Off-Piste Skiing Demand Patterns and Climate Change Adaptation Pathways in La Grave, France

Authors: Yoshizawa, Nao, Cognard, Jonathan, Berard-Chenu, Lucas, and Bourdeau, Philippe

Source: Mountain Research and Development, 45(2)

Published By: International Mountain Society

URL: https://doi.org/10.1659/mrd.2023.00032

Mountain Research and Development (MRD)
An international, peer-reviewed open access journal
published by the International Mountain Society (IMS)
www.mrd-journal.org

MountainResearch
Systems knowledge

Off-Piste Skiing Demand Patterns and Climate Change Adaptation Pathways in La Grave, France

***Nao Yoshizawa*[1]*, *Jonathan Cognard*[2,3], *Lucas Berard-Chenu*[2,4,5], *and Philippe Bourdeau*[3,6]**

* *Corresponding author: nao-yoshizawa@imc.hokudai.ac.jp*

[1] *Hokkaido University, RFMC, CATS, Kita 17 Jou, Nishi 8 Chome, Kitaku, 060-0817, Sapporo, Japan*
[2] *University of Grenoble Alpes, INRAE, LESSEM, 2 Rue de la Papeterie, Saint-Martin-d'Hères, 38402, France*
[3] *Labex ITTEM, University of Grenoble Alpes, 1221 Av. Centrale, 38400 Saint-Martin-d'Hères, 38402, France*
[4] *University of Angers, ESTHUA, CNRS, SFR CONFLUENCES, 6590 Espaces et Sociétés, 49100, Angers, France*
[5] *Joint Institute of Ningbo University and University of Angers, 818 Fenghua Road, 315211, Ningbo, People's Republic of China*
[6] *University of Grenoble Alpes, PACTE, 14 bis Av. Marie Reynoard, 38100, Grenoble, France*

Off-piste skiing is an adventurous niche segment of ski tourism that is gaining in popularity. However, its demand dynamics remain unclear. This study aimed to elucidate daily off-piste skiing demand patterns by developing a regression model for La Grave, located in the French Alps, where all visitors engage in off-piste skiing. We found that the amount of fresh snow positively influenced skier visits and forecasted avalanche risk did not affect skier visits. Vacation periods did not positively influence skier visits, whereas the post-COVID period has had a negative effect. We also discuss the impact of climate change and adaptation strategies in the area. La Grave depends heavily on off-piste skiing. Because one of the purposes of this activity is to ski on fresh natural snow, it cannot rely on snow management practices such as grooming and snowmaking, which are widespread adaptations in conventional ski areas. The winter business model in La Grave is expected to face further challenges in the future because of climate change. In addition, both a new development plan and opposition movements have emerged. La Grave appears to be undergoing a transition away from a model heavily dependent on off-piste skiing.

Keywords: *tourism demand modeling; freeriding; backcountry skiing; ski area management; climate change adaptation.*

Received: *30 July 2024* ***Accepted:*** *17 December 2024*

Introduction

The ski industry plays an important role in the socioeconomy of snow-covered mountain regions by generating significant income and employment (Pröbstl-Haider et al 2019; Vanat 2022). However, climate change poses challenges for the ski industry (Steiger et al 2019). Both snow depth and duration have decreased throughout the European Alps (Matiu et al 2021). Climate models predict a notable rise in temperatures and a decrease in natural snowfall (Beniston et al 2018). An assessment of the reliability of ski resorts in France, based on future climate change scenarios, highlighted the predominance of ski areas at higher elevations and difficulties at lower elevations (Spandre et al 2019). Under these circumstances, snowmaking is a widespread adaptation strategy used by ski areas to increase the adaptability range for climate variability (Berard-Chenu et al 2020, 2023).

