Understanding Climate Change Impacts and Adaptation Potentials at Utah Ski Resorts

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UNDERSTANDING CLIMATE CHANGE IMPACTS
AND ADAPTATION POTENTIALS
AT UTAH SKI RESORTS

by

Rachel Nia Hager

A thesis submitted in partial fulfillment
of the requirements for the degree
of
MASTER OF SCIENCE
in
Ecology

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UTAH STATE UNIVERSITY
Logan, Utah

2021
ABSTRACT

Understanding Climate Change Impacts and Adaptation Potentials at Utah Ski Resorts

by

Rachel Nia Hager, Master of Science

Utah State University, 2021

Major professor: Dr. Patrick Belmont

Department of Watershed Sciences

Increasing temperature and shifting precipitation regimes due to climate change are a significant threat to winter recreation. Some businesses such as high-elevation ski resorts are especially vulnerable to the impacts of climate change. However, ski resorts may be able to mitigate the impacts of climate change by proactively implementing adaptation strategies. The overall goal of this study was to investigate the impact of climate change on Utah ski resorts, and to understand adaptation perception, barriers, and strategies for different resorts across the state.

To meet that goal, we used a mixed-methods approach including examining temperature shifts at all Utah ski resorts 1980-2018 and climate change projections under RCP 2.6, 4.5, and 8.5 for 2021-2100, in addition to semi-structured interviews with ski resort managers. The interviews with resorts addressed how leadership perceives climate change threats and impacts, how the report is implementing adaptation strategies, and addressing barriers to adaptation. Since 1980, the minimum daily temperature has increased at all 14 Utah ski resorts, and at 12 of the 14 resorts the number of early season days with a minimum temperature at or below \(-5^\circ\text{C}\) (the temperature needed to make snow) has significantly decreased. Climate projections show that minimum temperatures are expected to rise during the prime ski season of December-March by
up to 6.0°C in Northern Utah and up to 6.6°C in Southern Utah by 2100 under RCP 8.5. Resort managers are aware and concerned about the shrinking and shifting ski season especially with less snow and of a lower quality. Of the eight Utah ski resorts interviewed, most resort managers have already begun to implement adaptation measures such as diversifying winter and other season activities, increasing snowmaking capacity, and closing high-maintenance slopes. Resort managers face moderate to extreme barriers in adaptation including financial and water limitations. Utah ski resorts are already impacted by climate change and as the impacts become more severe, adaptation strategies will be needed to minimize negative impacts of higher temperature and lower quality and quantity of snow.

(59 pages)
PUBLIC ABSTRACT

Understanding Climate Change Impacts and Adaptation Potentials at Utah Ski Resorts

Rachel Nia Hager

Climate change is a threat to ski resorts, the ski industry, and mountain communities that rely on ski tourism. Ski resorts may be able to mitigate some of the social and economic impacts caused by climate change with proactive adaptation strategies. Using historical weather data, future climate projections, and interviews with ski resort managers in Utah, this research investigates the effects of climate change on ski resorts across the state. We examine temperature change at all resorts within the state from 1980 – 2018, and climate projections from 2021 – 2100 under different climate change scenarios (RCP 2.6, 4.5, and 8.5). We also report on semi-structured interviews with resort managers to provide insights into how resort leadership perceives the impacts of climate change, are implementing adaptation strategies, and are addressing barriers to adaptation. Many resorts in Utah are warming faster than global averages, and minimum temperatures are rising faster than maximum temperatures. By the end of the century, winter (December – March) minimum daily temperatures in Utah could warm an additional 6.0°C under the RCP 8.5 scenario near Northern Utah resorts, and 6.6°C near Southern Utah resorts. Resort managers are concerned about shorter season lengths, shifting ski seasons, less snow cover, and poorer snow quality. Many resorts are already adapting, with the most common adaptations being snowmaking and diversifying outdoor recreation offerings (particularly during the summer and shoulder seasons). Barriers to adaptation reported by managers include financial costs, adequate water availability for snowmaking, and uncertainty.
about climate change projections. Climate change is already impacting Utah ski resorts, but adaptation practices can reduce the negative impacts to some degree at most resorts.
ACKNOWLEDGMENTS

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CHAPTER 1: INTRODUCTION

Anthropogenic climate change, the emission of greenhouse gasses into the atmosphere, results in widespread impacts on human and natural systems (IPCC 2014). Increasing greenhouse gas emissions are the root of significant changes to the biological, physical, and human systems (Rosenzweig et al. 2008; Mooney et al. 2009; Hoegh-Guldberg et al. 2019). These changes can fundamentally alter and degrade entire ecosystems as well as disrupt human activities (Mooney et al. 2009; Pecl et al. 2017). An increase in global temperature by only a few degrees could have significant environmental and economic impacts (IPCC 2014). Economic sectors will vary in their vulnerability to climate change; those that are better able to adapt to a changing climate may persist or even prosper while those that cannot may not survive.

Investigations into local impacts of climate change including small-scale temperature shifts and climate-driven businesses are crucial to planning and mitigating the effects of climate change. Climate change and social science research presented in this thesis aims to identify the impacts of climate change on winter recreation resorts in the western U.S. with a focus on Utah ski resorts. By quantifying potential climate scenarios for local ski resorts, this research fills a knowledge gap that ski-industry professionals can use to create actionable climate mitigation plans.

Climate change is anticipated to have disproportionately profound consequences for the highly climate-sensitive tourism sector (Gössling and Hall 2005; IPCC 2007). Tourism is one of the largest global economic sectors, with 2019 estimates reaching $9.1 billion in economic activity, contributing 10.4% to the global GDP, and sustaining 334 million jobs, or 1 in 10 jobs globally (WTTC 2020). Tourism is one of the most weather and climate-sensitive global economic sectors. The impacts of climate change on tourism are likely to manifest themselves in
a number of different ways according to local conditions such as extreme heat in the seaside resorts of the Mediterranean, increased sea level rise in island nations, and decreased snowfall at ski resorts (Viner and Agnew 1999; Kajan and Saarinen 2013). Globally, ski resorts are the cornerstone industries of the local economy (Winkler et al. 2009); but unfortunately, they are usually situated at higher elevations, which are warming faster than lower elevations (Minder et al. 2018).

