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LETTER

Downhill skiing & climate change adaptation in Wisconsin: perspectives from key stakeholders

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Abstract

Climate change is currently impacting various facets of our local systems with many stakeholders and industries working to adapt to these changing conditions. There is a growing recognition that adaptation practices need to be directed within specific industries, communities, and stakeholders. A key area that is being impacted is the snow sports industry which is facing various challenges due to localized climatic changes. Previous work has indicated that climate change may leave these snow-dependent industries in the U.S. Midwest unviable in the future, so it is imperative to understand how these stakeholders are adapting to climate change and how they view the future of their industry. To do this, we conducted in-depth interviews with owners and operators in Wisconsin to understand 1) the climate change impacts they are facing, 2) their adaptation strategies, and 3) their views of the future of Wisconsin downhill skiing. Our results outline various environmental and social changes that participants associate with climate change and document their current adaptation strategies. Operators are optimistic about the future, but there is a recognition that adaptation practices and planning will likely intensify. This letter concludes with an outline for future research and support for adaptation practices that blend qualitative methods with physical and technological research that can aid this industry's adaptation strategies.

Introduction

Climate change has induced local warming that is being experienced over people's lifetimes (King *et al* 2023), and there is a need for adaptation strategies to limit these impacts (IPCC 2022). However, the most recent IPCC report states that there are various constraints to climate change adaptation practices that need to be continually examined (IPCC 2022). Understanding adaptation practices from the environmental and social perspectives is needed to inform research that develops recommendations for local communities and industries, but current research tends to focus on the environmental or physical aspects of adaptation (IPCC 2022, Sietsma *et al* 2021). Sietsma *et al* (2021) note that there needs to be a more integrated approach to climate adaptation for stakeholders. In this letter, we share our approach to integrating previous literature on the physical *need* to adapt to climate change with in-depth perspectives from those attempting to do so in the U.S. Midwest. We draw from the body of evidence that supports the recommendation that adapting to climate change is a necessity for the winter sports industry and the findings of interviews conducted with eight operators of ski hills in Wisconsin to understand 1) how/if they are being impacted by climate change, 2) the adaptation measures they are taking, and 3) their perspectives on the future of their industry. Our results highlight that operators are experiencing a variety of challenges associated with the physical and social dynamics of climate change and that they are currently working to adapt. Regardless, they are optimistic about the future of skiing in Wisconsin due to recent events and existing social networks. The remaining sections highlight the relevant background literature on

climate change and downhill skiing, provide a methods overview, and discuss our results' connection to previous literature. The conclusion reiterates the importance of these findings, shares some potential options for industry support, and outlines avenues for future research.

Background

Climate change is affecting the U.S. Midwest in diverse ways (Wilson *et al* 2023), with critical changes in temperatures and precipitation already impacting winter tourism and recreation in the region (Chin *et al* 2018, Wilson *et al* 2023, Wobus *et al* 2017). Previous research on the U.S. Midwest has shown that there will be a shortening of the season for winter sports (Wobus *et al* 2017) due to a reduction in snowfall and fewer ideal days for snowmaking (Chin *et al* 2018). In terms of impacts on Wisconsin specifically, the Wisconsin Initiative on Climate Change Impacts (WICCI) report documents the varied impacts that climate change has on tourism industries and outdoor recreation in the state (WICCI 2022). The main findings of the report state that climate change is expected to make Wisconsin warmer and wetter with less consistent seasonality, which will interfere with when and how recreation occurs in the state. However, these impacts may disproportionately impact winter recreational activities and enhance the need for adaptation practices (WICCI 2022). To better understand these climate impacts and planning efforts, we expand upon this research to see how winter tourism stakeholders are currently being impacted and how they are adapting in Wisconsin. Due to the different impacts and adaptation strategies for various winter activities (Wobus *et al* 2017), we focus on one sport: downhill skiing, which is an important part of snow recreation in the state (Headwaters Economics 2020). A recent report from Headwaters Economics shows that snow activities combined accounted for nearly $84M in GDP in Wisconsin in 2022 (Lawson 2023).

Outside of the literature examining the physical climate change impacts on downhill skiing, there is little research that directly examines the social components of these impacts, though it is growing (Steiger *et al* 2019). Previous literature highlights the economic impact of changing climatic conditions on downhill skiing (Chapagain *et al* 2018, Falk and Hagsten 2016, Falk and Vieru 2017, Hamilton *et al* 2007, Shih *et al* 2009). For example, Falk and Vieru (2017) found that as snowfall decreased, so did the revenue for ski lifts in Finland, with resorts in southern regions experiencing greater losses. Interestingly, these results occur despite 96% of the lifts in the study having snowmaking capabilities (Falk and Vieru 2017). However, a 2009 Michigan study found that changes in environmental conditions, such as temperature, snow depth, and windchill, also impact ski ticket sales (Shih *et al* 2009). Other literature examining skier perceptions and decision-making in the context of climate change has also noted behavior changes (Dawson *et al* 2011, Demiroglu *et al* 2018, Fang *et al* 2024).