The ski market size has stagnated in Europe and North America (Vanat 2022). In contrast, off-piste skiing, which refers to skiing outside the groomed ski run, has recently grown in popularity (Mannberg et al 2021). In the European Alps, off-piste skiing can be divided into 2 main components: freeriding and ski touring. Freeriding is characterized by using ski lifts to ascend slopes. In contrast, ski touring, also called alpine touring, ski mountaineering, or backcountry skiing, involves hiking independently, often using climbing skins. In France, the popularity of ski touring is increasing, partly because of the closure of ski resorts during 2020/21 in response to the COVID-19 pandemic (Cazé 2021). In the United States, Snowsport Industries America has estimated that there were more than 2.2 million ski touring participants in 2023 and that this number had tripled over the previous 3 years (Freeskier 2023). Over the longer term, the evolution of equipment and ski design has contributed to this growth—particularly the introduction, since the early 2010s, of skis with wider waists, reverse-camber shapes, and early-rise tips and tails, which have significantly improved performance and made it easier to ski in deep and fresh snow (Truong et al 2020). Progress in risk management skills and the spread of avalanche transceivers also support this type of skiing (Brugger et al 2007; Tremper 2013).

Off-piste skiing is considered a more adventurous sport than conventional alpine skiing, because it involves risks associated with avalanches, falls, and becoming lost in uncontrolled areas (Frühauf et al 2019; Mannberg et al 2021). Most previous studies about freeriding have focused on practitioners' risk-taking and motivation (Frühauf et al 2020; Malterud et al 2021; Tøstesen and Langseth 2021). For ski touring, studies have focused on avalanche risk management for accident prevention (McCammon 2004;

Furman et al 2010; Hallandvik et al 2017; Marengo et al 2017; Fisher et al 2022). However, the demand patterns for off-piste skiing have received little attention in the literature. Rupf et al (2019) analyzed Swiss winter backcountry practitioners' behavior and pointed out that they are sensitive to crowding, often choosing less crowded areas. Nevertheless, the influence of other factors on demand remains unclear. This study aimed to fill this gap by analyzing daily off-piste skiing demand patterns.

Literature review

Tourism demand modeling seeks to understand what determines the number of visitors from an econometric perspective and is mainly used to support effective destination planning. Generally, fluctuations in tourism demand are caused by 2 fundamental factors (Parrilla et al 2007). The first encompasses temporal natural phenomena, such as weather and seasonality patterns, whereas the second is social, taking the form of policies governing specific customs and legal vacations, such as school calendars, public holidays, and other events.

Few studies have investigated daily tourism demand in ski areas using regression analyses to determine the relevance of different variables. Shih et al (2009) analyzed the influence of weather variations on daily ski pass sales in 2 ski areas of the United States. The results indicated that weather variables, such as minimum and maximum temperatures, snow depth, and wind, significantly affect ticket sales. Hamilton et al (2007) focused on the impact of climate variability at the local scale, using daily data from 2 ski areas in the United States. A regression model that included snow depth, snowfall, and temperature variables in mountain and nearby urban areas and the day of the week explained half to two thirds of the daily demand variation. Malasevska et al (2015) examined the variations in skier visits at Norwegian ski resorts. They found that weather conditions, day of the week, and holidays significantly affected the daily number of skiers. These studies provide insights that contribute to effective ski area management through the analysis of skier demand based on natural and social conditions. However, they were conducted in ski areas that target alpine skiers. To our knowledge, off-piste skiing demand has not yet been analyzed.

The total number of participants in winter backcountry activities, including freeriding, ski touring, and snowshoeing, remains poorly estimated (Langford et al 2020). Counting backcountry activity participants who move freely within natural areas is technically challenging. It requires various monitoring methods, such as automatic infrared cameras, cell phone usage data, and passive infrared counters, all of which have disadvantages, such as cost or nonconformity with data privacy requirements (Rupf and Stäuble 2018; Langford et al 2020). In most ski areas, it is impossible to count how many skiers venture outside the managed areas. However, the high mountain area in La Grave in the French Alps, which is this study's research area, presents a unique case that differs from conventional ski areas. In La Grave, all skiers practice off-piste skiing, with access via a cableway. Accordingly, the ski pass control system can be used to measure off-piste skiing demand.