Warming temperatures in the western U.S. are leading to hotter and drier summers (Mann and Gleick 2015; Prein et al. 2016) with increased water scarcity, including shifts in timing and quantity (Christensen et al. 2004; Rasmussen et al. 2016; Mahat et al. 2017), which are further exacerbated by reduced snowpack and earlier snowmelt during the winter months (Gergel et al. 2017; Roades et al. 2017). Reduced water availability and increased prevalence of drought puts a strain on agriculture, industry, urban areas, and recreation (Gleick 2010), which all draw water from a dwindling shared supply. However, these impacts are also part of a wider trend of more extreme weather events. For example, 2016 - 2017 was one of California’s wettest periods while the worst droughts on record were 2011 - 2016 and 2019 to present (California’s Fourth Climate Change Assessment 2019). The Western U.S. must plan and adapt to a wide range of climate change shifts.

The state of Utah, like many of its Western U.S. counterparts, also faces severe droughts, shrinking snowpack, decreased water availability, and extreme heat events in the predicted future. Globally world temperatures have increased, on average, about 1°C in the past 100 years, while in Utah the rate is more than 2°C over the same time period (Khatri and Strong 2020). These rates are expected to accelerate in the coming decades. By 2100 average air temperatures in Utah may increase by 3.5°C in winter and by 4.7°C in summer relative to current temperature
normals (IPCC 2014; Reichler 2009). Warmer temperatures will have cascading impacts throughout the seasons and the years in Utah. For example, warmer winters may mean more precipitation will fall as rain instead of snow, resulting in a smaller snowpack (Knowles et al 2006; Gillies et al. 2012; Khatri and Strong 2020) and contributing to lower water availability during the hotter summer months when there is higher water demand. Spring snowmelt is occurring 2-4 weeks earlier than in the 1900s (Dawson and Scott 2013; Hoerling et al 2013) and these trends are likely to continue in the coming decades (Khatri and Strong 2020).

The climatic changes in Utah will change the state’s tourism-based economy, especially winter and snow-related tourism. In 2019, travelers spent a record $10 billion in Utah and the top spenders were skiers and snowboarders who spent over $1.5 billion to experience the “Greatest Snow on Earth™” during 4.4 million skier-days (Leaver 2020). Changes in the quantity, quality, and timing of snow could have severe consequences to ski resorts and winter tourism businesses (Gilaberte-Burdalo et al. 2014). In 2009 Park City Mountain Resort evaluated the impacts of warmer temperatures on their snowpack and economic activities that depend on winter recreation. According to their predictions by 2050, the snowpack will be 27-43% smaller than the snowpack today resulting in $27-66 million in lost income, respectively (Stratus Consulting 2009). Additionally, a warmer fall and earlier spring snowmelt may result in a lack of skiable snowpack for the popular Thanksgiving and Spring breaks, two of the most profitable weekends for Utah ski resorts (Leaver 2020). Historically low snow years in Utah have resulted in a 7% decrease in skier visits at an average loss of $53 million per year to the state’s economy (Hagenstad et al. 2008).

To counteract the impacts of climate change ski resorts will need to adapt to changing conditions, a process many ski resorts internationally have already started. Globally, high-
elevation communities are among the fastest warming (Minder et al 2018; Pepin et al 2015). As the climate warms and the reliability of snow shifts, ski resorts have employed adaptation strategies to minimize economic losses and to make the resorts more resilient to future warming. Snowmaking is the primary adaptation strategy ski resorts use if water is available (Wolfsegger et al 2008). Snowmaking is only possible at -5°C without additives, or at 1°C with the addition of products like Snowmax®, which contains bacteria that act as nucleation sites for ice crystal formation (Cochet and Widehem 2000; Murray et al. 2012). Other popular adaptation strategies include diversifying resorts’ revenue, such as investing in summer recreational activities and joining ski conglomerates to offset costs and gain stability (Scott and McBoyle 2007; Wolfsegger et al 2008). An assessment of Vermont’s ski resorts found that the historic shrinking ski market (81 ski areas in 1966 to 18 areas in 2007) will continue due to the financial pressures of winter recreation in a warming climate, including increasing capital investment requirements and greater operational costs (Dawson and Scott 2007). A review of the climate change risk for 27 countries around the world found that the extent and timing of climate change impacts to ski resorts, destination communities, tourism-based employees, and tourism policymakers, all hinged on the adaptation capacity of ski resorts (Steiger et al. 2017).

Changes in temperatures and precipitation regimes due to climate change threaten ski resorts, which are critical to Utah’s economy and culture as the home to the “Greatest Snow on Earth”. Using historical weather data, future climate projections, and interviews with Utah ski resort managers, this research investigates the effects of climate change on ski resorts across the state and examines adaptation practices already in use and those likely to be used in the future. The overall goals of this research are: (1) to quantify the historic and projected future
temperature trends for Utah ski resorts; and (2) to develop an understanding of how Utah resort managers perceive adaptation strategies, barriers to adaptation, and the effects of climate change.

The body of my thesis — Climate change and Utah ski resorts: Impacts, perceptions, and adaptation strategies — investigates how localized climate change in Utah may affect ski resorts throughout the state and how the resort managers are adapting their businesses to the predicted changes. We approached this knowledge gap in two interdisciplinary ways. First, we used historical weather data and climate projections to understand past and future temperature and precipitation trends in Utah. Second, we conducted interviews with Utah resort managers to provide insights into how adaptation/mitigation strategies, barriers to adaptation, and the effects of climate change factor into the decision-making process. Through these two approaches, we interpreted the strength of a resort’s viability under predicted climate change shifts and provided viable options for ski resort climate mitigation plans.