Additional studies have examined views on climate change and the adaptation measures being used at ski resorts outside of the U.S. Midwest (Haanpää *et al* 2015, Rice *et al* 2024, Scott and McBoyle 2007, Wilkins *et al* 2021). A recent study by Wilkins *et al* (2021) found that ski resorts in Utah are already experiencing the impacts of climate change and are working to adapt. Snowmaking and adding other outdoor recreational activities were the most commonly used strategies, but there were financial and resource barriers associated with them (Wilkins *et al* 2021). Examining these perspectives in Wisconsin is vital to expanding adaptation literature as well as identifying areas for future research and practice development within the downhill skiing industry.

The climate change adaptation literature for downhill skiing is similar to other bodies of adaptation literature that focus more on physical impacts than social (Sietsma *et al* 2021). The literature that does exist tends to focus on climate-induced weather changes and impacts to ticket prices (Falk and Vieru 2017). Studies about operator perspectives have found that they are being impacted by climate change and that operators are aiming to adapt in various ways (Haanpää *et al* 2015, Rice *et al* 2024, Scott and McBoyle 2007, Wilkins *et al* 2021). However, there is currently no work examining these issues in Wisconsin or the U.S. Midwest, and there is a need to continue to expand this research to improve stakeholder engagement (Steiger *et al* 2019). Additional work in this field is especially imperative because 65% of U.S. ski resorts have closed from 1969 to 2019, with many occurring within the Midwestern U.S. (Moscovici 2022) and these difficult conditions are unlikely to improve (Chin *et al* 2018, Wilson *et al* 2023, Wobus *et al* 2017). Studying these issues in Wisconsin is vital to aiding the state's adaptation measures and future planning as well as to identifying areas for future adaptation research where environmental and social perspectives are integrated to develop recommendations for local communities and industries (Sietsma *et al* 2021). Our study aims to provide this information by interviewing owners and managers in the downhill skiing industry to understand their perspectives on these pertinent issues. The following research questions guide this study:

1. What are stakeholders' perceptions of the current impacts of climate change on downhill skiing in Wisconsin and their businesses?

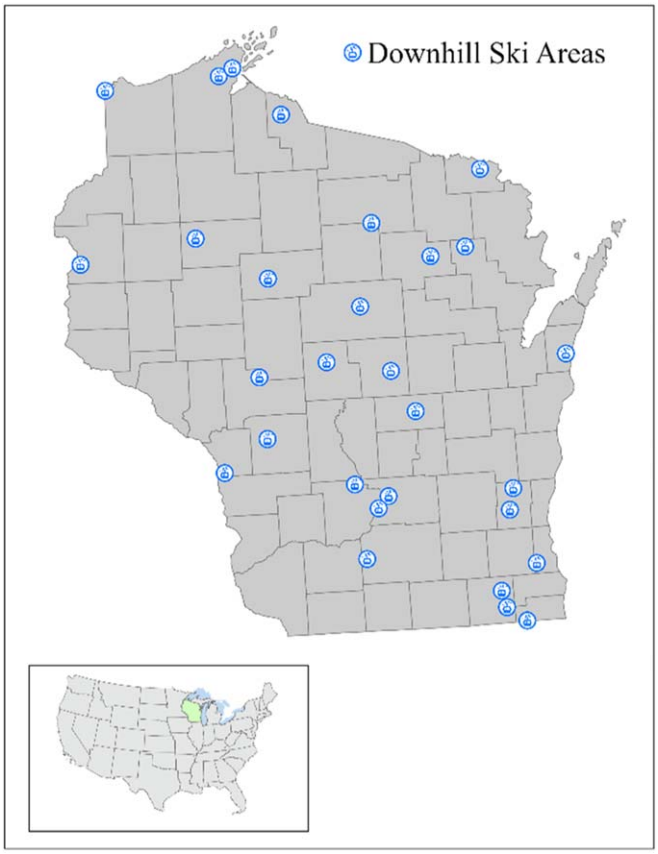

Figure 1. Downhill ski areas in Wisconsin. This map was generated using the Wisconsin Outdoor Recreation Inventory produced by the Wisconsin Office of Outdoor Recreation (WOOR 2023).

2. What adaptation measures are currently being implemented in Wisconsin, and what are their views of future practices?
3. What personal impacts are stakeholders experiencing and how do they feel about the future of the Wisconsin ski industry?

Methods

To answer these questions, our research team conducted semi-structured interviews with individuals who work directly in the downhill skiing industry in Wisconsin during the summer of 2023. Purposive sampling was used to identify key stakeholders and snowball sampling was used to expand from the initial list of contacts (Patton 2002). Participants were also asked to fill out a brief survey about their operation's characteristics and adaptation practices. Each interview was transcribed for analysis and thematically coded using a codebook based on existing literature with open codes to account for Wisconsin-centric codes (Saldaña 2016). The three members of our research team coded one interview transcript and met to discuss any disparities and ensure the triangulation of our overall results (Patton 2002). Afterward, authors independently coded each transcript and derived their themes. The research team met to discuss and finalize themes within each research question (Patton 2002), which are presented as our results. This research received exempt protocol approval (protocol number: 2023–33) from the University of Wisconsin-Steven Point's Institutional Review Board on May 12th, 2023, which required participants to be given an informed consent document and have it read to them before providing verbal consent to participate in the study.

