same or more during the record-warm winter), it also signals there is a limit to their willingness to ski (i.e., 57% skied less), and highlights growing concerns about future conditions (i.e., >82% highly or extremely concerned), which are projected to worsen over time (IPCC, 2023b). Furthermore, with snowmaking production expected to increase across all regions to maintain ski seasons (Steiger et al., 2019), understanding skiers' perceptions about the sustainability of this adaptation strategy is critical. Ski resorts rely heavily on snowmaking and negative perceptions of snowmaking could deter skiers from engaging in the sport while also preventing new participants from joining, threatening the financial sustainability of the industry. Moreover, public opinion on snowmaking

influences policy and regulations that could impact the industry, making it important for the industry to understand perceptions and engage in stakeholder management approaches to align the industry with public values, securing the long-term sustainability.

Ultimately, this research serves as a stepping stone for a deeper understanding of how skiers will adapt to climate change and how they perceive the role of snowmaking and its impacts on the future of the ski industry. The ski industry is a vital economic driver for mountain communities and key tourism stakeholders across Canada, including ski operators, local governments, and hospitality sectors. Therefore, enhanced transparency and communication will be essential to support effective adaptation strategies. It is hoped that this study will inspire proactive engagement from the ski industry to prioritize sustainability. Furthermore, this study underscores the importance of continued research into the long-term behavioural shifts of skiers and the viability of snowmaking across different markets in an era of climate challenges.

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Appendix A

Survey Questionnaire

Hello,

You are invited to participate in a survey being conducted by researchers at the University of Waterloo, Canada. Over the past few years, variable temperature and snowfall conditions have interrupted the winter ski season. Your participation in this study involves completing an online 10-minute survey to better understand skier/snowboarder perspectives on changes in ski conditions, including perceptions of snowmaking as a weather management strategy. The survey will also ask questions about your ideal and unacceptable conditions for skiing/snowboarding, including weather and crowding conditions.

This study is voluntary, with the freedom to decline to participate at any point, and no personal information is required to participate. You may decline to answer any question(s) you prefer not to answer by skipping to the next question or closing your web browser. Only responses that have been submitted will be included in the study analysis.

Your identity will be kept strictly confidential. When results are reported they will be combined with other responses so that your individual identity is confidential. Data collected during this study will be retained for at least seven years in a locked office or on a password-protected computer and then erased. There are no known or anticipated risks to participation in this study.

This study has been reviewed and received ethics clearance through a University of Waterloo Research Ethics Board (REB #46070). If you have questions for the Board, contact the Office of Research Ethics, toll-free at 1-833-643-2379 (Canada and USA), 1-519-888-4440, or reb@uwaterloo.ca For all other questions contact ablopezf@uwaterloo.ca

Sincerely,
Ana Beatriz Lopez

Consent to participate

By agreeing to participate in the study you are not waiving your legal rights or releasing the investigator(s) or involved institution(s) from their legal and professional responsibilities.

With full knowledge of all foregoing, I agree, of my own free will, to participate in this study.

- ☐ I agree to participate (1)
- ☐ I do not wish to participate (Please close the web browser now) (2)

Skip To: Q1 If Consent = I agree to participate

Skip To: End of Survey If Consent = I do not wish to participate (Please close the web browser now)

Q1 When did you last go skiing/snowboarding in Canada?

- a. This season (2023/2024) (1)
- b. Last year (2022/2023) (2)
- c. 2 years ago (2021/2022) (3)
- d. 3-4 years ago (2019/2021) (4)
- e. 5+ years ago (on or before 2018) (5)
- f. I have never been skiing/snowboarding in Canada (6)

Skip To: Q8 If Q1 = I have never been skiing/snowboarding in Canada

Q2 In what province do you typically ski? (Check all that apply)

- a. Alberta (1)
- b. British Columbia (2)
- c. Manitoba (3)
- d. Newfoundland and Labrador (4)
- e. New Brunswick (5)
- f. Nova Scotia (6)
- g. Ontario (10)
- h. Prince Edward Island (7)
- i. Quebec (8)
- j. Saskatchewan (9)

Display This Question:

If Q1 = This season (2023/2024)

Q3 Canada experienced record warm conditions during the 2023/2024 season, resulting in the temporary closure of ski resorts (e.g., late start to the ski season, early end to ski season, interruptions during the season). Did the poor snow conditions impact the frequency of your skiing/snowboarding during this 2023/2024 season?

