OPPORTUNITIES AND LIMITATIONS FOR ASSESSING SKI AREA VULNERABILITY AND POTENTIAL LOW-SNOW ADAPTATION STRATEGIES IN THE CHANGING CLIMATE

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ABSTRACT

The ski industry in the United States is being threatened by climate change due to rising snowlines, earlier spring melt, and more winter precipitation falling as rain. Snow depth, duration, and timing all are critical factors in the number of skier visit days. The ski industry, worth over $10 billion nationally, is important for the economic vitality of mountain communities in thirty-seven states, but profits decline in warm, dry winters. There are limited climate change mitigation and adaptation strategies available to the industry. Artificial snowmaking is utilized to ameliorate the experience of limited snowfall but is energy-intensive, water-demanding, and has high upfront costs. In addition, artificial snowmaking may be limited by warming winter temperatures and, in certain basins, access to water in the next few decades. In order to better plan future investments in snowmaking equipment and other adaptations, climate projections are needed at a sub-regional scale. However, uncertainty and assumptions increase when downscaling from global climate models. Downscaling with Multivariate Adaptive Constructed Analogues couples climate variables and is capable of accounting for complex terrain, and therefore offers the best projections for natural snow coverage and snowmaking viability by mid-century. (KEYWORDS: ski industry, climate change, adaptation, snowmaking, customer perception)

INTRODUCTION

The western United States is expected to warm by 1-2°C by the middle of the twenty-first century, likely resulting in greatly diminished snowpack (Barnett et al. 2004). Higher temperatures change precipitation regimes from predominantly snow to predominantly rain, increase the rate of snowmelt, and result in earlier spring melt (Jefferson et al. 2008). For mountain communities, changes to the amount of snowfall, duration and consistency of snow cover, and number and timing of snowfall events can significantly impact winter recreation revenue. In a single winter season, recreation and tourism added an estimated $6.17 billion to the economy in twelve western states, and over 85% of that economic impact was directly or indirectly associated with downhill skiing and snowboarding (Burakowski and Magnusson, 2012). Skier visit days have been shown to noticeably decline in poor snowfall years in many ski regions of the world (Elsasser and Burki, 2002; Pickering and Buckley, 2010; Burakowski and Magnusson, 2012). In the western United States, skier visitation decline during low-snowfall years has been greater than 20% in Oregon, New Mexico, Arizona, Washington, and Alaska, but less than 10% in Wyoming, Colorado, California, and Montana (Burakowski and Magnusson, 2012). However, these differences result in vastly dissimilar economic outcomes. For example, the 31% decline in skier visitation from poor snow in Oregon reportedly signifies a $38 million reduction, whereas California's 4.7% decline in skier visit days represents $75 million less to the economy (Burakowski and Magnusson, 2012). This differential vulnerability to poor snow seasons is related to many factors from a range of human dimensions and environmental circumstances. Ski areas have limited adaptation options for reducing vulnerability to climate change. One adaption strategy is making artificial snow, which is already a vital component of the ski industry in many regions of the world (Scott et al. 2006), but it is no cure-all for seasons with poor natural snowfall, especially in regions already experiencing water shortages or high winter temperatures. As Barnett et al. (2004) emphasizes, "current demands on water resources in many parts of the West will not be met under plausible future climate conditions, much less the demands of a larger population and a larger economy." For ski areas in the western U.S. to remain not only operational but also competitive internationally, more resorts will be vying for water for snowmaking. In order to anticipate future water demands by ski resorts, a holistic understanding of ski resort-scale climatological context, ski industry vulnerability, and adaptation challenges is needed.

