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Climate change and Quebec's ski industry

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Abstract

This study presents the results of a second-generation climate change assessment for three key ski regions of Quebéc incorporating snowmaking as a climate adaptation strategy. Potential economic ramifications for ski operators are assessed separately for the main revenue-generating period and shoulder seasons. The paper concludes that climate change does not pose a threat to the Quebéc ski industry under 2020s scenarios and that, while adequate snow base can be maintained with additional snowmaking under even the warmest scenario for the 2050s, the combined economic impact of lost revenue opportunities from a shortened ski season and increased snowmaking costs will likely prove prohibitive for some ski operators.

Keywords: Climate change; Tourism; Skiing; Canada; Quebec

1. Introduction

Although outdoor recreation and related tourism are inherently sensitive to climate conditions, our understanding of how climate variability affects the sector and how the sector has adapted to climate remains very limited (de Freitas, 2003; Scott et al., 2004). As a consequence, the vulnerability of recreation activities and tourism regions to global climate change has not been adequately assessed (Wall, 1992; World Tourism Organization (WTO), 2003). Relative to other economic sectors (e.g., agriculture, forestry, fisheries), tourism has been largely neglected by the climate change impact research community (Scott et al., 2004). Similarly, until recently climate change has not garnered substantive attention from the tourism research community or the tourism industry (Scott et al., 2005a). Butler and Jones (2001, p. 300) contend that '(Climate change) could have greater effect on tomorrow's world and tourism and hospitality in particular than anything else we've discussed … The most worrying aspect is that … to all intents and purposes the tourism and hospitality industries … seem intent on ignoring what could be *the* major problem of the century (*original emphasis*)'.

Winter tourism and the ski industry more specifically, have been repeatedly identified by governmental climate change assessments (Canada Country Study, 1998; ACACIA, 2000; Intergovernmental Panel on Climate Change (IPCC), 2001; US National Assessment Team, 2001; WTO, 2003) and the scientific literature as particularly vulnerable to global climate change. Climate change impact assessments of the ski industry have been conducted in a number of countries (Australia—Galloway, 1988; Hennessy et al., 2003; Austria—Breiling et al., 1997; Japan—Fukuskima et al., 2003; Canada—McBoyle and Wall, 1987, 1992; Lamothe and Périard Consultants, 1988; Scott et al., 2003, 2005b; Switzerland—König and Abegg, 1997; Elsasser and Bürki, 2002) and all project varying negative consequences for the industry.

Some of the earliest research on the potential impact of climate change on the ski industry in the international literature was conducted in Ontario and Québec (Canada). Harrison et al. (1986) estimated that the ski season in southern Ontario would contract substantially or possibly be eliminated (40–100% reduction) under a doubled atmospheric carbon-dioxide climate change scenario (approximately the 2050s). Using similar methods and climate change scenarios, McBoyle and Wall (1987, 1992)

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projected a 40–89% reduction in the ski season in the Lower Laurentian region of Québec, whereas Lamothe and Périard Consultants (1988) projected that the number of skiable days in southern Québec would decline by 42–87%. These early studies were the basis for the generalized economic extrapolation by Cline (1992), who estimated a 2.5 °C warming would reduce the length of the ski season across the United States by 60%, which was assumed to reduce skier visits nationally by an equal proportion and cause economic losses of approximately US$1.7 billion annually. This projected economic loss was also cited by the IPCC in its second assessment in 1995.

These early studies of climate change and skiing in eastern Canada had three important limitations. The first was that the criteria used to define a skiable day were based on the work of Crowe et al. (1973), who defined the minimum snow depth for ski operations as 2.5 cm. Few ski runs will operate with such little snow because it is unsafe and will cause damage to both ski equipment and the landscape. The second was the omission or limited consideration of snowmaking as a climate adaptation strategy. Snowmaking has been an integral component of the ski industry in Ontario and Québec for more than 20 years, with resorts making multi-million dollar investments in snowmaking technology in order to reduce their vulnerability to current climate variability and increase the average length of their ski seasons. Today all ski areas in southern Ontario and 40% of ski resorts in southern Québec have snowmaking coverage on 100% of their skiable terrain. The remaining 60% in southern Québec have skiable terrain coverage of between 50% and 90%. Lamothe and Périard Consultants (1988) acknowledged the importance of this climate adaptation by assuming ski areas with snowmaking would need less natural snow, but were unable to integrate snowmaking into any physically based snow model. The limited relevance of the long timeframes examined in earlier studies (doubled-carbon-dioxide climate change scenarios that approximate the 2050s) to contemporary business planning horizons was also problematic from the ski industry's perspective.