The research presented here will further the science of climate change adaptation and improve our knowledge of Intermountain West effects of, and possible adaptations to, climate change. The climate of the Southwest U.S., including Utah, is highly variable year-to-year and season-to-season; but improved climate change predictions of both temperature and snowfall will improve the tourism industry’s ability to adapt to the changing conditions. The changing climate will continue to alter the hydrologic cycle in Utah, resulting in direct and indirect impacts on both water availability for winter recreation as well as other demands such as agriculture, residential, industrial, and wildlife. Ski resorts are a highly influential and profitable industry in Utah, but they are not exclusive in their need to prepare for predicted changing climate conditions.
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CHAPTER 2:

Introduction

Many mountain communities have snow-based recreational and tourism opportunities, such as skiing, that are extremely vulnerable to climate change (Gilaberte-Búrdalo et al 2014; Steiger et al 2019). Mountain communities are often at higher elevations, which are warming even faster than other environments (Minder et al 2018; Pepin et al 2015). Changes in the climate have impacted recreational aspects of mountain environments as well as the people who live there (Hock et al 2019). As the climate continues to warm and the amount of precipitation occurring as snow declines, the length of the ski season is expected to get shorter and more variable (Dawson and Scott 2013). This is likely to increase the reliance on snowmaking (Scott et al 2019; Steiger and Scott 2020), and make some resorts commercially unviable (Scott et al 2006; Dawson and Scott 2013). Snow quality is also influenced by changes in temperature. For instance, snow density usually increases with higher temperatures and humidity (Meløysund et al 2007). This is important for ski resorts, as skiers prefer dryer and less dense snow, characteristics often used by resorts in their marketing campaigns. Despite its importance, snow quality is one of the lesser studied characteristics of snowpack due to its high spatial and temporal variability (Mizukami and Perica 2008; Bormann et al 2013).

In many parts of the Western U.S., including the state of Utah (USA), climate change has already decreased snowpack depths and reduced the amount of winter precipitation falling as snow (Fyfe et al 2017; Knowles et al 2006; Safeeq et al 2016; Siler et al 2019; U.S. Environmental Protection Agency 2016; Zeng et al 2018). Despite decreased snowpack, Utah currently has a booming ski tourism industry. During the 2018 – 2019 season, ski tourism in Utah generated 1.8 billion dollars in economic activity and provided 5.1 million skier days
The geography and climate of Utah create storms that generate dry, low-density snowfall events; this results in deep and high-quality powder (Steenburgh 2014). Visitors cite Utah’s quality of snow and snow conditions as top reasons for skiing within the state (Leaver 2018). Recent research has shown that dry, low-density snowfall events occur on fewer days in a warmer than average year (Rutty et al 2017). Additionally, statewide analyses have found that winters with particularly high levels of snow contributed an additional $49 million to the state’s economy, while low snow years resulted in a 7% decrease in skier visits and a loss of $53 million to the Utah economy (Hagenstad et al 2018). However, adaptation strategies have the potential to limit economic losses and make resorts more resilient to future warming.

Ski resorts can adapt to climate change in a variety of ways. Resort managers often perceive snowmaking to be the most important technological adaptation (Wolfsegger et al 2008; Morrison and Pickering 2013; Hopkins 2014) as it can increase season length and protect against weather variability (Scott et al 2019; Scott et al 2020). Snowmaking usually requires temperatures below -5°C, although chemical additives may make snow production possible at -1°C (Scott et al 2006, 2008). Recently, snowgun manufacturers have noted being able to make snow at -2°C if the humidity is low (e.g., Snowmakers n.d.). Snowmaking is likely to be an increasingly less viable adaptation strategy in the future (Scott et al 2019; Steiger and Scott, 2020) because of higher production cost at warmer temperatures (Stanchak 2002) and water availability or energy consumption concerns (Pickering and Buckley 2010; Morrison and Pickering 2013). Besides snowmaking, other adaptation strategies include moving to higher elevations, slope development, and cloud seeding (Scott and McBoyle 2007). Geographic characteristics such as slope, and availability of terrain at higher elevations can drive the decision on which adaptations are most appropriate for a resort (Scott and McBoyle 2007).
Resorts can also adapt by altering their business decisions by diversifying revenue sources, joining ski conglomerates, marketing their offerings more aggressively, and sharing the cost of snowmaking with nearby resorts (Scott and McBoyle 2007; Wolfsegger et al 2008). Diversifying revenue sources most often comes through the transition from a single-season to a four-season destination (Bicknell and McManus 2006; Morrison and Pickering 2013; Knowles 2019). This often involves adding recreational activities that are not snow dependent, such as hiking, mountain biking, wildlife viewing, or events (Knowles 2019; Sauri and Llurdés 2020). Where some resort managers adapt specifically due to climate change, others do so to mitigate risks and increase resilience (Hopkins and Maclean 2014; Trawöger 2014). There is less literature on potential barriers to adaptation in the ski industry. One study noted that the media’s portrayal and framing of climate change may be a barrier to adaptation (e.g., using extreme disaster narratives) (Knowles and Scott 2020). Economic feasibility, in addition to the framing of climate change, can also be a large barrier to adaptation. In Switzerland for example, economic feasibility is the largest barrier to adaptation in the tourism industry (Matasci et al 2014).

Ski resorts are important to local communities and economies in Utah; thus, it is critical to understand how climate change may affect the ski business and how the managers are adapting to the changes across the state. With warming temperatures and increased variability in both temperatures and snowfall (Khatri and Strong 2020), the future of Utah’s ski industry is uncertain. The overall goals of this research are: (1) to quantify the historic and projected future temperature trends for Utah ski resorts; and (2) to develop an understanding of how Utah resort managers perceive adaptation strategies, barriers to adaptation, and the effects of climate change. We use historical weather data and climate projections to understand past and future temperature trends at Utah ski resorts. We also conducted interviews with resort managers to provide insights
into how they perceive adaptation strategies, barriers to adaptation, and the effects of climate change.

Methods

Study sites

Study sites included all 14 ski resorts in Utah, USA (Figure 1). Three of these resorts currently do not have the capacity to make snow, while 11 do. Base elevations range from 1760 m – 2926 m with peak elevations ranging from 1951 m – 3328 m. The total skiable lift-served area ranges from 0.5 km$^2$ – 12.1 km$^2$. Specific characteristics of each resort can be found in Table 1.

