Climate Change and the Sustainability of Ski-based Tourism in Eastern North America: A Reassessment

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Climate Change and the Sustainability of Ski-based Tourism in Eastern North America: A Reassessment

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The sustainability of skiing tourism has been repeatedly identified as vulnerable to global climate change. Earlier research, however, did not fully consider snowmaking as an adaptation strategy, which is integral to the ski industry in eastern North America. This study examines how it reduces the vulnerability of ski areas to climate change in six study areas by developing a model to assess the impact of climate change on season length, probability of operations during critical tourism periods, snowmaking costs, and water requirements. It suggests that in the 2020s, even the warmest climate change scenario poses only a minor risk to four of the six ski areas. The reassessment for the 2050s period found that only the warmest scenario would jeopardise the sustainability of three of the ski areas examined. The confluence of climatic changes and other non-climate business factors will advantage certain ski areas and likely result in further contraction and consolidation in this regional ski market.

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Introduction

Weather and climate strongly influence tourism and recreation activities throughout the world. For more than 20 years, researchers have examined the potential implications of climate change for this sector (Scott *et al.*, 2005). Wall (1992), Perry (2000), Agnew and Viner (2001), and Scott (2006) provide recent overviews of the potential implications of global climate change for the tourism sector in various regions of the world. Together with Butler and Jones (2001), World Tourism Organisation [WTO] (2003) and Gösling and Hall (2006), these authors have expressed concern that our understanding of the potentially profound impacts of global climate change on this important economic sector remains very limited.

The winter tourism industry, in particular alpine skiing, has been repeatedly identified as potentially vulnerable to climate change (Abegg *et al.*, 1998; Wall, 1992; WTO, 2003) and has received greater attention from researchers. König and Abegg (1997) and Elsasser and Bürki (2002) indicated that the Swiss tourism industry has not fully recovered from low snowfall years during the late 1980s and project that climate change in the 21st century could jeopardise the industry by reducing the number of 'snow reliable' ski resorts from 85% to between 44% and 63%. In Austria, Breiling *et al.* (1997) estimated that changes in snow cover could put several major low elevation resorts (including Kitzbühel) at risk, resulting in winter tourism revenue losses of 10%. With various economic multipliers included, the projected losses approach 30%, or roughly 1.5% of Austrian GDP. Fukuskima *et al.* (2003) conducted an assessment of the Japanese ski industry (61 ski areas) and estimated that increasing winter temperatures by 3°C would reduce skier visitation by 30%. Ski areas in the southern regions were most vulnerable with skier visits declining by 50% assuming winter temperatures warm by just 2°C. The impact of climate change was projected to be negligible in some northern high altitude ski areas. Galloway (1988) examined the impact of changes in Australia's snowfields for its three main ski areas (Perisher, Hotham and Mt Selwyn) and projected that the mean ski season would decline from 54 to 81%, rendering the ski areas unprofitable under climate change. A more recent study in Australia that incorporated snowmaking (Hennessy *et al.*, 2003) concluded that with sufficient investment in snowmaking systems, the six ski areas examined would be able to manage the impact of projected climate change until at least 2020.

The North American skiing industry is also highly weather-sensitive and experiences considerable inter-annual variability in operating conditions. For example, between 1982–1983 and 2001–2002 the length of the ski season in the major ski regions of the US has varied as follows: Pacific 109–151 days, Rocky Mountains 121–145 days, Midwest 78–105 days, Northeast 101–136 days and Southeast 78–110 days (National Ski Areas Association, NSAA, 2002). In recent years, recognition of the climate change issue by the North American skiing industry has been increasing.

North American ski area operators have begun to acknowledge and confront their potential vulnerability to climate change. The National Ski Areas Association (NSAA) in the US launched the 'Keep Winter Cool' campaign during the 2002–2003 ski season to educate ski resort visitors about climate change and member ski areas have begun to invest in a range of energy efficiency and alternative energy projects to reduce their greenhouse gas emissions. As Best (2003: 57) stated, 'This is a remarkable turnaround for an industry that just five or six years ago had largely shrugged off global warming'. The greater interest in climate change is partly a function of press coverage of research that has identified significant vulnerabilities in eastern North American sites to even modest changes in temperature and precipitation.

The earliest studies on the potential impact of climate change on the North American ski industry were completed in the Great Lakes region. Harrison *et al.* (1986), using the climate change scenarios of that period, found that the ski season to the north of Lake Superior would be reduced by 30% to 40%. Skiing conditions would also be curtailed in central Ontario resulting in the contraction or possible elimination of the ski season (40% to 100% reduction). Skiing in the Lower Laurentian Mountains of Québec was projected to experience a 40% to 89% reduction in season length (McBoyle & Wall, 1992). Lamothe and Périard Consultants (1988) similarly projected that the number of skiable days in southern Québec would decline by 50% to 70%. Comparable results were also projected for US ski areas in the Great Lakes region. For example, Lipski and

McBoyle (1991) estimated that the Michigan ski season would be reduced by 30% to 100%. Using similar techniques as the aforementioned studies, Badke (1991) examined Killington, Vermont, and projected that the ski season would contract by an estimated 56% to 92%. An important limitation of these first generation climate change impact studies was the inadequate consideration of snowmaking as a climate adaptation strategy (Scott *et al.*, 2002, 2003; and Hennessy *et al.*, 2003 being the exceptions).

Snowmaking has become an integral component of the ski industry in eastern North America during the past 30 years. In order to reduce vulnerability to climate variability, ski areas in eastern Canada and the Midwest, Northeast and Southeast regions of the US have invested million of dollars in snowmaking technology and operations. Based on a review of ski area websites and other marketing materials, virtually all ski areas in Ontario have snowmaking systems that cover 100% of the skiable terrain. In Québec, all ski areas have snowmaking systems, although the proportion of skiable terrain covered by snowmaking varies (usually in the 50% to 90% range). In 2001–2002, all of the ski areas in the Northeast, Southeast and Midwest ski regions of the United States had snowmaking systems. The average skiable terrain covered by snowmaking varied in these regions, from 62% in the Northeast region, to 95% and 98% in the Southeast and Midwest regions, respectively (NSAA, 2002). The former director of the Ontario Snow Resort Association emphasised the importance of snowmaking in the region when he stated (MacDonald, 1988), 'If we had to rely on snow from the heavens, the ski industry would be bankrupt'. In an even earlier reference, the president of a major ski area in Vermont commented, 'We learned one thing this winter [1979–1980]: how to operate entirely on machine-made snow' (Robbins, 1980: 81).