A more recent second-generation climate change assessment of the ski industry in southern Ontario by Scott et al. (2003) overcame the aforementioned limitations by developing a model with operational thresholds and decision rules based on interviews with ski area managers in the region, fully integrating snowmaking into daily snow cover calculations, and using new transient climate change scenarios and downscaling techniques (weather generator parameterized to local climate stations) to assess the implications of climate change in timeframes more relevant to contemporary business planning (i.e., the 2020s). A comparison of results for similar climate change scenarios (doubled-atmospheric carbon dioxide equivalent scenarios for the 2050s) between Harrison et al. (1986) and Scott et al. (2003) demonstrated how important snowmaking was in reducing the vulnerability of the ski industry in southern Ontario to climate change. Scott et al. (2003) projected that with current snowmaking capacities the average ski season would be reduced 7–32% in the 2050s (versus a 40–100% loss projected by Harrison et al., 1986). The authors recommended that similar reassessments be completed in Québec and the eastern United States where previous climate change studies projected very large impacts on ski industry.

The increasing relevance of climate change to business planning is another reason for undertaking new climate change assessments that reflect the realities of snowmaking in the ski industry of eastern Canada and the United States. There is growing general awareness of climate change risk in the business community (Reuters, 2004; The Wall Street Journal, 2005). Innovest Strategic Value Advisors (2003) noted that Hypovereinsbank and Credit Suisse now consider climate change in credit risk and project finance assessments. More specific to the ski industry, Swiss banks now provide very restrictive loans to ski areas at altitudes below 1500 m asl (Elsasser and Bürki, 2002) and banks in Ontario are known to have discussed the implications of climate change during ski resorts' financial negotiations (Scott, 2005). A report prepared for the United Nations Environment Program and International Olympic Committee (IOC) that summarized much of the international scientific literature on climate change and skiing, garnered substantial international media attention in December 2003, in part because the IOC indicated that it would include climate change in its considerations of where to hold future winter games. The Canadian Tourism Commission's (2002) winter tourism product development strategy also identified climate change as one of three key threats to Canada's winter tourism market (ageing populations and the decline in long-haul travel after September 11, 2001 were the other two). Although not all ski resort executives share his view, Patrick O'Donnell, the Chief Executive Officer of Aspen Skiing Company, recently referred to climate change as 'the most pressing issue facing the ski industry today' (Erickson, 2005).

The objectives of this study are twofold. First, building on the recommendation of Scott et al. (2003) this study will re-examine the implications of projected climate change for the ski industry of southern Québec with a methodology that fully incorporates snowmaking and that utilizes the most recent climate change scenarios available from the IPCC (2000) for the periods of the 2020s (2010–39) and 2050s (2040–69). Second, the study will examine the potential economic implications of climate change for the Québec ski industry by assessing impacts on ski operations during key revenue periods during the ski season and by estimating increased costs of snowmaking. In order to facilitate a comparison of results for the 2050s with earlier research by Lamothe and Périard Consultants (1988), the same three ski areas will be examined in this study (Québec City, Sherbrooke, and Ste. Agathe-des-Monts—Fig. 1).

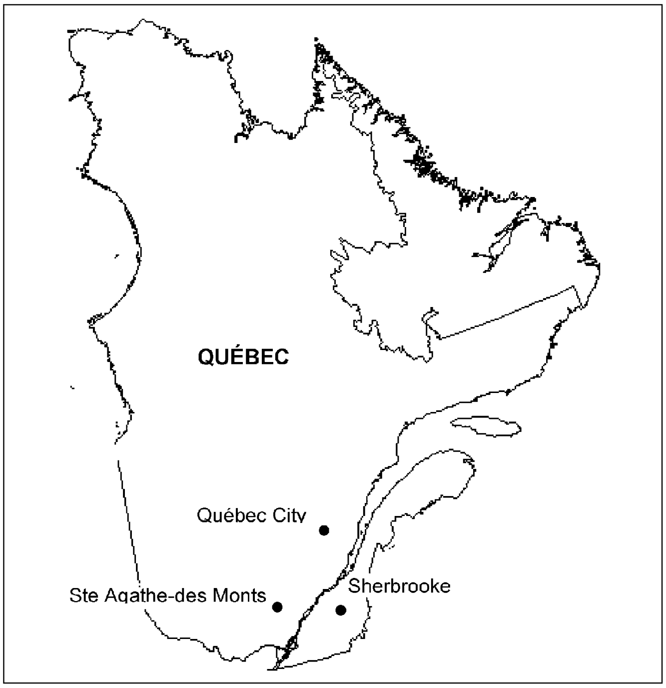

Fig. 1. Study areas.