- a. I skied/snowboarded LESS than most seasons (1)
- b. I skied/snowboarded about the SAME as most seasons (2)
- c. I skied/snowboarded MORE than most seasons (3)
- d. The 2023/2024 season was my first time skiing/snowboarding in Canada (4)

Display This Question:

If Q3 = I skied/snowboarded about the SAME as most seasons Or If

Q3 = I skied/snowboarded MORE than most seasons

Q4 Where did you ski/snowboard when your preferred Canada ski resort was temporarily closed due to poor conditions this 2023/2024 season? (Select all that apply)

- a. I waited for my preferred resort to open and then increased the frequency of my skiing/snowboarding to compensate for a shorter season (1)
- b. I travelled WITHIN my province to ski at a different resort (s) (2)
- c. I travelled OUTSIDE of my province to ski at a different resort(s) (3)
- d. I travelled INTERNATIONALLY to ski at a different resort (5)
- e. Other: (4) _____

Display This Question:

If Q1 = This season (2023/2024)

Q5 Please indicate whether you have experienced the following winter conditions in the 2023/2024 winter season* where you typically ski/snowboard in Canada from Never to Always:

	Never (11)	Sometimes (12)	About half the time (13)	Most of the time (14)	Always (15)
Natural snowfall (powder conditions) (1)					
Groomed snow/packed powder (16)					
Ice conditions on ski trails/slopes (2)					
Machine made snow (17)					
Wet snow (18)					
Rain (5)					
Warm temperatures (19)					
Fog/reduced visibility (20)					
Thin/bare patches on the slope (3)					
Narrow snow coverage (i.e., exposed terrain along the sides of the slope) (21)					
Reduced hill access (i.e., not all slopes and chairlifts open) (22)					
Crowded slopes (6)					
Long wait times at the chairlift (7)					
Crowded chalet restaurants (23)					
Other (10)					

* Or previous winter seasons if Q1= last year, 2 years ago, 3-4 years ago, 5+ years ago

Q6 Rate the following Canadian ski resort conditions from unacceptable to ideal

	Unacceptable (i.e., would not go ski/snowboard) (11)	Slightly unacceptable (12)	Neutral (13)	Acceptable (14)	Ideal (15)
Natural snowfall (powder conditions) (1)					
Groomed snow/packed powder (16)					
Ice conditions on ski trails/slopes (2)					
Machine made snow (17)					
Wet snow (18)					
Rain (5)					
Warm temperatures (19)					
Fog/reduced visibility (20)					
Thin/bare patches on the slope (3)					
Narrow snow coverage (i.e., exposed terrain along the sides of the slope) (21)					
Reduced hill access (i.e., not all slopes and chairlifts open) (22)					
Crowded slopes (6)					
Long wait times at the chairlift (7)					
Crowded chalet restaurants (23)					
Other (10)					

Q7 What would you do if your preferred Canadian ski resort had UNACCEPTABLE conditions?