To examine off-piste skiing demand patterns, in addition to the analyses often done in conventional ski areas, it is necessary to assess factors that specifically influence off-piste skiing. First, previous research on off-piste skiing has indicated that one of the significant motivations is sensation seeking, including skiing on untracked fresh snow (Furman et al 2010; Marengo et al 2017). Therefore, an appropriate analysis must include the amount of fresh snow as a variable. In addition, off-piste skiers must manage their risks, especially avalanche risk. In the European Alps, daily avalanche risk assessment is widespread. It is a safety criterion for winter backcountry activities (Haegeli et al 2010; Marengo et al 2017; Fisher et al 2022). Therefore, it is likely to influence off-piste skiing demand.

With this study, we aimed to elucidate daily off-piste skiing demand patterns by applying an econometric method. Because off-piste skiing in La Grave is lift served, our study is a mix of backcountry activity monitoring and alpine ski demand modeling, and results may not be representative of other backcountry visitation trends. To achieve our aim, we developed a regression model testing the following hypotheses specific to off-piste skiing:

- H1: Skiers are expected to prefer days with the best fresh snow conditions. Therefore, off-piste skiing demand is positively affected by the availability and amount of fresh powder snow.
- H2: Skiers are expected to avoid high-avalanche-risk days to manage their safety. Therefore, off-piste skiing demand is negatively affected by high-avalanche-risk days.

