THE ECONOMIC CONTRIBUTIONS OF WINTER SPORTS IN A CHANGING CLIMATE

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PHOTO: JOHN FIELDER

CLIMATE ECONOMICS AND THE GYRO MAN

PROTECT OUR WINTERS BOARD MEMBER AUDEN SCHENDLER

One night this December, I walked back to my hotel after the annual Powder Awards in Breckenridge. It was one of the driest and warmest starts to the Colorado ski season in memory. Having missed dinner, and being, well, a skier, I had spent four hours drinking Moscow mules and beer, growing increasingly hungry, but taking energy from the community feeling of the event. It was the very beginning of ski season, but the streets were bustling like mid-winter. Even without the snow, there was vibrating energy and joy.

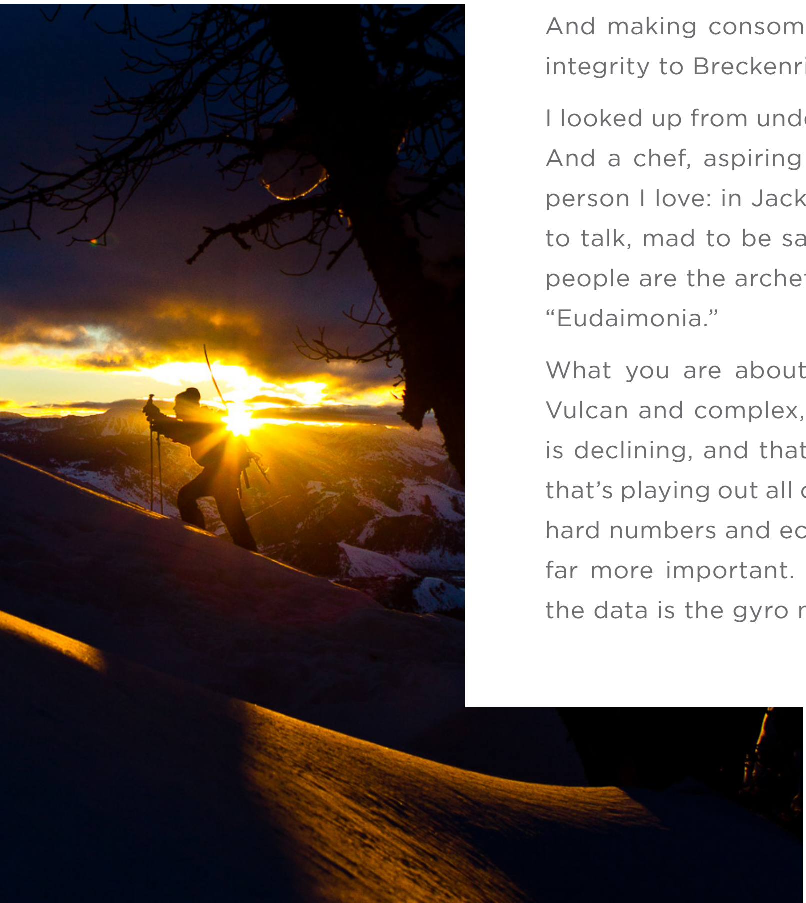
I'd resigned to go to bed hungry when I stumbled upon a gyro stand.

"What are you guys doing open this time of night, so early in the season?" I asked, delighted.

"Dude, we're killing it," said the gyro man, a bearded, long-haired, typical ski-town type. He was young, and fired up—almost alarmingly so. I placed my order. Behind me was a group. "Lots of jalapenos!" they yelled. As is the case in all ski towns, the gyro man knew one of them. "You got it! And dude: I want to sincerely thank you for opening Artisan. That duck poutine. And making consommé out of the same duck! Thanks for bringing some integrity to Breckenridge cuisine. Seriously."

I looked up from under my hood as I waited. So the gyro man was a foodie. And a chef, aspiring or actual. Smart and ambitious. He was the kind of person I love: in Jack Kerouac's words "the ones who are mad to live, mad to talk, mad to be saved, desirous of everything at the same time." These people are the archetypes of human flourishing, or what the Greeks called "Eudaimonia."

What you are about to read is a work of hard science and economics, Vulcan and complex, but with a simple message: winter is warming, snow is declining, and that trend hits our communities in the wallet. It's a story that's playing out all over the United States this very season. But behind the hard numbers and economic theory, the models and analysis, is something far more important. It is something ineffably, unshakably human. Behind the data is the gyro man.



Economies and jobs are at stake, sure, but more importantly, a way of life is in jeopardy. Embodied in Breckenridge for me that short night was the whole world of skiing and riding, sledding and skating, snowshoeing and snowman building. The whole of winter. And it made me think: what we are working to protect is not so much the snow or the outdoors, but the spirit and grace it imbues in us. (The film that won the award that night was called, not surprisingly to me, "Numinous.")

I walked to my hotel room, gyro in my goggle pocket warm against my stomach, wondering if we might dignify this man's pride in work and joy in life through our own struggle to protect the climate. Not to save skiing entirely, because we can't do that now, but to protect a piece of it—the bigger the better—so that even in a warmer world, we might retain remnants of the things that bring us joy.

And so, we study this report, yes. And then we wake up, and we caffeinate, and we skin up something, and then we get to work early, and we grind away with the determination of mountaineers, knowing the obvious: that the struggle is the destination itself. You, we, POW, we're on the trail. Rugged, dusty, winding, suffused with profound risk, but also with opportunity that is sacred and divine.

I lay back in my bed and clicked on the TV. But then I raised my foil-wrapped gyro in a late-night toast to an idea: that I might honor this man's passion with my own; and that we together might make our lives more meaningful, more whole, and more joyful, through the pursuit of difficult-to-achieve but noble goals.

AUDEN SCHENDLER

Protect Our Winters Board Member

ACKNOWLEDGEMENTS

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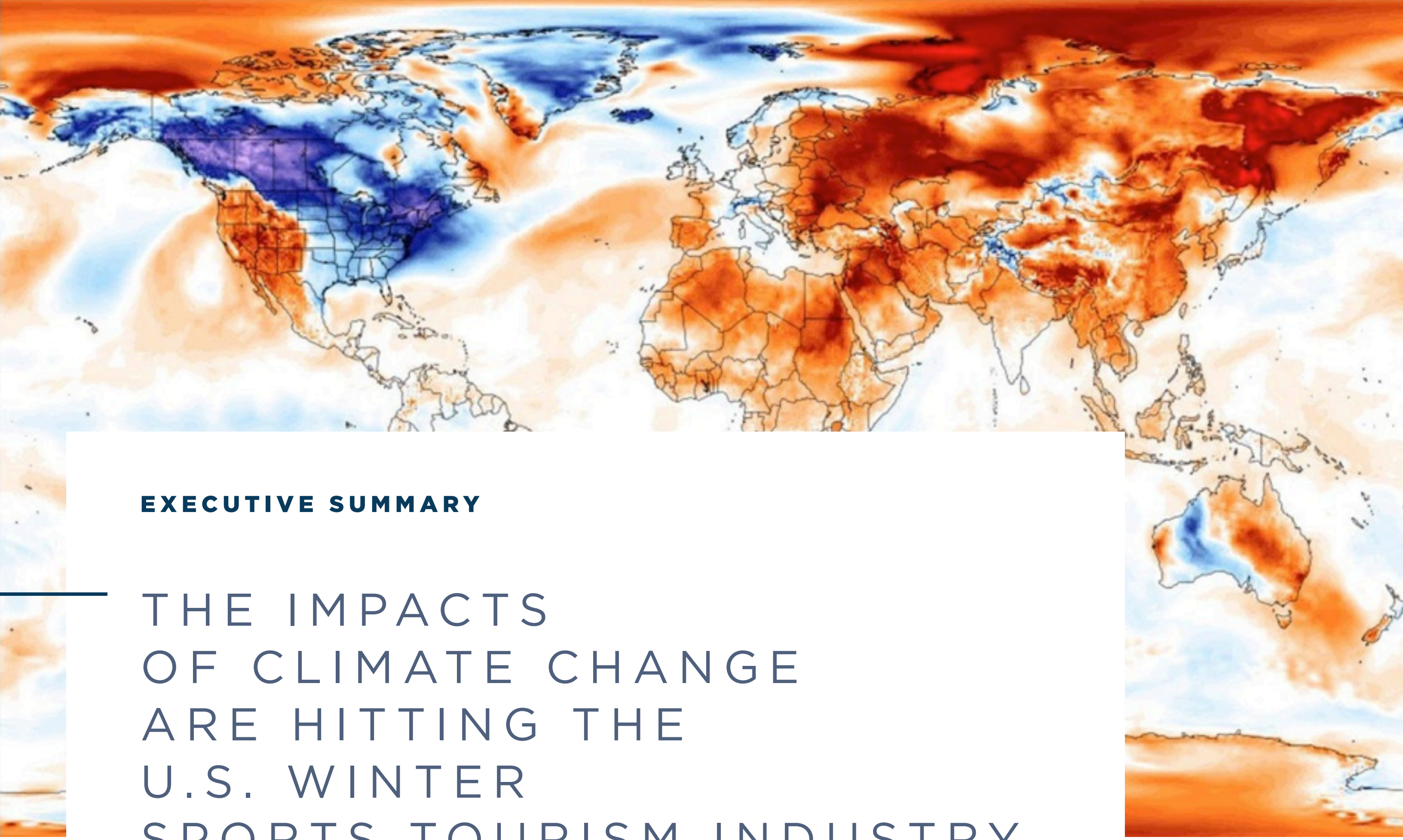


EXECUTIVE SUMMARY

THE IMPACTS OF CLIMATE CHANGE ARE HITTING THE U.S. WINTER SPORTS TOURISM INDUSTRY PARTICULARLY HARD.

In mountain towns across the United States that rely on winter tourism, snow is currency. For snow lovers and the winter sports industry, predictions of a future with warmer winters, reduced snowfall, and shorter snow seasons is inspiring them to innovate, increase their own efforts to address emissions, and speak publicly on the urgent need for action.

This report examines the economic contribution of winter snow sports tourism to U.S. national and state-level economies. In a 2012 analysis, Protect Our Winters and the Natural Resources Defense Council found that the winter sports tourism industry generates $12.2 billion and 23 million Americans participate in winter sports annually. That study found that changes in the winter season driven by climate change were costing the downhill ski resort industry approximately $1.07 billion in aggregated revenue over high and low snow years over the last decade.

Top Photo Source: University of Maine, Climate Change Institute
Surface temperature anomaly (relative to the 1979-2000 average) for Friday December 29, 2017, illustrating the “warm west, cool east” temperature pattern in the United States. Note that while the Eastern U.S. experienced record to near-record cold temperatures during this cold snap, the rest of the globe was warmer than average.

This analysis updates the 2012 study and furthers our understanding of how warming temperatures have impacted the industry since 2001, what the economic value of the industry is today (2015-2016) and what changes we can expect in the future under high and low emissions scenarios.

Taking another look at the changing winter sports tourism sector in America, we find:

- In the winter season of 2015–2016, more than 20 million people participated in downhill skiing, snowboarding, and snowmobiling, with a total of 52.8 million skiing and snowboarding days, and 11.6 million snowmobiling days.
- These snowboarders, skiers and snowmobilers added an estimated $11.3 billion in economic value to the U.S. economy, through spending at ski resorts, hotels, restaurants, bars, grocery stores, and gas stations.
- We identify a strong positive relationship between skier visits and snow cover and/or snow water equivalent. During high snow years, our analysis shows increased participation levels in snow sports result in more jobs and added economic value. In low snow years, participation drops, resulting in lost jobs and reduced revenue. The effects of low snow years impact the economy more dramatically than those of high snow years.
- While skier visits averaged 55.4 million nationally between 2001 and 2016, skier visits during the five highest snow years were 3.8 million higher than the 2001-2016 average and skier visits were 5.5 million lower than average during the five lowest snow years.
- Low snow years have negative impacts on the economy. We found that the increased skier participation levels in high snow years meant an extra $692.9 million in value added and 11,800 extra jobs compared to the 2001–2016 average. In low snow years, reduced participation decreased value added by over $1 billion and cost 17,400 jobs compared to an average season.
- Climate change could impact consumer surplus associated with winter recreation, reducing ski visits and per day value perceived by skiers.
- Ski resorts are improving their sustainability practices and their own emissions while also finding innovative ways to address low-snowfall and adapt their business models.

The winter sports economy is important for the vitality of U.S. mountain communities. This report shows the urgency for the US to deploy solutions to reduce emissions and presents a roadmap for the winter sports industry to take a leading role in advocating for solutions.

WHAT OF JUSTICE?

This report is about the challenge that climate change poses to winter sports economies, but in the end, it's about the impact warming is having on snowsports themselves. Which brings up an important question related to climate justice: Who cares? In the last year, climate-enhanced disasters—the sorts of catastrophes we can expect more of as the world continues to warm—have had a tremendous impact on human beings' ability to simply survive, let alone ski.

In the face of disasters like we saw in Puerto Rico or Houston this year which included the loss of lives, grid shut-downs, health crises, and housing crises, why worry at all about snowsports?

To many Americans, the fading of winter is a visible reality, and the consequences create an emotional reaction connected to a sense of place and personal experience. Talking about snow is one particularly accessible way to engage the American population on an issue that has been viciously difficult to bring to the fore. By protecting winter and snow in mountain communities, we are also protecting the most vulnerable communities and connecting both. We hope that this report will help galvanize all Americans to act on climate —for skiing, snowboarding, and snowball fights, sure, but most importantly for a safer, more equitable future for all. Snowpack doesn't only support winter sports, it also serves as a water reservoir and increases the albedo effect.

Photo Credit: Eric Overton

Ultimately, winter sports join ranks with arts and culture, literature, music and song, to create the space for reflection that enables citizenry to care about more than just themselves and their powder turns, but also about what their role is in society. Losing snow to a warming world when we have human innovation and all of the technology at hand to save it, would be a greater loss than pure numbers can quanitfy.

THE TOURISM INDUSTRY IS PARTICULARLY AFFECTED BY CLIMATE CHANGE

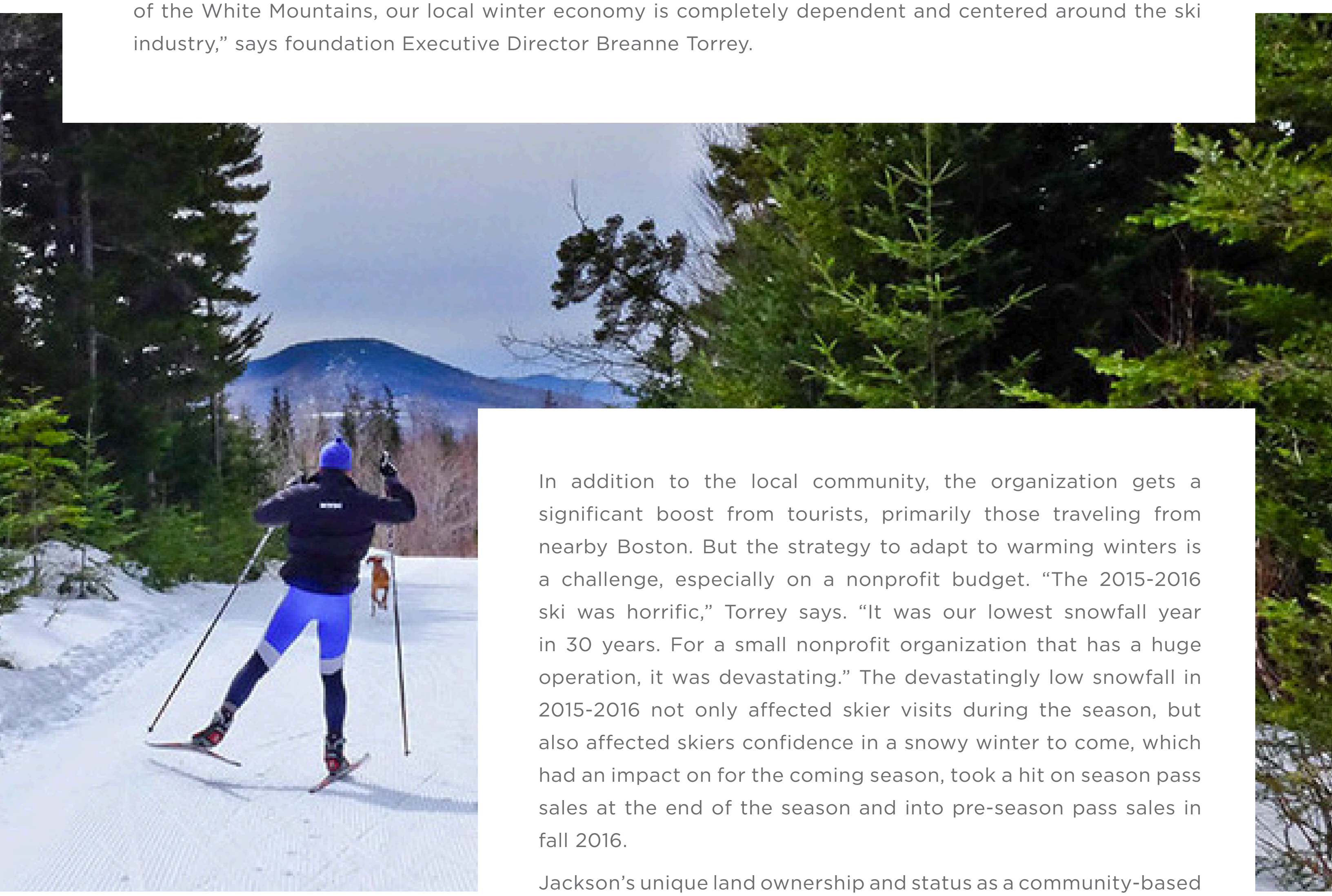
Last spring, thousands of racers flocked to Wisconsin to partake in "The Birkie," North America's largest cross-country ski marathon. Unseasonably warm weather rendered the course unsafe, leading to the first cancellation in more than four decades.

In March, Aspen Snowmass hosted the 2017 Audi FIS World Cup Finals. Battling 60°F (15.6°C) temperatures, race officials had to heavily salt the course to keep it frozen, while festivities in the downtown park took place in melted snow-water puddles.

Eighty-nine percent of ski resorts use snowmaking and a small minority of resorts have honed in on skillful snow harvesting to extend their seasons and improve snow quality. Many resorts are bolstering their business model with year-round revenue streams. Nonetheless, unchecked warming would pose a threat beyond the ability of the winter snowsports industry to adapt.

CASE STUDY: JACKSON XC NH

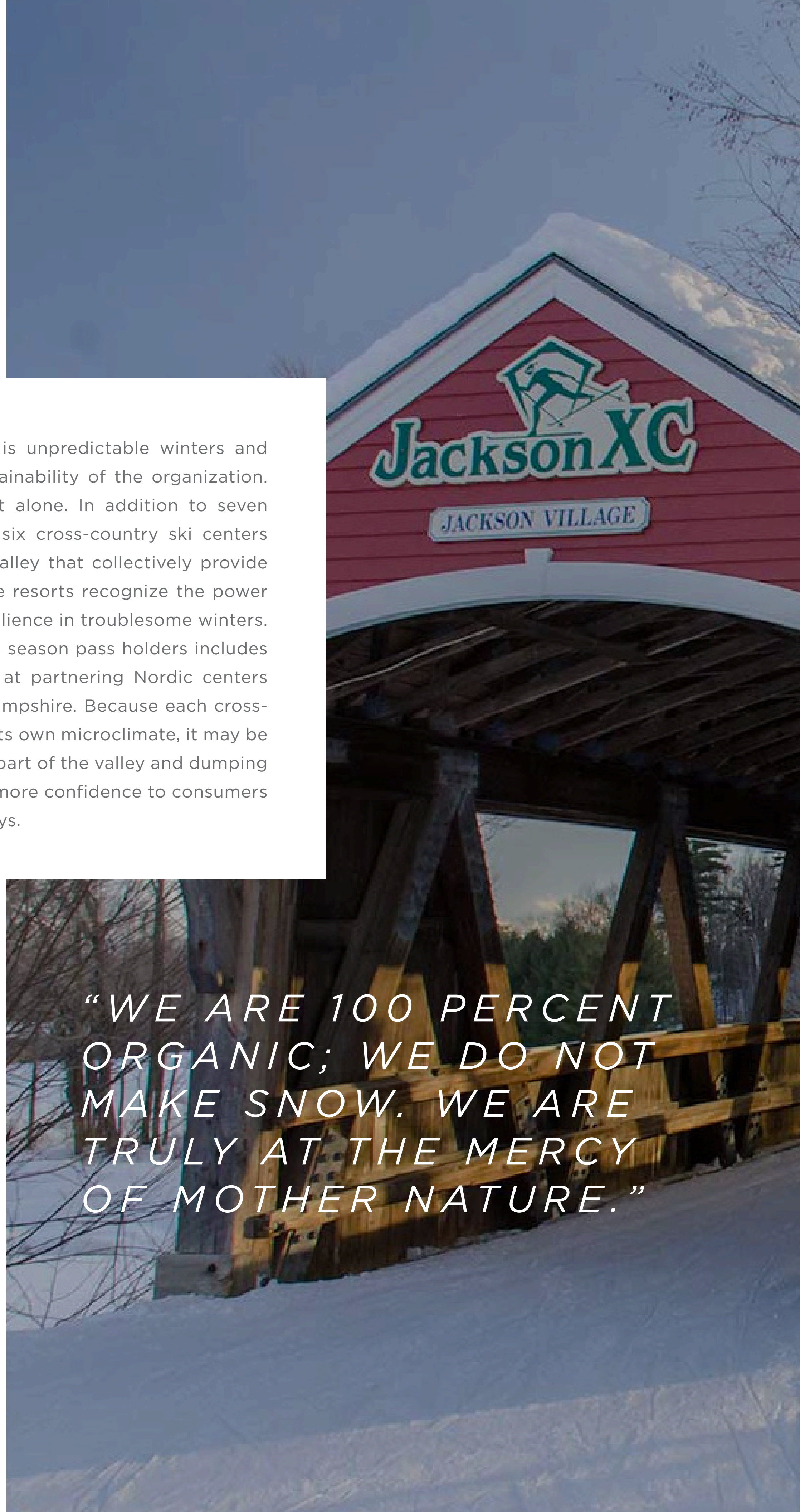
Nestled in the breathtaking Mount Washington Valley of New Hampshire, the Jackson Ski Touring Foundation offers 100 miles of cross-country skiing trails. A 501(c)(3) nonprofit organization founded in 1972, Jackson partners with over 70 private landowners to maintain the trails, including residential lands and conservation commissions, in addition to a special use permit from the White Mountain National Forest. With a history of providing free skiing for all children under 10 and free training for athletes of all ages, the foundation is an essential thread in the fabric of the Jackson community."Up here in the heart of the White Mountains, our local winter economy is completely dependent and centered around the ski industry," says foundation Executive Director Breanne Torrey.