2. Study area

Québec represents the largest regional ski market in Canada with 80 alpine skiing facilities concentrated in the southern portion of the province. According to the Canadian Ski Council (2004a) 30% (919,000) of the active alpine skiers in Canada reside in Québec, with Montréal representing the largest single ski market in Canada (416,000 skiers). Québec City and the Eastern Townships have the largest share of the Québec ski market with 21% and 17% of skier visits in 1999–2000 (Archambault et al., 2000). In 2002–03, Québec had over 6.9 million skier visits (Archambault et al., 2003) representing about 37% of the ski market in Canada and 9% of the North American ski market. The direct economic impact of the ski industry in Québec in 2002–03 is estimated to exceed CDN$434 million, employ 13,300 people and generate an additional 18,700 indirect jobs in related businesses (lodgings, restaurants, bars, boutiques, service stations, etc.) (Archambault et al., 2003).

The ski market in Québec is primarily intra-provincial, with 76% of skier visits in 1999–2000 originating within the province (Archambault et al., 2000). Other important markets are Ontario and the Northeastern US, representing 15% and 5% of skier visits, respectively. With the large majority of skier visits originating within the province, two key provincial holiday periods dominate the distribution of skier visits during the ski season. In 1999–2000, approximately 55% of skier visits in Québec occurred during the Christmas-New Year (20%) and Spring School Break (35%) holidays (Archambault et al., 2000). The interim period in January and February accounted for 34% of skier visits, while the early season (before 20 December) and late season (after 15 March) represent only 3% and 8% of skier visits, respectively. As a consequence of the temporal concentration of skier visits, not all segments of the ski season are as economically important to the ski industry. This assessment will therefore examine the potential impact of climate change on each of the five segments of the ski season.

3. Methods

The ski operations model used for this analysis is based on the model developed and validated in southern Ontario by Scott et al. (2003). The model consists of several subcomponents (snow model; snowmaking module; ski operations rules; and climate change scenarios) that are described below.

3.1. Baseline climate data

Climatological data were obtained from the Meteorological Service of Canada (1999). At each study area the selection of the climate station was based on two criteria: the proximity to ski area(s) (both in terms of distance and elevation) and the availability of a complete climate data set (daily temperature—maximum, minimum and mean; daily precipitation—rain and snowfall; and daily snow depth) for the baseline period of 1961–1990 (Table 1). Climate stations nearer to the base elevation of the ski areas in each study area were selected because this is the most vulnerable portion of ski areas to climate change. The results of this analysis are only valid for the climate station location and surrounding areas that exhibit similar climatological characteristics. The ski area(s) of interest are often several kilometres away from available climate stations and may have microclimatic features that enhance or reduce natural snowfall or conditions for snowmaking.

3.2. Snow model and snowmaking module

At the core of the ski operations model is a physically based, locally calibrated daily snow depth model. The snow depth model is based largely on methods used to develop the *Canadian Daily Snow Depth Database* (Brown and Braaten, 1999) and *Water Balance Tabulations for Canadian Climate Stations* (Johnstone and Louie, 1983). Using daily temperature and precipitation inputs, the model estimates snow depth based on the calculation of three parameters: amount of precipitation that falls as snow and rain; snow accumulation; and 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 (i.e., a precipitation typing analysis). Snowfall was added to the snow pack assuming a constant density of 400 kg m^{-3}. The snowmelt equation used in the

Table 1
Climate stations and nearby ski areas

Study area	Climate station	Lat (°N)	Long (°W)	Elevation (masl)	Nearby ski areas	Elevation range of ski areas (m asl)
Québec City	Québec City Airport	46.8	71.2	74	Mont-Ste-Anne, Stoneham Ski Resort, Massif du Sud, Mont Grand Fonds	175–800
Sherbrooke	Sherbrooke	45.3	71.4	241	Owl's Head, Mont Sutton, Montjoye, Mont Orford	155–747
Ste. Agathe-des-Monts	Ste. Agathe-des Monts	46.3	74.1	395	Mont Tremblant, Vallee Bleue, Belle Neige, Gray Rocks	265–915

model was developed by the US Army Corps of Engineers (1956):

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

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

The performance of the snow 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 1961–90 baseline period. The model predicted the occurrence of days with snowfall in the study areas with over 93% accuracy (Québec City = 94%, Sherbrooke = 94%, and Ste. Agathe-des-Monts = 93%). The model underestimated the number of days meeting the 30 cm snow depth criterion by less than 5% at all locations. These results suggest that the model is suitable for comparing potential shifts in the statistics of 10- or 30-year periods. Comparison of individual years is however less reliable.