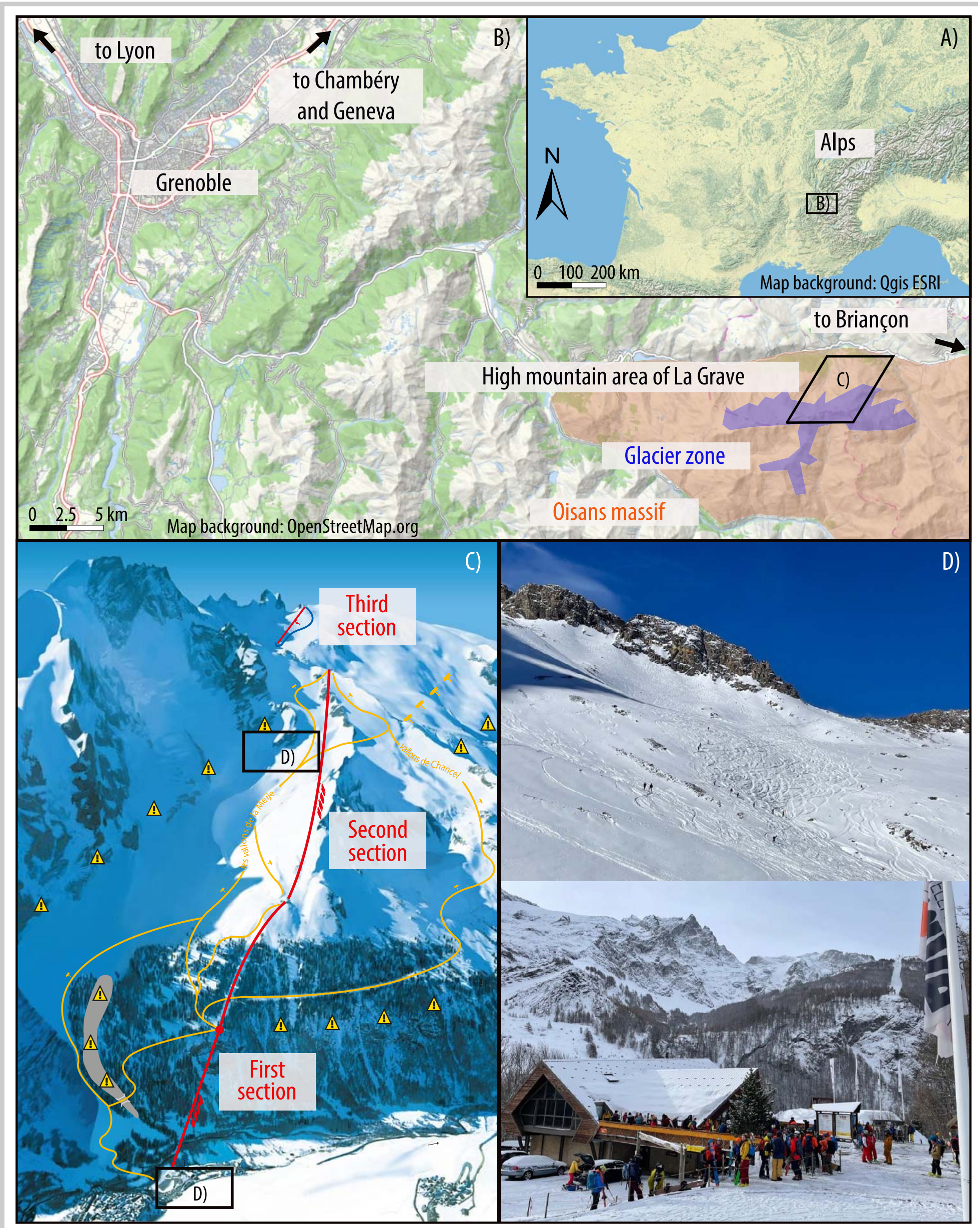
Material and methods

High mountain area in La Grave

Our case study focuses on the high mountain area of La Grave, located in the Oisans massif in the French Alps (Figure 1A). La Grave is located within the perimeter of Ecrins National Park. By car, it takes 2 hours to reach it from Lyon and 1.5 hours from Grenoble (Figure 1B). Conventional ski resorts offer many types of infrastructure, such as lifts and ski runs. However, La Grave differs greatly from this. It offers almost exclusively off-piste itineraries, where skiers can make their paths in barely marked areas, called the high mountain area.

The high mountain area in the La Grave operation is equipped with a single cableway that allows skiers to ascend from 1400 to 3200 masl (Poulain and Garcia 2024). It consists of 2 sections (Figure 1C). The first connects the village, which is situated at 1400 masl, to the intermediate station at 2400 masl, and the second connects the intermediate station to the upper station at 3200 masl. The same cableway equipment has been in operation since the opening of the cableway in July 1976. It has a capacity of 30 people, with a group of 5 gondola cabins arriving at the upper station every 5 minutes. This relatively low capacity limits the number of skiers. At the end of the second section, at 3200 masl, skiers can take a T-bar ski lift, which was installed in 1990 on the Girose glacier, to reach the top of the mountain at 3550 masl. The cableway company is responsible for its customers' safety until they exit the cableway station, as well as inside the

FIGURE 1 Multiscale map of La Grave, 45°02′39.6″N; 6°18′12.2″E. (Map by Lucas Berard-Chenu; photos by Nao Yoshizawa)