SKI AREA VULNERABILITY

The differential vulnerability of ski areas or regional ski economies to climate change may at first seem contingent solely upon *climatological variables*, like rising average winter temperatures and reduced total

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precipitation. However, a suite of interacting factors will determine a given ski area's vulnerability, which may or may not influence the vulnerability of another nearby ski area or distant ski region. *Temporal variables*, such as having enough skiable snow at Christmas, New Year's, and Easter holidays; national school holidays; and weekends all winter long directly impact industry profitability (Elsasser and Burki, 2002). In addition, shortened winters decrease the rate of return on infrastructure investments. The rapidity of climate changes felt at a ski area will be contingent upon *site variables*. Location choices, typically made decades ago by ski area founders, influence the microclimate of ski resorts and include base and summit altitudes, elevation gradient, and aspects covered. High-altitude ski resorts may see greater earnings, at least initially, due to reduced competition from nearby low altitude areas (Wolfsegger, 2005). At a larger scale, latitude will influence which ski regions have a reputation of snow-reliability, which in turn will influence *clientele variables*. Customers' interest in skiing will be impacted by insufficient snow coverage, wet or icy snow, or skiing in rain. Perceived or anticipated bad experiences alone can be sufficient to reduce ticket sales. For example, rural operations and those supported by nearby metropolitan centers tend to be visited by skiers that can check snow conditions before driving to the mountain. Large 'destination ski resorts,' on the other hand, receive reservations months in advance and skiers will arrive despite poor snow conditions. However, if winter snow coverage becomes less reliable, destination skiers may travel further or lose interest in skiing altogether. In a survey of Australian skiers in 2007, 90 percent of respondents said they would ski less frequently, travel overseas to ski, or give up skiing if five consecutive winters produced low natural snowfall (Pickering, Castley, and Burtt, 2009). With snowpack in decline world-wide, demand for skiing, especially by beginners and young people, is expected to drop (Elsasser and Messerli, 2001).

Closely influencing clientele choices are *financial variables*, which determine each ski resort's adaptive capacity. Several resort conglomerates own multiple ski areas across the continent and around the globe, so if one resort experiences a poor snow year, profits made at other resorts could absorb any monetary losses. In addition, chain resorts are often seen at higher elevations compared to independent ski hills in the same ski region, and have more capital to allocate to artificially improving snow conditions. Chain resorts also tend to have a diversity of recreation offerings and 'base-area' shops and activities. Independent ski areas will have trouble competing given more frequent warm winters. If current trends continue, independent ski areas are at risk of closing or getting bought up by the conglomerates. Finally, ski industry adaptation is regulated by *legal and policy variables*. Ski areas may have difficulty securing water rights, or increasing volumes on existing rights, in western basins. Many ski areas are located near, or leased on, federal lands and therefore have limitations on adaptation strategies due to environmental laws for federal lands.

ADAPTATION OPTIONS FOR WESTERN U.S. SKI AREAS

While the National Ski Areas Association has developed the 'Sustainable Slopes Program' and the 'Keep Winter Cool' campaign to reduce operators' and customers' greenhouse gas emissions, mitigation measures alone are no hedge against warming winters. Therefore, each ski resort will have to plan its own adaptation strategy to remain operational and continue attracting customers. Most resorts already have snow grooming for safety and enjoyment of ski runs. Strategic grooming has the added advantage of creating a firmer 'base' that will take longer to melt and reduces the chance of encountering rocks on thin snow (Agrawala, 2007). Moving to higher terrain and expanding glacier skiing may be two viable options in the European Alps (Agrawala, 2007), but few ski resorts in North America can extend to higher terrain as most already reach to mountain summits. A few however, like Whitefish Mountain Resort in Montana, have been able to expand north-facing terrain, but this option will be highly influenced by surrounding land ownership and permitting on federal lands. As snow cover seasons begin later, a good case could be made to revise the ski area operation window. In many regions, snow cover extends late into the spring at high elevations. However, clientele perception and holiday schedules require resorts to be open by Christmas to capture the peak winter tourist season, and convincing customers to recreate on snow in April is difficult. In winters with very low natural snowfall, resorts can still attract visitors with alternative recreation and entertainment offerings. This has proven profitable for high elevation resorts in Australia as low elevation areas experienced notable reductions in visitors (Pickering, 2011). Many resorts around the world have diversified their wintertime offerings, or have invested in year-round recreational activities but research suggests that skiers will still want to ski, thus alternate attractions will not replace the demand for skiable terrain (Elsasser and Messerli, 2001).