Historic data and climate projections

As the ski season is different for each resort, we acquired the opening and closing dates for each resort over five recent seasons (2014/15 – 2018/19) from resort websites, social media pages, local news outlets, and skicentral.com. This enabled us to analyze weather data within the dates that encompass a recent typical ski season at each resort. After identifying recent opening and closing dates for each resort in Utah over five recent seasons, we defined the season for each resort as the earliest opening date and the latest closing date during this period. We chose the longest recent season to represent the season length, given that historical seasons may have been longer. We included an additional two-weeks on both ends of the season to account for the variability in operations and to account for conditions leading up to the opening of the resort each year.

We downloaded daily historic maximum and minimum temperature at each resort from 1980 – 2019 from Daymet version 3, using the R package daymetr (Hufkens et al 2018;
Thornton et al. (2018). Daymet has temperature data on a 1 km grid, and we downloaded these data for the grid cell that contains the main lodge for each resort. We aggregated daily data at the seasonal level for each resort, only using days within each resort’s season (as defined above). For each resort, we used daily minimum temperatures to find the proportion of the early season with a daily minimum temperature at or below \(-5^\circ\text{C}\), which indicates snowmaking is possible without chemical additives (Scott et al. 2006, 2008). Here, we defined the early season as two weeks before opening through January 2. This time period contains holidays (Thanksgiving, Christmas, New Years) that tend to see high visitation, making snowmaking critical during this period. We ran Mann-Kendall Trend tests with Sen’s slope on these data to identify trends in temperature from 1980 – 2018 (Sen, 1968). We tested for statistical significance at the \(\alpha \leq 0.05\) level.

We downloaded snow water equivalent (SWE) and snow depth data from SNOTEL sites across the state to explore if freshly fallen snow density has already been altered as a result of climate change (USDA NRCS n.d.). These data are available for individual SNOTEL stations across Utah; time periods for each sensor vary, but the data range from 1999 – 2018. We used the seven stations across the state that had data for this entire period of record (Station names: Tony Grove Lake; Brighton; Louis Meadow; Ben Lomond Peak; Timpanogos Divide; Midway Valley; and Big Flat). As there are only seven stations across the state with data during this period, we analyzed the data at the state-level rather than at individual resorts. All measurable snow events were identified for each selected station. We measured snow events by subtracting the start of day SWE values from the previous start of day SWE. For days with recorded changes in SWE and snow depth, the density of the snow was estimated using Equation 1.
SNOTEL data reports SWE rounded to 0.254 cm (0.1 inch) and snow depth rounded to 2.54 cm (1 inch); this rounding is a source of error, but is consistent over time. This density analysis was done only for freshly fallen snow at SNOTEL monitoring sites.

We used the probability of exceedance (Equation 2) to find the probability that a snow event was equal or greater to a specific density for each winter season, and compared density probabilities from the 1999/2000 – 2018/2019 winters. We ranked each snow event for each selected station. The data between the 10th and 90th percentile (probability of exceedance between 0.10 and 0.90) was used for the analysis to accommodate noise due to outliers or measurement errors.

We used climate projection data for Utah from 2021 – 2100 to explore how winter (December - March) temperature is expected to change in Utah through the 2099/2100 winter season, under RCP 2.6, RCP 4.5, and RCP 8.5 scenarios of the Intergovernmental Panel on Climate Change (IPCC) (van Vuuren et al 2011). RCP 2.6 represents a mitigation scenario that aims to keep warming below 2°C globally, while RCP 4.5 is an intermediate scenario, and RCP 8.5 assumes high greenhouse gas emissions with little to no efforts to reduce emissions (IPCC 2014). Monthly projections for the RCP scenarios between 2021 – 2100 were acquired using the EC-Earth general circulation model for boundary conditions (Hazeleger et al 2012), and Rossby Centre Regional Climate ensemble model (RCA4) (Samuelsson et al 2011), through NA-
CORDEX (Mearns et al 2017). This analysis is at a larger spatial scale, rather than at individual resorts, because climate projections do not currently have fine enough spatial resolutions to generate resort-specific projections. The spatial resolution of projection data is 50 km, and Figure 1 shows the two areas (Northern and Southern Utah) we used to calculate climate projections. We analyzed future projections for minimum temperature, maximum temperature, and precipitation.

We ran Mann-Kendall Trend tests with Sen’s slope on the winter temperature projection data for each scenario to understand the projected temperature anomalies by the 2099/2100 winter season. All analyses and visualizations were performed in R and the data and code are publicly available [citation redacted for blind review].

**Key informant interviews**

Semi-structured key informant interviews were conducted with Utah ski resort managers or senior employees (Ayres 2008). We used a mixed-method sampling technique that included criterion sampling (i.e., contacting people who met our criteria for a year-round management position at any Utah ski resort) and snowball sampling to reach other people identified by interviewees as possibly helpful (Palinkas et al 2015). We contacted managers at all 14 resorts; representatives from two resorts declined to participate, and four did not respond to emails or phone calls. We interviewed two individuals at one resort, and one individual at seven resorts ($n = 8$ resorts; $n = 9$ interviews). These represent one (out of two) resort in the southern part of the state, and seven (out of 12) resorts in the northern part of the state.

The full interview script can be found in the supplementary material (Appendix A). Interview questions focused on background information, general questions relating to the impact
of climate change, adaptation measures, barriers to adaptation, and how various climate related scenarios would impact the resort. Most of the questions were open-ended, but three questions had Likert-type response scales (i.e., ordered categories, such as “not a barrier” to “extreme barrier”). For the questions on adaptation perceptions, some question wording was adapted from Wolfsegger et al (2008). All participants were given a copy of the questions at least 48h before the interview. Interviews took between 20m – 1h and were recorded if participants agreed; recorded interviews were transcribed. The Institutional Review Board at Utah State University approved this study under protocol #9773.

Responses to open-ended questions were coded using semantic coding and coding categories (Braun and Clarke 2006; Lune and Berg 2016). We conducted a top-down thematic structural coding analysis approach in two rounds (Gorden 1992). Codes are defined as “tags or labels for assigning units of meaning to the descriptive or inferential information compiled during a study” (Miles and Huberman 1994: 56). Coding categories, including major and minor themes, can be found in the supplementary material (Appendix B). Interviews were coded independently by two authors and compared for accuracy (Lune and Berg 2016). Resulting themes and patterns were summarized and explored in the context of the literature and research questions (Attride-Stirling 2001).