In addition to the local community, the organization gets a significant boost from tourists, primarily those traveling from nearby Boston. But the strategy to adapt to warming winters is a challenge, especially on a nonprofit budget. "The 2015-2016 ski was horrific," Torrey says. "It was our lowest snowfall year in 30 years. For a small nonprofit organization that has a huge operation, it was devastating." The devastatingly low snowfall in 2015-2016 not only affected skier visits during the season, but also affected skiers confidence in a snowy winter to come, which had an impact on for the coming season, took a hit on season pass sales at the end of the season and into pre-season pass sales in fall 2016.

Jackson's unique land ownership and status as a community-based nonprofit makes it difficult to implement traditionally popular adaptation strategies like snowmaking. The organization's mission also emphasizes connections with nature and land conservation. "We are 100 percent all natural, all organic; we do not make snow. We are truly at the mercy of Mother Nature," Torrey says. Instead the organization relies on land and snow management techniques to preserve snowpacks in spite of warm temperatures.

Jackson's biggest concern is unpredictable winters and how they threaten the sustainability of the organization. And that community is not alone. In addition to seven alpine ski areas, there are six cross-country ski centers in the Mount Washington Valley that collectively provide over 450 miles of trails. The resorts recognize the power of community to bolster resilience in troublesome winters. A new benefit for 2017/2018 season pass holders includes 50 percent off day passes at partnering Nordic centers around the State of New Hampshire. Because each cross-country resort experiences its own microclimate, it may be raining in the southwestern part of the valley and dumping snow in the north. "It gives more confidence to consumers to buy their pass," Torrey says.



"WE ARE 100 PERCENT ORGANIC; WE DO NOT MAKE SNOW. WE ARE TRULY AT THE MERCY OF MOTHER NATURE."

1.

THE ECONOMIC VALUE OF WINTER SPORTS

The Jackson Ski Touring Foundation is the first of many stories recounting effects of climate change on the winter tourism industry in the United States. To better understand the extent of these economic impacts, this report examines the economic contributions from expenditures in winter sports tourism in high- and low-snow years, to show how climate change is impacting the winter tourism economy.

The IMPLAN software was originally developed by the US Forest Service, and establishes the characteristics of economic activity in terms of 528 economic sectors. Drawing on 2016 data collected by federal and state government agencies, the IMPLAN model uses regional industry purchasing patterns to examine how changes in one industry will affect others. The model calculates employment, labor income, and overall value added and output to the economy (see Appendix A for a full discussion of the methodology).

1.1

NATIONAL- AND STATE-LEVEL ECONOMIC CONTRIBUTIONS OF SKIING AND SNOWMOBILING

The IMPLAN model was used to determine the overall size of the US ski (downhill ski and snowboard) and snowmobile industries and provide estimates of state-level economic contributions.* In the winter season of 2015–2016, more than 20 million people participated in downhill skiing, snowboarding, and snowmobiling, with a total of 52.8 million skiing and snowboarding days and 11.6 million snowmobiling days. The profits generated from winter sports extend beyond the slopes as tourist dollars also help support surrounding community hotels, resorts, restaurants, bars, grocery stores, sporting goods stores and gas stations. In total participation in skiing and snowmobiling in 2015-2016 supported over 191,000 jobs and generated a total of $6.9 billion in wages, and added a total of $11.3 billion in economic value to the national economy.

2016 EXPENDITURES ON US SKI AND SNOWMOBILE INDUSTRIES

Supported over

191,000 JOBS

Generated

$6.9 BILLION IN WAGES

Added a total of

$11.3 BILLION

Expenditures include money spent on:

- hotels
- resorts
- restaurants
- bars
- grocery stores
- sporting goods stores
- gas stations

*This study determines economic contributions, and does not account for substitution effects and opportunity costs, and thus does not estimate economic impacts. Economic contributions look at how economic activities cycle through a region's existing economy, and look at gross changes to an economy, as opposed to net changes (Watson et al, 2007).

As shown in Table 1, ski resort operations contributed the most to winter tourism employment and value added to the overall economy, with 73,000 employed (53 percent of total winter tourism employment) and $2.6 billion in added economic value (41 percent of total economic value added) in 2009–2010. Dining (bars and restaurants) was the second greatest contributor to the economy, with 29,000 employed (21 percent of total winter tourism employment) and $779 million in added economic value (12 percent of total economic value added).

Winter sports tourism is also a contributor to local, state, and federal tax revenue. However, these revenues were not estimated.

The economic contributions from skiing and snowmobiling were also estimated for thirty states. Colorado led the nation in economic contribution from these sports, with over 43,000 jobs (Figure 1) and $2.56 billion in total economic value added in 2016. California had the next highest level of economic activity, with over 21,000 employed and $1.24 billion in economic valued added in 2016 (Figure 2). Vermont and New York led the eastern United States in winter tourism economic activity, collectively supporting 20,000 employees and generating more than $1.2 billion in value added to their economies.

A complete list of skier days, snowmobile days, and contributions to employment, labor income, value added and output by state is shown in Appendix A (Table A2). The National Ski Areas Association aggregates skier visits for the following state pairs: PA/NJ, VA/MD, IL/IN, and CT/RI.

Industry	Winter Tourism Employment (thousands)	Labor Income (millions)		Value Added (millions)	
Resort operations	73.0	$	1,707.2	$	2,603.7
Full-service restaurants	29.0	$	706.9	$	778.8
Accommodations	15.2	$	579.9	$	1,135.8
Real estate	5.1	$	132.6	$	804.7
Food and beverage stores	3.9	$	126.3	$	185.9
General merchandise stores	3.2	$	90.5	$	151.4
Gasoline stores	2.5	$	93.9	$	107.8
Wholesale trade	2.1	$	191.1	$	361.8
Employment services	2.1	$	86.3	$	124.4
Fast-food restaurants	2.0	$	40.9	$	99.0

Table 1. National economic impact in the top 10 industries, ranked by employment

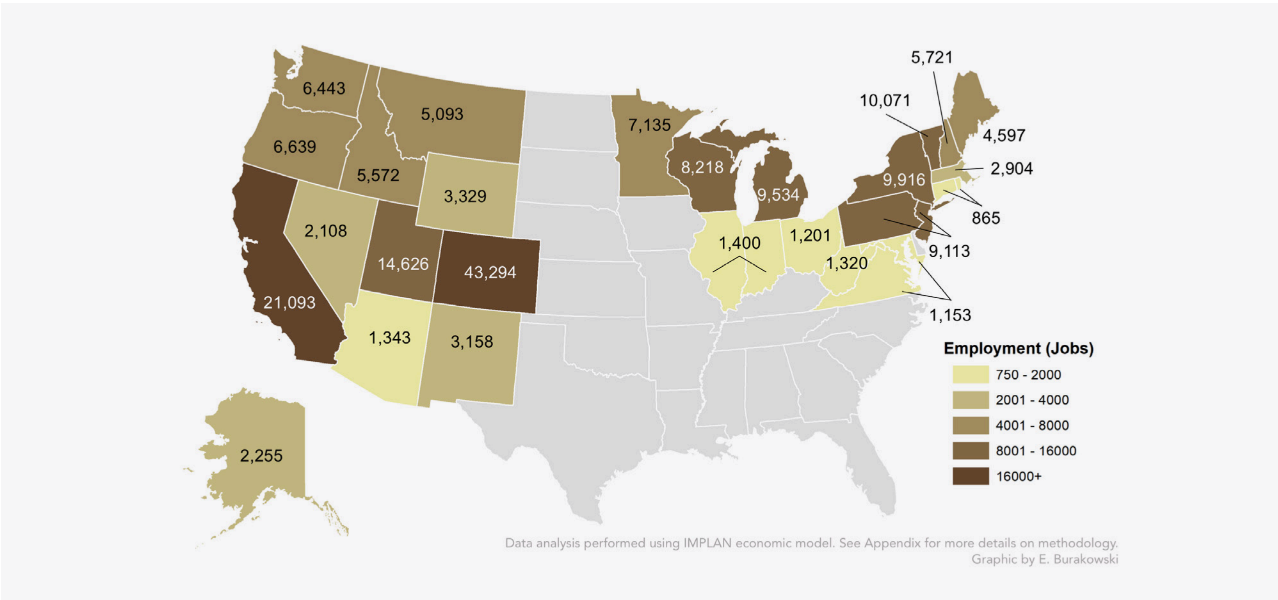


Figure 1. Map of employment supported by the winter tourism industry. (referenced on p. 13).

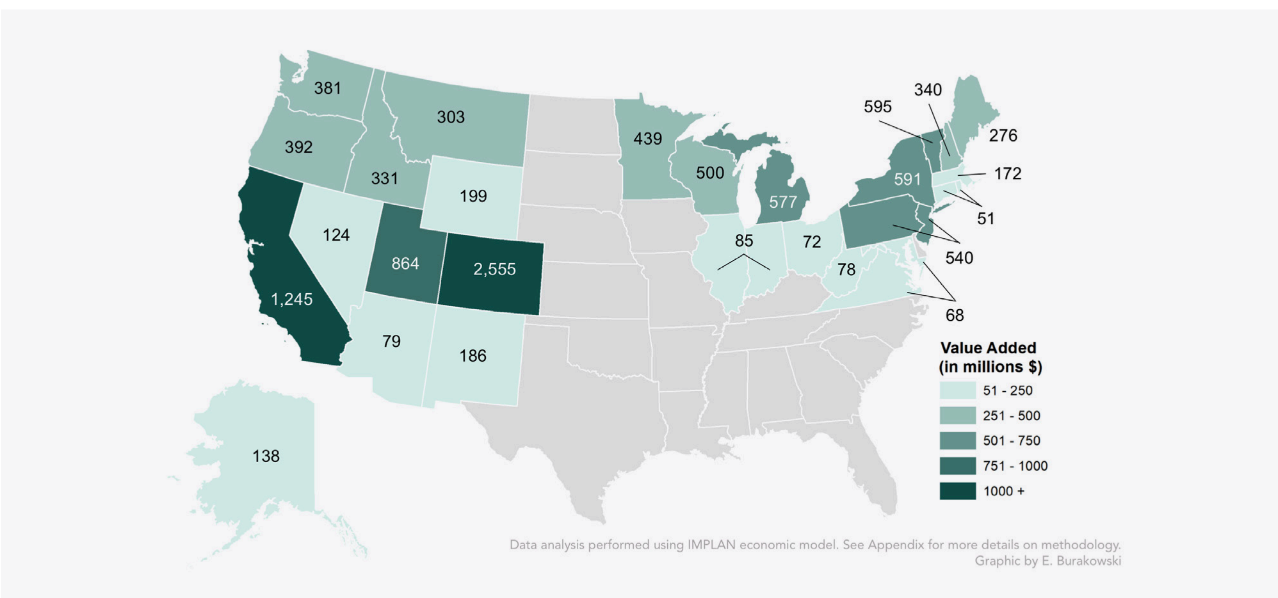
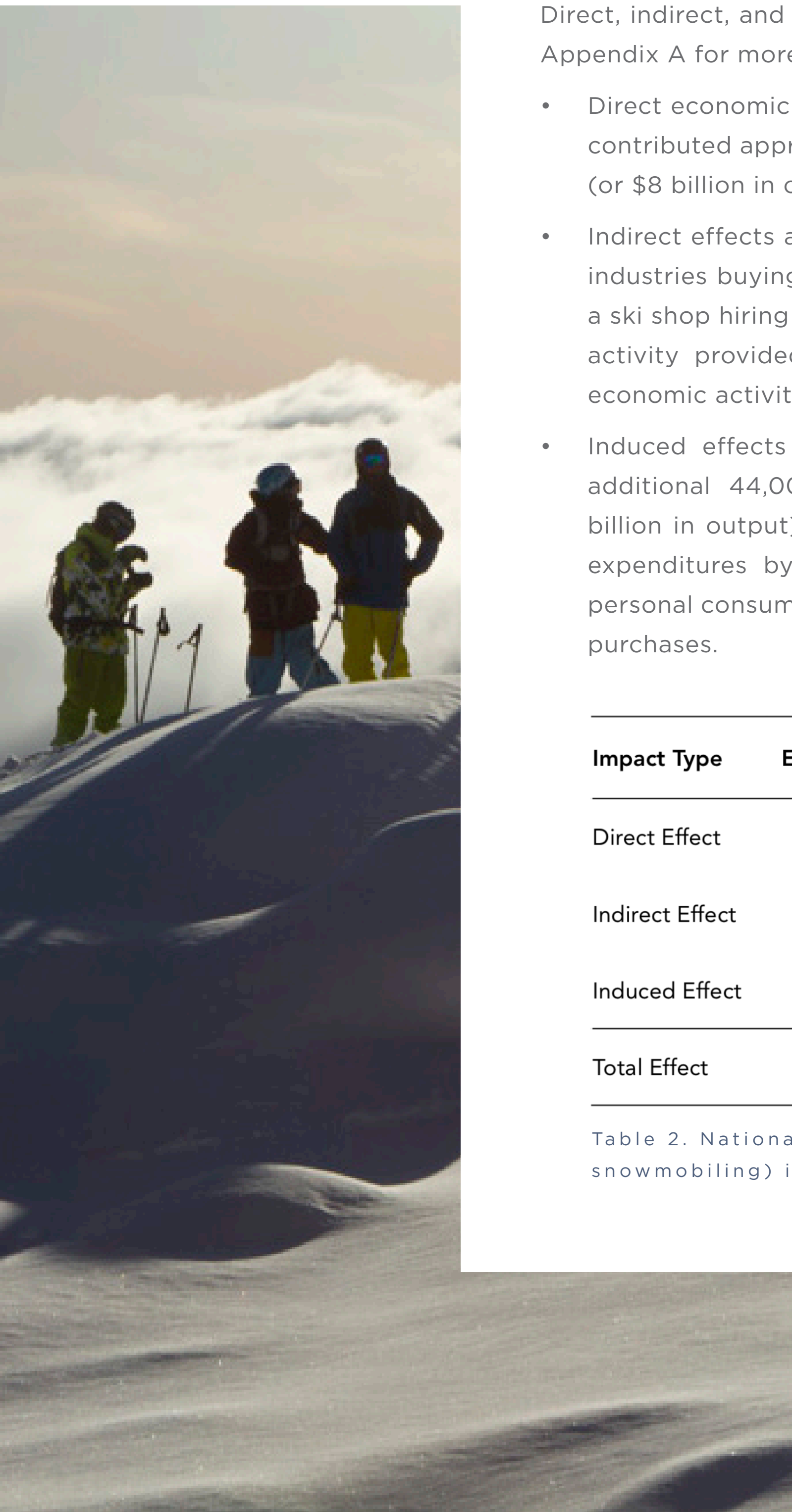


Figure 2. Map of value-added (referenced on p. 13)

1.2

ADDITIONAL ECONOMIC INSIGHTS ON THE RECREATIONAL SNOW SPORTS INDUSTRY



Direct, indirect, and induced effects were also estimated (see Table 2; see Appendix A for more detailed definitions).

- Direct economic activities from skiing and snowmobiling expenditures contributed approximately 121,000 jobs and $4.7 billion in value added (or $8 billion in output) to the national economy.
- Indirect effects arise due to linkages in the supply chain, such as local industries buying goods and services from other local industries (e.g., a ski shop hiring a local accountant). Indirect winter tourism economic activity provided 27,000 additional jobs and added $2.8 billion in economic activity (or $5.2 billion in output).
- Induced effects are a result of employee household spending. An additional 44,000 jobs and $3.9 billion in added value (or $7.2 billion in output) to the national economy was attributed to induced expenditures by employees from direct and indirect industries on personal consumption, including bill payment, health care, and grocery purchases.

Impact Type	Employment	Labor Income ($ Billions)	Total Value Added ($ Billions)	Output ($ Billions)
Direct Effect	121,000	$ 3.10	$ 4.66	$ 7.95
Indirect Effect	27,000	$ 1.57	$ 2.78	$ 5.22
Induced Effect	44,000	$ 2.24	$ 3.91	$ 7.16
Total Effect	191,000	$ 6.90	$ 11.35	$ 20.33

Table 2. National economic impacts from winter sports (skiing and snowmobiling) in 2015-2016.

The Outdoor Industry Association found that expenditures from recreational snow sports generated more than 695,000 jobs and $72.7 billion in trip-related spending (Southwick Associates, 2017). This study included spending from cross-country skiing and snowshoeing, in addition to skiing, snowboarding and snowmobiling.

Further economic contributions occur from winter events (such as ski races) and other winter sports including cross-country skiing, snowshoeing, skate skiing, backcountry skiing, splitboarding, heli-skiing, cat skiing, snowshoeing, sledding, snow tubing, and ski biking. Data limitations prevented their inclusion in the economic modeling, but their economic contributions are noteworthy.

Daily expenditures for cross-country skiing are similar to that of snowmobiling (Stynes and White, 2006); the total annual economic contributions for cross-country skiing are more than snowmobiling since participation is higher (4.6 million cross country skiers in 2016, compared to 3.3 million snowmobilers). Expenditure data was not found for snowshoers, but there were 3.5 million snowshoers in 2016.

Human-powered snow sports (e.g., snowshoeing and backcountry skiing) are the fastest growing segment of winter recreation (Winter Wildlands Alliance, 2017), yielding significant economic contributions:

- Snowsports Industries America (SIA) reported more than a 200 percent increase in uphill gear sales from 2015–2016. Sales of backcountry ski and snowshoe gear surpassed $50 million in 2016 (SIA, 2016a).
- Backcountry equipment sales increased 14 percent in 2016 and backcountry accessories grew 52 percent (SIA, 2016a).
- The Grand Teton and West Yellowstone region reported an annual direct economic contribution of $22.6 million from winter backcountry recreation (Newcomb, 2013).

Though participation in heli-skiing and cat skiing is low, the associated costs are high: a single day of heli-skiing typically costs over $1,000.

IMPACTS IN ALASKA AND BRECKENRIDGE, COLORADO

ALASKA: PRESERVING A TRADITION

While employment and value-added results for downhill skiing and snowmobiling in Alaska are modest in comparison to the rest of the US, contributions from other winter sports in Alaska are large, such as from heli-skiing, mountaineering, and the Iditarod Trail Dog Sled Race. The most recent study on the economic contribution of the Iditarod estimated the race contributed $16 million to the Alaskan economy in 1993, the equivalent of $26 million in 2016 (Pardus, 2002). Given the substantial increase in the popularity of the race over the past few decades, the present-day value is likely much higher. Lack of adequate snow and ice coverage at the beginning of the trail in 2015 and 2017 forced a northward shift of the Iditarod start line from outside of Anchorage to Fairbanks (Manning, 2015; Goldenberg, 2016). A shift in economic spending accompanied the course relocation, with villages along the southern stretch of the race passing their economic boon to villages further north (Manning, 2015).

CASE STUDY: BRECKENRIDGE, COLORADO

Breckenridge, Colorado, relies heavily on tourist dollars to support its local economy. Traditionally, Christmas marks the beginning of a busy tourism season that continues through February. Though this period continues to be a popular time for visitors, town officials are concerned about loss of snow in the spring months.

"My worry is about the edges of the season, not the middle," says Breckenridge Mayor Eric Mamula. He says March of 2016 was the first time he can recall that time of year having such unfavorable conditions.

Rocky Mountain states receive nearly 25 percent of their skier visits during the month of March; loss of March snowpack could have big impacts on the Breckenridge economy without compensatory increases in winter visitation.

Toward the end of winter and into early spring, temperatures in Denver start to warm, putting skiing out of mind for many potential visitors. Mamula says people start golfing and biking sooner, essentially forgetting ski season in the mountains (supporting the "backyard effect" theory reported by Hamilton et al., 2007).

Addressing climate change is a top priority for the town of Breckenridge. A community-driven initiative was recently launched to commit the town to 100 percent renewable energy by 2025. In 2017, the town of Breckenridge assigned a representative to the Compact of Colorado Communities, an organization that strives to build capacity in local governments and enhance community collaboration to rapidly scale up and advance climate action planning. Breckenridge is also a part of the High Country Conservation Center, an organization focused on waste reduction, energy efficiency and clean energy, water conservation, and sustainable food production. The town has put $4 million into their transit system in an effort to reduce carbon dioxide emissions from personal vehicles and from their transit fleet.

THE WARMING OF EARTH'S ATMOSPHERE IMPACTS BOTH THE TIMING AND DISTRIBUTION OF SNOWFALL.

Warmer winter temperatures also affect the characteristics of accumulated snow on the ground, including snow depth, how long the snow stays on the ground, and snow "slushiness."

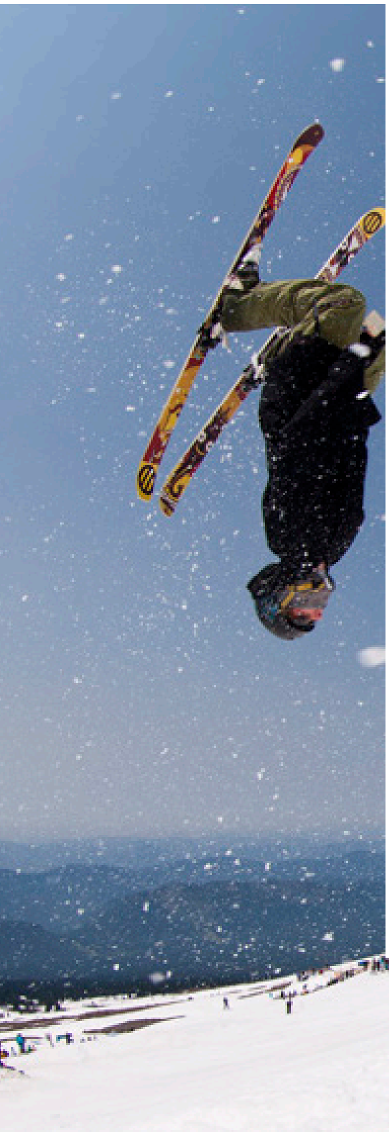
2.