To complete the modelling of daily snow depth, a snowmaking module was integrated with the snow model. The 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., start/end dates, target snow pack depth to maintain) are based on Scott et al. (2003) and are outlined in Table 2.

Table 2
Standardized impact assessment model parameters

Snowmaking capacities and decision rules
- Start date = 22 November (Julian day 326)
- End date = 30 March (Julian day 90)
- Minimum snow base to maintain until Julian day 90 = 60 cm (a)
- Temperature required to start snowmaking = −5 °C
- Snowmaking capacity = 10 cm/day
- Power cost as percentage of total snowmaking costs = 32%

Skiable day
- Minimum snow base = 30 cm
- Maximum temperature = 15 °C
- Maximum liquid precipitation over two consecutive days = 20 mm

Ski area
- Size = 250 acres

(a)—Although 30 cm is the minimum operational snow base and the climate suitability threshold used to define an operational ski day, ski areas in the region produce a thicker snow base (usually 50–75 cm) early in the ski season in order to have a reserve of snow in case of poor weather conditions (high temperatures, rain) later in the ski season. To emulate this management strategy, the snowmaking module was designed to maintain a 60 cm snow base until the end of March when possible (after the economically important 'March-break' school holiday period in the study area).

3.3. Ski season modelling

The climatic criteria defining an operational ski day were also adopted from Scott et al. (2003), who derived the criteria from an examination of 20 years of daily ski operations data from ski areas in the province of Ontario and communications with ski industry stakeholders. Ski areas were assumed to close whether any of the following climatic conditions occurred: snow depth less than 30 cm; maximum temperature greater than 15 °C; and when the 2-day liquid precipitation exceeded 20 mm (Table 2). It is acknowledged that these criteria may differ slightly in other ski regions. However, consultations with stakeholders from the Québec ski industry (Bourque and Scott, 2004) confirmed these criteria were generally suitable for most ski areas in the province.

An important difficulty in attempting to model the length of the ski season (which is a socio-economic system) with only climatic criteria is the inability to account for the business decision-making factors that influence ski area operations. For example, ski area managers may not always abide by the decision-making rules that define our model and may decide to open the ski area with less than the preferred 30 cm snow base because a nearby competitor has opened. We recognize that these potential sources of error can never be fully captured in an abstracted model of ski operations. Nonetheless, a comparison of the observed and modeled ski seasons in the original southern Ontario study area revealed that over the 17 years where observed data were available, the average observed and modeled season lengths were 124 and 123 days, respectively (minimum seasons were 111 and 99 days and maximum seasons 140 and 152 days) (Scott et al., 2003). Overall the ski season simulation model performed reasonably, missing the observed season length by more than 7 days (approximately 5% of an average season) in only five of 17 years. Unfortunately, a historic record of the length of ski seasons was not available for ski regions or individual ski resorts in Québec to further validate the model.

3.4. Climate change scenarios

The climate change scenarios used in this study were developed from monthly global climate models (GCMs) available from the Canadian Climate Impacts and Scenarios (CCIS) Project. The scenario data available from CCIS are constructed in accordance with the guidelines set out by the United Nations Intergovernmental Panel on Climate Change (IPCC) Task Group on Scenarios. The 19 scenarios considered for this analysis represent a broad range of GCMs and future emission levels. In order to limit the number of scenarios to a manageable number while still considering the full range of potential climate futures, five scenarios representing the upper and lower bounds of change in December–January–February (DJF) mean temperature and precipitation were selected for analysis. For the purposes of concise presentation, only the results of two climate change scenarios are reported here. The two climate change scenarios utilized in this paper are the National Center for Atmospheric Research B2 scenario (NCARPCM-B2—a low greenhouse gas emission future) and the Centre for Climate System Research A1 scenario (CCSRNIES-A1—a high greenhouse gas emission future), which, respectively, represent the smallest and largest increase in winter mean and summer maximum temperatures in southern Québec (Table 3). Theoretically, each scenario is considered equally feasible. The socio-economic assumptions related to each scenario can be found in IPCC (2000).

Each scenario provided estimates of temperature and precipitation change relative to the 1961–90 (1970s) baseline for each month for the 2020s (average changes over 2010–39) and 2050s (average changes over 2040–69). Results for the 2020s are of greatest relevance to ski area operators due to the smaller range in uncertainty of climate change projections and because they are within the lifetime of existing infrastructure and long-term business planning horizons.