Scott *et al.* (2002) was the first study to fully integrate snowmaking as an adaptation strategy to climate change and found substantially lower climate change impacts relative to previous assessments of the ski industry in central Ontario. Using a range of climate change scenarios recommended by the United Nations Intergovernmental Panel on Climate Change (IPCC), Scott *et al.* (2003) projected that, with current snowmaking capabilities, a 7% to 32% reduction in average ski season length in central Ontario would occur in the 2050s. With technologically improved snowmaking capabilities, modelled season losses were reduced to between 1% and 21%. The findings clearly demonstrated the importance of snowmaking, as the vulnerability of the ski industry was reduced relative to previous studies that projected a 40% to 100% loss of the ski season in the same study area for approximately the same timeframe (~2050s) (McBoyle & Wall, 1992). Scott *et al.* (2002, 2003) subsequently recommended that similar reassessments be completed in areas of eastern North America where previous, and widely cited, climate change studies projected very large impacts on the ski season.

Building on this recommendation and the methods developed by Scott *et al.* (2002, 2003), this study examined the impact of projected climate change on four factors that affect the sustainability of the ski industry in eastern North America: ski season length, probability of being operational during economically critical periods (Christmas–New Year and spring school break holidays), costs of additional snowmaking, and the water requirements for additional snowmaking.

By examining the potential impact of projected climate change with a common methodology, this assessment provides insight into the relative vulnerability of ski areas at each study area.

Methods

Study area

The ski areas used in the study are located in Ontario and Québec, Canada, and Michigan and Vermont, USA (Figure 1). Table 1 provides an indication of the relative size and economic significance of the ski industry by province or state. In 2002–2003, over 10 million skier visits occurred in the provinces of Ontario and Québec (Canadian Ski Council, 2003), representing 56% of the Canadian ski market. Ski areas in Québec directly employed 13,300 people and generated an additional 18,700 indirect jobs in related businesses (lodgings, restaurants, bars, boutiques, service stations, etc.) (Archambault *et al.*, 2003). Although equivalent information was not available for Ontario, the overall economic impact of the industry is estimated to be in the range of US$100 million (it has approximately one-third the skier visits as the Québec industry) to upwards of US$400 million (it is larger than the Michigan ski industry in terms of skier visits). The 2.2 million skier visits to Michigan resorts during the 2000–2001 season produced an estimated US$437 million impact in the state and supported 4900 direct jobs (Stynes & Sun, 2001). The broader Midwest ski region, including Michigan, recorded 7.6 million skier visits in 2000–2001 (NSAA, 2002), representing 13% of the US ski market. The Vermont ski industry is even larger, with 4.5 million skier visits generating over US$1 billion in economic activity during the 2000–2001 ski season (Smith, 2001). The broader Northeast ski region centred on the State of Vermont, received 13.7 million skier visits in 2000–2001 (NSAA, 2002), representing 24% of the US ski market. As these statistics indicate, the combined ski industries within the study area are significant elements of the North American ski industry and local economies.

As indicated, snowmaking is an expensive yet integral component of the ski industry in eastern North America that has compensated for the inherent

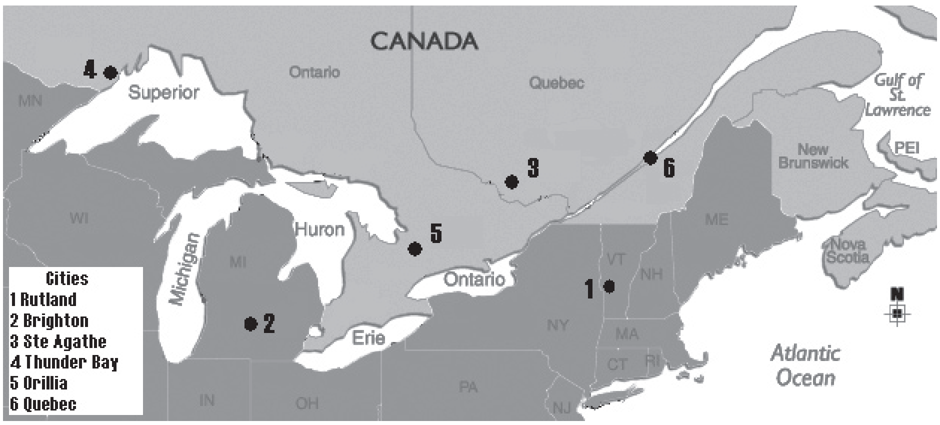

Figure 1 Location of study areas

Table 1 Characteristics of the ski industry in the study area

Province / State	*Skier visits (millions)*	*Economic size of industry (millions US$)*
Michigan	2.2[1]	$437[1]
Ontario	3.2[2]	no data
Québec	6.9[2]	$330[2]
Vermont	4.5[3]	$1,000[3]

[1] 2000–2001 ski season (Stynes & Sun, 2001)
[2] 2002–2003 ski season (Archambault *et al.*, 2003)
[3] 2000–2001 ski season (Smith, 2001)

variability of natural snowfall. Several ski areas in Ontario and Michigan have sophisticated snowmaking systems that, even without any natural snowfall, can make the majority of ski runs operational in less than a week, given sufficiently cold temperatures for snowmaking. The average cost of snowmaking at ski areas in the Northeast ski region was US$728,000 in 2001–2002 (for an average of 252 acres) (NSAA, 2002).

Climate data and climate change scenarios

The selection of the climate stations for this study was based on two considerations: the proximity of the climate station to the ski area(s) of interest (both in terms of distance and elevation) and the length and quality of the climate record (minimally 1961–1990). For each location a climate station was chosen to represent the elevation of the base of the nearby ski area, because this is the most vulnerable portion of the ski area to climatic change. The climate stations and associated ski areas are listed in Table 2. Complete records of daily temperature (maximum, minimum and mean) and precipitation (rain and snowfall) were obtained for the 1961 to 1990 baseline period. The climate data for Canadian locations were obtained from the Meteorological Service of Canada and the data for US locations were obtained from the National Climatic Data Center. The December-January-February (DJF) mean temperature and precipitation for the 1961–1990 (1970s) baseline period are presented for each location in Table 3. The mean DJF temperature at the four Canadian locations is substantially colder than the two more southern US sites. The two study areas in the province of Québec also received substantially more precipitation in the DJF period than three of the other locations (three times that of Thunder Bay and twice that of Brighton), suggesting that these two sites are climatically advantaged for winter tourism relative to the other locations in this study.