Results

Past temperature trends

Analysis of historic weather data indicates the minimum daily temperatures by ski resort season increased from 1980 – 2018 for all 14 resorts (Figure 2). These trends are statistically significant for all resorts at $\alpha = 0.05$, with $n = 39$ seasons (see supplementary material, Appendix
C for full statistical results by resort). Sen’s slope for these trends range from 0.067 – 0.172; these values can be interpreted as the expected annual increase (°C) in the mean minimum daily temperature over this time-period, during the ski season. A slope of 0.067 suggests a 2.6°C increase in minimum temperature from 1980 – 2018, while a slope of 0.172 would suggest an increase of 6.7°C. However, there is always annual variability, and these data only represent a 1 km grid cell that contains the main lodge of each resort. Mean minimum daily temperature by ski resort season from 1980 - 2018 has been increasing faster than maximum temperature (see supplementary material, Appendix D). The increase in mean maximum daily temperature by season is statistically significant for six of the 14 resorts, with Sen’s slope ranging from 0.039 – 0.106 for those that are significant (Appendix C).

The proportion of most resort’s early/holiday season with a minimum daily temperature at or below -5°C has decreased steadily, with annual variation (Figure 3). These trends are statistically significant at 12 of the 14 resorts, with coefficients ranging from -0.003 – -0.008 (Appendix E). The two resorts that did not have significant trends were the two farthest north resorts (Cherry Peak and Beaver Mountain). A coefficient of -0.005 indicates the proportion of the early season with daily temperatures at or below -5°C has decreased by 0.005 each season, or by 0.195 from 1980 – 2018. Trends in the reduction in the proportion of days with minimum daily temperature at or below -5°C are even greater when considering the full ski season, and not just the critical early/holiday period (Appendix F).

Ski resort manager perceptions

The interviews with managers revealed varying perceptions of what constitutes a “successful season,” with visitation (maintaining current numbers and increasing visitors), good
quality snow, and season pass sales all mentioned frequently. Respondents indicated that snow quality and snow quantity play a key role in a successful ski season, but these criteria are weather- and water-dependent. Resort managers reported their resort would need to be open 97 – 120 days each season to remain viable.

Several managers knew that increasing temperatures and shifts in snowfall patterns will affect the length of their ski season. One resort manager said,

Climate change will change the length of our season, the quality of our snow, causing more rain on snow events. It will impact where people will want to ski and snowboard, and it will impact the bottom line, as a shorter winter season will have, obviously, less skier days.

A shift in the ski season and negative impacts were mentioned by another manager who noted,

I’ve seen that we get less and less snow in November and December and we get more snow in May than we do in November and December. So, there’s a shift in the pattern of when the snow actually happens. The challenge with the ski industry is that we’ve become accustomed to skiing between Thanksgiving and Christmas. And generally, people get out their boats and their golf clubs about mid-April especially in this valley, in Salt Lake where it starts to really warm up in the month of April. But we are still expecting about a third of the actual snowfall that will fall in this watershed in April and May.

Another resort manager intimated that although high temperatures and low snowfall have happened in the past, “I would say they’re becoming more frequent as far as later opening dates … I mean, you name it, warmer temperatures, less precipitation, we’re seeing them more
frequently.”

Adaptation measures

We asked the resort managers to rank various adaptation measures on a scale with response options ranging from very inappropriate to very appropriate. Specific measures and their responses are in Table 2. Most resort managers indicated they have already diversified winter and all-season activities at their resort in some capacity. Seven of the eight Utah ski resorts represented in our interviews have multiple winter activities besides skiing and snowboarding such as snow tubing, snowshoeing, educational programming, and cross-country skiing. Activities in other seasons range from sporting activities, such as mountain biking (sometimes extensive trail systems), obstacle courses, horseback riding, disc golfing, to events such as conferences and festivals, and complimentary services such as spas, restaurants, and rentals. These offerings are diversified to adapt to climate change and to help expand revenue sources alike.

Seven of the resort managers we interviewed have snowmaking at their resorts, either for most of their terrain or just to supplement critical areas. Resorts either have storage ponds for water or purchase water for snowmaking. Methods to increase snowmaking capacity are common at many resorts, as a resort manager noted that it has “been a major push in the last ten or so years.” Various methods were noted to increase snowmaking capacity at resorts. One resort manager said the resort used chemical additives, while another said they might consider using them in the future; others opt against it. Four resort managers spoke about alternative ways to increase snowmaking efficiency at their resort, such as cooling water storage ponds before snowmaking and investing in snow gun technology. One resort manager indicated they do not have snowmaking capacity and did not presume a necessity for it in the future.
Resort managers reported a variety of issues related to slope maintenance and snow coverage. Avoiding slopes that require too much snow is a consideration for many resorts, however, these areas are usually just closed for longer periods or, if they are essential, given more snowmaking capacity. Three resort managers stated that in the future they may have to close slopes for longer periods of time. Slope maintenance included clearing brush and obstacles, so less snow was needed for a safe level of coverage. One resort manager reported the resort “also implemented mowing the brush, that way you can open up with minimal snow.” Another manager discussed contouring the slopes, so the coverage needed is equal across the skiing area.

Most resorts are as high in elevation as they can feasibly go, with lease agreements often limiting moving to higher elevation, but a few have plans to move higher. Two resort managers mentioned having higher base lodges, giving them an advantage in the future.

**Barriers to adaptation**

We asked the resort managers to rate potential barriers to climate change adaptations at their resort on a scale with response options ranging from *not a barrier* to *extreme barrier*. Specific barriers and their mean responses are visualized in Table 3. Resort managers face moderate to extreme barriers in financial costs to adaptation. Prioritizing the need to receive a return on investment combined with large overhead costs limits the ability of ski resorts to invest in additional adaptation methods. One manager noted, “it can be an extreme barrier because you see the potential of being able to do and adapt all these different things at once, but then you have to prioritize and it takes time.” Some resorts also face additional challenges based on their size and lack of corporate backers, which limits their financial abilities to adapt.
At resorts that have snowmaking capability, water availability and temperature required to make snow were noted as major barriers to snowmaking. Some resorts own artificial water storage ponds, others receive a certain allotment from public utilities, setting a limitation on snowmaking ability. Resorts that receive water from public utilities receive a reduced price because it is untreated water from natural creeks. Using water for snowmaking is considered a non-consumptive use, although sublimation losses can be considerable (4 - 41%) (Reba et al., 2012). Snowmaking also requires snowmaking guns, plumbing, increased electricity, and labor, adding additional barriers of aging infrastructure and snowgun efficiency.