A difficulty noted by the climate change impacts research community is that many impact assessments, including this study, require climate change information at finer temporal and spatial scales than are generally available from GCMs (Wilby et al., 2004). There are several methodological approaches to producing higher resolution climate change scenarios, including regional climate models (RCMs), statistical downscaling, spatial and temporal analogues, and simple application of 'climate change factors' to a reference climate. As Wilby et al. (2004) note, all have strengths and weaknesses depending on the application.

To produce daily temperature and precipitation data for input into the snow model, this study makes use of the Long Ashton Research Station (LARS) stochastic weather generator (Semenov et al., 1998) to downscale monthly climate change scenarios. Weather generators are inexpensive computational tools that replicate the statistical attributes of a local climate and can be used to produce site-specific, multiple-year climate change scenarios at the daily timescale (Semenov et al., 1998; Wilby et al., 2004). LARS was selected for this study because it has been found to simulate precipitation statistics in Canada better than other weather generators (Qian et al., 2004). The LARS weather generator was first parameterized to the climate station at each location using baseline climate data (1961–90) and then monthly climate change vectors from the NCARPCM-B2 and CCSRNIES-A1 scenarios were applied for each future time period (2020s and 2050s).

3.5. Climate change assessment approach

In order to compare the relative impact of projected climate change at the three study areas a standard ski area (identical in size and snowmaking capacities—Table 2) was modeled at each site. This approach isolates the importance of climate and projected climate change at each location, rather than assessing the relative technological (e.g., snowmaking) and business (e.g., four season operation) advantages of each ski area. The technical capacity of the modeled snowmaking system reflects the snowmaking capabilities of advanced snowmaking systems in place at

Table 3
Comparison of climate change scenarios (DJF) in study areas

Study area	Baseline		2020 s				2050 s			
	(1961–90)		CCSRNIES-A1		NCARPCM-B2		CCSRNIES-A1		NCARPCM-B2	
	T (°C)	P (mm)	$T\Delta$ (°C)	$P\Delta$ (%)	$T\Delta$ (°C)	$P\Delta$ (%)	$T\Delta$ (°C)	$P\Delta$ (%)	$T\Delta$ (°C)	$P\Delta$ (%)
Québec City	−11.0	264	2.8	7	1.6	5	7.9	16	2.3	7
Sherbrooke	−10.1	234	2.8	10	1.4	4	7.4	14	2.0	6
Ste. Agathe-des-Monts	−11.5	286	2.8	10	1.4	4	7.4	14	1.9	6

T = temperature (°C); P = precipitation.

some ski areas in Ontario and Québec. Not all ski areas have this capacity currently, but with investment could develop similar capabilities. All of the parameters used in this standardized analysis can be adjusted in the model to reflect the specific characteristics of an existing ski area (micro-climate factors; skiable acres; snowmaking capacity; snowmaking costs/acre; start-end of ski season and snowmaking period; key tourism periods) if a site-specific climate change assessment were to be undertaken.

4. Results

4.1. Projected changes in natural snow conditions

Fig. 2 illustrates the average daily natural snow depth at Québec City for the baseline period of the 1970s, as well as for the least-change and warmest climate change scenarios for the 2020s and 2050s. In the least-change scenario (NCARPCM-B2) for both the 2020s and 2050s, reductions in snow depth occur throughout the winter until late March, but are less pronounced in the early part of the ski season. Notably, the warmest scenario (CCSRNIES-A1) for the 2020s indicates a greater reduction in the depth of the natural snow pack than the least-change scenario for the 2050s. The greatest reduction occurs under the warmest 2050s scenario which at no time throughout a climatically average winter does the depth of natural snow reach the threshold of 30 cm needed for ski operations. This suggests that as important as snowmaking is to the ski industry for coping with current climate variability, its salience under climate change will increase markedly.

4.2. Projected changes in ski season length

During the baseline period (1970s) the three study areas had an average ski season of between 152 and 163 days (Table 4). In the 2020s, projected changes in the length of the ski season were modest and generally similar in magnitude at the three locations. Under the least-change scenario (NCARPCM-B2), losses to the ski operation days were negligible (between 0% and 2%). Ski season losses

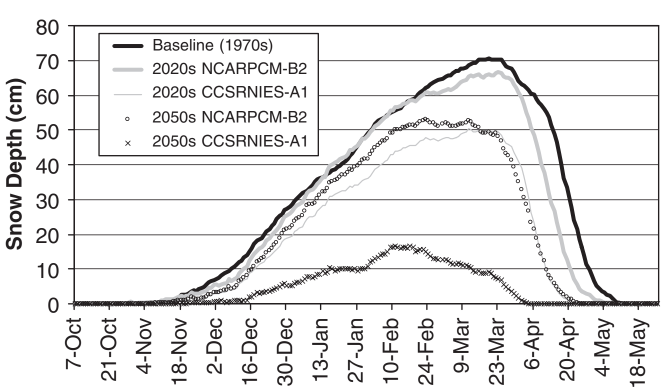

Fig. 2. Modeled natural snow conditions at Québec City.