The climate change scenarios used in this analysis were obtained from the Canadian Climate Impact Scenarios project (CCIS, 2003) and were constructed in accordance with the methodological recommendations of the United Nations Intergovernmental Panel on Climate Change (IPCC) Task Group on Scenarios for Climate Impact Assessment. A total of 25 possible scenarios representing a broad range of global climate models and future emission levels were considered for this analysis. Each scenario consists of single estimates of possible temperature and precipitation change for each month during three future periods: the 2020s (average changes over 2010–2039), the 2050s (average changes

Table 2 Climate stations representative of ski areas

Study Area	*Climate station*	*Lat (°N)*	*Long (°W)*	*Elevation (masl)*	*Nearby ski area*	*Elevation (masl)*	*Skiable acres*
Brighton, Michigan	Brighton Bishop A	42.6	83.5	235	Mt Brighton	335–405	130
Orillia, Ontario	Muskoka A	44.6	79.2	282	Horseshoe	312–406	61
Québec City, Québec	Québec City A	46.5	71.2	74	Mont Sainte-Anne	175–800	428
Rutland, Vermont	Cornwall	43.6	73.1	400	Killington	355–1293	1182
Ste Agathe-des-Monts, Québec	Ste Agathe-des Monts	46.3	79.2	395	Mt Tremblant	265–915	610
Thunder Bay, Ontario	Thunder Bay A	48.2	89.2	199	Loch Lomond	213–442	90

Table 3 High and low impact climate change scenarios (DJF)

Study area	*Baseline 1970s*		*2020s*				*2050s*			
	Temperature	*Precipitation*	*CCSRNIES-A11*		*NCARPCM-B21*		*CCSRNIES-A11*		*NCARPCM-B21*	
	(°C)	*(mm)*	*T△ °C*	*P△ %*	*T△ °C*	*P△ %*	*T△ °C*	*P△ %*	*T△ °C*	*P△ %*
Brighton, Michigan	–3.9	45.7	2.8	6	0.9	–1	7	4	1.7	1
Orillia, Ontario	–9	85.9	3.1	7	1.4	1	8.2	15	2.2	1
Québec City, Québec	–10.8	91.1	2.8	7	1.6	5	7.9	16	2.3	7
Rutland, Vermont	–5	63.5	2.8	10	1.4	5	7.1	14	1.9	8
Ste Agathe-des-Monts, Québec	–11.5	94.2	2.8	10	1.4	4	7.4	14	1.9	6
Thunder Bay, Ontario	–13	32.4	3.2	–1	1.4	9	8.7	8	2.2	11

over 2040–2069) and the 2080s (average changes over 2070–2099). Changes are relative to the 1970s baseline (average 1961–1990). In order to limit the number of scenarios to a manageable number, while still considering the full range of potential climate futures, scenarios representing the upper and lower bounds of change in December-January-February (DJF) mean temperature and precipitation were selected for analysis. The five scenarios analysed included: Japanese Centre for Climate Research Studies Scenario A11 (CCSRNIES-A11), European Centre/Hamburg Model 4 Scenario A21 (ECHAM4-A21), Canadian Centre for Climate Modelling and Analysis Scenario A2x (CGCM2-A2x), Hadley Centre for Climate Prediction and Research Scenario A1F1 (HADCM3-A1F1) and USA National Center for Atmospheric Research Scenario B21 (NCARPCM-B21). For the purposes of concise presentation, only the results of two climate change scenarios, a low impact scenario (least climate change) and high impact scenario (greatest climate change) are reported. The mean DJF temperature and precipitation change of the low (NCARPCM-B21) and high (CCSRNIES-A11) impact scenarios are compared for the six study areas in Table 3. Both scenarios are equally likely to occur and represent the range of climatic futures that the ski industry may face over the next 50 years. Additional information regarding greenhouse gas emissions and other assumptions supporting each scenario may be found in IPCC (2000).

Results for the 2020s are of greatest relevance to ski area operators owing to the smaller range in uncertainty of climate change projections and because they are within the lifetime of existing infrastructure and long-term business and investment planning horizons. Scenarios for the 2050s and 2080s were also analysed. The 2050s scenarios are reported here as indicators of the long-term risk of climate change to the ski industry in the study areas. The 2080s are not reported on because ski industry stakeholders do not consider them relevant to contemporary planning.

To produce daily temperature and precipitation data for the two climate change time series (2010–2039 and 2040–2069), monthly climate change scenarios from the two GCM scenarios were downscaled using the LARS stochastic weather generator (Semenov *et al.*, 1998). The weather generator was parameterised to the climate station at each location using climate data from the baseline period 1961–90.

Snow modelling

Daily temperature and precipitation data downscaled using LARS were used to drive a locally calibrated snow depth model that was based largely on methods used to develop the *Canadian Daily Snow Depth Database* (Brown & Braaten, 1999) and *Water Balance Tabulations for Canadian Climate Stations* (Johnstone & Louie, 1983). The technique involved estimating three parameters: (1) amount of precipitation that falls as snow and rain, (2) snow accumulation, and (3) snowmelt. Historical precipitation data were analysed for each station to determine the minimum, maximum and/or mean daily temperature thresholds that best-predicted observed snowfall amounts over a 30-year period. Snowfall was added to the snow pack assuming a constant snow pack density of 400kgm^{-3}. This is an acknowledged compromise, as the density of both natural and machine-made snow can vary substantially and the ability to vary the density of snow during snowmaking is a considerable asset to ski areas. A US Army Corps of Engineers (1956) equation was used for daily snowmelt calculations:

$$M = k[(1.88 + 0.007R)\ (9/5T) + 1.27],\ T > 0$$

where:
M is snowmelt water (mm day $^{-1}$)
k is a locally calibrated snowmelt factor
T is mean daily air temperature (°C); and
R is mean daily rainfall (mm).

Note: T and R were generated for each future time series (2010–2039, 2040–2069) with the LARS weather generator.

Because only daily rainfall and mean temperature data are required by the equation, it was found to be suitable for the current study. The locally calibrated snowmelt factor, added to the original equation by Brown and Braaten (1999), was excluded (i.e. assumed to equal 1.0) from this analysis since it represents a separate, station-specific empirical correction factor that could confound results and make comparisons among ski areas more difficult.