Possible scenarios

Resort managers were asked to rate the impact of possible future scenarios on a scale with response options ranging from no impact to extreme impact (Table 4). In Utah, the 2017 – 2018 season was a particularly warm and low snowfall year; we specifically asked about this year given its recency.

Resorts managers had varying responses when asked about a potential decrease in snowpack. Two thought a decrease would have slight or no effect due to their annual snowfall being extremely high, with some resorts reporting over 1,200 cm annually. One manager responded, “[other resort’s] average is 230 inches [585 cm], … but our average is 500 inches [1,200 cm] plus and at 20% decrease [in snowpack] we still have got decent coverage. So, it’s a different scenario.” Some resort managers thought less snow would not affect their resort if they still had the temperature to make snow. Increases in temperatures to a level above where snowmaking is efficient would be more of an issue with one manager who stated, “sometimes along with less snowfall comes warmer temperatures which doesn’t allow you to make snow.”
Less snowfall at the end of the season is less of a concern than snowfall at the beginning of the seasons when the base is being built at the resort. According to one resort manager, short periods with less snow may not have much of an impact, but longer stretches of no snow could have a much larger impact. One manager noted,

A couple of seasons ago when a lot of ski areas couldn’t even open because there wasn’t enough snow, especially in the Northwest and the Midwest and parts of the East and stuff, we ended up getting higher skier visits.

The manager explained that in contrast to nearby ski resorts, they drew visitors as they could open many areas of the resort due to their snowmaking and grooming capabilities.

Since warmer winters with less snow are likely to become more common, we asked resort managers what the effect would be if seasons such as 2017 – 2018 became more common. Two managers thought there would only be a slight effect, while five others stated it would have an extreme effect on their resorts. However, one manager of a resort with extensive snowmaking abilities mentioned they benefitted that winter because they drew from other resorts that had no snow.

**Snow quality and density**

When asked about high-quality snow, six managers replied that quality snow is the cold, dry powder for which Utah is renowned; one replied “cold and copious.” One resort manager responded that quality snow depends on the skier, “beginners may prefer different snow than a ski racer or a powder hound.” Two resort managers stated that unlike before, the focus is on coverage and long-lasting snow instead of cold, copious powder. One manager noted, “it’s now kind of like, well we’ve got enough snow to cover the rocks and the trees and stumps and it may
be icy, but at least there’s enough coverage. So that’s kind of the direction now that we’re looking at.” With coverage, more of the mountain can be open and exposure of rocks and other obstacles becomes less of a risk; the season can continue for a longer period.

The density of snowfall events in Utah from 1999 – 2017 seems to have increased slightly (Figure 4), possibly indicating less of the cold, dry powder in recent years. The trend of slightly denser snow events in the last decade is consistent across all seven SNOTEL stations (Appendix G). Overall, resort managers felt that seasons with less high-quality snow would reduce the number of visitors and decrease user experience. A potential implication of lower quality snow mentioned by resort managers was that fewer skiers may purchase season passes and instead buy day tickets to seek the best conditions. This approach may make resorts with high grooming/snowmaking capacity more attractive.

**Climate projections**

The majority of resort managers indicated an increase of 3°C would have moderate to extreme effects at their resort. Though large variability exists in the year to year predicted values, temperatures during winter (December – March) in Utah are likely to increase by the end of the century. Figure 5 shows the increase in minimum temperature from the 2021/2022 winter to the 2099/2100 winter season. Under the RCP 2.6 scenario, there is not a statistically significant change in winter temperature from 2021 – 2099 in either Northern or Southern Utah (Mann-Kendall Trend test results in Appendix H). Under RCP 4.5, the minimum temperature in Northern Utah is projected to increase by 2.0°C in the winter from 2021 – 2099 (0.026°C per year), while Southern Utah is expected to warm by 2.3°C (0.030°C per year). Under the RCP 8.5 scenario, winter temperatures for Northern Utah are projected to increase by about 6.0°C by the
end of the century (0.076°C per year), and 6.6°C in Southern Utah (0.084°C per year). Given there is always uncertainty in climate projections, confidence intervals for all Sen’s slopes can be found in Appendix H.

Similar trends are projected for maximum temperatures in the winters (Appendix H and I). Specifically, there is not a significant change in maximum temperature from 2021 – 2099 under RCP 2.6. Under the RCP 4.5 scenario, both Northern and Southern Utah are expected to warm 2.4°C by the end of the century. Under the RCP 8.5 scenario, projections show an increase in maximum temperatures of 7.3°C in Northern Utah and 6.1°C in Southern Utah.

It is important to note that NA-CORDEX projection data is colder than Daymet data from 2006 – 2018 winters, indicating actual future temperature projections may be higher (projections are about 0.9 – 3.0°C colder for minimum temperature, and 5.1 - 6.5 colder for maximum temperature; see Appendix J). This does not affect the change over time projections (as described above), but does affect the raw projected values.

Precipitation projections indicate no substantial and consistent change in total winter (December – March) precipitation from 2021 – 2099 (see Appendix K). There is high variability in seasonal precipitation projections. However, with winter temperatures rising, we would expect that in the future, more precipitation will fall as rain, and less precipitation will fall as snow.

Discussion

Globally, average annual temperatures have risen by 1°C from pre-industrial levels (IPCC 2018). Ski resorts in Utah have been warming even more rapidly in the winter than the global trend. A similar trend is predicted in the future, with Northern Utah expected to see 2.0°C additional warming in the winter by the end of this century under a moderate emissions scenario.
(RCP 4.5), or over 6.0°C with high emissions (RCP 8.5). Although there is not a projected change in precipitation, warmer winter temperatures will cause more precipitation to fall as rain rather than snow, and there may be more variability in precipitation events (Khatri and Strong 2020). Resort managers are aware of these changes and are somewhat concerned about climate change and its impacts on their resorts. The impacts most relevant to the state’s ski industry are the shortening of the winter season, the increase in temperatures, and the quantity of snow.