Table 4
Projected changes in ski season length

Study area	Baseline average (days)	Climate change scenario	% Change from 1970s baseline	
			2020s	2050s
Québec City	160	NCARPCM-B2	−1	−5
		CCSRNIES-A1	−13	−34
Sherbrooke	152	NCARPCM-B2	−2	−7
		CCSRNIES-A1	−15	−39
Ste. Agathe-des-Monts	163	NCARPCM-B2	0	−4
		CCSRNIES-A1	−13	−32

under the warmest scenario (CCSRNIES-A1) for the 2020s varied from 13% to 15%. The projected impacts of the two climate change scenarios began to diverge in the 2050s. Changes in ski season length remained minor (−4% to −7%) at all three study areas under the least-change scenario (NCARPCM-B2). The warmest scenario for the 2050s (CCSRNIES-A1) portrays a potentially very different and challenging future for the ski industry in Québec. Under this scenario, ski season losses exceed 30% at all three locations. It should be noted that even these ‘worst-case’ ski season losses for the 2050s are considerably less than the results of Lamothe and Périard Consultants (1988), which projected losses under doubled-carbon dioxide scenarios (~2050s) of 70% at Québec City, 87% at Sherbrooke, and 87% at Ste. Agathe-des-Monts.

4.3. Projected changes in snowmaking requirements

As indicated, one of the key parameters that improved this impact assessment over earlier studies in Québec has been the physical integration of snowmaking. The incorporation of snowmaking in the model reflects the reality of the ski industry in Québec. Table 5 identifies the average amount of machine-made snow (in cm) required to attain the length of the ski season under the baseline climate conditions at each of the three study areas. In order to attain the number of operational ski days estimated under the climate change scenarios for the 2020s and 2050s, additional snowmaking will be required at all locations. In the 2020s, the percentage increases in machine-made snow will range from a low of 8% to 24% at Québec City to a high of 25% to 59% at Sherbrooke. Under the warmest 2050s scenario (CCSRNIES-A1), at least a doubling of current snowmaking volumes will be required at all study areas. In overall terms the situation will be most critical at Sherbrooke, where its southerly location requires a higher level of snowmaking compared to the other two ski areas (nearly 60% more under baseline climate conditions).

The feasibility of producing the required amounts of snow in the future depends on several factors. Two of the

Table 5
Modeled snowmaking requirements

Study area	Baseline average (cm)	Climate change scenario	% Change from 1970s baseline	
			2020s	2050s
Québec City	77	NCARPCM-B2	8	18
		CCSRNIES-A1	24	116
Sherbrooke	132	NCARPCM-B2	25	44
		CCSRNIES-A1	59	127
Ste. Agathe-des-Monts	78	NCARPCM-B2	11	27
		CCSRNIES-A1	45	150

most important are cost and water availability. Snowmaking costs do not increase proportionately to increased volume of machine-made snow required, because as average temperatures increase snow will need to be made at warmer temperatures (especially during the 'early season'), which requires more energy and is more costly. Modelling of potential changes in snowmaking costs was based on the technical analysis of Stanchak (2002), which compared the energy 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) at various temperatures. For this analysis, the energy 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 ski regions based on NSAA (2002) data for the past 5 years.

Snowmaking costs were projected to increase the least in Québec City (13–22% in the 2020s, 31–108% in the 2050s). Increases in snowmaking costs in the 2020s were highest in Sherbrooke (18–53%), but became highest in Ste. Agathe-des-Monts in the 2050s (29–142%) because of the shortened ski season and reduced snowmaking needs in Sherbrooke.

In ski areas of the northeast ski region of the US, snowmaking represented 5.6% of total ski area operating costs in 2001–02 (NSAA, 2002). If snowmaking expenses represent a similar percentage at Québec ski areas, then the additional snowmaking requirements projected under the warmest scenario for the 2050s (CCSRNIES-A1) would add an additional 6% (Québec City and Sherbrooke) to 8% (Ste. Agathe-des-Monts) to total operating costs of ski areas.

Water availability may prove another limiting factor in some locations. The estimated water requirement for snowmaking was determined by converting the volume of machine-made snow to a snow water equivalent value using a constant snow density. This means that the projected average increase in water requirements for snowmaking is identical to the percentage increase in snowmaking in Table 5. Under the warmest scenario for the 2050s (CCSRNIES-A1), the average water requirements could potentially double at all three of the study areas. This may require additional water withdrawal approvals, investment in additional reservoir capacity, and the need for related environmental impact assessments in the future.