The model was evaluated by comparing the predicted and observed number of days with snow and days when snow depth met or exceeded the assumed operational requirement (30 cm) over the 1961–1990 baseline period. The model predicted the occurrence of over 90% of the observed days with snowfall at all locations. The model underestimated the number of days meeting the 30 cm snow depth criterion by less than 3% at all locations with the exception of Thunder Bay, where estimates were 8.9% less than observed. These results suggest that the model is suitable for comparing potential shifts in the statistics of 20 or 30-year periods; however, comparisons of individual years is less reliable.

Ski operations modelling

To complete the modelling of snow conditions at each ski area, a snowmaking module was integrated with the snow cover model. The estimated technical capacities (e.g. minimum temperature at which snow can be made economically, daily snowmaking capacity and decision rules for the snowmaking module [e.g. snowmaking season start/end, target snow pack depth to maintain] were derived from communications with ski industry stakeholders and ski industry literature and are summarised in Table 4.

As indicated, climate stations for this analysis were chosen to represent the elevation of the base of the nearby ski area(s), because this is the most vulnerable portion of the ski area to climatic change. For the three ski areas that have a vertical drop of less than 300 m (Brighton, Orillia, Thunder Bay) the differences in climate and snowmaking conditions at the base and summit of the ski area are minor and therefore are considered representative of the entire ski area. The snowmaking analysis at the three ski areas with vertical drops of more than 600 m (Québec City, Rutland, Ste. Agathe-des-Monts) is only considered representative of the base and lower regions of the ski area and, at higher eleva-

Table 4 Standardised model parameters for the hypothetical ski area[1]

Snowmaking Parameters	*Skiable Day Parameters*
• Start Date = 22 November (Julian day 326) • End Date = 30 March (Julian day 90) • Snow base to maintain until Julian day 90 = 60 cm • Temperature required to start snowmaking = –5°C	• Minimum snow base = 30 cm • Maximum temperature = 15°C • Maximum liquid precipitation (over two consecutive days) = 20 mm
• Snowmaking capacity = 10 cm / day • Power cost as percentage of total snowmaking costs = 32%	*Ski Season Parameters* • Analysis period = 1 November to 30 April • Christmas–New Year holiday = 23 December to 3 January
Ski Area • size = 250 acres	• Spring school break holiday = third week of March

[1] All of the parameters used in this standardised analysis can be adjusted in the model to tailor the model to the specific characteristics of an existing ski area (microclimate factors, skiable acres, snowmaking capacity, snowmaking costs/acre, start/end of ski season and snowmaking period, key tourism periods)

tions, likely underestimates natural snowpack and overestimates snowmaking requirements.

Climate change will directly affect future snowmaking activities in four ways: (1) less natural snow will require more snowmaking, (2) greater snowmelt due to warmer average temperatures will require more snowmaking, (3) warmer average temperatures will reduce the duration and number of opportunities for making snow and increase the costs of snowmaking, and (4) changes in precipitation and hydrologic regimes (more runoff during winter months) may adversely or positively affect water supply for snowmaking. This study incorporates the impact of the first three factors on snowmaking requirements, but modelling changes in water supply for snowmaking is beyond the scope of this study and it is therefore assumed that unlimited water supply is available for snowmaking at each ski area.

The climatic criteria for a skiable day were adopted from Scott *et al.* (2003), which were derived from an examination of 20 recent years of daily observed ski operations data from ski areas in the province of Ontario and consultations with ski industry stakeholders. Ski areas were assumed to be closed if any of the following conditions occurred: snow depth less than 30cm, maximum temperature greater than 15°C, or when two-day rainfall amounts exceed 20 mm. It is acknowledged that these criteria may differ slightly in the other ski regions included in this analysis, but data were not available to make regional adjustments.

Ski season length is only partially determined by climatic criteria. Although much more difficult to define and model, socio-economic and business decision-making factors also significantly influence ski area operations. For example, ski area managers may not always abide by the decisionmaking rules that define our model. They may decide to open the ski area with less than the preferred 30 cm snow base because a nearby competitor has opened or started making snow before an optimal temperature is reached in order to open on a weekend. We recognise that these business decisions can never be fully captured in an abstracted model.

While snowmaking is an effective climate adaptation strategy, it is not without associated challenges; both capital and operating costs are substantial and there are large water requirements. Snowmaking costs represent a sizable share of annual operating expenses of ski areas in eastern North America. During the 2001–2002 ski season, snowmaking represented 5.6%, 6.7% and 4.5% of the total operating costs[1] in the Northeast, Southeast and Midwest ski regions, respectively (NSAA, 2002). The cost of snowmaking at individual ski areas varies according to the efficiency of the snowmaking system, power and labour costs, and climatic conditions (temperature, humidity, wind). For example, the average proportional cost of power for snowmaking operations, relative to labour and other costs, in the Northeast ski region over the last five years varied from 52% in 2001–2002 to 32% in 2000–2001 (NSAA, 2002).

The additional snowmaking requirements and greater energy demands to make snow at warmer average temperatures could be sufficiently great to affect the profitability of some ski operations; particularly when coupled with shorter average operating seasons (reduced revenue). The snowmaking cost component of this analysis was based on Stanchak (2002) and data from NSAA (2002). The former conducted a comparative analysis of the power costs of snowmaking systems with three common snowmaking gun types (ground-based air water snow gun, low air tower snow gun, and ground-based electric fan snow gun). Stanchak's (2002) comparison provided a minimum and maximum cost of power to produce an acre-foot of snow at different temperatures. In this study, the power costs for snowmaking were calculated each day by multiplying the volume of snow produced by the cost range defined by Stanchak (2002) at the daily minimum temperature and then summed to estimate the average annual cost. Total annual snowmaking costs were determined by applying ratios of power, labour and other costs of snowmaking for the Northeast, Southeast and Midwest ski regions based on NSAA (2002) data for the past five years..

Large quantities of water are required to support snowmaking activities. Many ski areas have built reservoirs to supply their snowmaking needs; however some ski areas draw water from lakes and streams. Water withdrawals from natural water bodies and the potential impact on fish and other aquatic habitat are important environmental concerns in some areas. This analysis calculates how changes in snowmaking patterns would affect water requirements. Ski areas have tremendous control over the density of machine-made snow, including the ability to make very dense snow to increase the durability of the snow base. The use of a single snow density in this model is a simplification that likely causes the model to underestimate the amount of water used in snowmaking.