Utah ski resort managers are primarily concerned with how climate change will decrease season length. Shorter season length decreases visitation, a key metric for financial viability. One study found that ski resorts across the Rocky Mountain region may open around 10 days later on average under RCP 4.5 by 2050 (Wobus et al 2017). Another study concluded that season length is likely to decrease by more days at lower elevation resorts in the Western U.S., and that natural ski days (i.e., without snowmaking) may decline by around 30 days per season across Utah resorts by 2050 under RCP 8.5 (Lackner et al 2021). Utah ski resort managers reported needing to be open for 97 – 120 days a season, with most stating they required over 100 days, which is a common threshold used in the literature (Koenig and Abegg 1997). Climate projections show warming temperatures decreasing the length of the ski season in Utah; this could threaten visitation and profit margins for Utah ski resorts, especially for resorts that require longer seasons to remain viable.

Visitors come from around the world to experience Utah’s cold, dry powder (Leaver 2017). Consequently, maintaining the high quality and quantity of snow is important to Utah ski resort managers. Utah’s low temperature and low humidity have historically accounted for low-density, good quality snow (Roebber et al 2003; Steenburgh and Alcott 2008). Our data show a possible slight increase in snow density from 1999 – 2018; it is possible snow density may
change more in the future. Lower quality snow may have negative impacts on ski tourism; however, the ski resort managers we interviewed were more concerned with snow quantity and cover as opposed to quality.

Despite facing some barriers, all the resort managers we interviewed indicated adaptations were occurring at their resorts. Not all adaptations were implemented specifically due to climate change, but will nonetheless benefit the resorts as they face climate change impacts in the future. The most common adaptations are snowmaking and diversification of offerings, similar to the most popular adaptation measures in other locations (Morrison and Pickering 2013; Sauri and Llurdes 2020). Many of Utah’s resorts are experiencing success with diversification of their resorts already and this will better prepare them to remain viable in the future.

Despite using an array of climate adaptation strategies, resort managers considered snowmaking as the primary strategy to maintain business. Many managers indicated that if temperatures remained low enough to make snow, a 20% decrease in snow quantity over a season would not have extreme effects at their resort. However, this strategy is resource- and climate-dependent. Although snowmaking can extend operational days in the short-term, the water use, temperature constraints, as well as infrastructure and operational costs may make this an unsustainable strategy in the long-term (Hopkins 2014; Steiger et al 2019). Temperatures at or below -5°C are generally needed to make snow without additives (Scott et al 2006, 2008). However, this does not consider factors such as humidity, and previous analysis shows that snow can be made at or below a wet-bulb temperature of -2°C (Stull 2011). In any case, our analysis shows a substantial decrease in the proportion of winter season days that snowmaking was viable at Utah resorts between 1980 – 2018; this trend is similar to results from a ski resort in New
Hampshire (USA) that also shows a decrease in snowmaking days (Wilson et al 2018). The majority of the resort managers we talked to say they would never consider using additives (particularly resorts in protected watershed areas) at their resorts; also, sometimes government policies or public resistance might not allow their use (Scott and McBoyle 2007). Overall, expenses are a moderate barrier to adaptation, particularly with snowmaking; it may be difficult to allocate sufficient financial resources to this one technological adaptation.

The adaptation practices at resorts indicate the negative effects of climate change may not impact resorts as much as the temperature trends alone may suggest. Snowmaking is unlikely to be a viable adaptation by itself, as minimum temperatures continue to rise and render fewer days where snowmaking is possible, and as water limitations may be a challenge in the future. As resorts diversify their offerings, they are creating a stronger platform for their success as climate change potentially accelerates.

Limitations and future research

We interviewed managers at eight Utah resorts; the data from interviews may not be representative of all ski resorts within the state. Resort managers who agreed to participate may be more likely to believe that climate change was real and impacts their resort. Additionally, since we were only able to interview one individual at most resorts, their views are not necessarily representative of the entire resort. Future research could aim to interview more employees at each resort and see how perceptions may differ based on job position.

Many resorts in Utah focused on snowmaking as an important adaptation strategy. Additional research is needed to investigate future water availability, use, and rights across Utah for snowmaking. For analysis on historical water use, snowpack, and hydrological changes in
Utah, see Khatri and Strong (2020). Additionally, more research on projected changes to snowfall and snowpack at Utah resorts is needed to better understand future water and snowmaking needs (e.g., Lackner et al 2021). Future studies could also examine how the characteristics of a resort (e.g., size, location, visitor profile, etc.) relate to the ability of a resort to adapt, and their perceptions of barriers to adaptation. The climate and physiography of Utah are similar to other states in the Western U.S., thus similar trends may be expected in nearby states. However, additional research is required to explore if similar patterns would be observed in the other locations.

**Conclusions**

The climate in Utah will likely warm dramatically, and according to ski resort managers, it will have moderate to extreme impacts on resort operations. The resort managers we interviewed are aware of climate change and its potential for adverse effects on their resorts. Many ski resorts in Utah have adaptations already in place, but many adaptations have related barriers that may limit their effectiveness (e.g., snowmaking). Climate change will continue to impact resorts and their surrounding communities in significant ways, but adaptation measures may help resorts remain viable throughout the end of this century.
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Figure 2.1: Locations of the 14 ski resorts across Utah, USA. The two boxes represent areas used to explore temperature projections to 2100 (classified as Northern and Southern Utah).
Figure 2.2: Trends in the mean minimum daily temperature (°C) by ski resort season (1980 – 2018). Numbers on each panel represent Sen’s slope.
Figure 2.3: Trends in the proportion of days in the early season with a minimum daily temperature below -5°C by ski resort (1980 – 2018). The early season is defined as 2 weeks before opening (varies by resort) through January 2, to capture the holiday season. Numbers on each panel represent Sen’s slope.
**Figure 2.4:** Snowfall event density in Utah from 1999 – 2017, by percentile. The 25th percentile indicates that 25% of the snowfall events for that year are less dense (below the point), while 75% are denser (above the point).
Figure 2.5: Projections for average daily winter minimum temperature for December – March, by winter season, for Northern and Southern Utah. Background lines represent the projections for each winter season, whereas the straight lines represent linear trends from 2021 – 2099.
### Tables