4.4. Potential economic impacts

As indicated, one of the economic indicators used in previous climate change impact assessments of the ski industry in Europe is the '100-day rule' (König and Abegg, 1997; Elsasser and Bürki, 2002). This general indicator of profitability has also been referred to by stakeholders in the North America ski industry (Erickson, 2005). The modeled changes to the length of the average ski season in Table 4 indicate during average ski seasons Québec City and Ste. Agathe-des-Monts will achieve the '100-day'economic threshold even during the warmest climate change scenario for the 2050s (CCSCNIES-A1) but Sherbrooke will fall below the threshold. The '100-day rule' is limited as an economic indicator because it does not consider in what part of the ski season operational ski days are lost nor considers the increased costs of snowmaking.

In order to assess whether the key economic periods are at risk and to better understand the potential economic impact of climate change, the number of operational ski days was modeled for each of the five segments of the ski season (Table 6). At all three of the study areas, most of the lost ski days occur in the 'early' and 'late season'. A critical finding is that in both scenarios for the 2020s and the least-change 2050s scenario (NCARPCM-B2), there will be no operational ski days lost at any of the three locations during the key economic periods ('holiday', 'mid-season', 'school break') when 89% of the skier visits in Québec occur. This implies that the economic core of the Québec ski season (20 December to 15 March inclusive) can be largely maintained with additional snowmaking in all but the warmest scenario for the 2050s.

If the seasonal distribution of revenues in the ski industry is assumed to mirror skier visits, then the proportion of potential annual revenues available to ski operators in the three study areas remains largely unchanged by climate change except under the warmest scenario for the 2050s (CCSRNIES-A1). Under this scenario some operational ski days are lost in the three economically important segments of the ski season (Table 6) at all three locations, though the bulk of losses still occur in the 'early' and 'late' shoulder seasons. When skier visits, and it is assumed ski area revenues, are prorated for each of the five segments of the ski season by the proportional losses in operational ski days under the warmest scenario for the 2050s, the total potential annual

Table 6
Modeled changes in ski season segments (operational ski days)

Study area		Early season (1)	Holiday period (2)	Mid-season (3)	School break (4)	Late season (5)
Québec City	Baseline (1970s)	32	16	46	22	42
	2020s NCARPCM-B2	34	16	46	22	39
	2020s CCSRNIES-A1	25	16	46	22	30
	2050s NCARPCM-B2	31	16	46	22	37
	2050s CCSRNIES-A1	10	14	44	21	16
Sherbrooke	Baseline (1970s)	34	16	45	21	34
	2020s NCARPCM-B2	35	16	45	21	29
	2020s CCSRNIES-A1	25	16	45	21	22
	2050s NCARPCM-B2	31	16	45	21	27
	2050s CCSRNIES-A1	10	12	40	19	11
Ste. Agathe-des-Monts	Baseline (1970s)	37	16	46	22	42
	2020s NCARPCM-B2	37	16	46	22	42
	2020s CCSRNIES-A1	28	16	46	22	31
	2050s NCARPCM-B2	33	16	46	22	39
	2050s CCSRNIES-A1	15	14	45	21	16
% of skier visits in Québec in 2003		3%	20%	34%	35%	8%

(1) 1 November–19 December; (2) 20 December–4 January; (3) 5 January–20 February; (4) 21 February–15 March; (5) 16 March–30 April.

skier visits and revenues decline by 12% at Ste. Agathe-des-Monts, 13% at Québec City, and 20% at Sherbrooke. This analysis also assumes no behavioural adaptation by skiers to ski more frequently in a shortened ski season (e.g., temporal substitution of lost ski visits in early and late shoulder seasons to other parts of the ski season). Although data on annual ski area utilization levels were not available for Québec, Scott (2005) found some evidence for this type of behavioural adaptation by skiers in the northeast ski region of the US. To the extent that skiers make this type of adaptation to shortened average ski seasons, the impacts on revenues outlined above would be reduced.