In order to create skiable terrain where it would otherwise not exist or be unsafe, the most widely used adaptation strategy in the ski industry is artificial snowmaking (Scott and McBoyle, 2007). Snow guns have proven capable of extending the snow cover season by 55-120 days, on average, at ski areas in eastern North America (Scott et al., 2006). To cover an acre of ski slope with 30 cm of snow (the convention used for minimum operational threshold) requires roughly 681,300 liters of water. In drought-riddled Australia, there is already competition for water between the ski industry, agriculture, municipal use, and power generation (Pickering and Buckley, 2010), and ski resorts in the arid western U.S. are confronted with similar contentions. The high upfront installation costs as well as high energy and labor costs of making snow will exacerbate the differential vulnerability of small, independently-run resorts versus chain resorts. Snowmaking technology continues to advance, allowing resorts to produce snow at warmer temperatures and on automated, weather-sensing systems. Ski areas in the western U.S. are also getting more creative in sourcing their water for snowmaking, from catching melting snow in ponds to recycle for continuous use throughout the season, to making snow from treated effluent. As global temperatures increase, the need for snowmaking will increase while the number of nights cold and humid enough for snowmaking decrease (Pickering and Buckley, 2010).

METHODOLOGICAL CHALLENGES AT THE SKI-AREA SCALE

Adaptation decisions are complicated by interannual variability, both in averages and extreme events. While a single, well-timed extreme snowfall event during the peak Christmas and New Years' holiday period may 'save' a resort during an otherwise dry or warm year, relying on or planning for such events is impossible. Alternatively, several extreme events during midweek, non-holiday periods may still result in decreased total annual skier visit days. Adaptation planning at ski resorts must be highly site-specific and should consider 50 years or more into the future. Arriving at temperature and precipitation projections at the necessary spatial scales needed for this type of planning is challenging for several reasons. First, uncertainty from global climate models is carried through to downscaled regional climate models, with additional uncertainty added while trying to capture physical processes at the smaller scale (Minder, 2010). Spatial analyses often violate the modifiable areal unit problem and commit ecological fallacy when aggregating to various areal units in potentially arbitrary groupings, or when scaling between aggregated data to individual units (Amrhein, 1995). Furthermore, downscaling procedures often are not flexible for complex topography, nor capable of handling dependent variables, thus violating basic principles of meteorology (Abatzoglou and Brown, 2012). To avoid violations and reduce uncertainty, physically-based snowpack models are increasingly proving robust at the mountain-range scale (Minder, 2010), but these do not help ski resort operators plan for snowmaking needs in terms of acreage. Finally, historical records reflecting the exact conditions at a ski area is typically lacking. Ski areas have various methods of recording snowfall, but reported amounts are often primarily for marketing purposes. Without standardized recording systems over time or between ski areas, using these records in scientific analyses would be insufficient without additional data sources. Using nearby SNOTEL and/or Cooperative Observer Program stations should reflect the range of conditions at the ski area in terms of elevation range and aspect if snowmaking requirements are to be anticipated. If using multiple types of stations for interpolation, a high density of stations is required and care must be taken to ensure all stations have followed the same quality control procedures over time (see Kunkel et al., 2007). Using analogues from past low-snow years to determine potential snowmaking needs and anticipate customer response has several advantages (Dawson, Scott, and McBoyle, 2009), but estimates are based on persistent hydrologic and socio-economic conditions through time.

CONCLUSION

To anticipate and plan for the economic impacts of climate change for ski regions, as well as for the water conflicts arising from the most commonly utilized adaptation strategy, changes in temperature and precipitation by mid-century first must be determined. Downscaling from GCMs with Multivariate Adaptive Constructed Analogues is capable of accounting for complex terrain, which is important for mapping future snow cover in mountains, where the interaction of local topography and atmospheric patterns produce unique local conditions, and has the additional advantage of coupling climate variables to avoid unrealistic predictions (Abatzoglou and Brown 2012).

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