#### Table 2.1: Characteristics of each resort in Utah.

<table>
<thead>
<tr>
<th>Resort</th>
<th>Utah Region</th>
<th>Elevation at main lodge (m)</th>
<th>Base Elevation (m)</th>
<th>Peak Elevation (m)</th>
<th>Lift-served Skiable Area (km²)</th>
<th>Snowmaking</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brighton</td>
<td>North</td>
<td>2,683</td>
<td>2,668</td>
<td>3,200</td>
<td>4.25</td>
<td>Yes</td>
</tr>
<tr>
<td>Alta</td>
<td>North</td>
<td>2,611</td>
<td>2,600</td>
<td>3,215</td>
<td>8.9</td>
<td>Yes</td>
</tr>
<tr>
<td>Powder Mountain</td>
<td>North</td>
<td>2,521</td>
<td>2,103</td>
<td>2,872</td>
<td>11.59</td>
<td>No</td>
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<tr>
<td>Solitude</td>
<td>North</td>
<td>2,499</td>
<td>2,436</td>
<td>3,197</td>
<td>4.86</td>
<td>Yes</td>
</tr>
<tr>
<td>Snowbird</td>
<td>North</td>
<td>2,468</td>
<td>2,365</td>
<td>3,353</td>
<td>10.12</td>
<td>Yes</td>
</tr>
<tr>
<td>Beaver Mountain</td>
<td>North</td>
<td>2,208</td>
<td>2,164</td>
<td>2,682</td>
<td>3.35</td>
<td>No</td>
</tr>
<tr>
<td>Deer Valley</td>
<td>North</td>
<td>2,203</td>
<td>2,002</td>
<td>2,917</td>
<td>8.2</td>
<td>Yes</td>
</tr>
<tr>
<td>Park City</td>
<td>North</td>
<td>2,121</td>
<td>2,073</td>
<td>3,048</td>
<td>29.54</td>
<td>Yes</td>
</tr>
<tr>
<td>Snowbasin</td>
<td>North</td>
<td>1,952</td>
<td>1,951</td>
<td>2,850</td>
<td>12.14</td>
<td>Yes</td>
</tr>
<tr>
<td>Sundance</td>
<td>North</td>
<td>1,851</td>
<td>1,859</td>
<td>2,514</td>
<td>1.82</td>
<td>Yes</td>
</tr>
<tr>
<td>Cherry Peak</td>
<td>North</td>
<td>1,763</td>
<td>1,760</td>
<td>2,149</td>
<td>0.81</td>
<td>Yes</td>
</tr>
<tr>
<td>Nordic Valley</td>
<td>North</td>
<td>1,639</td>
<td>1,646</td>
<td>1,951</td>
<td>0.49</td>
<td>Yes</td>
</tr>
<tr>
<td>Eagle Point</td>
<td>South</td>
<td>2,933</td>
<td>2,774</td>
<td>3,200</td>
<td>2.63</td>
<td>No</td>
</tr>
<tr>
<td>Brian Head</td>
<td>South</td>
<td>2,930</td>
<td>2,926</td>
<td>3,328</td>
<td>2.63</td>
<td>Yes</td>
</tr>
</tbody>
</table>

*Note.* Base elevation, peak elevation, skiable area, and snowmaking data are from Ski Utah (2018). Elevation at the main lodge was downloaded from the USGS Point Elevation Query Service using the *elevatr* package in R (Hollister et al., 2020).
Table 2.2: Responses from resort managers about adaptation measures at their resort. $n = 8$ resorts.

<table>
<thead>
<tr>
<th>Adaptation measure</th>
<th>Very inappropriate</th>
<th>Moderately inappropriate</th>
<th>Moderately appropriate</th>
<th>Very appropriate</th>
<th>Already doing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diversify all-season offerings</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>7</td>
</tr>
<tr>
<td>Snowmaking</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>7</td>
</tr>
<tr>
<td>Diversify winter offerings</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>6</td>
</tr>
<tr>
<td>Joining ski conglomerates</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>6</td>
</tr>
<tr>
<td>Avoiding southern exposure of the slopes</td>
<td>0</td>
<td>1</td>
<td>3</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Enhancing marking to intensity season</td>
<td>2</td>
<td>0</td>
<td>2</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Increasing capacity of lifts</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>Giving up slopes that need too much snow</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Moving to higher altitudes</td>
<td>5</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Sharing snowmaking costs with others</td>
<td>4</td>
<td>2</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Snowmaking with chemical additives</td>
<td>5</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

1 One manager did not respond to this measure.
Table 2.3: Responses from resort managers about barriers to adaptation at their resort. $n = 8$

resorts.

<table>
<thead>
<tr>
<th>Barrier</th>
<th>Not a barrier</th>
<th>Slight barrier</th>
<th>Moderate barrier</th>
<th>Extreme barrier</th>
</tr>
</thead>
<tbody>
<tr>
<td>Financial costs</td>
<td>0</td>
<td>1</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td>Environmental resources</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Uncertainty about short-term predictions</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Uncertainty about long-term predictions</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Lack of staff time to focus on this issue</td>
<td>2</td>
<td>3</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Internal challenges</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>Lack of municipal community support</td>
<td>3</td>
<td>1</td>
<td>4</td>
<td>0</td>
</tr>
</tbody>
</table>
Table 2.4: Responses from resort managers about impacts of different future conditions on their resort. \( n = 8 \) resorts.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>No effect</th>
<th>Slight effect</th>
<th>Moderate effect</th>
<th>Extreme effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conditions of 2017-2018 being a new normal</td>
<td>1</td>
<td>2</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>Increase in average temperature by 3°C</td>
<td>1</td>
<td>0</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>20% decrease in average snowfall</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Less snowfall at the start of the season</td>
<td>0</td>
<td>2</td>
<td>6</td>
<td>0</td>
</tr>
<tr>
<td>10% decrease in average snowfall</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>Less snowfall at the end of the season</td>
<td>3</td>
<td>4</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>