Climate change assessment approach

In order to compare the relative impact of projected climate change at the six locations selected for this study, it was decided to model the impact of climate change on a standardised hypothetical ski area, identical in size (skiable terrain) and snowmaking capacities, at each study area (Table 4). This effectively isolates the importance of climate and projected climate change at each location, rather than the relative advantages of the specific snowmaking systems in place at each ski area.

Although the start and end dates for snowmaking were based on regional averages, some ski areas attempt to open earlier and continue to make snow into April to extend the season. The target snow base level was derived from observed management practices at major Ontario ski areas during the past 10 years. The technical capacity of the snowmaking system reflects the snowmaking capabilities of advanced snowmaking systems in place at some ski areas in the region. Not all ski areas have this capacity currently, but with investment could develop similar capabilities. Although snow can be made at temperatures of approximately –1°C (with low humidity levels and special snowmaking additives like 'SnowMax'®), ski area operators and snowmaking equipment manufacturers generally identify –5°C as a threshold for efficient snowmaking. The proportional cost of power for annual snowmaking operations (32%), relative to labour and other costs, is conservative relative to the 52% and 48% power costs recorded in the Northeast and Southeast ski regions in 2001–2002 and 2000–2001, respectively.

The results of this analysis are only valid for the climate station location and surrounding areas that exhibit similar climatological characteristics. The ski areas in the vicinity are sometimes several kilometres away and may have microclimatic features that enhance or reduce their natural snowfall or suitability for snowmaking. Results should not be extrapolated to the entire province or state. Analysis of a larger sample of ski areas would be required to assess the full implications of climate change for each jurisdiction represented in this study and the implications for competitive relationships within this regional ski market.

Results

Projected changes in natural snow conditions

Simulations of baseline and future natural snow conditions were prepared for the six study areas. Figures 2 and 3 illustrate the average daily snow depth for the baseline (1970s) period and both the low and high impact climate change scenarios for the 2020s and 2050s at the Québec City and Brighton study areas. Two important observations about the baseline period should be made. First, if a 30 cm snow base were considered the operational threshold for skiable conditions, the average natural ski season at each location differed considerably between the northern and southern illustrative study areas during the baseline period: approximately 99 days at Québec City and six days at Brighton, Michigan. Considering the average ski season in the Midwest ski region (where the Brighton case study is located) from 1983–1984 to 2001–2002 was 93 days, the importance of snowmaking for extending current ski seasons is apparent.

Second, the baseline period (1961–1990) already includes the warming trend observed since the early 1970s in much of the study region. Hamilton *et al.*'s (2003: 68) analysis of the historical contraction and consolidation of the ski industry in the State of New Hampshire (also in the Northeast ski region), concluded that

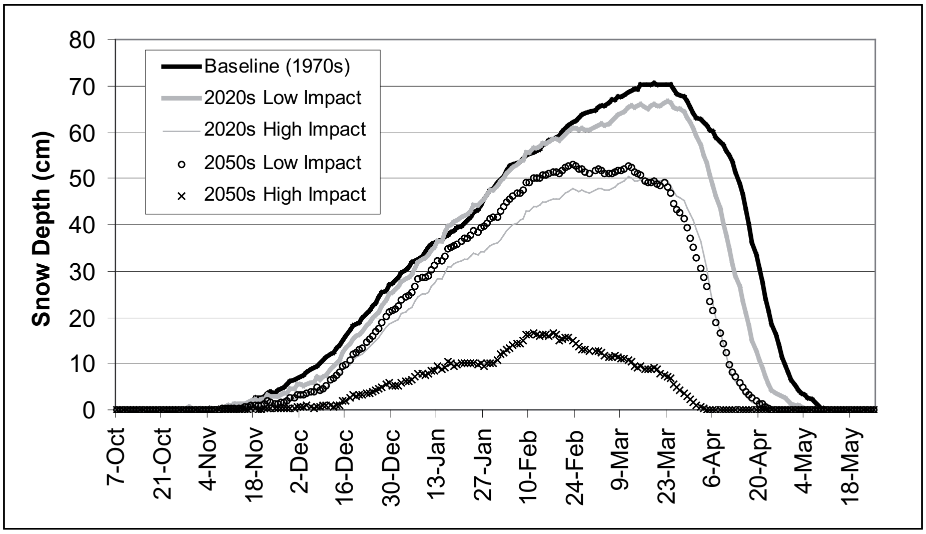

Figure 2 Modelled natural snow conditions at Québec City, Québec

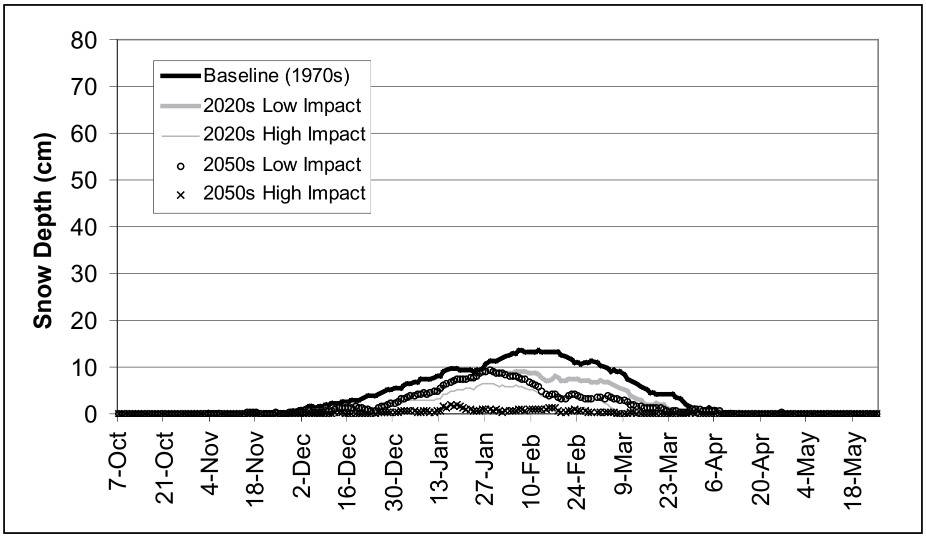

Figure 3 Modelled natural snow conditions at Brighton, Michigan

the 'Extinction of the small (ski) areas, and concentration of the (ski) industry into a few high-investment, high-elevation northern areas, was driven partly by a changing climate'; specifically the warming trend since 1970 and related reduction in natural snowfall.