OVERVIEW OF WINTER CLIMATE CHANGE IN THE UNITED STATES

"IT'S NOT THAT WE DIDN'T HAVE SNOWFALL. IT'S THAT WHEN THAT SNOW WAS EXPOSED TO THE SUN OR WARM TEMPERATURES, IT DISAPPEARED."
— AARON SMITH, SKI PATROLLER AT ASPEN HIGHLANDS SKI AREA

Temperature and precipitation both affect snowpack. As the climate continues to warm, the number of days that can support snowfall are expected to decrease. Changes in precipitation are more important in colder locations and higher elevations where they determine whether any or how much precipitation falls.

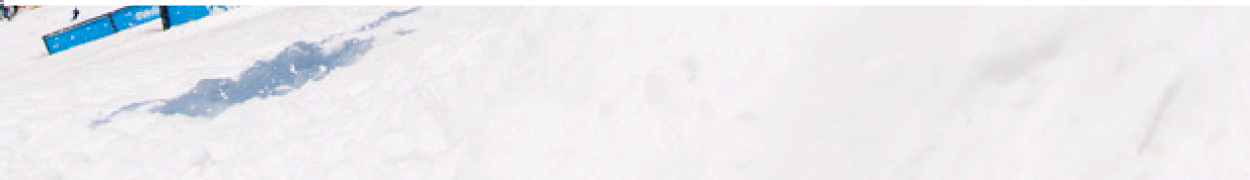
At lower elevations where temperatures are near the freezing point, global warming is causing a significant shift from snowfall events to rainfall events (Klos et al., 2014; Scalzitti et al., 2016). Even small changes in temperature can determine whether snowpacks melt and whether precipitation falls as rain or snow. Global warming is also strongly tied to declining overall snowpack and increased spring temperatures that can cause earlier and faster snow melts (Sharma et al., 2013; Cooper et al., 2016).



Resort towns at elevations in the transition zone are especially vulnerable to global warming because incremental warming increases the number of rainy, rather than snowy, days. Minimum temperatures are rising at a faster rate than maximum temperatures, undermining the efficiency of snowmaking. The ideal temperature for snowmaking is below the freezing point, at 28°F, dependent on humidity (McCusker and Hess, 2018).

Across the entire Northern Hemisphere, scientists have identified significant declines in spring (March through May) snow cover extent since the 1920s, with most of the decline occurring since 1970 and equaling an area roughly the size of California, Alaska, New York, Texas, and New England combined (Rupp et al. 2013). Regions in the United States with average winter temperatures ranging from 23°F to 41°F (-5°C to 5°C) are most likely to have decreasing snow cover duration trends and will be most vulnerable to snow loss in the future (Brown and Mote, 2009).

Warmer winter temperatures also affect the characteristics of accumulated snow on the ground, including snow depth, snow cover duration (how long the snow stays on the ground), and snow density (how slushy snow is).



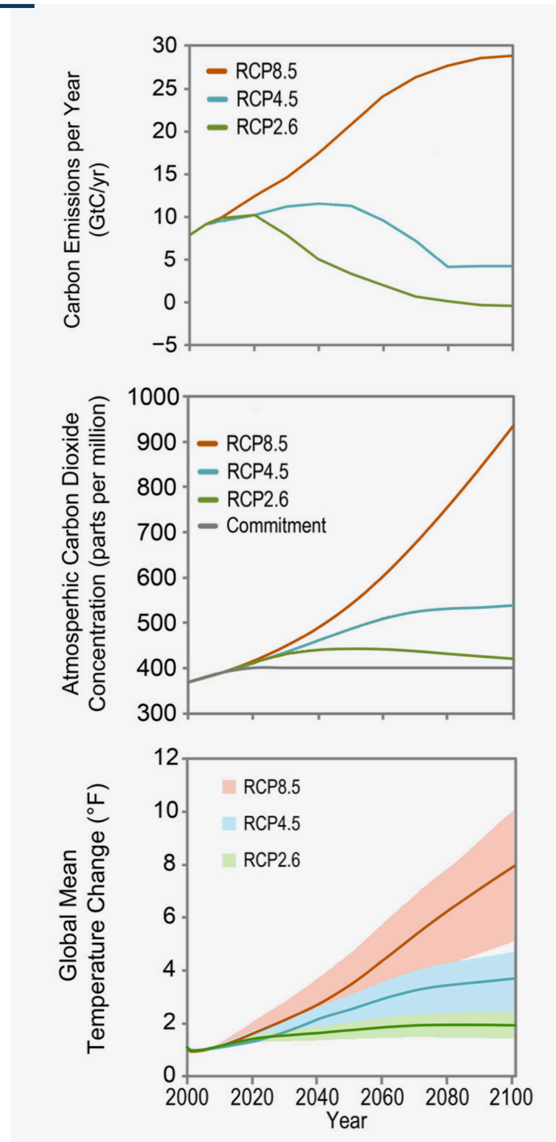
The amount of water contained in snowpacks, called the snow water equivalent (SWE), is also sensitive to warming temperatures. The western United States keeps detailed records of SWE via the SNOTEL network (SNOTEL, 2017), which has been tracking snow at remote, high elevation stations since the 1960s. Based on this detailed dataset, scientists have observed a 10–20 percent loss in annual maximum snow water equivalent (Fyfe et al. 2017). Scientists used sophisticated fingerprinting techniques to detect and attribute the cause of the declining trend in SWE and found that it cannot be explained by natural factors (e.g., volcanoes and changes in solar activity). The fingerprints of human activity are evident in the loss of snow, and human-induced warming is reducing the amount of water available from the snowpack. Though the northeastern United States lacks robust SWE records, numerous stations track snow depth in the region, where the number of days with snow cover has decreased by one to two weeks since 1970 (Hayhoe et al. 2007; Burakowski et al. 2008).

Snow water equivalent: the amount of water contained in snowpacks

TEMPERATURES ARE WARMING
AND SNOWFALL IS DECREASING.

WHAT DOES THE FUTURE HOLD?

Figure 3. Representative Concentration Pathways (RCP) scenarios used in climate models to project future climate. RCP8.5 is considered the highest emission, or worst-case, scenario. Figure modified from Figure 4.1 in the Fourth National Climate Assessment Climate Science Special Report (USGCRP, 2017).

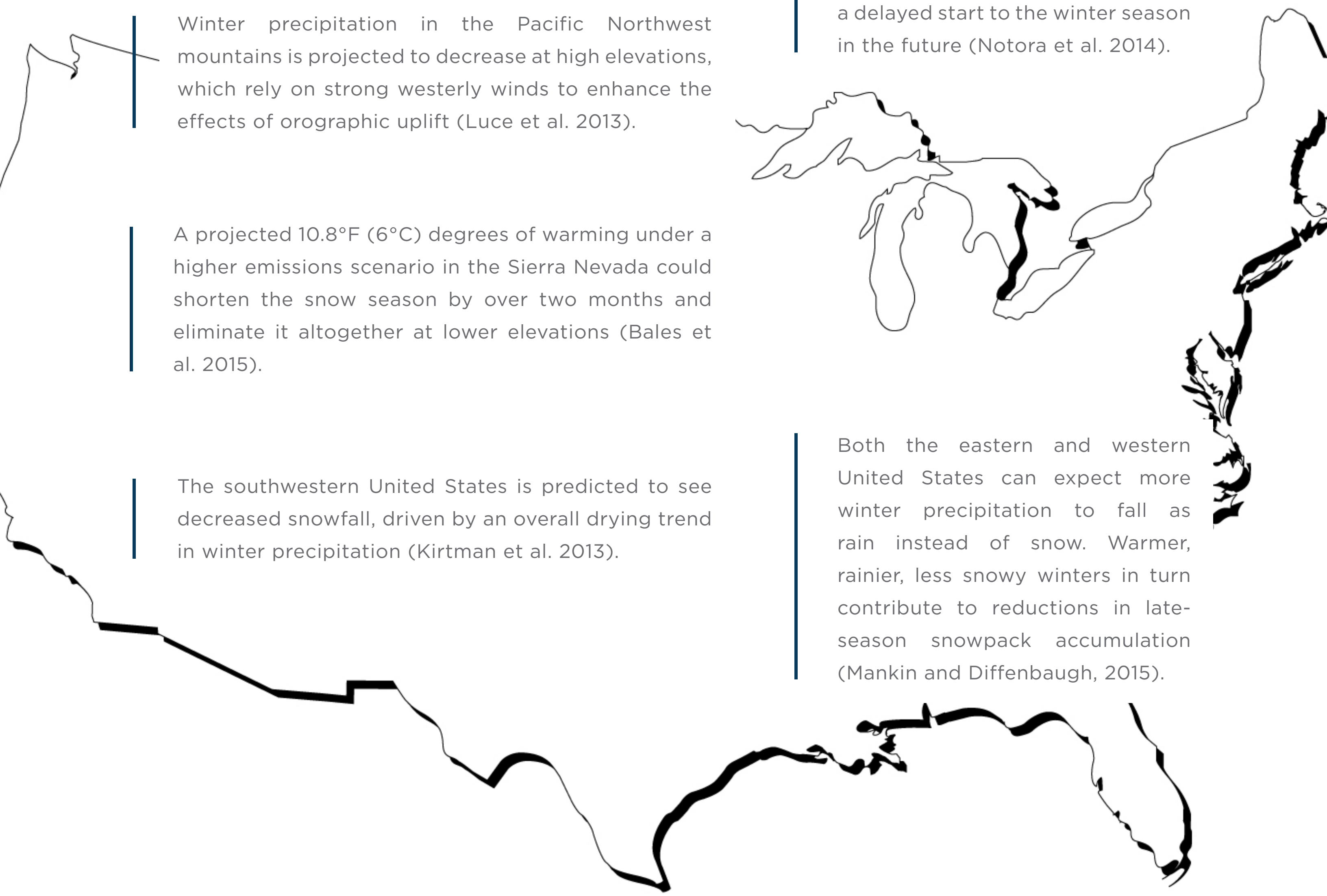


Scientists use sophisticated computer models to understand and project future changes in climate. The models have proven to be quite accurate, tending to slightly underestimate the types of changes we see on the ground. Planners use these models to prepare for the future. For example, New York City uses projected ranges of sea level rise to help them determine how or if to develop in coastal regions.

The most commonly used representative concentration pathways (RCP), or scenarios, for what the future might look like based on modeling in the scientific literature are RCP4.5 and RCP8.5 (Figure 3). Currently, atmospheric concentrations of carbon dioxide are about 405 ppm and increasing. In RCP4.5, concentrations of carbon dioxide stabilize at 650 parts per million by 2100 and the average global temperature is 4.3°F (2.4°C) warmer than preindustrial times. RCP4.5 requires lower emissions and carbon capture technology and expansion of forests (Thomson et al. 2011). In contrast, RCP8.5 assumes industrial growth, and follows a rapidly increasing trajectory in carbon dioxide concentrations to 936 ppm by the year 2100 and an increase in global temperatures 8.8°F (4.9°C) warmer than the preindustrial average, also known as "business as usual." (Riahi et al. 2011).

A third scenario, RCP2.6, assumes that the nations of the world take immediate aggressive action to reduce greenhouse gas emissions, in the form of renewable energy, energy efficiency, and implementation of scalable carbon capture and storage to pull carbon out of the atmosphere (van Vuuren et al., 2011; Sanderson et al. 2016). This scenario projects CO_2 concentrations of 490 ppm and warming of 2.7°F (1.5°C) (van Vuuren et al. 2011). It's important to note that this scenario would blunt the impact of warming significantly, and avoid the worst impacts of warming on business and society. It's also worth noting that many of the policy tools and technology needed to achieve this scenario are on the shelf today, with the exception of scalable carbon capture and storage.

WHAT THE STUDIES SAY ABOUT REGIONAL WEATHER CHANGES IN THE UNITED STATES:



Winter precipitation in the Pacific Northwest mountains is projected to decrease at high elevations, which rely on strong westerly winds to enhance the effects of orographic uplift (Luce et al. 2013).

A projected 10.8°F (6°C) degrees of warming under a higher emissions scenario in the Sierra Nevada could shorten the snow season by over two months and eliminate it altogether at lower elevations (Bales et al. 2015).

The southwestern United States is predicted to see decreased snowfall, driven by an overall drying trend in winter precipitation (Kirtman et al. 2013).

In the central and eastern United States, models project declines in early winter snowfall, indicative of a delayed start to the winter season in the future (Notora et al. 2014).

Both the eastern and western United States can expect more winter precipitation to fall as rain instead of snow. Warmer, rainier, less snowy winters in turn contribute to reductions in late-season snowpack accumulation (Mankin and Diffenbaugh, 2015).

2.1

REGIONAL CLIMATE IMPACTS

NORTHEAST

- Northern U.S. states are warming slightly faster than southern states. In the Northeast, annual temperatures are likely to warm 9.0°F (5.5°C) by the end of the century under a high emissions scenario (USGCRP, 2017).
- The rain-snow transition zone will likely shift northward by up to 4° in latitude in the central and eastern United States by the end of the 21st century under a higher emissions scenario. Under a lower emissions scenario, the northward shift could be reduced to about 2° in latitude (Ning and Bradley, 2015).
- Average snow water equivalent across the Northeast between November and May is likely to decrease -0.4 to 1.2 inches (-10 to -30 mm) under a higher emissions scenario by 2070–99, relative to 1971–2000 (Maloney et al., 2014).
- Looking at the spectrum of projected shifts in snow days (ie: days with solid precipitation, or snowfall) between the northern and southern regions of the U.S. Northeast and Midwest, the number of snow days is projected to be reduced between 13.6 percent in northern regions and by 45.7 percent in southern regions by the end of the century under a low emissions scenario. Assuming high emissions, snow days in the northern region would likely be reduced by 25 percent, compared to 59 percent toward the South. This is consistent with the northward shift in the transition zone between temperatures cool enough to support snow versus rain (Demaria et al., 2016; Ning and Bradley, 2015).
- Under a higher emissions scenario, the total amount of seasonal snowfall would be projected to decrease by 10-30 percent by the end of the 21st century. (Figure 4; Zarzycki, 2017).

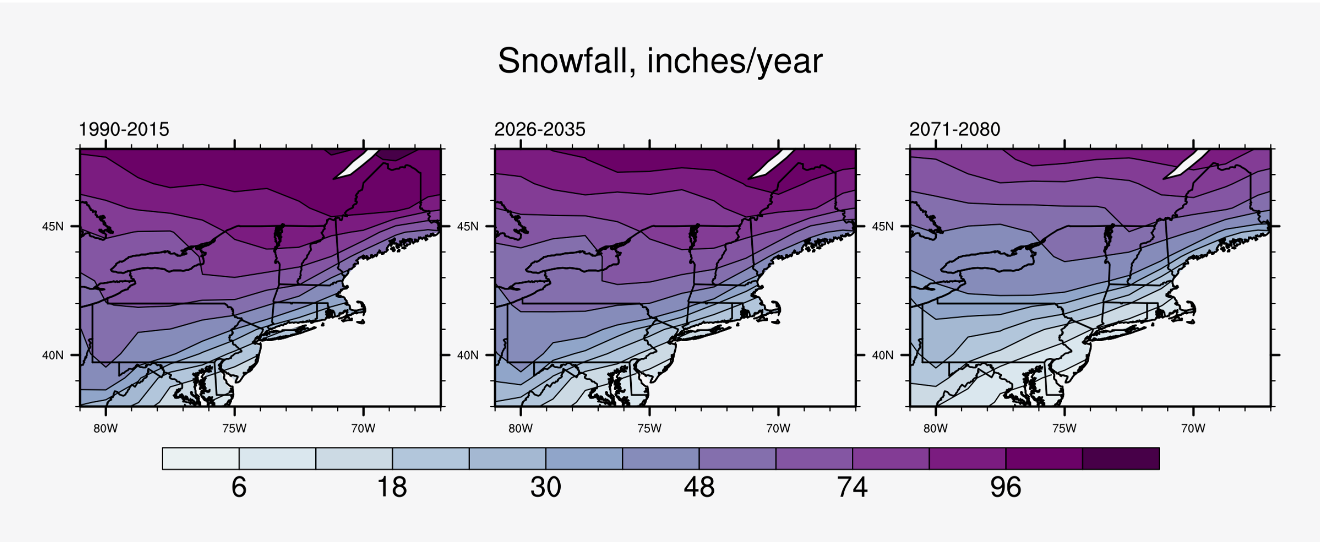


Figure 4. Historical (1990-2015), mid-century (2026-2035), and late-century (2071-2080) snowfall as modeled by the Community Earth System Model (CESM) large ensemble. Future projections use the RCP8.5 scenario, in which carbon dioxide concentrations in the atmosphere continue to increase at a rapid pace (Zarzycki, 2017).

CASCADES AND THE SIERRA NEVADA

- In the western U.S., the extremely dry winter of 2014–2015 followed three previous dry winters, causing extreme drought across the region. At Donner Summit in the Sierras, end-of-season snowpack on April 1, 2015 was the lowest on record, at only 0.51 inches (1.3 cm), or less than 2 percent of the long-term average. This followed the previous record low in 2014 (California Department of Water Resources, 2015).
- Under a high emissions scenario, average winter (November–March) temperature increase would exceed 7.2°F (4°C) by the 2080s in the Southern Cascades (Rhoades et al., 2017).
- The Cascades and Sierra Nevada Mountains would see 65 percent decline in SWE by the end of the century, assuming continued high emissions (Gergel et al., 2017).
- Snowfall in the Cascades and Sierras would decrease 55 percent by the end of the century, assuming continued high emissions (Rhoades et al., 2017).
- By the 2080s, the Cascades would lose up to 81 percent of April 1 SWE storage—or up to 11.3 cubic miles (47.3 cubic kilometers), 2.5 times the volume of Oregon's Crater Lake. The Sierra Nevadas could lose up to 76 percent of SWE storage, or up to 3.2 cubic miles (13.4 cubic kilometers) of total SWE (Gergel et al., 2017).

*The average interval in years between events equaling or exceeding a certain magnitude

ALASKA

- In Alaska, the 2016 May statewide snow coverage of 372,000 square miles (595,000 square km) was the lowest on record dating back to 1967. The snow coverage of 2015 was the second lowest, and 2014 was the fourth lowest (USGCRP, 2017).
- Warming rates are greater at higher latitudes, a trend driven in part by a decrease in snow cover. Under a high emissions scenario, temperatures in Alaska could increase more than 12.0°F (6.7°F) by late century (relative to 1976-2005) (USGCRP, 2017).

- End-of-season SWE has declined since 1980 in the western United States and is associated with springtime warming (Pederson et al., 2013).
- Winter season (December through February) snowfall in the Rockies is projected to decrease by 16 percent by the end of the century under higher emissions scenario (Figure 5; Rhoades et al. 2017).
- Average snow season (November–March) temperature increase exceeds 9°F (5°C) by the 2080s in the Northern and Southern Rockies, under a high emissions scenario (Gergel et al., 2017).
- The White Mountains in Arizona and the lower Colorado are projected to experience reductions in winter precipitation. The southern part of the lower Colorado basin, in particular, shows a reduction greater than 30 percent by the 2080s under a high emissions scenario (Gergel et al., 2017).
- The White Mountains could experience a 95 percent decrease in SWE by the 2080s, assuming high emissions (Gergel et al., 2017).

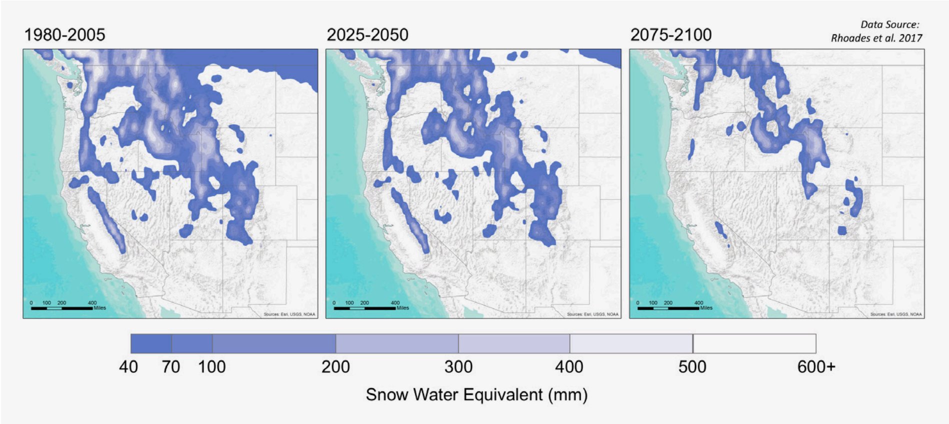


Figure 5. Less water in the West: average winter (December through March) snow water equivalent (SWE) in the western United States for historical (1980-2010), mid-century (2025-2050) and end of century (2075-2100). Future projections use the RCP8.5 scenario, in which carbon dioxide concentrations in the atmosphere continue to increase at a rapid pace. A lower-emissions scenario would reduce snowpack loss. Graphic by E. Burakowski.