Results

Eight participants were interviewed (via Zoom, in-person, or phone) in the study, which accounts for ~ 25% of the ski hills in Wisconsin (Travel Wisconsin 2024, WOOR 2023) (figure 1). The participants are owners or

Table 1. Participant & hill characteristics.

Site Characteristics	Total	Average
Participant Experience in Snow Industry	199 years	~25 years
Years Hill in Existence*	622 years	~62 years
Number of Employees	1,971	~246
Number of Runs Operated	217	~27

Table 1. Due to confidentially concerns we only provide general demographic information via totals and averages. * The number was divided by 10 due to some participants owning or managing multiple operations.

managers of one or more ski areas in Wisconsin. Interviews were conducted in the summer of 2023 and referenced the winter season of 2022–2023.

The types of hills interview participants operate are representative of the various types of downhill ski operations in Wisconsin, differing in geographic location, size of operation, and number of employees (table 1). The geographic distribution of participants across the state allows us to better understand impacts in areas with similar geographies.

Current impacts & adaptation strategies

Each of our participants stated that their operation was being impacted by climate change in a variety of ways that have been documented in other studies (Steiger *et al* 2019). We found that climate-induced weather changes, customer behavior, and operating costs were the main impacts facing participants, with the severity of impacts differing based on geography and visitor demographics. Participants in this study are already starting to adapt to these changing physical and social conditions using a variety of strategies described in the following sections.

Changing weather

Regarding climate-induced weather changes or, as referred to by participants, changes in the weather or weather changes, there were two main impacts described by participants. First is the inconsistency or volatility of weather. Many described recent challenges around having snowfall or correct temperatures to make snow, followed by a quick rise above freezing accompanied by rainfall that completely removes the snow or significantly degrades the quality of a run. This pattern seemed to be cyclical throughout the ski season, which resulted in more input in terms of resources and employee labor. One participant described this volatility in the ski season below.

> Yeah, so I think the biggest thing that we see is the increased volatility... We are seeing maybe more consistent thaws where it's almost expected that we're going to face some challenging weather. The most recent season [2022-2023] that's obviously fresh in our mind was by far the most volatile season we've ever had as far as number of freeze thaw cycles, warm ups, rain… so I think that's the biggest change we've seen. I'd say it still gets cold enough for us to make snow. But those windows seem to get shorter sometimes and less consistent.

While these sentiments were common throughout the interviews, participants in the southern regions of Wisconsin experienced these challenges more frequently, which was acknowledged by operators in the more northern regions of the state. As one participant stated:

> Well, Wisconsin this past winter [2022–2023], and I think the prior winter really seemed to have two weather zones, the lower half of the state and the upper half of the state… and I know that in the southern half of the state, last winter was pretty rough…

Figure 2 provides context for these statements and demonstrates the disproportionate impact that anomalies in precipitation and temperature averages had on southern regions of Wisconsin, where many ski hills are located (Study Area - figure 1). From November 2022-April 2023, the southern regions of the state had higher temperatures and precipitation (both frozen and non-frozen precipitation (Kantor *et al* 2023)) which negatively impact snowmaking and slope maintenance.

Additionally, our participants noted that the length of the winter season seems to be changing in Wisconsin. Depending on location, participants described their opening date shifting later in the year from November to