With the exceptions of Thunder Bay and Québec City in the low impact scenario for the 2020s, all of the future scenarios lead to substantive reductions in both the duration of the natural snow cover season and the average snow depth modelled for the study areas.

Projected changes in ski season length

Table 5 presents the modelled baseline ski season (in days) at the six study areas as well as the projected impact of climate change in the 2020s and 2050s. The modelled average baseline ski season was the longest at more northerly locations (Québec City, 160 days; Ste Agathe-des-Monts and Thunder Bay, 163 days), while the most southerly and lower elevation study area had the shortest average baseline ski season (Brighton, 114 days).

The projected impact on the average ski season length differed substantially among the high and low impact climate change scenarios and across the six study areas (Table 5). Unlike earlier climate change impact studies that only examined doubled-carbon dioxide conditions (~2050s based on current emission trends), this study analysed the impact of climate change scenarios for the early decades of this century, which are the most relevant to business planning and investment timeframes. The 2020s low impact climate change scenario produced minor impacts on the length of the average ski season, with less than a 5% reduction at all six locations. Under the much warmer high impact 2020s scenario, more

Table 5 Modelled ski season length

Study Area	*Baseline average (days)*	*Climate change scenario*	*% Change from 1970s baseline*		*% Change in earlier studies (~2050s)*
			2020s	*2050s*	
Brighton, Michigan	114				–59 to –100[1]
		Low Impact	–5	–12	
		High Impact	–28	–65	
Orillia, Ontario	149				–40 to –100[2]
		Low Impact	–3	–8	
		High Impact	–19	–46	
Québec City, Québec	160				–42 to –70[3]
		Low Impact	–1	–5	
		High Impact	–13	–34	
Rutland, Vermont	119				–56 to –92[4]
		Low Impact	–5	–14	
		High Impact	–25	–60	
Ste Agathe-des-Monts, Québec	163				–48 to –87[3]
		Low Impact	0	–4	
		High Impact	–13	–32	
Thunder Bay, Ontario	163				–30 to –40[2]
		Low Impact	–2	–4	
		High Impact	–17	–36	

[1] Lipski and McBoyle (1991)
[2] Harrison *et al.* (1986)
[3] Lamothe and Périard Consultants (1988)
[4] Badke (1991)

substantive impacts are projected at the two most southern locations (Brighton –28% and Rutland –25%) relative to other locations where projected season losses ranged from 13 to 19%.

The range of projected impacts on the average ski season length increased substantially in the 2050s, portraying two distinct operational futures for the six ski areas examined. Once again, only minor impacts occurred in the low impact scenario, with the average ski season length diminishing by less than 10% at four of the six study areas. Only the two most southerly locations, Rutland and Brighton, had losses of greater than 10% (14% and 12% respectively). Notably, the range of season losses projected under the 2050s low impact scenario were less than the high impact scenario for the 2020s and remained within the range experienced throughout the baseline. The 2050s high impact climate change scenario presents a much more challenging scenario for the sustainability of the ski industry. Large season losses were projected for three of the study areas (Orillia –46%, Rutland –60%, Brighton –65%). It is questionable whether ski operations at Orillia and Brighton could be sustainable under the high impact climate change scenario of the 2050s. Rutland is a different situation. This analysis indicates ski conditions at the base of the ski area will be difficult to maintain, but because skiing will be available at higher elevations, the ski area at this location is likely to continue to be sustainable.

Consistent with Scott *et al.* (2003), the range of season losses projected by this study in the 2050s is much lower than earlier studies that did not account for snowmaking (Table 5). In most cases, the losses projected under the high impact 2050s scenario in this study ('worst case') approximated the low end of the impact range ('best case') from earlier studies. This finding reinforces the importance of incorporating snowmaking in climate change impact assessments, particularly where snowmaking systems are already an integral component of ski operations.

The distribution of skier visits during the ski season is dominated throughout the study region by two important tourism periods, the Christmas–New Year holiday and the spring school break holiday in late February and early March. For example, during the 1999–2000 ski season 19% of skier visits in Québec occurred during the Christmas–New Year period and 35% during the spring school break holiday, representing over half of the ski demand that season (Archambault *et al.*, 2000). In the US ski regions, the Christmas–New Year period is also a peak period for skiing demand, with 18% and 23% of the 2000–2001 skier visits in the Northeast and Midwest regions, respectively (NSAA, 2002). Although data for an equivalent spring school holiday period were not available for US ski regions, a large proportion of the 2000–2001 skier visits occurred from 19 February to 31 March (36 % Northeast and 45% Midwest).

These holiday periods are critical to the economic sustainability of the ski industry and therefore were examined in greater detail for this study. The Christmas–New Year holiday is virtually identical throughout the study area and was defined as 23 December to 3 January for this analysis. The dates of the spring school break holidays vary among the jurisdictions in the study area, but generally occur between late February and mid-March. To account for this difference the latter portion of this period (the third week of March), which was considered to be potentially the most vulnerable to climate change, was analysed

Table 6 Probability of the ski area being closed during entire key economic periods

Study Area	*Baseline probability (%)*		*Climate change scenario*	*Probability (%)*			
	Christmas–New Year 1970s	*Spring school break 1970s*		*Christmas–New Year*		*Spring school break*	
				2020s	*2050s*	*2020s*	*2050s*
Brighton, Michigan	0	0					
			Low Impact	7	8	0	3
			High Impact	7	48	37	70
Orillia, Ontario	0	0					
			Low Impact	0	0	0	0
			High Impact	0	17	0	0
Québec City, Québec	0	0					
			Low Impact	0	0	0	0
			High Impact	0	0	0	0
Rutland, Vermont	0	0					
			Low Impact	0	0	0	0
			High Impact	3	53	3	57
Ste Agathe-des-Monts, Québec	0	0					
			Low Impact	0	0	0	0
			High Impact	0	0	0	3
Thunder Bay, Ontario	0	0					
			Low Impact	0	0	0	0
			High Impact	0	7	0	0

as representative of the spring school break. For each of these economically important holidays, the probability of the ski area being closed for the entire period is presented in Table 6. It should be noted that this does not preclude the ski area from being closed during at least part of these critical tourism periods.