The combination impact of lost revenues (12%, 13%, and 20% at Ste.Agathe-des-Monts, Québec City and Sherbrooke, respectively) and increased costs (8% at Ste. Agathe-des-Monts, 6% at Québec City, and 6% at Sherbrooke) on profitability will vary for each individual ski operator, but a general analysis can be done using North American Industry Classification System data for the Canadian ski industry (provincial level data were not available). According to Statistics Canada (2005), operating profit margins (defined as operating revenue minus operating expenses, and expressed as a percentage of operating revenues) for the Canadian ski industry have averaged 13.9% between 1997 and 2004. Adjusting the average operating revenues and operating expenses for this 7- year period by the proportional changes in revenues and operating expenses projected for the warmest 2050s scenario (CCSRNIES-A1) resulted in expenses exceeding revenues at all three locations. Consequently, although it may be physically possible to maintain a ski season of over 100 days in the Ste. Agathe-des-Monts and Québec City regions, the costs of doing so with machine-made snow may be uneconomic for some ski area operators.

5. Conclusions

The findings of this study suggest that in the 2020s, even the warmest climate change scenario (CCSRNIES-A1) poses only a very minor risk to ski operations at each of the three study areas. However, climate change will not be the only factor affecting skier visits in Québec over the next two decades. Because of industry trends and demographic projections (ageing, increased ethnic diversity) in Canada, the Canadian Ski Council (2004b) estimates that Québec's ski market could contract 30% from 6.9 to 4.8 million skier visits. Without strategies to develop new markets and retain existing markets, projected demographic changes in the skier marketplace would have greater implications for the economic sustainability of the ski industry in Québec than climate change over the next 20 years. Importantly, the projected impacts of demographic and climatic change would act synergistically, with both potentially reducing skier visits, to create more challenging business conditions for Québec ski operators in the 2020s.

By the 2050s only the worst climate change scenario poses a significant risk to the sustainability of the Québec ski industry. Even under this scenario the projected annual losses in operational ski days will be considerably less than the 'best-case' scenario of the earlier study by Lamothe and Périard Consultants (1988).

Other than for the warmest scenario for the 2050s, the model indicates that the existing core ski season at the three study areas—20 December to 15 March—can be maintained, if ski areas are prepared to invest in greater snowmaking. These findings are consistent with the reassessment of earlier climate change impact studies of the ski industry in Ontario by Scott et al. (2003).

Nonetheless, the projected season length reductions and increased snowmaking costs in the warmest scenario for the 2050s will not be insignificant. Using the '100-day rule' as a very general indicator of profitability, only ski operators in the Sherbrooke area appear to be economically at risk under this scenario (average ski season declined to 93 days). The more detailed economic analysis that took into account operational ski days that were projected to be lost together with the increased costs of snowmaking, again found that ski operators in the Sherbrooke region were most at risk to climate change, but importantly also found that the combination of decreased potential revenues and increased operating expenses created potentially uneconomic conditions in the Québec City and Ste. Agathe-des-Monts regions as well.

Although this assessment represents a substantial improvement in our understanding of the potential vulnerability of the ski industry in Québec to projected climate change, it does not capture the full complexity of the impact of climate change on this industry. This analysis assumes no behavioural adaptation by skiers in Québec and incorporates additional snowmaking as the only adaptive response by ski area operators. There are of course many strategies that could be employed by the ski industry to reduce the potential impacts of climate change; see Scott (2005) for a climate adaptation portfolio for the ski industry. An obvious strategy to address the projected imbalance in operating revenues and expenses brought about by climate change is to raise the price of lift tickets and other services at ski areas. However, raising prices may reduce the number of active skiers by making it too expensive for moderate-income families, which has already been a concern raised by the ski industry. Resorts with ski areas could continue to diversify their revenue streams to other seasons (e.g., golf courses, water parks) or other business lines that are not climatically sensitive (e.g., spas, conference facilities). For some ski areas however, this is not feasible because of land use restrictions or lack of capital, and where this is the case ski operations will continue to represent the sole or main source of income. It is the disparate adaptive capacity of individual ski areas that will determine the 'survivors' in an era of climate change. Ski areas that have greater adaptive capacity (larger, well diversified resort operations; efficient snowmaking systems; adequate water supply; part of a larger company or ski resort conglomerate that can provide financial support if needed during poor business conditions) will remain in operation and be in a position to take advantage of a climatically altered business environment. If skier demand remains relatively stable and competition is reduced from other ski areas going out of business, then those that remain would gain market share and could potentially improve their economic performance even with a reduced ski season and higher snowmaking costs.

This diversity of outcomes for individual tourism operators would be even more pronounced if the implications of climate change on the ski industry were examined at a national scale. Consequently, additional regional assessments in North America are required for two reasons. First, to improve the assumptions of any future generalized assessment of the economic implications of climate change for the future of the tourism sector (like Cline, 1992). Second, because climate change is beginning to influence decision-making in various business sectors, including tourism, such assessments would provide information to ski operators and investors that better reflects the economic vulnerability of the ski industry to projected climate change.

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