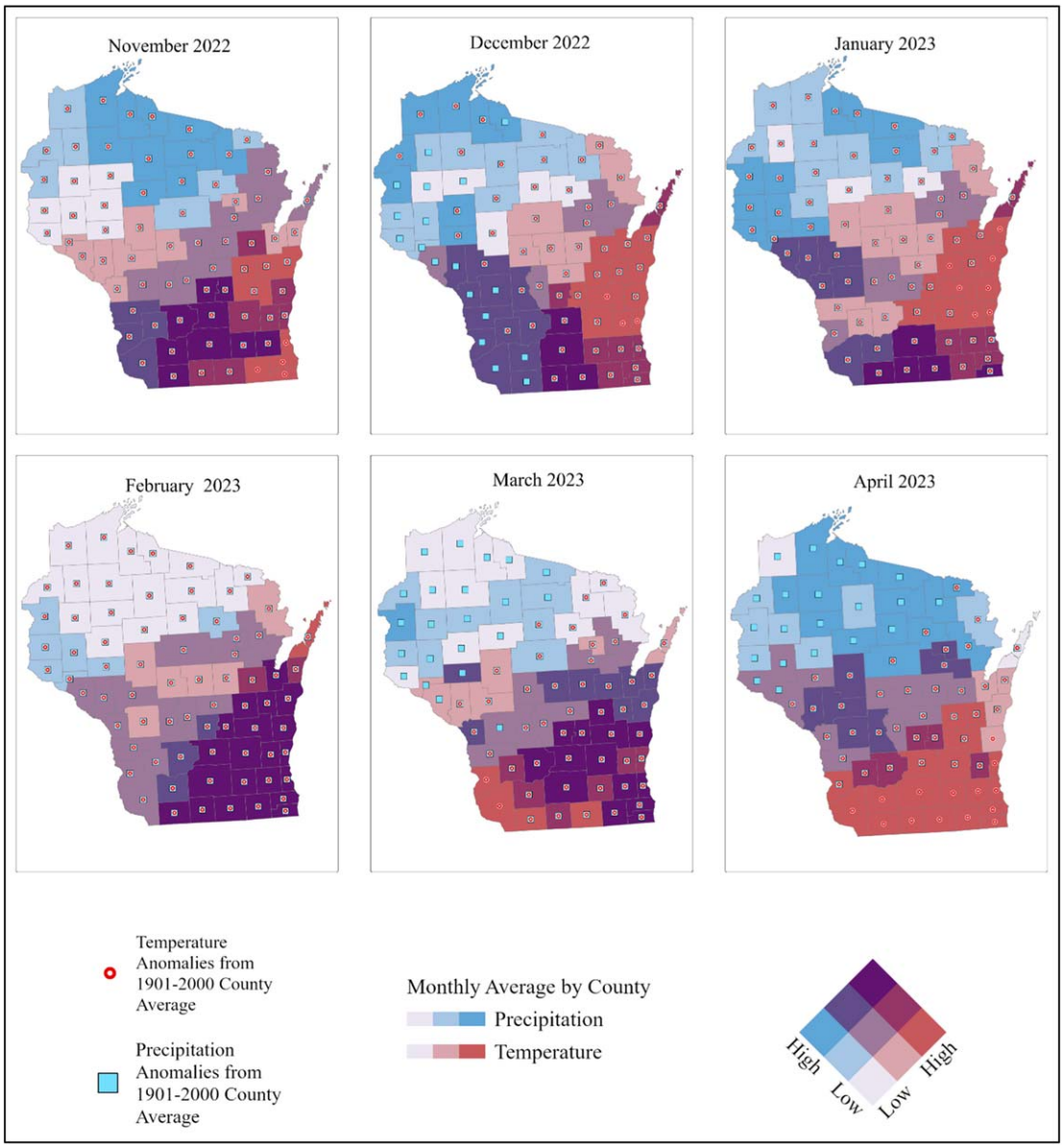

Figure 2. Wisconsin Winter Season 2022–23. These maps were created using the NOAA (2024) *Climate at a Glance County Mapping* dataset. This data was downloaded and used to produce bivariate maps in ArcPro (ESRI 2024). These demonstrate the overlap between average temperature and precipitation during the winter of 2022–2023. The darker shaded areas indicate both high average temperatures and precipitation in each county. The ○ symbol represents a higher average temperature compared to the historical average. The □ symbol represents a higher average precipitation compared to the historical average. The ◎ symbol denotes those counties that have both higher average precipitation and temperature.

December with their closing date remaining around March or April (depending on the operation). One example of this:

> …we are seeing shorter seasons. And this could get much worse. I don't know if we know the full impact of it yet. I do know that at the time that I purchased the ski area back in 19[70 s], and looking at the operating data sheets for the roughly 15 to 20 years before that, before we owned it, it was not at all unusual for the majority… to be open Thanksgiving or even earlier in November. Now that number is a lot less than it used to be… and in the last five years, I've seen two winters that we didn't open until December 27th. So I think the season is getting shorter on the front-end and on the back-end…

It should be noted that climate-induced weather changes and shorter seasons are interconnected phenomena that impact how and when Wisconsin ski hills operate. Another participant described the shorter season but expanded on the role that volatile weather plays in how long they operate throughout the season.