Based on model results, all six locations were operational for the Christmas–New Year holiday period in every baseline year. This pattern continued after the low impact scenario of the 2020s was applied, with the exception of Brighton, where conditions did not support opening during the holiday period in two of the 29 seasons modelled (i.e. 7% chance of being closed). Even under the high impact scenario, only Rutland and Brighton had a probability of being closed during the entire Christmas–New Year period (3% and 7%, respectively). The 2050s low impact scenario also did not appear to have a substantial affect on the probability of being operational during the Christmas–New Year period (Table 6). Only in the 2050s high impact scenario does the potential for closures during this critical economic period become a meaningful probability in some of the study areas. Under this scenario it is projected that Orillia may be closed during the entire Christmas–New Year period one winter in five, while Rutland and Brighton could be closed nearly every second winter.

The model correctly projected that the spring school break was a less vulnerable holiday period at all study areas, in large part, because ski areas are able to produce snow throughout the winter and 'bank' it for the spring season. Even if spring temperatures are very warm and snow cannot be made during the spring school break holiday period, the reserve of snow on the ski hill that was generated throughout the winter ensures that there will be adequate snow available during this period. The frequency of ski areas being closed during the entire spring school break holiday during the baseline period was zero for all study areas. In the 2020s scenarios, the probability of being closed during the entire spring school break holiday remained near zero, with the exception of Brighton under the high impact scenario (37%). Even in the 2050s, the probability of being closed during this entire period remains very low (virtually zero) at four locations. The probability of closure during this period is only meaningful at the two more southern locations (Brighton 70% and Rutland 57%).

Projected changes in snowmaking requirements

Additional snowmaking will be required to minimise losses in the length of the ski season under climate change. The projected amount of additional machine-made snow required is identified for each study area and scenario in Table 7.

Table 7 Modelled snowmaking requirements

Study area	*Baseline average (cm)*	*Climate change scenario*	*% Change from 1970s baseline*	
			2020s	*2050s*
Brighton, Michigan	165			
		Low Impact	14	22
		High Impact	17	21
Orillia, Ontario	105			
		Low Impact	47	62
		High Impact	66	151
Québec City, Québec	77			
		Low Impact	8	18
		High Impact	24	116
Rutland, Vermont	172			
		Low Impact	32	37
		High Impact	33	57
Ste Agathe-des-Monts, Québec	78			
		Low Impact	11	27
		High Impact	45	150
Thunder Bay, Ontario	92			
		Low Impact	28	40
		High Impact	52	161

In the low impact scenario of both the 2020s and 2050s, projected increases in required snowmaking were generally minor (less than 20%) at Québec City. The additional snowmaking requirements at the other study areas under the low impact scenario were moderate, ranging from 11–47% in the 2020s to 22–62% in the 2050s. Again, the high impact scenario projected a very different future for the ski industry. In the 2020s, three study areas had increases of more than 40%, while in the 2050s significant increases in snowmaking volumes (more than 100% increase versus 1970s levels) were required in four study areas. The only two study areas that did not see snowmaking requirements double under this scenario were the more southern locations of Brighton and Rutland. Here baseline snowmaking volumes were already double those of the other locations and temperatures began to be too warm for efficient snowmaking, translating into the larger season losses for these locations (Table 5).

The costs of additional snowmaking requirements, identified by location and scenario in Table 8, reflect both greater snowmaking demands and reduced efficiencies due to warmer temperatures. In the baseline period, the minimum cost represents the lowest cost snowmaking technology from Stanchak (2002) and the maximum cost represents highest cost snowmaking technology. In the climate change projections, the minimum cost represents the low impact climate change scenario combined with lowest cost snowmaking technology, while the maximum cost represents the high impact climate change scenario combined with highest cost snowmaking technology.

In the 2020s scenario, climate change raised the minimum average annual cost at all locations. The largest percentage increase in average annual snowmaking costs in the 2020s (low and high impact scenarios) was at Orillia. Percentage cost increases were the lowest at Québec City, Brighton and Rutland. In the case of Brighton and Rutland, this is because these locations already made twice the amount of snow than the other location during the baseline period and at warmer average temperatures. In the 2050s high impact scenario, snowmaking costs

Table 8 Modelled snowmaking costs (in $US)

Study area	*Baseline cost ($ 000)*		*2020s Cost ($ 000)*		*2050s Cost ($ 000)*	
	Minimum	*Maximum*	*Minimum*	*Maximum*	*Minimum*	*Maximum*
Brighton, Michigan	1629	3147	1808	3493	1954	3619
Orillia, Ontario	1005	1867	1467	2968	1618	4368
Québec City, Québec	752	1445	857	1748	985	2962
Rutland, Vermont	1660	3123	2158	3841	2241	4497
Ste Agathe-des-Monts, Québec	745	1395	834	2036	953	3320
Thunder Bay, Ontario	876	1616	1130	2424	1235	3975

more than doubled at four of the study areas (Québec City 105%, Orillia, 134%, Ste Agathe-des-Monts 138% and Thunder Bay 146%). If snowmaking expenses at these ski areas represent a similar proportion of total operating expenses as in the Northeast ski region in the US (5.6% in 2001–2002) (NSAA, 2002), a doubling of snowmaking costs would increase total operating expenses by nearly 5% – a value that becomes more meaningful to the ski resort operator.

The feasibility of the projected new levels of snowmaking also depends on water availability. The water requirements for average annual snowmaking in the baseline period ranged from 282 million litres at Québec City to over 701 million litres at Rutland. Because the estimated water requirement for snowmaking in this analysis was determined by converting the volume of snow to snow water equivalent value using a constant snow density, the projected increase (%) in water requirements for snowmaking are identical to those for snowmaking volumes (Table 7).

With water requirements for snowmaking potentially doubling at some of the study areas under the high impact 2050s scenario, reservoir size or water withdrawal permits may also have to increase. Planning to increase a reservoir size, upgrade pumping infrastructure or renegotiate a permit for water withdrawal would not only have to take into consideration average water requirements, but also the maximum potential water requirement in a 'worst case' scenario to ensure adequate supply for snowmaking each year. During the baseline period the maximum water requirement in a year exceeded the average requirement by 40% at Thunder Bay to 109% at Orillia. Thunder Bay would need access to 395 million litres of water for snowmaking in the worst winter of the baseline period and just over a 1 billion litres in the worst winter of the high impact 2050s scenario. During the baseline period the ski area at Orillia would require access to 898 million litres in the worst year, increasing to 1.4 billion litres in the worst year of the high impact 2050s scenario. Estimating infrastructure costs to ensure adequate water supply (reservoir expansion, pipeline construction), and assessing environmental impacts from increased water extraction, are beyond the scope of this paper.