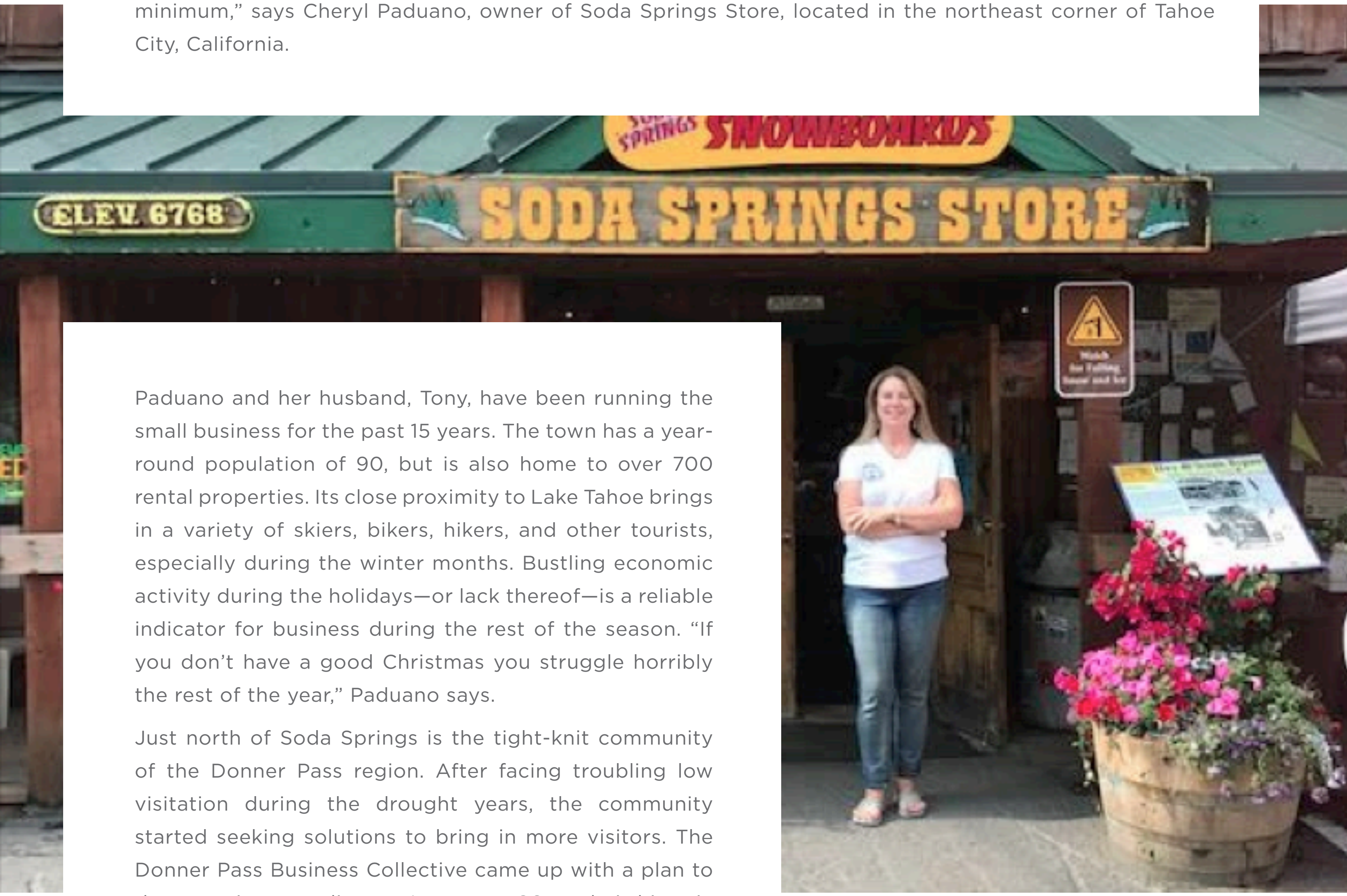
LARGE SNOWSTORMS ARE AN INDICATOR OF WARMING.

Snowfall depends on temperature; a warmer atmosphere holds more moisture. If the air is too cold, it cannot hold enough moisture for a heavy snowfall. If the air is too warm (greater than 32°F or 0°C), precipitation falls as rain instead of snow. When atmospheric circulation patterns converge with the right combination of cold temperatures and moisture-rich air masses, monster snowstorms reach the atmospheric “sweet spot” for big snow events like the “Snowmeggedon” that blanketed Washington DC in 2010, and the severe snowstorms in California that temporarily shut down highways and closed lifts in January 2017. While larger snowfall events are likely in a warming climate, the overall impact of warmer temperatures is a reduction in snowfall as more precipitation falls as rain instead of snow (Figure 4; Zarzycki et al. 2017).

CASE STUDIES: SODA SPRINGS AND SIERRA-AT-TAHOE, CALIFORNIA

SODA SPRINGS STORE—SODA SPRINGS, CALIFORNIA

After a string of back-to-back drought years in California, the winter tourism communities around Lake Tahoe in the northern Sierra Nevada were ready for a "normal" winter. "We had five drought years in a row. We were in a position where we couldn't buy new ski equipment; we had to keep our staff at a minimum," says Cheryl Paduano, owner of Soda Springs Store, located in the northeast corner of Tahoe City, California.



Paduano and her husband, Tony, have been running the small business for the past 15 years. The town has a year-round population of 90, but is also home to over 700 rental properties. Its close proximity to Lake Tahoe brings in a variety of skiers, bikers, hikers, and other tourists, especially during the winter months. Bustling economic activity during the holidays—or lack thereof—is a reliable indicator for business during the rest of the season. "If you don't have a good Christmas you struggle horribly the rest of the year," Paduano says.

Just north of Soda Springs is the tight-knit community of the Donner Pass region. After facing troubling low visitation during the drought years, the community started seeking solutions to bring in more visitors. The Donner Pass Business Collective came up with a plan to draw tourists traveling on Interstate 80 to their historic scenic byway on Highway 40, incentivizing tourists to stop and learn more about the history of Donner Pass, known widely for the ill-fated journey of the Donner Family. With some financial help from area ski resorts, historic placards were installed along the highway, along with a new monument at the exit ramp.

> *"WE HAD FIVE DROUGHT YEARS IN A ROW. WE WERE IN A POSITION WHERE WE COULDN'T BUY NEW SKI EQUIPMENT."*

SIERRA-AT-TAHOE SKI RESORT

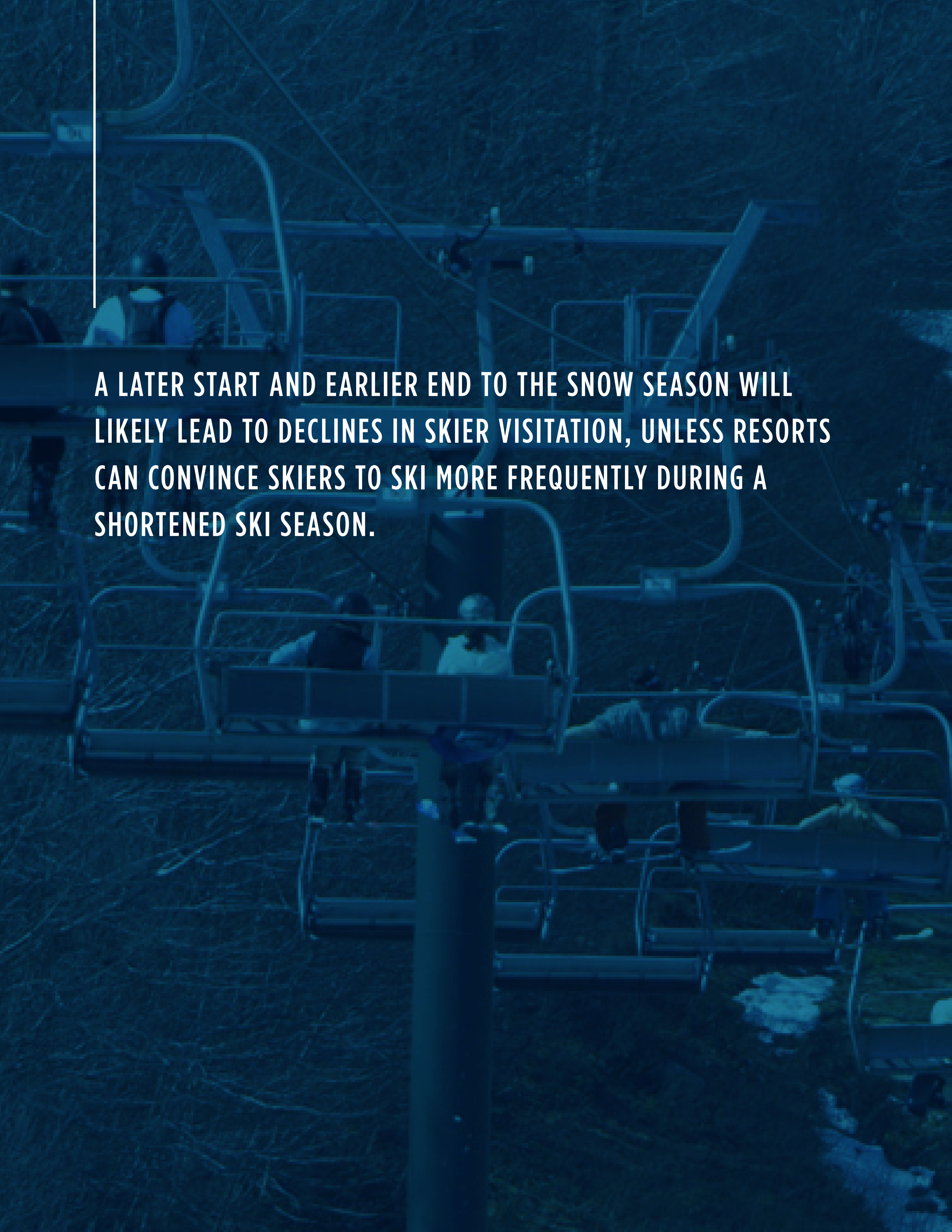
Sierra-at-Tahoe, a medium-sized ski resort south of Lake Tahoe, noted similar struggles with low visitation numbers during the California drought. "When we don't get snow—even when we have cool temperatures—we don't see the visitation," says Steven Hemphill, director of marketing and sales at Sierra-at-Tahoe. Unlike many alpine ski resorts across the United States, Sierra-at-Tahoe has not adopted snowmaking to compensate for low snowfall. During the exceptionally low snow year of 2014/2015, the resort went to great lengths to keep slopes covered, including harvesting natural snow. "We were taking snow literally out of the trees, putting it on our run, and doing our best with our grooming to make sure that snow would stay," Hemphill says.

December 2016 saw a slow start to the ski season, only to be followed by a series of aggressive storms in early January. Feet of snow fell in a matter of weeks. On January 11th, Squaw Alpine Resort, less than 10 miles west of Tahoe City, received 42 inches in a single day. The big storms hammered the Sierra Nevada well into March, marking the end of the multi-year drought.

But record-breaking snowfall brought as many troubles as the drought. "It was too much snow. The power was out. The freeways were closed," Paduano remarked of the snow season at Soda Springs.

Scientific research suggests that California's intense swings between drought and excessive precipitation could increase, with the latter resulting from greater moisture in the atmosphere as temperatures warm (the atmosphere can hold about 4 percent more moisture per degree Fahrenheit).

"It's not if, but when we do get another one of those low snowfall years," Hemphill says. And when those years come, it will be critical for the resort communities to come together and support one another to sustain the local economies.



A LATER START AND EARLIER END TO THE SNOW SEASON WILL LIKELY LEAD TO DECLINES IN SKIER VISITATION, UNLESS RESORTS CAN CONVINCE SKIERS TO SKI MORE FREQUENTLY DURING A SHORTENED SKI SEASON.

3

PARTICIPATION TRENDS IN OUTDOOR WINTER RECREATION IN THE UNITED STATES

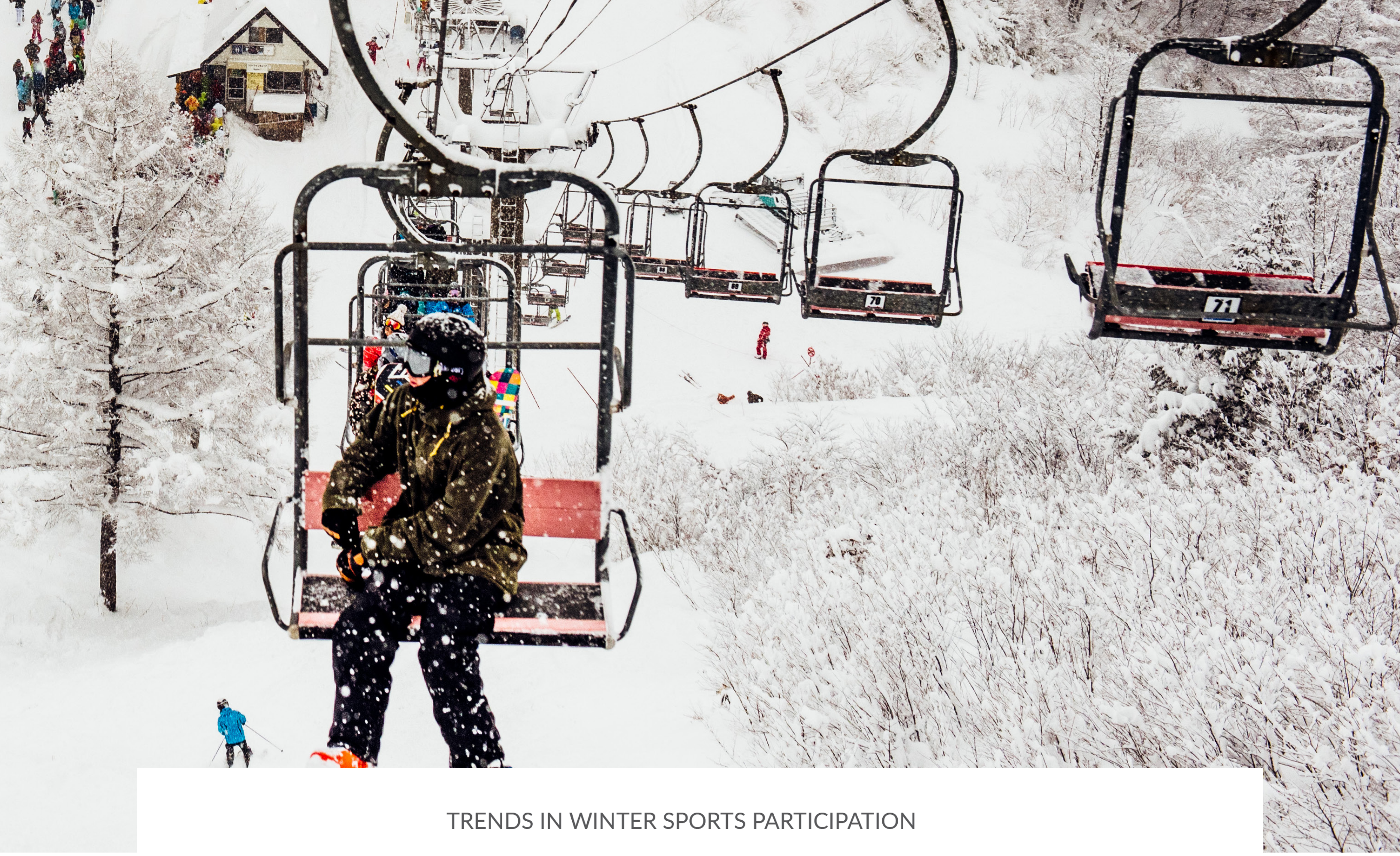
WINTER RECREATION PARTICIPANTS

The United States has the world's second-largest ski industry, following that of Europe. However, due to weather and economic conditions, the number of ski areas in the United States has been steadily decreasing since the 1980s, falling from over 700 operating ski areas to approximately 460 today (Vanant, 2017). Several large corporations now dominate the US industry, operating a number of integrated resorts across the country (Vanant, 2017).

Though the number of available resorts has decreased, participation has seen continued increases. Between 2007 and 2016, the number of US winter sports participants increased by 4 million (Figure 6). A total of 23.5 million Americans participated in winter outdoor recreation in the winter season of 2015–2016 (SIA, 2017). During this season, downhill skiing and snowboarding were the most popular winter sports, with 9.3 and 7.6 million participants, respectively (Outdoor Industry Association, 2017; SIA, 2017). There were 4.6 million cross-country skiers, 4.6 million freestyle skiers (using resort features such as moguls, halfpipe, jumps etc.), 3.5 million snowshoers, 3.3 million snowmobilers, and 2.8 million telemark skiers (Outdoor Industry Association, 2017). Figure 6 depicts the overall participation trends in each sport between 2007 and 2016.

POPULARITY OF WINTER SPORTS IN THE 2015–2016 SEASON

1. Downhill skiing
2. Snowboarding
3. Cross-country skiing
4. Freestyle skiing
5. Snowshoeing
6. Snowmobiling
7. Telemark skiing



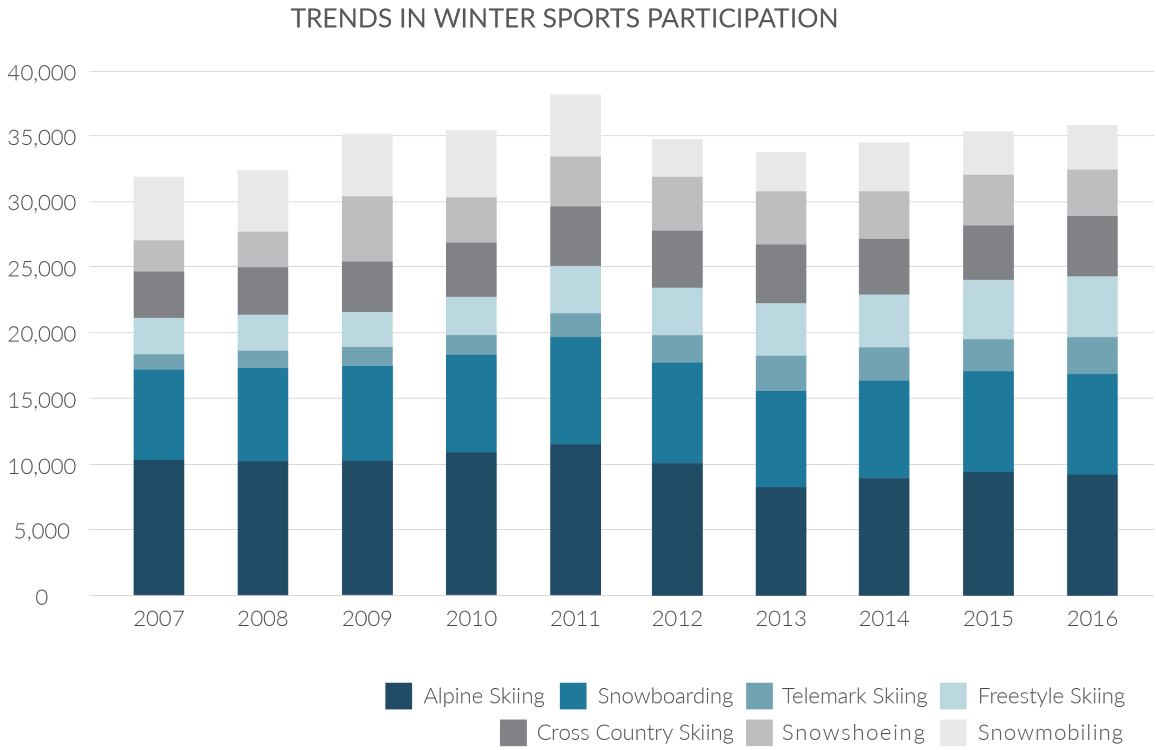


Figure 6. Trends in winter sports participation 2007–2016. Between 2007 and 2016, the number of US winter sports participants grew by 4 million. Alpine skiing saw increased participation in 2010, 2011, 2014 and 2015, but those increases were more than offset by decreases between 2012, 2013 and 2016. Snowboarding saw an increase in participation between 2007 and 2011, followed by a decline in 2012 and 2013. Telemark skiing, snowshoeing and freestyle skiing are growing sports, with average annual increases of 11 percent, 8 percent, and 6 percent, respectively. There has been a slight decline in snowmobiling. (Source: Outdoor Industry Association, 2017.)

3.1

RELATIONSHIP BETWEEN SKIER VISITS AND SNOW

The total number of winter sports participants nationally sees modest fluctuations year to year. The National Ski Areas Association (NSAA) tracks the number of days per year that alpine ski participants attend resorts, a metric known as skier visits. One skier visit is defined as one person visiting a ski area for all or any part of a day or night for the purpose of skiing, snowboarding, or other downhill sliding. Skier visits include full-day, half-day, night, complimentary, adult, child, season pass, and any other type of ticket that gives a skier or snowboarder the use of an area (NSAA, 2016).

Skier visit: one person visiting a ski area for all or any part of a day or night for the purpose of skiing, snowboarding, or other downhill sliding

While the number of people annually participating in skiing changes only modestly from year to year, the number of total annual skier visits (days) fluctuated considerably over the period 2001 to 2016, from over 60 million in 2008 to a low of under 50 million in 2012 (see Figure 7).

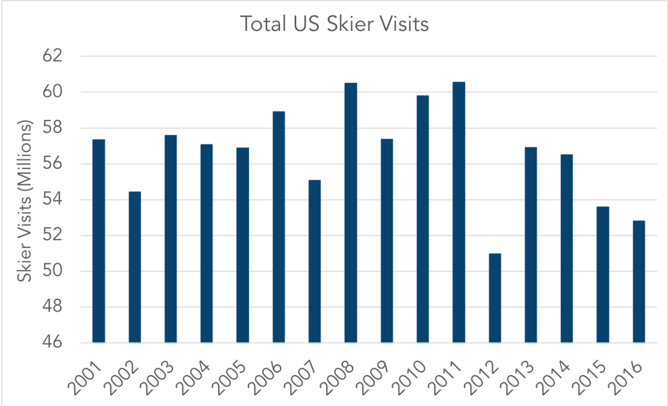


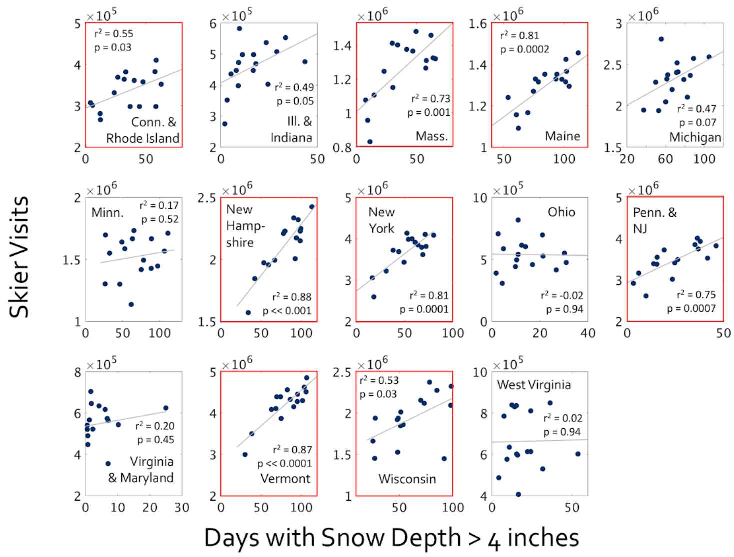
Figure 7. United States skier visits, 2000/2001 to 2015/2016. (Source: NSAA and RRC Associates, 2016.)

An individual's decision to ski is influenced by a set of factors that include amount of snow, ticket prices, travel costs, ski resort characteristics, skiing budget, leisure time, and skiing ability (Dawson et al. 2013; Englin and Moeltner, 2004; Hamilton et al, 2007; Malasevska, 2017; Morey, 1981; Taks and Ragoen, 2016; Shih et al, 2008; Vanat, 2017).