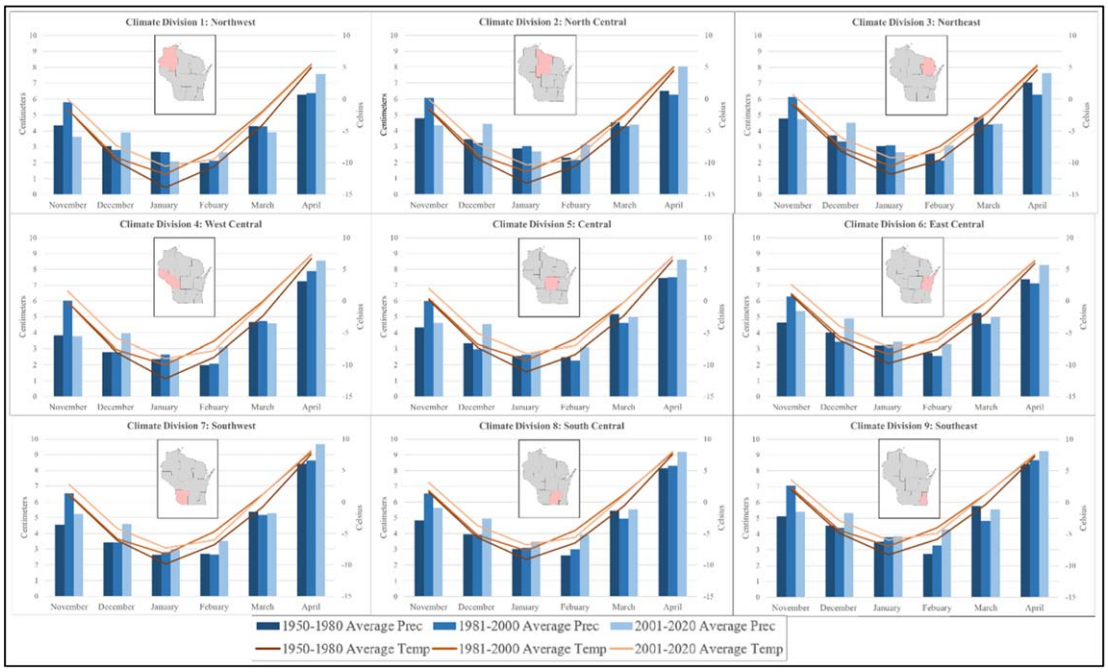

Figure 3. Temperature & precipitation change in Wisconsin climate divisions. This figure was created using precipitation (Hopkins 2024a) and temperature (Hopkins 2024b) data from the Wisconsin State Climatology Office for each climate division in Wisconsin. The location of each climate division is denoted in red on the map corresponding to each graph.

> But it's almost now the winter season… The ski season has shifted more to a mid-December to late March versus a early November to early March kind of deal. And we're seeing… Wisconsin winter hitting the end of February, which is usually more wrapping up. Last year, we closed the second week in March, and we had like a 6-inch snowstorm… the day we closed. And a lot of people were like, what are you doing? You're closing when it's snow 6 inches. But on the flip side of that the next day was like 50 degrees. So yeah, it's definitely weird the way the weather has shifted, the schedule of business and something that maybe will change the way we operate. And typically, the busiest and the best time for us has been the holiday break… that's typically our busiest time, which that'll probably stay your busiest time. But we've had some really key week-ends in February and January, MLK weekend and President's Day weekend that are just as important…

The early and late seasonal shifts impact operators during vital holidays or busy seasons, which result in difficult decisions about when and how to operate. These *perceived* changes coincide with documented historical temperature and precipitation Climate Division data curated by the Wisconsin State Climatology Office. Figure 3 highlights the increases in precipitation as well as the larger shift in temperature during the key holiday seasons, particularly in January and February, that the participant above describes. These changes seem to have a greater impact on the southern Climate Divisions in Wisconsin.

Similar to previous studies (Haanpää *et al* 2015, Rice *et al* 2024, Scott and McBoyle 2007, Wilkins *et al* 2021), we found that the main adaptation strategy being used to reduce the impacts of volatile weather and shorter seasons is snowmaking. Snowmaking allows ski hills to extend their season while also remaining operational during volatile weather periods. A participant explains the rationale below:

> …the one way we can battle [climate change] is by investing more into our snowmaking system. While we can't make snow when it's warmer, we know it's going to get cold enough, hopefully, always where we can make snow. So at the efficiency and the rate that we can get the hill covered is what we're focused on. So that's upgrading our pump station that pulls in water, that we can push more water uphill, doing all of our annual maintenance and our snow guns and making sure those are good to go for the next coming season, as well as adding more snow guns, and just trying to be as efficient as possible. So when we do get those three days of cold temps after it's been 60 degrees in December, we can get the hill open and we can operate our business.

Outside of the snowmaking systems themselves, operators also invest more heavily in planning and education surrounding the snowmaking process. Due to the need to understand the various facets of the snowmaking process, many operators invest in more accurate sensing equipment and meteorological data to aid in planning, like this participant:

> Along with improving the capability of our snowmaking system, we've also got to improve our critical thinking skills on planning as to when we're going to utilize that snowmaking system… we plan our snowmaking operations by detailed study of two-week forecasts. And we use a paid weather subscription service where we have predictions… and of course, those things can change. But it's a quantum leap from the old days of where your forecast information was. 'Well, it should be cold next week.' We can now look at the hourly operation and plan our operation accordingly… then next step is… we're in the process of ordering electronic wet bulb sensing equipment. And making your decision based on not only ambient temperature, but wet bulb temperature is critical in good snowmaking… and those wet bulb temperatures are desirable temperature ranges are happening less often and for shorter periods. And that's why part of the reason this year, I made the decision so that we got our good digital available equipment to monitor wet faults so we can make decisions faster.

It should be noted that investing in snowmaking generally starts as a business decision to extend the season or to aid in the creation of new runs. Over time, this investment has shifted from more of a luxury to a necessity due to the new realities of operating a ski hill in Wisconsin.

> I started making all this snowmaking investment, it wasn't as a reaction to changing weather patterns, it was a reaction to where the businesses needed to be. And as I feel that now, the weather patterns have been changing, and it is getting more volatile. Now it's a really good additional safety net that we have. And it's like, thank God we invested all that. Like I said, there's zero regrets into it. Like, thank God we did, because now we can recover from this stuff quickly.

These investments seem to be critical to withstanding the volatile conditions and shifting seasons our participants associate with climate change, which also seem to be interconnected with changes in customer behavior and the costs of operating a ski hill in Wisconsin.