Conclusion

This study provides a reassessment of the potential impact of projected climate change on the ski industry at six locations in eastern North America where previous impact studies had been completed. Several important advances over previous research were made, including the integration of snowmaking in the impact assessment methodology, the ability to examine an earlier time period (2020s) that is more relevant to ski industry stakeholders, the analysis of state of the art climate change scenarios, and the inclusion of multiple indicators of sustainability of the ski industry (ski season length, snowmaking requirements and operating costs, water requirements for snowmaking).

A central conclusion of this study is that climate change will create winners and losers in the ski industry of eastern North America. The confluence of climatic changes and other business factors (access to capital, demand trends, energy prices, water supply) will advantage certain ski areas and likely result in further contraction and consolidation in the industry. The findings suggest that in the 2020s, even the high impact climate change scenario poses only a very minor risk to ski areas at each of the study areas, except southern Michigan, where a series of poor winters could pose a reasonable business risk to smaller, less diversified ski areas. Consistent with Scott *et al.* (2003), a major finding of the reassessment was that ski season losses to climate change expected in the 2050s were not as severe as projected in earlier studies that did not adequately consider snowmaking. Nonetheless, the projected average season length reductions in the high impact 2050s scenario were not insignificant, particularly as snowmaking costs and the probability of closures during the important economic periods of Christmas–New Year and the spring school holiday increase. When potential reductions in the ski season are combined with projected increases in snowmaking costs, the sustainability of some ski operations could be jeopardised if the high impact climate change scenario for the 2050s were realised. Overall, ski areas at the two Québec locations appear to be the least vulnerable to climate change.

It must be emphasised that the findings of this study represent the projected impact of climate change at the base of the ski areas investigated. The base area of ski operations was the focus of this analysis because it is the most vulnerable to climatic warming. The base level impacts are representative of the entire ski areas where little elevational range exists (Brighton, Orillia, Thunder Bay). The projected base level impacts must be considered a 'worst-case' scenario for ski areas with greater elevational range (Québec City, Rutland, Ste Agathe-des-Monts), because cooler temperatures near the summits of these locations will reduce the impacts of climate change.

The different vulnerability of the ski areas to the range of climate change scenarios included in this analysis illustrated that achieving the low impact climate change scenario (the IPCC SRES-'B2' world future) is in the best interest of the ski industry in eastern North America. Characterised by increased concern for environmental and social sustainability, the SRES-B2 scenario is among the lower estimates of projected global climate change (see IPCC 2000 for a full explanation of the SRES scenarios). Programmes such as the 'Sustainable Slopes Charter' and 'Keep Winter Cool' campaign of the National Ski Areas Association in the United States should be further promoted as part of a near-term response by the global skiing industry to promote reductions in greenhouse gas emissions within the industry and by the skiing public.

However, the ski industry should not focus solely on climate change mitigation. The IPCC (2001) indicated that despite current and future efforts to reduce greenhouse gas emissions, we are already committed to some degree of warming as a result of past emissions. Consequently, the ski industry in North America needs to consider additional adaptation strategies to reduce the weather-related risk of its members and support further initiatives to examine its risk to projected climate change.

Investments in snowmaking equipment and associated technologies have formed the primary response of ski areas in eastern North American to weather variability. Since most areas already have complete or nearly complete snowmaking coverage, this form of adaptation offers only modest opportunities to further reduce weather-related risk through technical improvements (increased snowmaking capacity and efficient snowmaking at warmer temperatures). Other responses or strategies with considerably more potential include the purchase of insurance or weather derivatives. Ski areas have taken out weather insurance policies in the past. For example, Vail Resorts (Colorado) received an insurance payment of US$13.9 million as a result of lower snowfall in the winter of 1999–2000 (*Financial Post*, 2004). Weather derivatives are similar to insurance, but are a contract between two parties that stipulates what payment will occur as a result of the meteorological conditions that occur during the contract period specified (Zeng, 2000). Weather derivatives are highly flexible instruments that can be based on a wide range of meteorological variables (temperature, precipitation, sunshine, snow and ice conditions) and temporal periods (a one week festival or recreational event, weekends during the summer months, the ski season, etc.). For example, a ski area could establish a weather derivative contract based on a specified number of days in the critical Christmas–New Year period with adequate snowmaking temperatures or amount of natural snowfall before 20 December. Evidence that other industries are using this approach to reduce their weather risk can be found in the volume of trading on the Chicago Mercantile Exchange weather futures market (established in 1999), which had 18,000 contracts and over US$1.6 billion in trades in 2003. Unfortunately, even major ski tourism companies like Compagnie des Alpes and Intrawest have concluded that weather insurance and weather derivatives are currently too expensive (*Financial Post*, 2004). The current cost is therefore sure to exclude the small to medium size enterprises that are at greatest risk to climate change, because they are generally less diversified and do not spread their weather risk across a broader corporation or geographic region. A coordinated initiative by the ski industry to increase participation in weather insurance and thereby reducing premiums for the entire industry is a strategy that should be further examined.

Climate change is becoming a reality of business planning as corporations and investors begin to evaluate the implications of climate change for the competitiveness and profitability of companies and individual development projects. In a survey to Chairpersons of FT500 Global Index Companies (Innovest Strategic Value Advisors, 2003), fully 80% of respondents acknowledged climate change as a business risk. Significantly, this survey and a broader analysis of comparative corporate exposure to climate-related risk were commissioned by institutional investors who represent over US$4.5 trillion in assets. In addition, the World Wildlife Fund (2004) has documented 30 resolutions by shareholders of US companies seeking disclosure of financial risks associated with greenhouse gas emissions. These initiatives signify the early stages of the incorporation of climate change into contemporary business planning. This is a trend the ski industry (and broader tourism industry) should not ignore, because investors in this sector are also likely to demand that businesses report on their vulnerability to climate change.

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Note

1. Total operating costs include the following: lift operations, ski patrol, grooming, lift and vehicle maintenance, ticket sales, snowmaking, snow removal, lessons, food and beverage, retail stores, rental shop, accommodation, property operation, marketing, general and financial administration.

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