- a. I would ski/snowboard LESS and wait for my resort to have acceptable conditions (1)
- b. I would ski/snowboard LESS, traveling to other ski resorts that have acceptable conditions (6)
- c. I would ski/snowboard the SAME and wait for my resort to have acceptable conditions (i.e., increase my frequency during the shortened season) (7)
- d. I would ski/snowboard the SAME, traveling to other ski resorts that have acceptable conditions (2)
- e. I would STOP skiing/snowboarding (4)
- f. Other (please specify) (5) _____

Q8 Please indicate your level of agreement with respect to snowmaking (machine made snow), from disagree strongly to agree strongly :

	Disagree strongly (6)	Disagree (7)	Undecided/ Unsure (8)	Agree (9)	Agree strongly (10)
Snowmaking is necessary for ski resorts to maintain ski seasons. (1)					
Snowmaking capacity will need to increase in the next 5 years. (4)					
Snowmaking capacity will need to increase in the next 10 years. (5)					
Snowmaking negatively impacts the environment. (6)					
Additives in snowmaking negatively impact human health. (7)					
Snowmaking requires significant water to produce. (8)					
Snowmaking negatively impacts water resources. (9)					
Snowmaking requires significant energy (electricity) to produce. (10)					
Snowmaking results in significant greenhouse gas (GHG) emissions. (11)					
Snowmaking contributes to climate change. (12)					

Q9 At what point would you find the snow conditions (natural and machine made) on a ski slope to be UNACCEPTABLE for skiing/snowboarding in Canada (i.e., when would you not go skiing/snowboarding)?

- a. $\leq 90\%$ of the slope is covered in snow (1)
- b. $\leq 85\%$ of the slope is covered in snow (2)
- c. $\leq 80\%$ of the slope is covered in snow (3)
- d. $\leq 75\%$ of slope is covered in snow (4)
- e. $\leq 70\%$ of slope is covered in snow (5)
- f. $\leq 65\%$ of slope is covered in snow (6)
- g. If the resort is open, I will go skiing/snowboarding (7)

Q10 When answering the previous question, was it easy or difficult to visualize the percentage change in snow coverage?

- a. Extremely difficult (11)
- b. Somewhat difficult (12)
- c. Neither easy nor difficult (13)
- d. Somewhat easy (14)
- e. Extremely easy (15)

Display This Question:

If Q9 = $\leq 90\%$ of the slope is covered in snow

Q11 What do you think the likelihood is of your Canadian resort having $\leq 90\%$ of slope (insert answer from Q9) covered in snow?

- a. Improbable (unlikely to occur) (6)
- b. Remote (unlikely, although possible) (7)
- c. Occasional (likely to occur occasionally during ski seasons) (8)
- d. Probable (not surprised, will occur in a given time) (9)
- e. Frequent (likely to occur, to be expected) (10)

Q12 At what point would you find the ski slope to be too crowded to go skiing/snowboarding?

- a. $\leq 10\%$ more people than usual (1)
- b. 25% more people than usual (2)
- c. 50% more people than usual (3)
- d. 75% more people than usual (4)
- e. 80% more people than usual (5)

Q13 When answering the previous question, was it difficult to visualize the percentage of slope covered with other skiers/snowboarders?

- a. Extremely difficult (11)
- b. Somewhat difficult (12)
- c. Neither easy nor difficult (13)
- d. Somewhat easy (14)
- e. Extremely easy (15)

Display This Question:

If Q12 = $\leq 10\%$ more people than usual

Q14 What do you think the likelihood is of your Canadian resort having $\leq 10\%$ (insert answer from Q12) more people than usual?

- a. Improbable (unlikely to occur) (1)
- b. Remote (unlikely, although possible) (2)
- c. Occasional (likely to occur occasionally during ski seasons) (3)
- d. Probable (not surprised, will occur in a given time) (4)
- e. Frequent (likely to occur, to be expected) (5)

Q15 What is the maximum time you would be willing to wait in line for a chair lift at a Canadian ski resort during peak season?

- a. ≤ 5 min (1)
- b. 6-10 min (2)
- c. 11-15 min (3)
- d. 16-20 min (27)
- e. $+21$ min (28)

Display This Question:

If Q15 = ≤ 5 min

Q16 What do you think the likelihood is that you will have to wait ≤ 5 min for a chair lift at your preferred Canadian ski resort?