Customer Behavior

Our participants felt that the changing conditions of the physical environment have led to changes in customer behavior that impact the number of visitors on their slopes. This theme was commonly discussed by participants. Operators describe that despite having snow due to snowmaking, if the weather does not feel like winter, then visitors are less likely to want to participate in winter activities. In short, natural snowfall and winter conditions are the main drivers of participation more than the ability to create snow. This phenomenon has been documented in research examining ticket sales and snow events (Falk and Vieru 2017). Numerous participants used the phrase *snow in the backyard*, as the decision-maker for whether the general public is going to visit their hill, which has been noted in other studies (Hamilton *et al* 2007, Demiroglu *et al* 2018). A study by Demiroglu *et al* (2018) found that Norwegian skiers also use their local conditions or *backyard effect* as a driving factor in their decision to participate in summer glacier skiing. This seems to be a factor in downhill skiing in Wisconsin as well. The participant below describes the connection between snowfall and ticket sales.

> I mean, we see such a jump in ticket sales and overall attendance when we get an actual snowfall. And it's not a crazy powder day… even 3 or 4 inches of natural snowfall will boost sales for us. Even though we've had snow for months on our own. That's just educating those guests that just because there isn't snow in your backyard doesn't mean that we aren't open…

Others expressed frustration with trying to get the public to look beyond their own backyards to consider skiing in less-than-ideal winter conditions because their snowmaking capabilities allow for a high-quality skiing experience.

> People want to be outside, which is great. Natural snow definitely helps us market to people. If there's snow in the backyards, that brings more people in. That's one of the hardest things that I've tried to figure out is, how do we get across to you, Joe Blow, that we have snow even though you don't have snow…

However, many mentioned that their customer base includes a core group of highly knowledgeable skiers who understand snowmaking capabilities. This situation seemed to impact the hills that relied more heavily on non-local visitors, like those from the Chicago suburbs.

> I think for our local customer base that we draw from for our ski resorts specifically. I think they understand that we have really good snowmaking and that we're going to have a consistent product… and there's no doubt natural snow is still the number one driver of business for us… do we still do well when it's bare ground and people are looking at grass in their backyard? Yes. Because like I said, the customers have come to understand that we make snow. But there's still no better marketing than two inches of snow in someone's backyard. Like there's nothing that beats it…I think if Chicago gets some snow, it makes people think we should go do something fun in the snow.

Social media and marketing are adaptation strategies that our participants are using to address this change and combat the *backyard effect*. Participants mentioned new approaches to educate the general public about their operation and the quality of slopes that can be created through snowmaking and grooming. The participant below describes their attempts to reduce the impact of the *backyard effect* through marketing techniques and guest education.

> But I also think like marketing and messaging… i mean, that's a huge part of what our marketing department spends time on, is just communicating that, hey, we know that the weather doesn't look great and there's no snow in your backyard, but this is what we look like. And so it's communicating that is– I think that's a huge part of it from a marketing standpoint to the guests that it is good. And I think when they do come here and they realize that they weren't lying, it is pretty good, even though we had some rough weather, that's where word of mouth, and like I said, the guests have almost have an expectation now that we're always going to have snow and it's going to be good.

Other strategies included using live streams and posting Travel Wisconsin condition reports on their websites or social media pages to get the message out to potential visitors that you can ski, regardless of what your backyard may look like. In short, the public understanding that skiing is available during warmer periods is vital to profits, especially as operating costs continue to rise.

Operating costs

The final climate change impact mentioned by our participants relates to operating costs associated with the *need* to update technology and management techniques to meet changing conditions and customer behavior. The need to invest in snowmaking and the costs of making snow are described by one participant below.

> …it affects everything in that we have to spend way more money to keep the hill operating and going. And the investment in snowmaking and snowmaking itself is a very expensive process just from the electricity consumption. And so it's definitely a challenge.

Also, participants described how the need for additional equipment for the maintenance of ski runs (referred to as grooming) has changed over time.

> Yeah, we will have temperature swings come in the middle of the night, to where we can only groom for six hours. We can't groom for 10 to 12 [hours]. So that means that there's 6 vehicles out on the hill and not 3. And those vehicles are anywhere from a quarter to a half million a piece, so to have an extra vehicle sitting there is not cheap. I certainly thought about that being climate change, but it definitely is attributable to that.

However, these investments are necessary because they help create and enhance snow. As one participant stated, *the snow is our business. The snow is our product.* They elaborate more below.

> And so [snow is] what we sell, and that's why I've been such an advocate for investing so heavily in it, because without snow, we have nothing to sell. And in my early years when we'd get that thaw and be closed, it'd be like, well, now we have zero chance to make money. If we don't have snow, we are completely closed. Like there's not like, we don't run the restaurant, and the

> restaurant revenue would not be enough to sustain anything. So the climate change affects the snow, that affects the entire business. It is the business.

Additionally, many discussed how increasing operating costs have been exacerbated by the labor market and inflation, which has disproportionately impacted smaller resorts.

> If you're a smaller resort, you don't have the money to invest in snowmaking equipment, you're out of business. So if you look at the amount of skiers that there was in Wisconsin in 1990 versus 2023, there's about half as many.