IMPACT OF SNOW LEVELS ON SKIER VISITS IN THE NORTHEAST UNITED STATES:

Examining correlations between skier visits and snow levels gives insight into the influence of snowfall on skier participation. Between 2001 and 2016, data for the northeastern United States showed strong and significant positive correlations between days with greater than four inches of snow cover and skier visits (Figure 8). For the National Ski Areas Association, the Northeast includes Connecticut/Rhode Island, Massachusetts, Maine, New Hampshire, New York, Vermont, Pennsylvania/New Jersey and Wisconsin. These results are consistent with previous research that found aggregated skier visitation in the Northeastern United States was strongly and significantly correlated to season length (Wobus et al. 2017). Correlations are weaker and not statistically significant in the Southeast and Midwest, with the exception of Wisconsin.

Figure 8. Correlations Between Skier Visits and Days with Greater than Four Inches of Snow Cover in the Northeastern U.S. Plots highlighted in red are statistically significant, with $p < 0.05$.



IMPACT OF SNOW ON SKIER VISITS IN THE WESTERN UNITED STATES:

Unlike the eastern United States, the western United States has a sophisticated network of meteorological stations that track snow water equivalent (SWE) at remote, high elevation stations, some located near ski resorts. The analysis for this report found that snowpack persists well into late spring and summer at higher elevations. The snow season length at these stations often exceeds the ski season length at resorts, so using the same metric as the eastern United States (based on snow-covered days) does not work for the West. Alternately, an analysis of the correlation between skier visitation and SWE serves as a proxy for the relationship between snowfall and skier visits. Figure 12 shows the correlations between skier visits and total SWE in the West. Total SWE is the sum of all daily SWE values, or the area integrated under the seasonal (November through April) SWE curve. Results show strong positive correlation between skier visits and total SWE for most states in the western United States. Shelesky (2016) also found that average SWE is a significant driver of skier visitation in Colorado, and that variation in SWE is largely driven by precipitation (i.e., snowfall).

New Mexico was the only state with a statistically significant inverse correlation between skier visits and total SWE. This is a curious relationship that goes against expectations and requires further research to improve understanding.

Nationally, each year that showed a decline in skier visits correlated with low snow in states hosting a large proportion of national skier visits (Figure 9). The only exception occurred in the 2008–2009 season, which saw a 5 percent reduction in skier visits despite normal to above average snowfall in most NSAA regions. The 2008–2009 season coincided with an economic recession and supports the finding that skiers are responsive to economic conditions (Englin and Moeltner, 2004). All other winters in which participation declined were not in recession years. The winter of 2011–2012 had extremely low snow and warm winter temperatures across the country. This season experienced the largest decrease in skier visits, down by more than 9 million visits from the previous winter (2010–2011), and 5.7 million fewer visits than the long-term average between 2001 and 2016 (56.6 million).

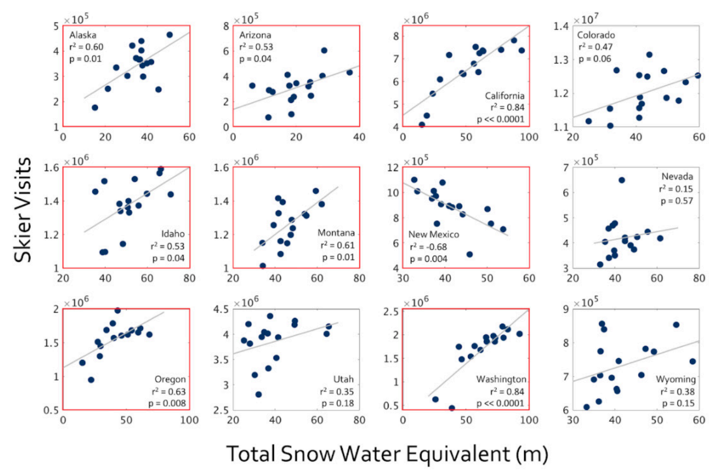
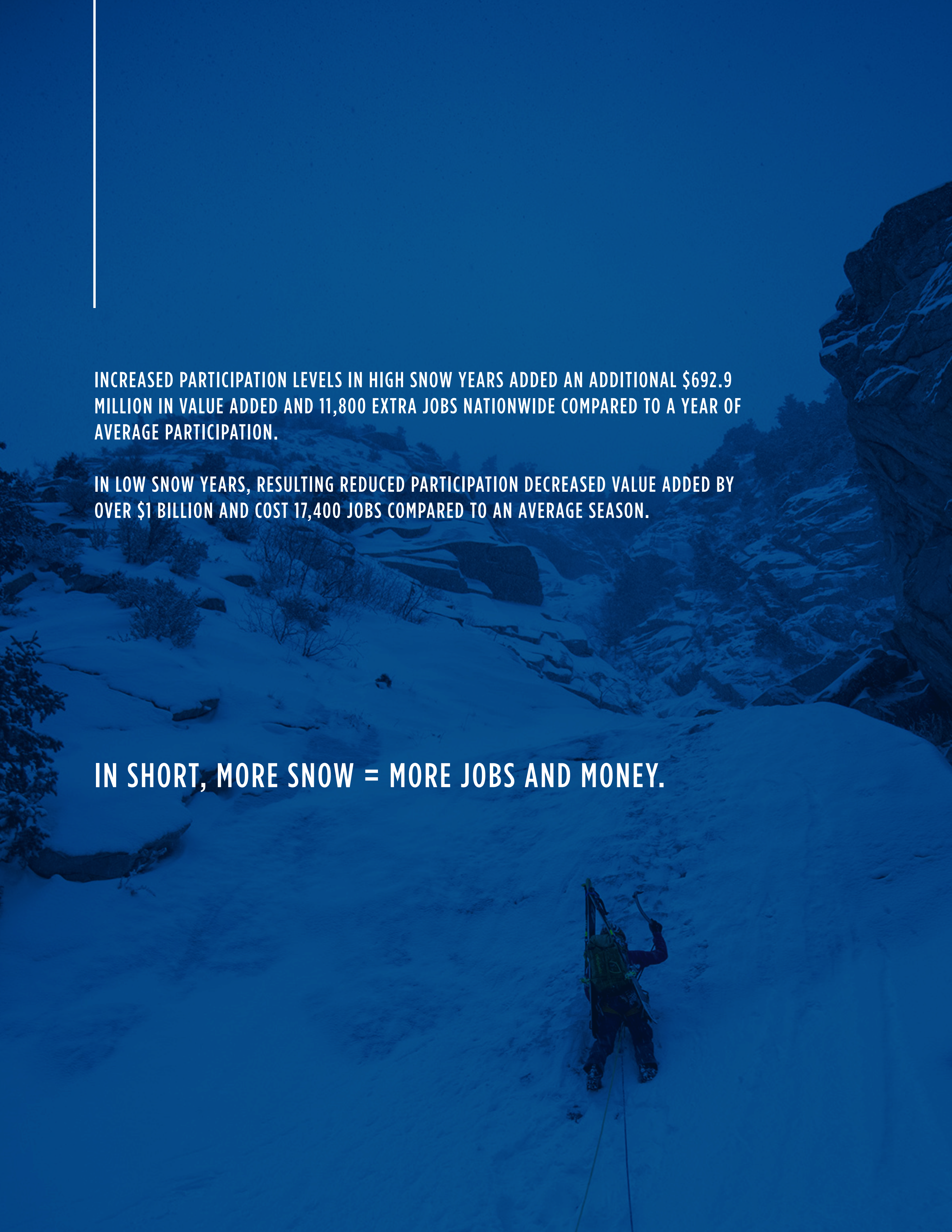


Figure 9. Correlations Between Skier Visits and Total Snow Water Equivalent (SWE) in the Western U.S. Plots highlighted in red are statistically significant, with $p < 0.05$. (Source: NSAA and RRC Associates, 2016.)



INCREASED PARTICIPATION LEVELS IN HIGH SNOW YEARS ADDED AN ADDITIONAL $692.9 MILLION IN VALUE ADDED AND 11,800 EXTRA JOBS NATIONWIDE COMPARED TO A YEAR OF AVERAGE PARTICIPATION.

IN LOW SNOW YEARS, RESULTING REDUCED PARTICIPATION DECREASED VALUE ADDED BY OVER $1 BILLION AND COST 17,400 JOBS COMPARED TO AN AVERAGE SEASON.

IN SHORT, MORE SNOW = MORE JOBS AND MONEY.

4

CHANGES IN ECONOMIC ACTIVITY FROM CHANGES IN VISITATION BETWEEN HIGH AND LOW SNOW YEARS

Skier visits vary significantly from year to year, and thus, economic activity varies from year to year.

This section examines the economic contributions from downhill skiing and snowboarding, focusing on how activity fluctuates with changes in participation. Due to data limitations, snowmobiling was excluded from the analysis in this section.

To understand the impact of varied snow conditions on economic contributions from the downhill ski and snowboarding industries, we first estimated the average participation and related economic contributions for the 16-year period from 2001–2016. We then determined the state-level average participation of the five highest snow years and of the five lowest snow years and compared those figures against the average participation over the 16-year period. Using the 2016 IMPLAN model, we then calculated the economic contributions that accompanied these varying levels of participation (see Appendix A1 for IMPLAN methodology).

Based on the 2016 IMPLAN model, we found increased participation in high snow years added an extra $692.9 million in value added and over 11,800 extra jobs nationwide compared to a year of average participation. In low snow years, resulting reduced participation decreased value added by over $1 billion and cost 17,400 jobs compared to an average season (Table 3).

Therefore, it appears that low snow years have larger (negative) impacts on the economy than the increases experienced in high snow years. In short, snow is directly tied to jobs and money. During a high snow year, resorts can reach capacity and may not be able to accommodate more ski-visits. In a low snow year, the bottom can drop out substantially lower.

Table 3 shows the average number of state-level skier visits between 2001–2016, the average percent change in skier visits, the difference in employment, labor income and value-added during the five highest and five lowest snow years. For states in the eastern United States, snow years were ranked based on the average number of days statewide that snow depth was greater than four inches. Measurements for these statewide averages came from stations located near the mountains and also in urban areas to account for the documented “backyard effect,” whereby skiers decide whether or not to go skiing based on whether it has snowed recently in their backyard (Hamilton et al. 2007). For states in the western United States, snow years were ranked based on total seasonal (November–April) snow water equivalent (SWE), the amount of snow contained in a snowpack, at high-elevation SNOw TELemtry (SNOTEL) stations (see Appendix A2 for more details on state-level snow year rankings).

California showed the largest differences in economic contributions between high and low snow years. While the state experienced a $175.7 million dollar increase over the average in high snow years, it endured a $246.6 million loss of value added during low years relative to average participation. Washington and Oregon showed the largest percent reduction in skier visits in response to low snow years, with losses of 31 percent and 18 percent, respectively.

State	Average Skier Visits 2001-2016	Average % change in skier visits in top five snow years	Average difference in jobs in top five snow years	Average difference in labor income in top five snow ($ millions)	Average difference in value-added in top five snow years ($ millions)	Average % change in skier visits in bottom five snow years	Average difference in jobs in bottom five snow years	Average difference in labor income in top five snow ($ millions)	Average difference in value-added in bottom five snow years ($ millions)
AK	343,551	0%	69	$2.5	$4.1	-14%	-152	-$5.4	-$9.0
AZ	310,251	31%	365	$13.0	$21.5	-11%	-240	-$8.6	-$14.1
CA	6,578,334	13%	2980	$106.6	$175.7	-17%	-4182	-$149.6	-$246.6
CO	12,008,432	2%	715	$25.6	$42.2	-4%	-1530	-$54.7	-$90.2
CT/RI	334,803	7%	81	$2.9	$4.8	-11%	-122	-$4.4	-$7.2
ID	1,378,992	7%	307	$11.0	$18.1	-5%	-254	-$9.1	-$15.0
IL/IN	459,206	8%	116	$4.2	$6.9	-17%	-254	-$9.1	-$15.0
MA	1,254,822	6%	262	$9.4	$15.4	-17%	-688	-$24.6	-$40.5
ME	1,298,778	6%	234	$8.4	$13.8	-9%	-372	-$13.3	-$21.9
MI	2,324,407	3%	212	$7.6	$12.5	-5%	-391	-$14.0	-$23.1
MN	1,520,787	3%	137	$4.9	$8.1	-2%	-76	-$2.7	-$4.5
MT	1,259,573	7%	271	$9.7	$16.0	-2%	-86	-$3.1	-$5.1
NH	2,116,948	7%	510	$18.2	$30.1	-12%	-813	-$29.1	-$47.9
NM	882,603	-17%	-237	-$8.5	-$14.0	14%	411	$14.7	$24.2
NV	419,859	-2%	-20	-$0.7	-$1.2	-5%	-72	-$2.6	-$4.2
NY	3,685,620	5%	635	$22.7	$37.4	-12%	-1407	-$50.3	-$82.9
OH	538,344	-1%	-20	-$0.7	-$1.2	-10%	-173	-$6.2	-$10.2
OR	1,556,083	7%	320	$11.4	$18.8	-18%	-890	-$31.8	-$52.5
PA/NJ	3,473,258	10%	1092	$39.1	$64.4	-11%	-1232	-$44.0	-$72.6
UT	3,855,421	7%	835	$29.8	$49.2	-7%	-899	-$32.2	-$53.0
VA/MD	549,543	-3%	-58	-$2.1	-$3.4	-11%	-198	-$7.1	-$11.6
VT	4,211,658	8%	1093	$39.1	$64.4	-9%	-1289	-$46.1	-$76.0
WA	1,692,472	20%	1117	$39.9	$65.8	-31%	-1569	-$56.1	-$92.5
WI	1,932,628	9%	552	$19.7	$32.5	-12%	-761	-$27.2	-$44.9
WV	662,658	3%	57	$2.0	$3.4	0%	4	$0.1	$0.2
WY	732,243	5%	127	$4.5	$7.5	-7%	-126	-$4.5	-$7.4
Total	**55,381,272**	**7%**	**11752**	**$420.2**	**$692.9**	**-9%**	**-17358**	**-$620.7**	**-$1,023.5**

Table 3. State-level average skier visits (2001-2016), percentage change in skier visits and associated change in economic contributions during the five highest and lowest snow years.

Results from other studies examining relationships between snow and skier visits include the following:

- Shih et al (2008) found ticket sales at two resorts in Michigan increased with increases in snowfall and lower temperatures.
- Hamilton et al (2007) found sales to increase with snowfall at two areas in New Hampshire. The study also found that the busiest 10 percent of days of the season accounted for over 30 percent of the season's revenue. Importantly, urban snow conditions increased skier demand ("backyard effect"), suggesting that snowmaking alone is not a foolproof adaptation strategy in the northeastern United States.
- Dawson et al. (2013) found that skier demand and projected decreases in supply (ie: shorter season, fewer economically viable mountains) are not likely to be proportionate. The survey results suggest that future participation may be similar to that seen during marginal snow seasons in the recent past. Furthermore, they project a geographical market shift (i.e. greater market share for the ski areas that can remain open in a warmer climate).

Skier visitation trends also vary by resort size. Resort size and growth can be examined using the metric of vertical transportation feet per hour (vtf/h). The NSAA calculates vtf/h by multiplying the vertical rise of a lift by the manufacturer's lift capacity rating. The resort's total vtf/h is the sum of the capacities of all a resort's lifts. Larger resorts have larger vtf/h.

Between 2001 and 2016, extra-large resorts experienced a yearly vtf/h growth close to 0.4 percent, while small- and large-sized resorts decreased in vtf/h by 0.8 percent (Figure 10). Medium-resorts saw the largest decrease in skier visitation, -3%. A sensitivity analysis revealed that growth rates in vtf/h are highly sensitive to start- and end-date, suggesting the trends reported here are not robust.

The combined effects of decreasing snowfall, increasing winter rainfall, and warmer temperatures challenge all ski areas. However, smaller ski areas typically have limited infrastructure investment funds compared to larger resorts, which restricts access to equipment that might be used for snowmaking and other resort improvements. Smaller ski areas also tend to be located at lower elevations, which compounds the challenges imposed by climate. Additionally, smaller ski areas face adversity from ownership transitions, aging buildings and facilities, rising skier expectations, ticket pricing models, and marketplace competition (SAM, 2015). Often, infrastructure and facilities such as parking in the base area limit growth, or limit the area's ability to respond to changes in the market (SAM, 2015).

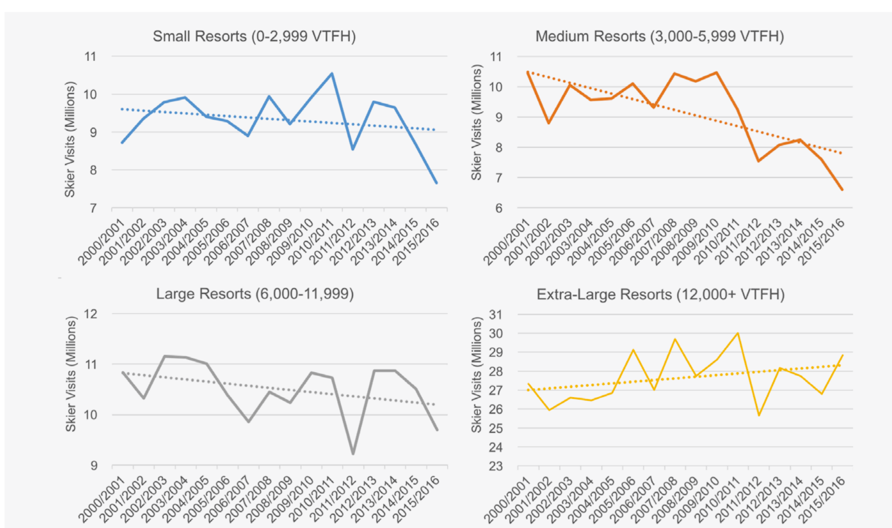


Figure 10. Trends in skier visits by resort size (vertical transport feet per hour, or vtf/h).

DATA SHOW STRONG AND SIGNIFICANT POSITIVE CORRELATIONS BETWEEN DAYS OF HIGH SNOW COVER AND SKIER VISITS.

CASE STUDY: ARAPAHOE BASIN KEYSTONE, COLORADO

Colorado's Arapahoe Basin Ski Area is one of the highest resorts in North America and has the longest season out of all the resorts in the state (typically October to June). But even a ski area with north-facing terrain and a base elevation of 10,780 feet isn't free from the effects of climate change. This was evidenced in the ski area's outlier 2011/12 season during which only 196" of snowfall was recorded, causing a drastic decline in skier visits and revenue. The ski area was forced to cease winter operations a month prior to its budgeted closing date.

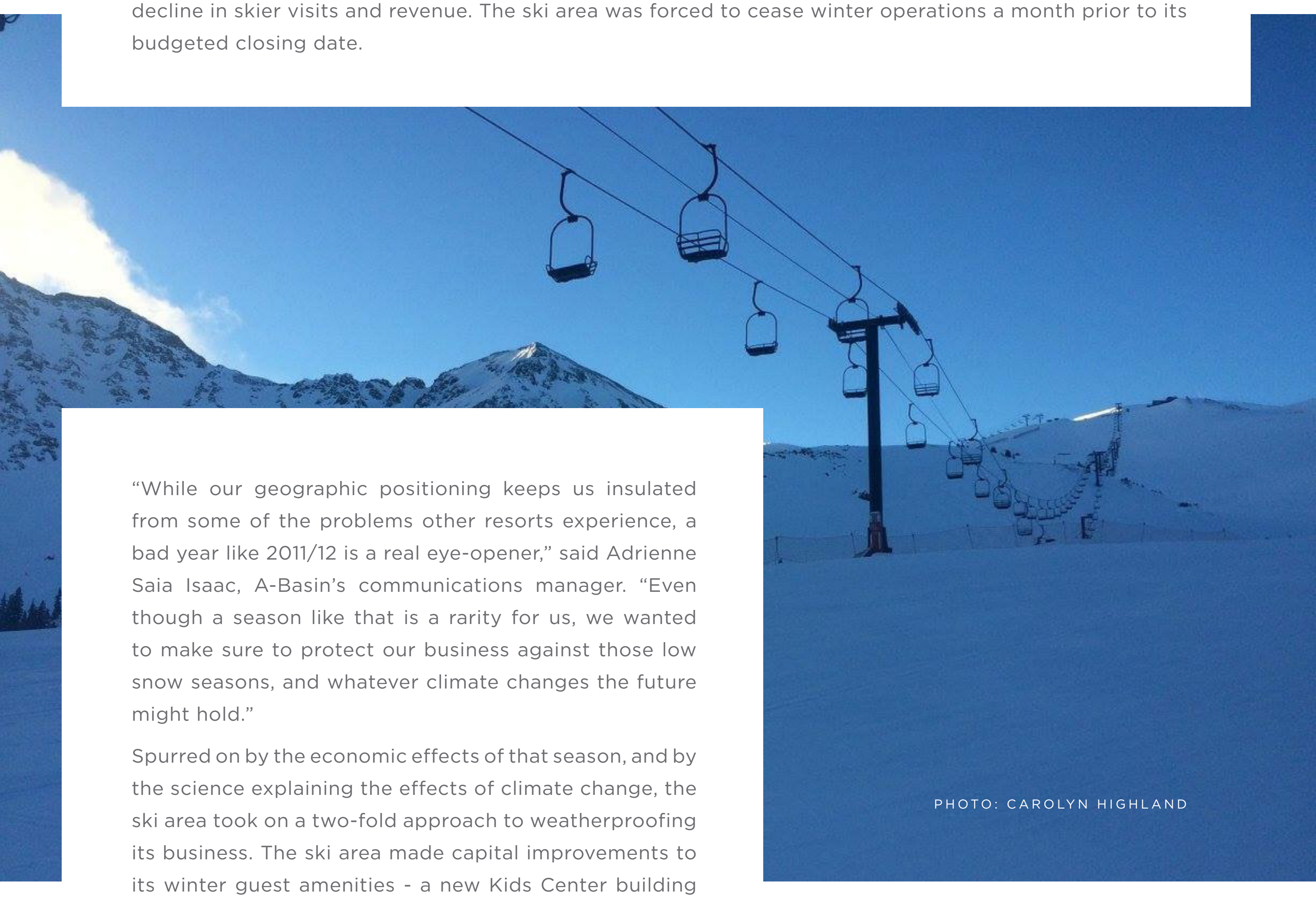
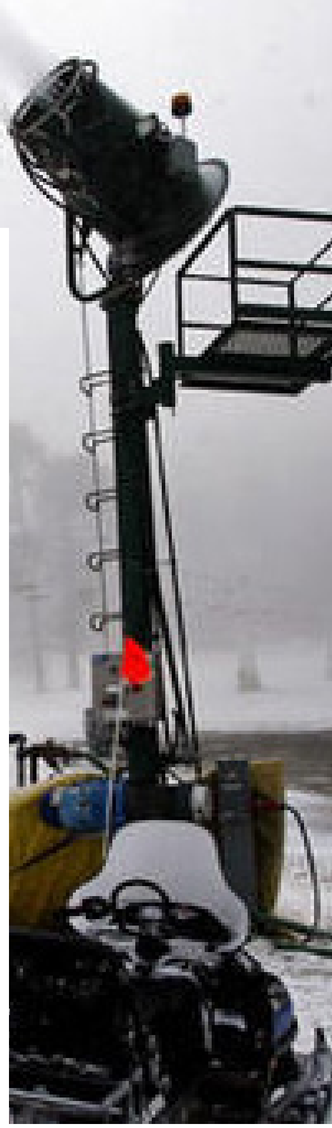


PHOTO: CAROLYN HIGHLAND

"While our geographic positioning keeps us insulated from some of the problems other resorts experience, a bad year like 2011/12 is a real eye-opener," said Adrienne Saia Isaac, A-Basin's communications manager. "Even though a season like that is a rarity for us, we wanted to make sure to protect our business against those low snow seasons, and whatever climate changes the future might hold."