- a. Improbable (unlikely to occur) (1)
- b. Remote (unlikely, although possible) (2)
- c. Occasional (likely to occur occasionally during ski seasons) (3)
- d. Probable (not surprised, will occur in a given time) (4)
- e. Frequent (likely to occur, to be expected) (5)

Q17 Rate your level of concern for each of the following statements, from not at all concerned to extremely concerned.

	Not at all concerned (1)	Slightly concerned (2)	Somewhat concerned (3)	Very concerned (4)	Extremely concerned (5)
I am concerned that changes in temperature and precipitation (rain, snow) are negatively impacting my CURRENT ski conditions (1)					
I am concerned that changes in temperature and precipitation (rain, snow) will negatively impact my ski conditions in 5 years (2)					
I am concerned that changes in temperature and precipitation (rain, snow) will negatively impact my ski conditions in 10 years (3)					

Q18 During periods with limited natural snowfall, what would you prefer your chosen Canadian ski resort to focus on?

- Close some trails/slopes to concentrate snowmaking on select trails/slopes (i.e., full snow coverage on select trails/slopes) (1)
- Open all slopes, but with narrow and/or thin snow coverage on each slope (e.g., bare terrain patches and/or no snow along the edges of the slope). (2)
- Increase lift ticket price to support full snowmaking coverage across the entire resort (i.e., all slopes open with full snow coverage) (3)

Display This Question:

If Q18 = Increase lift ticket price to support full snowmaking coverage across the entire resort (i.e., all slopes open with full snow coverage)

Q19 How much more would you be willing to pay for your lift ticket to support full snowmaking coverage across the entire resort (i.e., all slopes open with full snow coverage)?

- I would be willing to pay 5% more for full snowmaking coverage. (1)
- I would be willing to pay 10% more for full snowmaking coverage. (2)
- I would be willing to pay 15% more for full snowmaking coverage. (3)
- I would be willing to pay 20% more for full snowmaking coverage. (4)
- I would be willing to pay 25% more for full snowmaking coverage. (5)

Q20 How far do you typically travel to go ski/snowboarding?

- a. ≤ 49 km (1)
- b. 50-99km (2)
- c. 100-200km (3)
- d. 201-499km (4)
- e. 500+ km (5)

Q21 What is the maximum distance you would travel to go ski/snowboarding?

- a. ≤ 49 km (1)
- b. 50-99 km (2)
- c. 100-200 km (3)
- d. 201-499 km (4)
- e. 500+ km (5)

Q22 On which ski/snowboard trail do you feel the most comfortable?

- a. Beginner (green) (1)
- b. Intermediate (blue) (2)
- c. Expert (black diamond) (3)

Q23 How often in a season do you typically ski/snowboard in Canada?

- a. 3 or more times per week (4)
- b. 1-2 times per week (5)
- c. 3 times per month (6)
- d. 2 times per month (7)
- e. Once per month (8)
- f. Less than once per month (9)

Q24 When do you typically go skiing/snowboarding? Check all that apply

- ☐ Daytime (1)
- ☐ Night (2)
- ☐ Weekday (3)
- ☐ Weeknight (4)
- ☐ Weekends (8)
- ☐ Winter holidays (e.g., Dec 23- Jan 5) (5)
- ☐ School break (e.g., March Break) (6)
- ☐ Other (7) _____

Q25 When you go ski/snowboarding, what type of lift ticket do you typically purchase?

- a. 1-day pass (1)
- b. 2-day pass (2)
- c. Multi-day pass (e.g., 3-7 days) (5)
- d. Season pass (3)
- e. Other (e.g., weekday and/or evenings pass) (4)

Q26 How many years have you been skiing/snowboarding?

0-1 years (4)

- a. 2-3 years (5)
- b. 4-5 years (6)
- c. 6-10 years (7)
- d. 11+ years (8)

Q27 How old are you?

- a. 18-24 (2)
- b. 25-34 (3)
- c. 35-49 (4)
- d. 50-64 (5)
- e. 65+ (6)

Q28 How do you identify?

- a. Man (1)
- b. Woman (2)
- c. Non-binary (3)
- d. Undisclosed (4)