These perceptions have been documented in the literature, along with a reduction in ski areas across the U.S. Midwest (Moscovici 2022). This drop in ski areas in the United States has been connected with the rise of snowmaking (Scott *et al* 2024) with case studies linking the investment in snowmaking and other expenses as a key factor in the loss of ski hills (Hamilton *et al* 2003). These sentiments were present as participants were asked to describe the emotional and personal impacts of these changes.

Emotional impacts

The emotional impacts being experienced by interview participants varied, with some feeling more negative feelings, such as frustration around the volatile weather and the pressure to be open. One participant stated that: *From an operator standpoint, frustration, yeah. Defeat, sometimes. Yeah, it definitely plays with your emotions a little bit*. Others felt that these impacts and changes were a new part of running a downhill ski hill, but that this field of work has always been challenging… *in this industry, you just roll with the punches a little bit.*

Interestingly, some of our participants had experienced these local climatic changes throughout their lifetimes and career. During this section of the interview, some expressed nostalgia for the simpler times in the pre-2000's when working in this industry was less stressful. This participant describes the simplicity of snowmaking decisions that their predecessor needed to make when they began, which have become more complex today.

> Yeah, the weather patterns, he didn't have to deal with that back in the '70 s and '80 s, it was, it's cold. You didn't get snowfall, you have to make snow. It's that simple. It's not that simple anymore. It's much more deeper than that.

This sentiment was also present when participants described the differences in skier expectations that they felt now drive grooming and snowmaking as much as the change in weather. Even those who stated that they are not emotionally impacted do worry about the issues that the next generation of operators will have to navigate.

> My father didn't dream of some of the things that I'm having to do right now, and I can't help but wonder, what are my kids going to have to do? That, I can't imagine what they're going to have to deal with. So, I guess that's the emotional part that I deal with.

King *et al* (2023)'s recent global study notes the emergence of local climate change impacts across various regions while our paper provides a look at how these changes are impacting local businesses throughout a person's lifetime. These discussions about current impacts and adaptation strategies provided a reference point in the interview concerning the future of downhill skiing in Wisconsin.

Future of Wisconsin downhill skiing

Participants were asked various questions about how they perceive the future of their industry in Wisconsin. These questions focused on the need for future adaptation practices, views on the future of the industry, and potential solutions.

Future adaptation strategies

In terms of future adaptation strategies, most participants felt that the need for adaptation strategies would increase over time and become more intense. Most expected the need to start investing more heavily in snowmaking as the technology continues to change. Many stated that they will continue to update technology and techniques, with an added focus on efficiency for environmental sustainability and cost reduction purposes. Changes in marketing will also be needed to continue educating the public about snow availability and expanding social media presence. Some mentioned expanding the types of activities at their site to increase diversity in their income in other parts of the year.

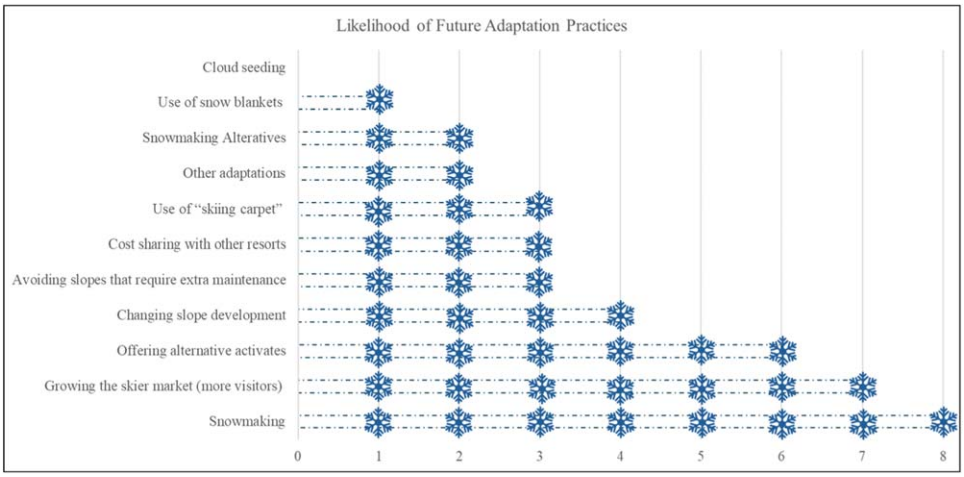

Figure 4. Participant Survey Responses. Participants were asked how likely they would begin using various adaptation strategies in the future. This figure shows the practices that participants rated with Likely or Very Likely. Each ❄ represents one participant stating they would Likely or Very Likely adapt the strategy.

> …we're really looking at different opportunities that may be less weather dependent at that location. And so that's one of the reasons why we're trying to improve, install, increase the number of miles, of trail, multi-use trail. Where if we have a rougher winter, users could still...utilize a part of that park… those trails that would offset some of the loss from the skiing and tubing.

In summary, all of our participants felt that adapting to climate change is a part of their profession that will continue into the future. Figure 4 summarizes results from the post-interview survey that indicate their likelihood of utilizing different adaptation strategies in the future.

Future of Wisconsin downhill skiing

Despite concerns about climate change, most participants were positive about the future of downhill skiing in Wisconsin. This was mainly due to the recent increase in participation in skiing that began during the onset of the COVID-19 pandemic and has continued since.