Spurred on by the economic effects of that season, and by the science explaining the effects of climate change, the ski area took on a two-fold approach to weatherproofing its business. The ski area made capital improvements to its winter guest amenities - a new Kids Center building and significant remodels to its base area restaurant and retail shop. A-Basin also added summer events and activities including weddings, a disc golf course, concerts and dining events. That poor 2011/12 season also galvanized the ski area's sustainability program, focusing first on internal procedures and expanding over subsequent seasons into environmental advocacy.



“Our push to be an industry leader in sustainability really took hold after that season,” said Sha Miklas, senior manager of sustainability at A-Basin. “Our executives realized that we as a business needed to do more to walk lighter on the planet, even in our ski boots.”

In 2011, A-Basin joined NSAA’s Climate Challenge, received its first Sustainable Slopes grant and embarked on its first major sustainability project – a complete lighting retrofit across the ski area. Mountain Operations focused on improving its snowmaking system. The ski area’s system is relatively small, making snow on only 125 of its 1,331 acres; Arapahoe Basin also operates its system under restrictions to ensure the health of its watershed, with a low diversion rate and an annual diversion end date of December 31. The ski area also built and strategically placed snow fences around the mountain to ensure that the natural snow stays where it is needed most.

Since then, the ski area has been fortunate to experience consecutive record seasons (in both skier visits and revenue), with snow totals hovering around the average of 350”. Arapahoe Basin has been recognized for its sustainability program, most notably with an NSAA Golden Eagle Award for waste reduction. But the message of environmental impact doesn’t stop with ski area employees – it resonates with the local Colorado community.

“People tell us they come here because of our sustainability efforts,” said Mike Nathan, Arapahoe Basin’s sustainability manager. “We really love to provide the community with ways that they can be more sustainable in their own lives.” The resort encourages greenhouse gas–reducing behavior with lift ticket discounts for skiers who carpool, as well as discouraging idling vehicles by following the National Ski Areas Association (NSAA) Sustainable Slopes Idling policy. All of Arapahoe Basin’s kitchen facilities compost and recycle, and new facilities have been constructed with solar panels to move toward renewable energy sources.

In addition to arming its customers and community with actionable solutions, Arapahoe Basin is bringing the science of climate change to the mountain. In April 2017, the resort hosted a panel discussion called “The Future of Skiing: The Science Behind Snow,” a free event open to the public and co-sponsored by Protect Our Winters. The well-attended event featured local Colorado climate experts who outlined the facts about winter climate and what the industry can expect to see in the future.

“The event at Arapahoe Basin on the future of the ski industry in the face of a changing climate was exceptional,” said Jim White, director of the Institute of Arctic and Alpine Research (INSTAAR) at the University of Colorado Boulder. “As a speaker, I learned so much from the other presenters, and found the lively Q&A that followed with the large crowd fun and enlightening.”

Arapahoe Basin plans to host similar events in the future to continue educating their skiers and share the spirit of hope and action.

5

VALUE OF OUTDOOR WINTER RECREATION TO RECREATIONISTS

5.1

CONSUMER SURPLUS OF OUTDOOR WINTER RECREATION

A report on the economic impacts of climate change on skiing would be incomplete without discussing impacts on consumer surplus.

Snow has an impact on each skier's perceived value of skiing. As with many recreational activities, the total value of skiing has two components: (1) the direct costs individuals actually pay to ski (e.g., ticket prices, equipment, transportation costs), and (2) what they would be willing to pay above the actual dollar value paid. The total value is referred to as "willingness to pay" (WTP).

While the first component (expenditures) was modeled by the IMPLAN analysis in Section 1, this section estimates the second component: the extra benefits participants receive, which are termed "consumer surplus."

WTP and consumer surplus are important measures of economic benefits used by the federal government when conducting benefit-cost analysis (U.S. OMB, 2000; U.S. Water Resources Council, 1983, used by the U.S. Army Corps of Engineers and U.S. Bureau of Reclamation).

ECONOMICS IN ACTION

What might this equation look like for a participant visiting a resort? Say Skier Sally wants to spend a day crushing turns at a nearby resort. She has a season pass for the resort, carpools with her crew and pays a small parking fee when she arrives. Her other costs are fuel for travel, the après-ski beer she purchased at the resort lodge, and the burrito she bought on the way home. What is her consumer surplus? Sally happened to hit an amazing powder day that resulted in a large reduction in her stress level, a bonding experience with her friends, and a series of very Instagrammable face shots. Though the lift ticket was covered by her season pass, the level of enjoyment she experienced from a great skiing day with friends was exceptionally high—she would've been willing to pay $100 over the amount she spent. Her consumer surplus would then be $100 (directly related to the value perceived from her experience).

5.2

CONSUMER SURPLUS VALUES FROM THE LITERATURE

Table 4 displays consumer surplus values estimated for skiing and snowmobiling, along with the number of studies and estimates available. These findings are reported in Rosenberger, et al., 2017, in which an extensive literature review of valuation studies for outdoor recreation was conducted for the US Forest Service. The average consumer surplus value is $77.63 per downhill skier or snowboarder, $36.84 per cross-country skier, and $60.61 per snowmobiler.

5.3

IMPACTS FROM CLIMATE CHANGE ON CONSUMER SURPLUS VALUES

Warming winters could impact consumer surplus associated with winter recreation in at least two ways:

- Less snow reduces the total number of ski visits per year and thereby reduces the collective annual value (total annual consumer surplus = $ per day x number of days per year).
- Less snow could reduce consumer surplus values by reducing a skier's enjoyment of skiing, and thus reduce the per-day value (Englin and Moeltner, 2004).

The same methods used in Section 1.3 can be applied to evaluate the impact of reduced visitation during low snow years on consumer surplus. For downhill skiing and snowboarding, low snow years had, on average, 10 percent less visits than an average year (Table 5). This results in a consumer surplus loss of $430 million for skiing and snowboarding. Applying the 10 percent reduction in visits to snowmobiling and cross-country skiing (due to lack of estimates particular for these sports), a loss of consumer surplus of $112 million would occur to cross-country skiers and $82 million to snowmobilers (see Table 5).

	Mean of Estimates of Consumer Surplus	Number of Studies	Number of Estimates	Std. Error of Mean	Range of Estimates
Downhill Skiing and Snowboarding	$77.63	5	13	$25.62	$7.85 - $277.86
Cross Country Skiing	$36.84	3	5	$6.93	$20.12 - $60.18
Snowmobiling	$60.61	14	49	$9.58	$9.06 - $462.96

Table 4. Consumer surplus values for outdoor winter recreation ($2016).

	Average number of days per year (2001-2016)	Consumer surplus per day	Total annual consumer surplus ($M)	Reduction in days per year from low snowfall (10% reduction in visits)	Reduction in total annual consumer surplus ($M)
Downhill Skiing and Snowboarding	55,381,272	$77.63	$4,299	-5,536,219	-430
Cross Country Skiing	30,358,000	$36.84	$1,118	-3,035,800	-112
Snowmobiling	13,553,568	$60.61	$821	-1,355,357	-82
Total	99,292,840	--	$6,239	-9,927,376	-624

Table 5. Consumer surplus losses due to climate change from reduced visitation.

The second way in which climate change could reduce consumer surplus is by reducing a skier's enjoyment of skiing, thus reducing their per-day value. While some skiers might not have a preference between natural snow and man-made snow, many skiers prefer natural snow, which is typically softer and less icy than man-made snow. Some skiers prefer larger quantities of natural snow, as reflected by increased visit numbers on ‘powder days,’ after 6 inches or more of snow has fallen overnight.

One study examined the impact snowfall has on consumer surplus values and found that overall, consumer surplus values increase with snowfall (Englin and Moeltner, 2004). The study also found that the marginal effect of temperature on expected demand is negative. “On average, therefore, riders prefer lower temperatures and more snow.... An abundance of fresh snow is especially desirable on more difficult and out-of-bounds runs... [L]ower temperatures allow for better and longer lasting ‘powder’ conditions.”

A 10–30 percent reduction in consumer surplus for skiers would lead to a further loss of $430 million to $1.3 billion, assuming the 2001–2016 average participation (See Appendix A3 Methods for further explanation). However, the loss in consumer surplus to skiers experienced to date is not known and therefore has not been estimated. The impact of reduced snow and higher temperatures on consumer surplus for snowmobiling, cross-country skiing, and other winter sports is also unknown. Sports reliant upon natural snow, such as backcountry skiing, would experience greater losses in per-day consumer surplus values than industries that can make snow.

On an individual skier basis, a ski experience with a high consumer surplus means that they are more likely to return to the same resort, recommend it to others and potentially pay a bit more in the future. Conversely, a decline or loss of consumer surplus means that that skiers aren't getting the same value from the experience and are less likely to be repeat customers or recommend the resort to others.

CASE STUDY: AMERICAN BIRKEBEINER, WISCONSIN

The American Birkebeiner, colloquially known as "The Birkie," is North America's largest cross-country ski marathon. More than 10,000 racers from all over the world gather for the 55 km classic ski race (50 km skate race) that threads through northwestern Wisconsin between the small towns of Cable and Hayward. The race attracts an estimated $25 million dollars in economic activity and sparks additional tourism outside the race event. "Eighty percent of the people that do the Birkie will return to this area sometime outside of the Birkie," says Birkebeiner Executive Director Ben Popp. "From a community standpoint, the more people introduced to this area through the Birkie, the more who will return at some other point during the year."

In 2017, the Birkie was cancelled due to unseasonably warm weather that rendered the course unsafe for racers. It was only the second time since 1973 that the Birkie has been cancelled due to poor snow conditions. Despite the cancellation, nearly 8,000 of the 10,000 skiers still came to the area, demonstrating the strength of the community that rallies around this iconic event. "If you cancel one year that's one thing, but if you start to cancel regularly and you can't be counted on year after year, that's when we start seeing patterns change from people's habits," Popp says.

"IN 2017, THE BIRKIE WAS CANCELLED DUE TO UNSEASONABLY WARM WEATHER THAT RENDERED THE COURSE UNSAFE FOR RACERS."

The Birkie nonprofit organization is focusing its next capital campaign on an adaptation strategy already widely embraced by downhill resorts: snowmaking. The multi-million dollar investment will ensure snow, as nature is no longer a reliable source. "When you start to look at snowmaking, you realize the huge volume of energy it takes to make snow," Popp says. "It's really not a very eco-friendly undertaking." Fortunately, snowmaking technology has been getting more and more energy efficient. Resorts today can make more snow and cover more acreage in a shorter period of time using less energy than they could a decade ago.

In addition to investments in snowmaking, the Birkie has expanded beyond the bounds of the classic cross-country ski race. "We're always looking for how we can diversify outside of just the ski race, because really skiing is more of a lifestyle than anything else," Popp says. Every September, the Birkie Trail Run Festival, now in its 16th year, draws thousands of participants from around the world. Last March, the Birkie course also hosted more than 500 riders in the fifth annual Fat Bike Birkie. Though the patchier snow is dangerous for skiers, riders on bikes adapted with thick tires are able to manage the thin conditions.

The Birkie organizers make their mission clear: "We want to be a part of the solution and hopefully make sure that winter is here for everyone." The Birkebeiner community is prepared to help the organization accomplish this mission. To date, there has been no historically significant decrease in registration for the February 2018 Birkie.

HOW CAN WE ENSURE THE FUTURE OF THE WINTER TOURISM INDUSTRY?

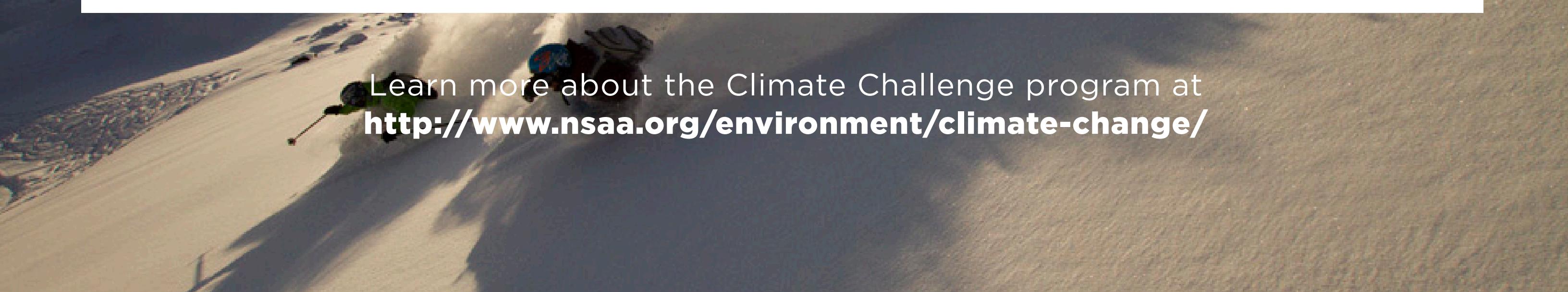
HOW RESORTS ARE ADDRESSING CLIMATE CHANGE

The National Ski Areas Association (NSAA) has led the way in advocating for environmental sustainability at ski resorts. In the year 2000, resorts across the United States adopted the NSAA Sustainable Slopes charter aimed at raising awareness of the potential impacts of climate change on weather-dependent business and the winter recreation experience, reducing greenhouse gas emissions, and encouraging others to take action (NSAA, 2000).

A 2010 NSAA survey revealed that only 10 percent of its resort survey respondents had completed a greenhouse gas emissions inventory, yet more than 80 percent were "very interested in addressing climate issues." In 2011, the NSAA initiated the Climate Challenge program* to challenge resorts to track and reduce their greenhouse gas emissions (http://www.nsaa.org/environment/climate-change/). In its first year, the Climate Challenge successfully recruited eight resorts. The program has proven immensely popular, growing to thirty-six member resorts as of the 2017–2018 season (NSAA, 2017). The program not only reduces greenhouse gas emissions at resorts, but often results in reduced operational costs and increased revenue through marketing and communications of their sustainability efforts. Perhaps the most important requirement of the Challenge is that resorts have to use their voices—their political leverage, their CEOs, their media opportunities—to advocate for government and policy solutions to climate change.

More than 75 percent of US ski resorts have launched efforts to improve their sustainability (Wortman 2014). Sustainability projects generally fall into six categories: (1) energy efficiency of buildings, (2) snowmaking efficiency, (3) utility energy management, (4) food and beverage waste reduction and recycling, (5) sustainability marketing and communications, and (6) human resource efforts to increase retention and worker productivity (Wortman 2014). Of the six programs, improving snowmaking efficiency requires the largest capital investment to implement (average about $550,000) yet saves resorts over $130,000 per year (Wortman, 2014). Eighty-nine percent of ski areas in the U.S. have snowmaking. Snowmaking energy efficiency has dramatically improved in the last decade (EMS Environmental, 2017; Lorenz, 2017; Wojcik, 2014). Resorts can now make more snow faster with less energy consumption than they could just ten years ago. Based on resort financial data, marketing and communications related to resort sustainability efforts requires a relatively low investment (average <$50,000) and has a payback within months.

In addition to adaptation measures during the ski season, resorts are increasing revenue during summer and fall seasons. Resorts have invested in heavily to offer year-round recreation options, including mountain biking, zipline and canopy tours, disc golf, climbing walls, ropes and challenge courses, mountain coasters and alpine slides, concerts and music festivals, and special events (i.e.: weddings, family reunions). Diversification of the resort business model is a key adaptation strategy that will minimize annual economic impacts, despite reductions in winter skier visitation.



*Learn more about the Climate Challenge program at **http://www.nsaa.org/environment/climate-change/***

7

WHAT YOU CAN DO

The efforts of NSAA and individual resorts are smart and business-focused. They save money, reduce emissions, and tell a positive story that helps attract and retain employees and guests. But in a world that has already warmed one degree Celsius—and with another degree C already in the system—these efforts are only the first step. Now more than ever, it's important that we—businesses and individuals— become climate activists, doing everything we possibly can to force positive change at the policy and government level. The Protect Our Winters Climate Activists Roadmap outlines seven ways to take action and fight climate change.

1. **Find Your Biggest Lever** — identify where you as an individual or business can exert the most influence. Often, for businesses, this influence comes in the form of voice: op-eds or letters to the editor, speaking engagements, or meetings with elected officials.

2. **Get Political** — talk to your representatives, senators, state and local government officials about climate impacts in your state and nationally. Tell them that climate change is an important issue and ask what they are doing to address it. Additionally, make sure to support representatives who are taking positive action with climate policy.

3. **Educate Yourself** — become a climate science expert by reading any number of popular blogs or books on climate science. These include climateprogress.org, grist.org, and the climate and energy reporting at vox.com. Books on the subject are too numerous to list, but include Porter Fox's *DEEP*, Bill McKibben's *EAARTH*, and Jeff Goodell's *The Water Will Come*.

4. **Speak Up** — the historical controversy around climate change must not stop you from talking about it among friends, family and co-workers. Now that you're educated, talk. Be respectful, but respond to any challenges to the science by asking for the peer reviewed science that argues against the facts behind anthropogenic warming. As climate scientist Jim White says, "Climate science isn't about belief, it's about physics."

5. **Talk to Businesses** — skiers and snowboarders should support brands and businesses that are committed to reducing greenhouse gas emissions.

6. **Change Your Ways** — walk the talk. Seek out carpooling and public transit options to resorts. Yes, change light bulbs, buy an efficient vehicle, downsize and take fewer trips by air. But don't stop there. Remember that climate is a global problem, and your responses have to go beyond yourself. Join POW, or any other nonprofit dedicated to solving the climate crisis.

7. **Contribute to Science** — citizen science is a powerful way to contribute to scientific understanding of climate change. For less than $35, you can put together your own snow measurement kit comprised of a rain gauge, a ruler, and a small plywood snowboard. With your kit, you can help scientists track changes in snow depth, snow water equivalent, and snowfall in your own backyard or at your favorite resort by participating in the Community Collaborative Rain Hail and Snow (CoCoRaHS) Network (www.cocorahs.org).

   Backcountry enthusiasts can also contribute to snow science in the remote, high-elevation terrain with the Community Snow Obs program (**http://communitysnowobs.org/**). Report snow depth values in the backcountry using your avalanche probe and the free MtnHub App.

8

CONCLUSION

On a blistering January day earlier this year, I visited a cross-country ski area outside of Carbondale, Colorado. The thin track had been refreshed by two inches of spindrift, and around one turn, some skiers had built two miniature snowmen all of ten inches high— scale replicas with raisin eyes and stick arms; an homage to past eras of abundance. Give people snow, and they will find a way to become alive.

Indeed, the electricity of a powder-day lift line might be the most abundant source of renewable power in the world. You only need spend a little time in the snowsports community—in such a lift line, or at après-ski in the Mangy Moose in Jackson, or on top of Highland bowl in Aspen—to feel the sizzle of energy, and understand why this is the place to grow a movement.

The skiers and riders are the doers and fixers; they will always rise to the occasion. Depending on season, they will thrive or enthusiastically make do.

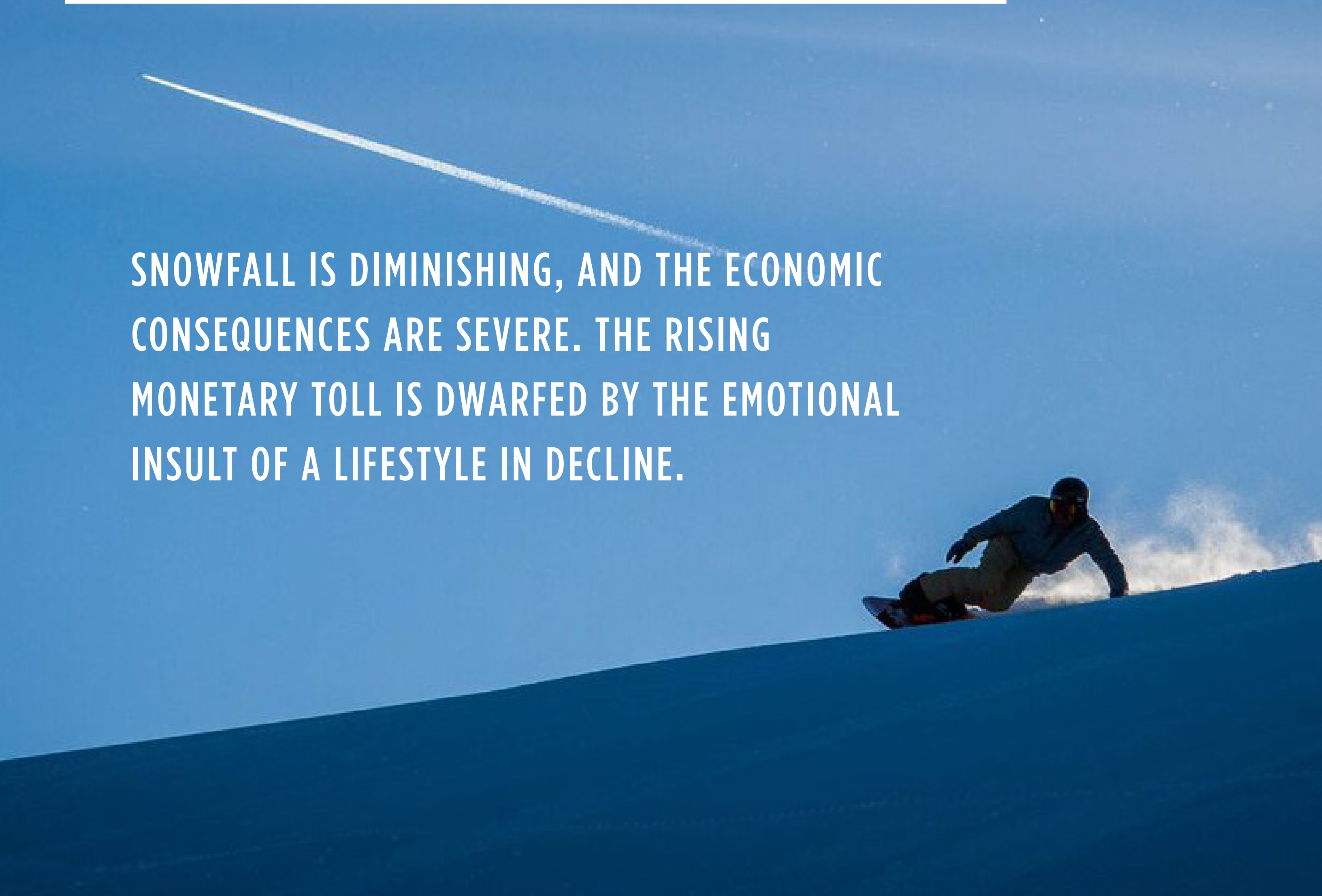
You can see this community spirit best in the stories of resilience and adaptation shared throughout this report. But those stories, inspirational as they may be, are also tinged with a sense of critical urgency. In response to this observation, Liz Burakowski, one of the researchers on this report, pointed to the concept of solastalgia.

The word, coined by philosopher Glenn Albrecht, describes the existential distress caused by environmental change, or the homesickness felt when one is still at home. It is the unease one feels during those warm, snowless winters. It comes from a combination of the Latin word solacium (comfort) and the Greek root -algia (pain). Albrecht notes that people's distress in the face of environmental change is "exacerbated by a sense of powerlessness or lack of control over the unfolding change process."

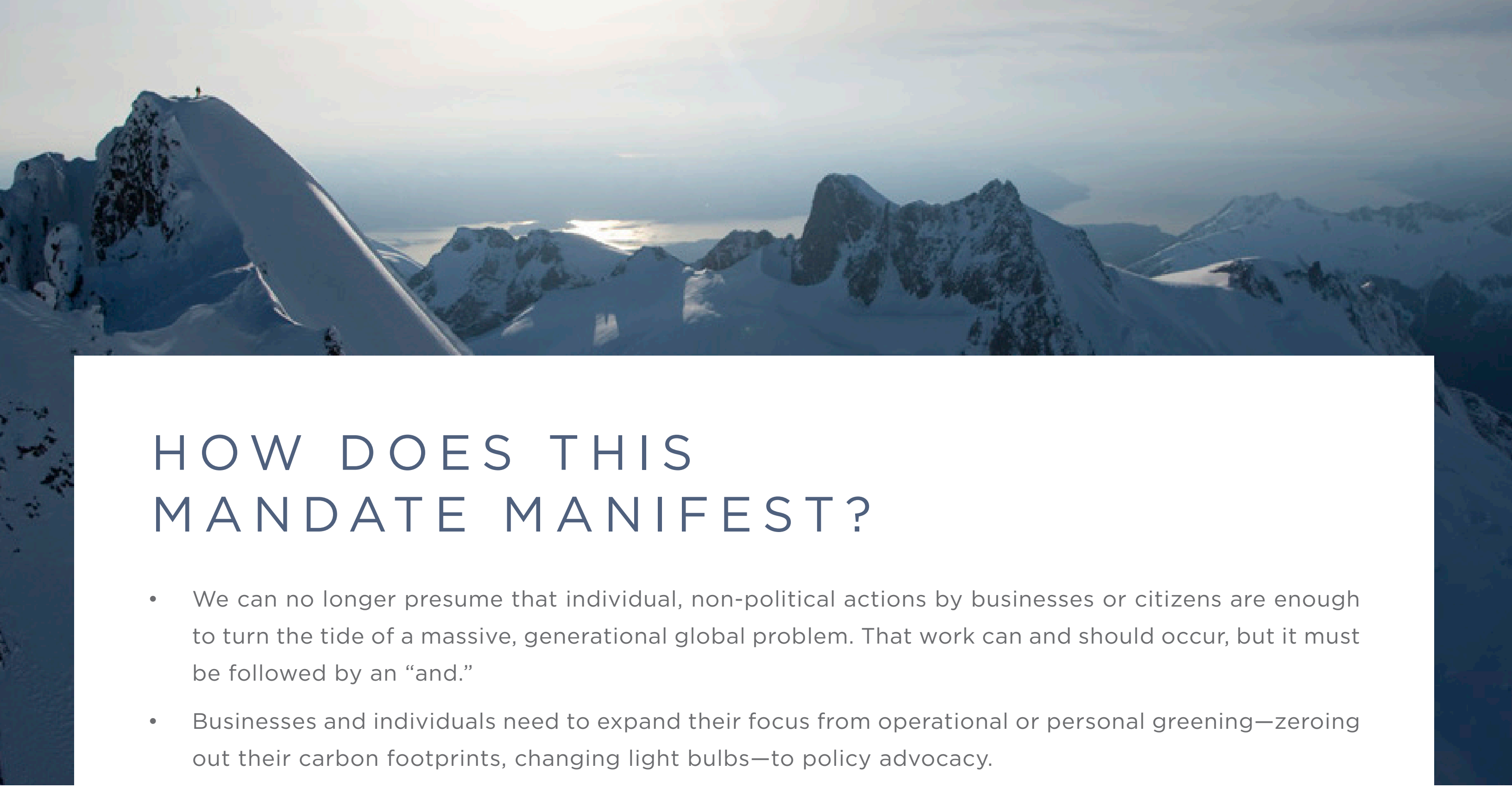
We know the facts, and need not lay them out again here in detail: snowfall is diminishing, and the economic consequences are severe. The rising monetary toll is dwarfed by the emotional insult of a lifestyle in decline.

The goal of this report is not to admire the problem, but to offer an antidote to solastalgia, initially by naming the problem, and then by tackling that sense of powerlessness by pointing to meaningful solutions.

If we do in fact value the snowsports world—its culture, its economy, its human ecology—we need to change how we are approaching the problem of climate change. We have to stop repeating the climate movement's mostly ineffective actions of the past and move on to those worthy of the challenge. The work will be more difficult and more painful, and it will require a brutal realism.



SNOWFALL IS DIMINISHING, AND THE ECONOMIC CONSEQUENCES ARE SEVERE. THE RISING MONETARY TOLL IS DWARFED BY THE EMOTIONAL INSULT OF A LIFESTYLE IN DECLINE.



HOW DOES THIS MANDATE MANIFEST?

- We can no longer presume that individual, non-political actions by businesses or citizens are enough to turn the tide of a massive, generational global problem. That work can and should occur, but it must be followed by an "and."
- Businesses and individuals need to expand their focus from operational or personal greening—zeroing out their carbon footprints, changing light bulbs—to policy advocacy.
- Snowsports participants need to reexamine the source of their power and vote with their dollars and their voices, holding businesses to the high standard of activism described above. Wielding this economic power forms the foundation of a social movement that enables electoral victories that will influence legislative action.
- Trade groups need to get far, far more proactive, using voice, education, and their convening power to elevate climate to the primacy it deserves, and hold elected officials to a new standard.
- The outdoor community needs to illuminate the link between public lands and climate, fearlessly wielding power just as effectively in this new realm. The community must create and develop C4 Super PACs, and play and fight with the same bare-knuckled brass as the proponents of fossil fuels and deregulation.

Ultimately what we face is a choice: do we take the hard but effective path of activism, with all its controversy, political street fighting, and risk? Or do we choose the easy path, where we continue to "attack" politically safer areas, take cover under the notion that we can only manage our own house, and slowly watch our industry fade away? Is there really a choice?

David Milliband, the president and CEO of the International Rescue Committee, tells a story about his grandmother and aunt, Belgian Jews who, in 1942, left Brussels and took shelter with a local farmer in a small village south of the city. By the end of the war, 17 Jews were living in that village. When Millibrand, as a teenager, was able to meet the farmer, Monsieur Maurice, he asked him: "Why did you do it? Why did you take the risk, suffer the inconvenience?" Maurice answered in French, with two words: "On Doit."

ONE MUST.

AUDEN SCHENDLER

Protect Our Winters Board Member

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APPENDIX A. METHODS

Using trip expenditure data collected from economic studies of the ski and snowmobile industry (Burakowski and Magnusson, 2012) we were able to model the national and state level, annual economic contributions of recreational downhill skiing and snowboarding as well as the snowmobiling industries. This per trip expenditure information was combined with number of trips taken and was entered into our National level IMPLAN model to create economic contribution information nationally and at individual state levels.

Economic contribution assessment is commonly used to determine the effects of an activity on the broader economy. Typically, any recreation-related industry's economic contribution on a local economy originates from participants spending money in the region. Generally, we report this effect in terms of 'output' (total sales), employment, and 'value added' (net revenues, the difference between what someone sells a good for and what one pays for all of the components used in producing the good (for reference, this is the same measure as Gross Domestic Product).

The economic contribution of winter sports is not limited to just skiing and snowmobile activities (the 'direct effect'). Direct expenditures affect related sectors of the economy, such as input suppliers and employee spending in other industries. To account for the full economic contribution of winter sports we must analyze these indirect and induced effects.

The direct effects of winter sports are the economic effects created by winter sport related visitor expenditures. For the most part, these are purchases at related businesses, such as expenditures for lodging, food, transportation, and entry fees. However, the total economic contribution of winter sports is larger than just this direct spending; there are spin-off effects from that spending. These spin-off effects arise from additional economic activity generated by direct visitor spending (commonly referred to as the 'economic multiplier' effect), which measures how the value of a dollar of initial sales may be multiplied throughout the economy. We calculated the total economic contribution to be the combination of the following direct and spillover effects:

- Direct effects: These effects are a result of actual visitor expenditures which were estimated using average per trip expenditures by category multiplied by the number of visitors. For example, a purchase of a $100 lift ticket would be a $100 direct effect of a visitor.
- Indirect effects: These effects arise due to linkages in the supply chain, such as local industries buying goods and services from other local industries. The cycle of spending works its way backward through the supply chain. For example, the resort from which the skier purchases their lift ticket will use part of that money elsewhere in the economy, such as purchasing supplies or hiring an accountant.
- Induced effects: These effects are a result of employee household spending. For example, when a skier purchases a lift ticket, some small portion of that dollar amount goes toward paying the wages of the sales attendant and other employees, who then recirculates those wages in the form of household purchases of things such as clothing or groceries.

Because of the spin-off effects (indirect and induced effects), we see that an initial dollar of purchases by a visitor at one winter sport related business can generate more than a dollar of total activity in the regional economy as it ripples through the other businesses and households buying goods and services. The multiplier process continues with each additional round of income/spending, but typically becomes smaller as money "leaks" out of the region to purchase goods and services from outside the region.

The most common approach to estimating the economic impacts of recreation-related activities is the use of the IMPLAN software model to examine how much economic activity is generated by visitor activity. The IMPLAN software (www.implan.com), originally developed by the U.S. Forest Service, establishes the characteristics of economic activity in terms of 528 economic sectors. Drawing on data collected by federal and state government agencies, the IMPLAN model uses regional industry purchasing patterns to examine how changes in one industry will affect others. The IMPLAN model has been used as the basis for thousands of economic analyses throughout the United States. The most recent version of IMPLAN data (2016) was used to determine the economic contributions of winter sports.

This modeling approach consists of a two-step process. First, the total unique visitor expenditures are estimated, by expenditure category. These expenditures are then applied to the IMPLAN model in order to estimate the total economic activity generated, including multiplier effects.

A1. METHODS USED IN THE NATIONAL- AND STATE-LEVEL IMPLAN ANALYSIS

The first step, approximating total expenditures by category, was accomplished using the per person per trip visitor expenditures listed in Table A1. These expenditures used the expenditures obtained in Burakowski and Magnusson (2012), updated to $2017 for inflation (BLS, 2017).

We then multiplied these per person expenditures by the total number of downhill visitors (which were collected from the Kottke survey (NSAA and RRC Associates, 2016) and total snowmobile visits (calculated by taking snowmobile registrations from ISMA, 2017, and multiplying by 9.64 visits per registration).

Once expenditures by category were determined, we used the IMPLAN input-output model to examine the economy-wide effects of these total expenditures. This involved matching the expenditure data with the IMPLAN industry sectors, and entering the appropriate expenditure amounts into the model. In doing so, we were able to estimate both the direct and indirect economic contributions to the region.

Note that not all recreation-related spending calculated accrues to the region as final demand. The reason for this is related to the nature of the retail purchase of goods. For goods that are manufactured outside the region, only the retail margin appears in the final demand calculated for the region. The cost (the producer's price) to the retailer or wholesaler of the good itself leaks immediately out of the region's economy, and cannot be considered a local impact. Recognizing this fact, we applied IMPLAN's default household margins for all retail sectors.

	Per Downhill Per Day	Per Snowmobiler Per Day
Food and Beverage Stores	$ 9.56	$ 17.92
Gasoline Stations	$ 12.75	$ 38.67
General Merchandise Stores	$ 7.97	$ 9.67
Amusement	$ 86.04	$ —
Accommodations	$ 23.90	$ 34.92
Food Service and Drinking places	$ 19.12	$ 26.51

Table A1. Per trip visitor expenditures for downhill skiing and snowmobiling.

A2. METHODS USED IN THE HIGH/LOW SNOW ANALYSIS

Daily snow water equivalent (SWE) data for the western United States were retrieved from the automated SNOw Telemetry (SNOTEL) Network (Serreze et al. 1999). SNOTEL stations are primarily located at high elevations in mountainous terrain, and many are in close proximity to major ski resorts. SNOTEL stations collect SWE using a snow pillow. Stations selected for analysis had no more than 25% of daily SWE values missing in a given snow season (November 1 through May 1) and no more than two seasons missing from the time series November 30, 2000 through April 1, 2016 (Figure A1). A total of 639 SNOTEL stations met the above criteria and were used in the final analysis. Snow seasons were ranked from high to low snow based on the sum of snow season SWE (Figure A1).

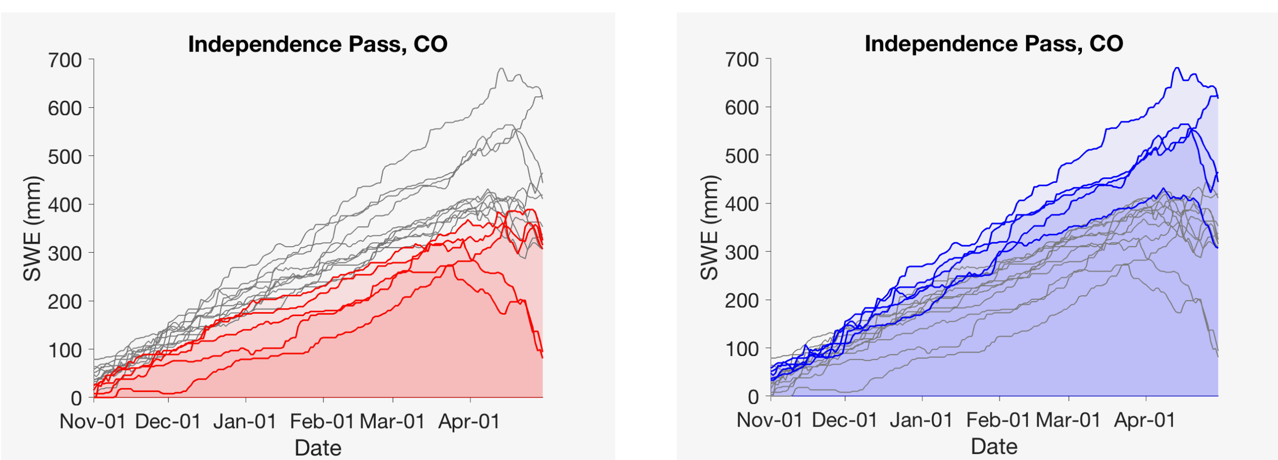

Figure A1. Daily snow season (November through April) snow water equivalent (SWE) at SNOTEL station at Independence Pass, Colorado, November 2000 through April 2016. The sum of snow season SWE (or total SWE) is the area integrated under the SWE curve, shown for the (a) five lowest years in red and (b) five highest years in blue.

In contrast to the western US, long-term records of SWE are sparse in the eastern US. As such, snow seasons were instead ranked based on snow depth data, specifically the number of days with daily snow depth greater than three inches (Burakowski et al. 2008). Daily snow depth data for the Eastern United States were retrieved from the Global Historical Climatology Network Daily (GHCN-Daily) database (Menne et al. 2012a,b). Stations selected for analysis had no more than 25% of daily snow depth values missing during a given snow season (November 30th through April 1st) and no more than two seasons missing from the time series November 30, 2000 through April 1, 2016, resulting in 652 stations for the final analysis (Figure A2). Winter seasons were ranked at the state-level by the average number of days per winter with snow depth values greater than three inches (76.2 mm). In three cases, two or more states were grouped together to reflect National Ski Areas Association skier visitation groupings; these include (1) Pennsylvania and New Jersey, (2) Illinois and Indiana, and (3) Connecticut and Rhode Island. For these state groupings, the average number of snow covered days per winter were calculated from the grouped set of stations in both states.

The five lowest snow years (Western United States Table - A2; Eastern United States Table - A3) were used to calculate differences in skier visitation and generate ski-tourism related employment and economic activity using the IMPLAN model. State-level skier visitation data come from the National Ski Areas Association (NSAA) Kottke End of Season Survey (NSAA and RRC Associates, 2016) .

Methods used for determining the economic contributions from low and high snow years is similar to the methods used in Burakowski (2012). However, the Burakowski and Magnusson (2012) report examined the difference in contribution between two highest and two lowest snowfall years between 2000 and 2010. This report examines how the average of the five highest and five lowest snow years differ from the 2001 to 2016 average. This tercile approach was done to minimize influence of the extreme outliers and develop a more robust assessment of the impact of marginal winters on participation. In addition, the snow metrics used to rank the winters differs between the two reports for the eastern United States. In the 2012 report, total seasonal snowfall was used to rank the eastern United States' winters, while the current report uses the total number of days with snow cover greater than four inches to rank winters. Due to difference in methods, numbers from both reports should not be compared. Lastly, skier participation was lower in 2016 than in the 2012 report, so the overall economic contribution of skiing was lower than estimated in the 2012 report.

	AK	AZ	CA	CO	ID	MT	NM	NV	OR	UT	WA	WY
Lowest	2015	2015	2015	2002	2001	2001	2001	2001	2015	2015	2015	2001
	2003	2006	2014	2013	2015	2005	2005	2015	2005	2007	2005	2010
	2014	2014	2012	2012	2010	2010	2015	2010	2014	2012	2001	2002
	2006	2003	2007	2015	2005	2016	2010	2007	2003	2003	2003	2007
	2011	2016	2001	2004	2013	2015	2016	2005	2001	2002	2014	2013
	2016	2011	2009	2007	2007	2003	2013	2003	2010	2013	2010	2016
	2007	2002	2013	2003	2003	2007	2007	2012	2013	2014	2009	2015
	2009	2007	2008	2010	2012	2013	2003	2013	2007	2010	2004	2005
	2013	2004	2010	2001	2009	2004	2004	2016	2012	2001	2016	2003
	2010	2013	2016	2006	2014	2002	2002	2004	2016	2016	2013	2004
	2004	2009	2003	2016	2016	2012	2012	2009	2009	2004	2007	2012
	2005	2001	2004	2014	2004	2009	2009	2002	2004	2009	2012	2009
	2002	2012	2002	2009	2002	2008	2006	2014	2011	2006	2002	2008
	2008	2008	2006	2005	2008	2006	2008	2008	2002	2008	2011	2006
	2001	2005	2005	2011	2011	2014	2014	2006	2006	2005	2006	2014
Highest	2012	2010	2011	2008	2006	2011	2011	2011	2008	2011	2008	2011

Table A2. Western United state rankings of high and low snow years, 2001-2016. Year listed is January-April of a given winter (i.e.: 2015 is the ranking for November 2014 through April 2015).

	CT/RI	IL/IN	MA	ME	MI	MN	NH	NY	OH	PA/NJ	VA/MD	VT	WI	WV
Lowest	2012	2016	2012	2012	2012	2012	2016	2012	2012	2012	2008	2016	2003	2012
	2002	2012	2002	2006	2002	2003	2012	2016	2002	2002	2007	2012	2002	2002
	2016	2002	2016	2016	2016	2002	2006	2002	2016	2016	2002	2006	2012	2008
	2007	2005	2007	2007	2003	2015	2007	2006	2006	2008	2012	2010	2016	2009
	2006	2013	2006	2004	2007	2007	2002	2013	2013	2013	2001	2013	2007	2006
	2010	2006	2010	2002	2013	2005	2013	2007	2007	2006	2009	2002	2006	2005
	2008	2003	2004	2010	2006	2016	2010	2008	2008	2009	2006	2007	2015	2001
	2004	2004	2013	2013	2010	2004	2005	2010	2001	2007	2005	2005	2005	2013
	2013	2007	2008	2011	2015	2006	2011	2009	2004	2005	2013	2014	2004	2007
	2009	2008	2014	2005	2004	2013	2004	2014	2005	2001	2011	2009	2013	2016
	2014	2009	2009	2003	2005	2009	2014	2005	2009	2014	2004	2011	2009	2015
	2005	2010	2001	2014	2011	2010	2009	2004	2003	2015	2014	2015	2010	2014
	2011	2015	2005	2009	2009	2008	2015	2001	2011	2010	2016	2004	2011	2004
	2015	2011	2011	2001	2008	2014	2003	2015	2015	2011	2003	2003	2001	2011
	2003	2001	2015	2015	2001	2011	2001	2011	2014	2004	2015	2008	2014	2003
Highest	2001	2014	2003	2008	2014	2001	2008	2003	2010	2003	2010	2001	2008	2010

Table A3. Eastern United state rankings of high and low snow years, 2001-2016. Years ranked based on number of days per winter (December through March) with snow depth greater than four inches. Year listed is January-April of a given winter (i.e.: 2015 is the ranking for November 2014 through April 2015).