> …COVID was a giant shot in the arm for our industry. And skiers came out in record numbers. And so many people discovered skiing for the first time or rediscovered skiing. And when COVID happened, I thought it was going to be kind of a unicorn one and done year where this was the first time people could get out and do something. But now we've had three seasons since COVID and we have sustained and grown the business since then. And this seems to be a trend nationwide… And so I think the customer demand is making all ski areas healthier financially that they're able to invest… I think the future is incredibly bright for our entire industry. And specifically in Wisconsin, I think things are really trending in the right direction.

Another participant stated that because they were able to innovate during the pandemic, climate change is something that can also be overcome. Additionally, a source of positive outlook is the strong ski network in Wisconsin. Many described the interconnectedness of ski hills, as the smaller, more beginner hills feed into the larger hills for more experienced skiers. They view other hills in Wisconsin as friendly competition with mutual benefits if all succeed. One participant explains below.

> …the people down South and around the big metropolitan areas, the base of skiers [is] huge… so I think the future looks good for Wisconsin, because there's a lot of little feeder areas down South, as long as they keep on getting the snow and they make the investment in infrastructure. Because the amount of skiers, the beginners… there's hundreds of thousands of them… so for them to make a day trip up here, I think it's a great thing for us, as long as those resorts stay alive.

Potential solutions

Given the challenge presented by climate change, participants were asked what support might be needed for their industry, and the responses varied. Some mentioned aid in trying to market and provide educational materials for the public.

> …advocating more for the sport of skiing and snowboarding. We look at our neighbors in Minnesota that do a great job at introducing this activity to kids… they have a fourth grade program that…gives every kid in fourth grade an option to go to the ski hill, and try it out for a super low cost. And while our Skiing Wisconsin…has done a ton it definitely feels like there's still maybe a little disconnect between ski areas and general public….

Other participants felt that there should be incentives for transitioning to more energy-efficient snow equipment, along the lines of programs that have been introduced in other areas of the United States. They explain below:

> …in Vermont, there's something that the state has in place that is specific to the ski industry… there's tax credits given to go to more efficient snowmaking guns and system components. And that would be nice to see something like that here…there's a lot of resorts that put off buying more efficient equipment, because it was expensive. And now with this program that [Vermont] has, they have made significant purchases to help run more efficiently.

Similarly, another participant mentioned that there could be a focus on grants to help smaller operations promote their hills or upgrade equipment. Finally, there were a few who felt that each hill needed to make decisions for themselves, which has been the source of innovation and success for Wisconsin downhill skiing in the past. Regardless of the specifics, support for the downhill skiing industry and other winter industries is likely needed as future trends suggest that conditions will not be favorable for success (Chin *et al* 2018).

Conclusion

Our study highlights how climate change is currently impacting downhill skiing in Wisconsin in various ways. Participants stated volatile weather and shorter seasons are the main physical impacts that have pushed them to invest more heavily in adaptation practices in recent decades. Some adaptations have been identified in previous literature. For example, investing in snowmaking equipment was a key adaptation strategy found in other studies (Wilkins *et al* 2021), but we also found that other types of technology are being utilized to support planning and maintenance. These seem to be vital components of snowmaking as an adaptation strategy in Wisconsin. For many of our participants, investments in snowmaking were initially a business decision but have shifted to a necessity over the last few decades. Participants noted that this shift seems to impact the smaller resorts in the southern region of the state, which was also found in a similar study in New Hampshire, where size and geography were factors in the loss of ski areas (Hamilton *et al* 2003). These practices increase operating costs, adding difficultly in an already challenging labor market. One impact that we found that has not been identified in previous literature is the need to adapt to changing customer behavior and expectations. Participants in this study also are increasingly experiencing the *backyard effect* (Demiroglu *et al* 2018, Hamilton *et al* 2007), in which the public does not visit ski hills if they do not see snow where they live. This idea has been noted in previous work connecting ticket sales with snowfall (Falk and Vieru 2017, Hamilton *et al* 2007), but our paper highlights how operators view and have been adapting to these phenomena, mainly through social media posts and other forms of client communication. When asked about the future, participants felt that the need for adaptation strategies is only going to increase with time, however, they also feel positive about the future of the skiing industry in the state. Despite this optimism, many were worried for the next generation of operators and felt that increased support through incentives or other programs would aid the industry moving forward. A recent example of this support in Wisconsin is the allocation of disaster loan program funds to snow dependent industries due to the lack of snow and loss of business (Evers and Baldwin 2024).

The need for additional support for the downhill ski and other winter sports industries as well as research to understand future challenges is essential. Based on our study, this could focus on providing frameworks and technology to better plan for volatile weather; increasing efficiency in equipment to ensure that snowmaking does not become a maladaptation strategy (Scott *et al* 2024); and new communication strategies, all of which will benefit from an interdisciplinary approach. In doing so, these new research areas will meet the call to integrate physical and social science research to provide local adaptation practices and policy measures that can be applied by stakeholders being impacted by climate change (Sietsma *et al* 2021).

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Data availability statement

The data cannot be made publicly available upon publication because they contain sensitive personal information. The data that support the findings of this study are available upon reasonable request from the authors.

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