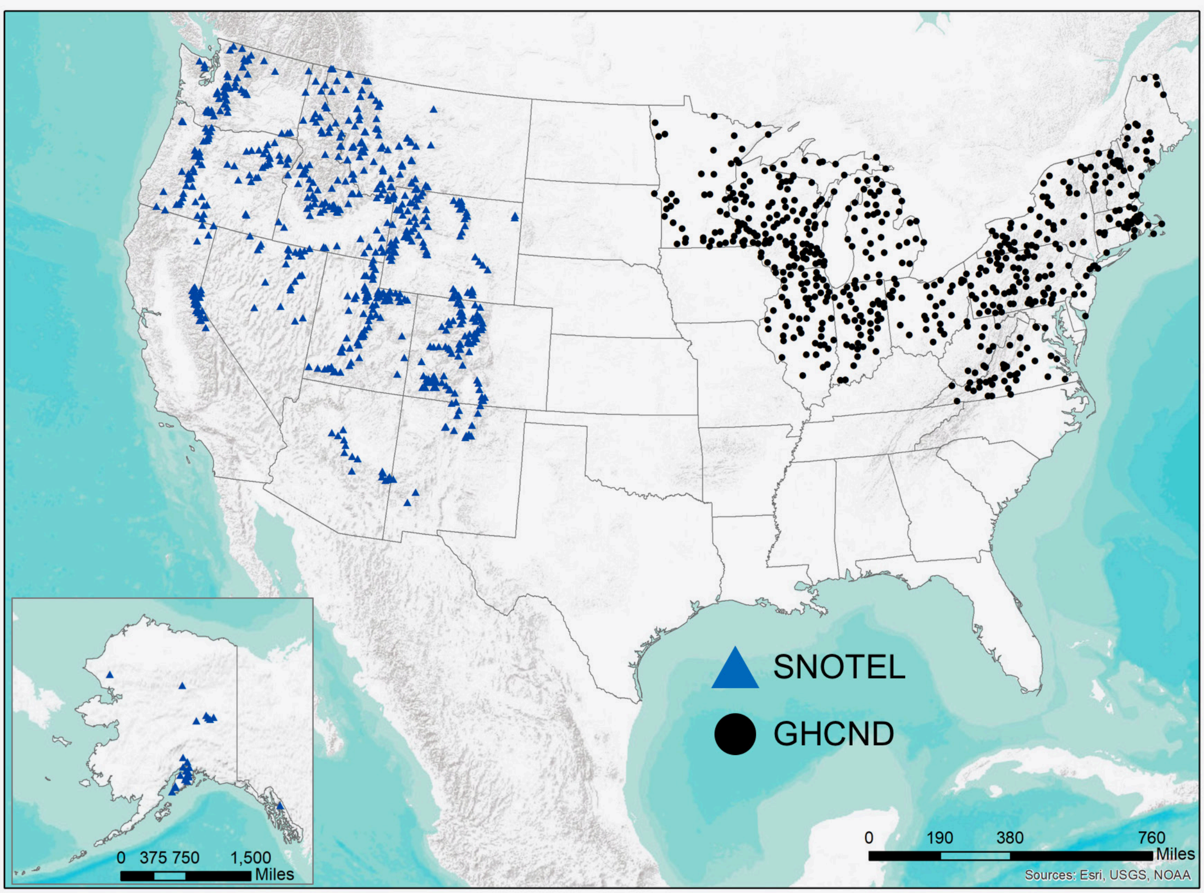

Figure A2. Global historical climatology network daily (GHCND) stations (black circles) and SNOw TELemetry (SNOTEL) network stations used in the high/low snow analysis.

A3. METHODS USED IN THE CONSUMER SURPLUS ANALYSIS

IMPACT TO CONSUMER SURPLUS FROM REDUCED SNOWFALL

Reduced snowfall and snow cover over the ski season may impact values to skiers in different ways. Some skiers might not have a preference between natural snow and manmade snow. Some skiers may prefer manmade snow, the consistency of a harder snowpack and not enjoy powder or ungroomed terrain. While other skiers prefer natural snow, which is typically softer and less icy than manmade snow. Some skiers prefer large quantities of natural snow, as reflected by the flocks of skiers heading to resorts on 'powder days,' after 6 inches or more of snow has fallen overnight.

One study examined the impact snowfall has on consumer surplus values and found that overall, consumer surplus values are strongly positively affected by snow conditions, as is trip demand (Englin and Moeltner, 2004). The study also found that the marginal effect of temperature on expected demand is negative. This means that, on average, people prefer more snow and lower temperatures. This study was however limited to college students from the University of Nevada Reno for the winter season of 1997-98 for 13 resorts in the Lake Tahoe area of Nevada and California.

Other results from Englin and Moeltner (2004) include:

- Snowfall increases trip demand albeit at a decreasing rate. At the sample mean of approximately 12 inches of new snow per week, the marginal impact of an additional inch on expected trip demand equals 0.018, or an increase of 1.8%. Meaning that after a foot of snow, more snow doesn't matter all that much to skiers.
- While riders do react to snow conditions, trip demand is generally more responsive to price changes. Meaning that skiing isn't free – and when prices increase, some skiers will not be able to afford to ski or may choose to ski less.
- An abundance of fresh snow is especially desirable on more difficult and out-of-bounds runs.
- Lower temperatures allow for better and longer lasting 'powder' conditions. Such conditions are desirable to the average rider in the study sample.

In a warmer future with less snow and a shorter ski season, some skiers may lose all of their WTP and chose not to ski at all. An example of zero WTP would be a skier choosing to golf instead of ski on a warm March day. For the purposes of this report, we assume that all skiers will continue to ski, but at a reduced consumer surplus. Due to lack of estimates on how much skiers lose in consumer surplus due to reduced snowfall, we examine a range of reductions in consumer surplus, of 10% to 30%.

ADDITIONAL NOTES ON SKIER VISITS

In this study, we found that in the five lowest snow years, that skier visits were reduced by 10%.

Warmer temperatures and reduced snowfall will continue to reduce the length of the ski season, which will likely continue to reduce visits. Snowmaking systems can help reduce the erosion of skiable days, but only so much.

Wobus et al. (2017) analyzed the number of days available for snowmaking and projected that from climatic changes, by 2050 it is possible that fewer than 40% of ski areas may be able (with current technology) to make enough snow to open before the Christmas holiday. They conclude a potential loss of about 30% of downhill skier and snowboarder visits (and revenue) by 2050 due to likely climate change scenarios. Additionally, they determined that season lengths will decline at all US ski resorts, in some cases by 50% in 2050 and 80% in 2090.

In Europe, climate change impacts on season length have been drastic. The length of the season has decreased by 38 days between 1960 and 2017, and the 2016 winter had the least snowfall ever, with snowpack in the southern French Alps just 20% of its typical snowpack (Kluger, 2017).

The Wobus study assumed a linear relationship between season length and skier visits. However, revenues from particular times, such as Christmas or spring break, are important for most resorts. In the winter of 2015-2016, most visits occurred in the middle of the season (January/February). December and March were also big contributors. However, November and April contributed less than 10%. Therefore, late openings and early closures do not currently entail as large impacts as they could if they begin to interfere with Christmas and spring breaks.

Total annual ski visits may also be reduced by a notion called the "backyard effect," whereby a skier makes a decision based on what he or she see outside their window (Hamilton et al. 2007). Climate model trends, such as less snow at lower elevations, and rain in winter, can result in less trips to ski resorts. Major metropolitan areas that provide skiers to northern New England will lose snow earlier than higher elevation, more northerly mountains. Skier visitation might decline in spite of more efficient snowmaking and better snow management. Skiers from Boston may choose to bike, golf or participate in other warmer weather activities and be less inclined to head to the mountains for skiing. Alternatively, the higher elevation more northerly resorts may see an increased market share if they remain economically viable compared to their lower elevation, more southerly resorts that struggle to stay operational in marginal snow years (Dawson et al. 2013).

METHODS FOR CALCULATING ANNUAL LOSS IN CONSUMER SURPLUS DUE TO CLIMATE CHANGE

Table A4 shows the annual loss in consumer surplus to downhill skiers and snowboarders from climate change. Consumer surplus values per day are multiplied by the number of skier days to obtain total annual consumer surplus. The low snowfall years have shown a 10% reduction in skier visits, resulting in a loss in consumer surplus of approximately $430 million. This loss, coupled by a 10% additional loss in consumer surplus due to reduced skiing experience, would result in a $817 million loss. A 30% loss in consumer surplus would result in a total loss of $1.6 billion per year. These consumer surplus values are values that a person holds on top of the costs incurred, such as ticket prices.

Scenario for skier visits	Scenario for loss in consumer suplus	Number of skier days	Consumer surplus per day	Total annual consumer surplus to skiers ($M)	Total loss in annual consumer surplus to skiers from climate change ($M)
Baseline (2001–2016 average)	No change in value of experience	55,381,272	$77.63	$4,299	NA
Low snowfall years (10% reduction)	No change in value of experience	49,845,053	$77.63	$3,869	$430
Low snowfall years (10% reduction)	10% reduction in consumer surplus	49,845,053	$69.87	$3,483	$817
Low snowfall years (10% reduction)	30% reduction in consumer surplus	49,845,053	$54.34	$2,709	$1,591

Table A4. Annual Loss in Value (Consumer Surplus) to Downhill Skiers and Snowboarders from Climate Change.

A4. METHODS USED IN THE STAKEHOLDER INTERVIEWS

Five of the six interviews with winter recreation communities and case study participants were conducted over the phone during July 2017. Interviewee names, positions, organizations, and interview dates are as follows:

- Sha Miklas, Senior Manager of Guest Services and Sustainability, and Mike Nathan, Sustainability Manager, Arapahoe Basin Ski and Snowboard Area, July 19, 2017
- Steven Hemphill, Director of Marketing and Sales, Sierra at Tahoe, July 20, 2017
- Breanne Torrey, Executive Director, Jackson Ski Touring Foundation, July 21, 2017
- Ben Popp, Executive Director, American Birkebeiner Ski Foundation, July 24, 2017
- Cheryl Paduano, Owner, Soda Springs General Store, July 31, 2017
- Eric Mamula, Mayor, Breckenridge, CO, October 16, 2017

Each interviewee was asked the following series of questions in order to stimulate conversation focused on how their business or organization is affected by climate change, and any future adaptation plans:

1. Recalling the most recent warm or low snowfall year, how did it affect your business?
2. How did that year affect your community?
3. Did you feel well-prepared to deal with that low snowfall year? What, if anything, would you do differently in the future?
4. Do you think bigger businesses are better-prepared to deal with low-snowfall years?
5. Scientists have projected warmer winters with more variable snow conditions in the future. What is your biggest concern regarding these projections?
6. What is the most important thing your business provides for the community?
7. What is your favorite part about the surrounding community?

APPENDIX B. STUDY GAPS, LIMITATIONS AND RECOMMENDED AREAS FOR FUTURE RESEARCH

The study identifies the following omissions, uncertainties and recommended areas for future research.

- The regional economic modeling (IMPLAN) only included changes in downhill skiing and snowboarding, and snowmobiling. If state-by-state visits were collected for other winter sports, they could be added to the analysis to portray a more complete picture of the winter sports contribution to the economy.
- Only IMPLAN data for the United States was obtained (as opposed to IMPLAN data for each of the evaluated states). We used the United States model with state level visitation data to calculate the state contributions.
- The economic contribution values were calculated using input-output analysis, which while this is the standard method for these types of calculations, there are a number of potentially problematic assumptions associated with input-output analysis including:

    - Constant Returns to Scale: The embedded production functions are linear, which means that output increases all inputs are increased proportionally
    - No supply constraints: the model assumes that there is unlimited access to raw materials, this assumption tends to not be a concern when looking at industry contractions only when looking at large industry expansions
    - Fixed input structure: Changes in the prices of inputs do not cause a firm to buy substitute goods. In reality, when faced with changes in the prices of inputs, firms will adapt to these price changes by changing the mix of inputs used
    - Homogeneous sector output: Proportions of all commodities produced by an industry remain the same regardless of total output
    - Homogenous industry technology: Industry uses the same technology to produce output regardless of the output level.
- The calculations in this report reflect economic contributions and does not account for substitution effects and opportunity costs, and thus does not estimate economic impacts. Contribution analysis looks at the gross economic activity of a given industry, and does not account for how spending in one industry may crowd out spending in another industry (Watson et al., 2007).
- Substitution effects also were not examined on impacts to consumer surplus. Some of the loss in consumer surplus will be offset by the consumer surplus of the substituting activity.
- This study did not estimate total Willingness-to-Pay (WTP). While sometimes benefits from expenditures may be added to benefits from consumer surplus, we do not add them in this study, and do not estimate total WTP.
- Snowmobile registrations were not available for all states reported in this study. When snowmobile registrations were not available, we assumed there were zero snowmobile visits.
- Snowmobile visitation numbers were not available. In absence of the snowmobile visitation numbers, we estimated snowmobile visitations from state snowmobile registrations with a conversion factor of 9.64 visits per registration (taken from the methodology from Burakowski and Magnusson, 2012).
- How areas and regions dependent on skiing for their economies adjust in the long term is unknown. It is expected that resort operations and revenue streams will adjust to offset a low snow winter by more non-ski activities.
- The decision to ski needs to be better understood. Skiers respond to ticket prices, amount of disposable income and amount of snowfall, among others. More research could be conducted to understand the influence of all variables involved in the decision to ski. Impacts of economic recessions on the skier behavior are a source of uncertainty (Taks and Ragoen, 2016). We don't know how people will respond to changing conditions and how they view skiing – as a luxury good or a necessity. Demographic trends and other factors should be further examined. The "2017 International Report on Snow & Mountain Tourism" points out that the "evolution of western demographics is a major issue, as well as increased worldwide competition in holiday and leisure activities, the improvement of retention rates and updated ski learning solutions" (Vanant, 2017).
- While a 10% reduction in downhill ski visits was found to have occurred during the five lowest snowfall years, data was not available to examine the reduction that has occurred to cross country skiing and snowmobiling visits. Therefore, a 10% reduction was also applied to these sports in the section on Consumer Surplus (Section 4.3). It is not known if the actual reduction is more or less for each of these sports.
- More research needs to be done on how consumer surplus values for winter sports change with reduced snowfall and higher temperatures, and to examine the differences in value between manmade snow and natural snow for various demographics.
- How skiers adjust behavior and chase after favorable snow conditions is an area that has not been studied and needs to be better understood.
- As lower elevation resorts drop out of the market, larger resorts could pick up their customers. These economic shifts were not examined. Also, this report did not examine if and how skiers may shift recreational visits to Canada, if more favorable conditions lure skiers north. The economic impact of this study is for US recreation.
- How skiing visitation reduces in the future is unknown. Depending on mitigating climate change actions taken over the next few years, the magnitude of ski season length reductions will vary. Timeframes for these expected season length reductions are uncertain. While Wobus et al. (2017) estimate that it is possible that season lengths for some resorts will reduce by 50% in 2050 and 80% in 2090, these projections are based on different combinations of time and climate assumptions. They are plausible outcomes informed by the research.
- Impacts on real estate in and surrounding ski areas were not examined. While a higher, colder resort like Jackson Hole is more likely to retain skiing through the end of the century, some lower, coastal resorts are likely to go out of business. California resorts experienced four years of continuous drought several years ago, just the kind of extreme weather we'd expect to see in a warming world.
- No studies were found which estimate consumer surplus or willingness to pay (WTP) for backcountry touring sports. As this is a growing sport, this is a recommended area of study to help frame discussions in economics

around this sport. Since backcountry recreationists need natural snow, they will likely have higher values for natural snow than a resort skier. Further studies on WTP for cross country skiing and snowshoeing would also help to further understand the value of winter sports.

AUTHOR BIOGRAPHIES

Marca Hagenstad is a consulting economist on energy, the environment and sustainability. She advises in corporate sustainability, especially in regard to transparency and sustainability in the supply chain. She helps companies determine and communicate climate risk and set emission reduction targets. She works with Walmart retailers in implementing 'Project Gigaton,' Walmart's initiative to cut one gigaton of emissions from operations and supply chains. Additionally, Marca conducts Natural Capital Assessments, which disclose full environmental and social impacts of businesses, and reports them to the Dow Jones Sustainability Index. She has consulted to the U.N., World Bank and U.S. EPA in environmental economics, valuing ecosystem services and impacts from climate change. She has also worked for electric utilities and public utility commissions as an evaluator, verifying energy reductions from energy efficiency programs. She has consulted with Anthesis Inc, Navigant Consulting and Abt Associates (formerly Stratus Consulting). Marca holds a B.A. in Economics from University of North Carolina at Chapel Hill and a M.Sc. in Economics from Utah State University. She is a splitboarder and teaches skiing and snowboarding part-time at Loveland Ski Area in Colorado.

Elizabeth Burakowski is a Research Assistant Professor at the University of New Hampshire in the Institute for the Study of Earth, Oceans, and Space and previously conducted research at the National Center for Atmospheric Research in Boulder, Colorado. Burakowski's research focuses on the interactions among climate, land use, and society with a regional emphasis on the Northeastern United States. Liz uses climate models, satellites, and ground-based meteorological data to understand how climate change impacts the Northeastern United States. She collaborates with interdisciplinary scholars to characterize how climate change impacts ecosystem processes, regional economies, and hydrology. Liz is also a member of the New Hampshire Education and Environment Team, providing climate change educational resources to underserved K-8 schools in New Hampshire and is also the state program coordinator for the Community Collaborative Rain, Hail, and Snow Albedo pilot project. Liz holds a B.A. in Geology from Wellesley College, and an M.S. in Earth Science and Ph.D. in Earth and Environmental Science from the University of New Hampshire. Liz has been snowboarding for over twenty years and enjoys backcountry splitboarding in her free time.

Dr. Rebecca Hill is a Research Scientist/Scholar II at Colorado State University. Rebecca is an agricultural and natural resource economist. She received her doctorate in 2012 from Colorado State University and has since worked there as a research scientist. Hill's research focuses on outdoor recreation, agritourism (on-farm tourism) as well as water use and allocation specifically focusing on the western U.S. Rebecca commonly works on economic impact and economic contribution studies including studies looking at the potential economic impacts to the San Luis Valley of Colorado of reductions in aquifer depletion and the economic impacts of decreased streamflows to fisherman on the Fryingpan River, which flows through Basalt, Colorado. Additionally, she is currently serving on the City of Fort Collins Water Board, where in the past she has served as both chair and vice-chair of the board. Rebecca loves living in Colorado and enjoys the outdoor recreation opportunities that Colorado has to offer.

GLOSSARY

Some of the terms used in the report include:

Climate, the measurement of the average and variability of relevant quantities of certain variables (such as temperature, precipitation or wind) over a period of time typically defined as 30-years (World Meteorological Organization).

Climate Change, a statistically significant variation in either the aveage state of the climate or in its variability, persisting for an extended period (typically decades or longer). Climate change may be due to natural internal processes or external factors such as persistent changes to the atmosphere or changes in land use (World Meteorological Organization).

Consumer surplus, the amount a recreationist benefits over what they actually pay to do the recreational activity. It is defined as the difference between the total amount that consumers are willing and able to pay for a good or service and the total amount that they actually do pay (i.e. the market price).

Economic Effects, the economic contribution of winter sports is not limited to direct expenditures. These expenditures affect related sectors of the economy, such as input suppliers and employee spending in other industries. To account for the full economic contribution of winter sports we must analyze direct, indirect and induced effects.

- Direct effects: These effects are a result of actual visitor expenditures which were estimated using average per trip expenditures by category multiplied by the number of visitors. For example, a purchase of a $100 lift ticket would be a $100 direct effect of a visitor.
- Indirect effects: These effects arise due to linkages in the supply chain, such as local industries buying goods and services from other local industries. The cycle of spending works its way backward through the supply chain. For example, the resort from which the skier purchases their lift ticket will use part of that money elsewhere in the economy, such as purchasing supplies or hiring an accountant.
- Induced effects: These effects are a result of employee household spending. For example, when a skier purchases a lift ticket, some small portion of that dollar amount goes toward paying the wages of the sales attendant and other employees, who then recirculates those wages in the form of household purchases of things such as clothing or groceries.

Expenditures, money spent by recreationists at hotels, resorts, restaurants, bars, grocery stores, sporting goods stores and gas stations.

Intermediate inputs, purchase of goods and services purchased from other industries or imported, as part of an industry's production process. With regard to winter snow sports, one example of an intermediate input would be ski bindings, a product which one may directly purchase and consume but are also used as an input to another product – a final set of skis sold with bindings attached. Many textiles are also intermediate goods: a textile such as GORE-TEX® is produced and goes as an input for further finishing. (GDP excludes intermediate goods to avoid double counting.)

Labor income, all forms of employment income, including employee compensation (wages and benefits) and proprietor income (payments received by self-employed individuals and unincorporated business owners.).

Output, total revenues, sales, or total value of the output. It includes intermediate inputs. In my testimony both output and value added are estimated (by the IMPLAN model) and reported on the total economic contribution of the two quantified winter sports to the Colorado economy.

Radiative Forcing, the change in energy at the top of the atmosphere as a result of a forcing imposed on the climate system. If the radiative forcing is greater than zero, this means that there has been a net gain of energy to the climate system, which results in warming. Radiative forcing less than zero indicates a net loss of energy to the climate system, resulting in cooling.

Representative Concentration Pathway (RCP), radiative forcing scenarios that indicate the change in radiative forcing at the top of the atmosphere by 2100. RCPs use the end-point radiative forcing value as a target and work backwards in time to construct a plausible emissions trajectory with corresponding policies and technologies to achieve the target. The associated pathway of annual carbon dioxide and other anthropogenic emissions of greenhouse gases, aerosols, air pollutants, and other short-lived species for each RCP is then used as input to future climate model simulations (from Chapter 4 of the USGCRP National Climate Assessment, 2017).

The four RCP pathways include RCP2.6, RCP4.5, RCP6.0, and RCP8.5. The numbers after RCP indicate the radiative forcing target for each scenario. For example RCP8.5 represents 8.5 W/m2 of radiative forcing by 2100. For context, the current level of anthropogenic (i.e. caused by human activities) radiative forcing is estimated to be 2.4 3 0.6 W/m2. (IPCC, 2013; Chapter 8)

Skier Visit, one person visiting a ski area for all or any part of a day or night for the purpose of skiing, snowboarding, or other downhill sliding. Skier visits include full-day, half-day, night, complimentary, adult, child, season pass and any other type of ticket that gives a skier or snowboarder the use of an area's facility.

Snow water equivalent, or SWE, the amount of water contained in a snow pack. Snow water equivalent is related to snow depth and snow density through the following equation:

SWE = snow depth * snow density

Where snow density is in decimal form (ie: 10% is 0.10). Snowpacks typically have a snow density between 5% (champagne powder) and 40% for slushy wet snow. Ice has a density of around 80-90%, depending on the amount of air bubbles trapped in the ice.