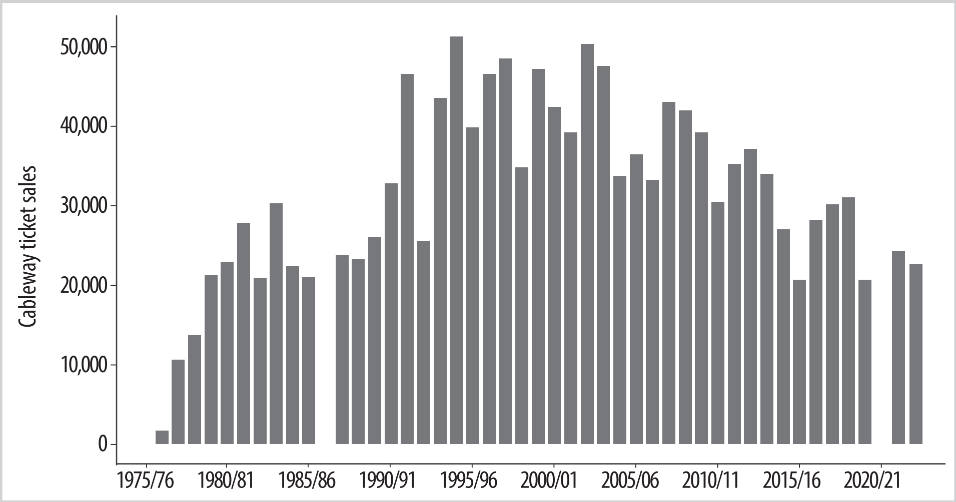
marked and secured area of the glacier tracks. Outside the boundary, skiers are free to ski at their own risk. The terrain for skiing is ungroomed and unmanaged, and there is no avalanche control (Figure 1D). Freeriding is the main activity in La Grave, but there are some routes reached by hiking from the 3200-masl station; therefore, ski touring is also practiced. As a result of this particular configuration, La Grave mainly attracts visitors who are capable of managing risks by themselves.

Despite a vertical drop of more than 2000 m, La Grave has attracted relatively few visitors, with 25,000 to 35,000 skier visits in the past 5 seasons. In comparison, Les Deux Alpes and L'Alpe d'Huez, 2 ski resorts located near La Grave, each had approximately 1.1 million skier visits during the 2018/19 season (Lagneux 2019). Figure 2 shows the annual number of La Grave cableway ticket sales in winter from 1976/77 to 2022/23. The number of ticket sales refers to the number of people who purchased one of the various offers for the cableways marketed by the operator. The cableway company markets 4 types of products: single pass, 1-day pass, several-day pass, and season pass. In the company's commercial statistics, each ticket sale is counted as 1 regardless of the ticket type. The number varied each year, with an increasing trend from 1976/77 to 1992/93 and a decreasing trend after the 2010s. Cableway operations were suspended because of insolvency in 1986/87 and the COVID-19 crisis in 2020/21. Figure 3 shows the average ratio of ticket sales by month for each decade. It indicates a seasonal shift in ticket sales from spring to winter.

Variables selected and data collected

Analyzing the determinants of off-piste skiing demand requires a finer scale of observation than the annual

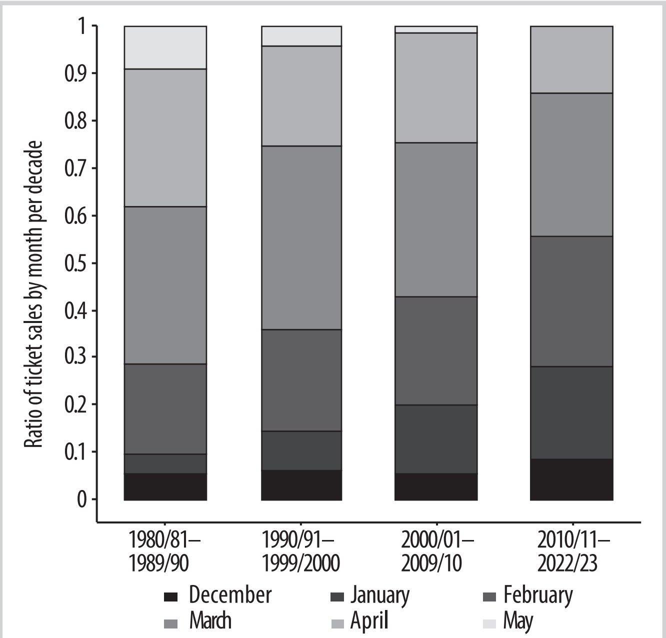
FIGURE 2 Annual number of ticket sales in winter in La Grave (1976/77–2022/23).



number of skiers. The dataset encompassed 5 ski seasons, 2017/18–2022/23, for which daily skier visit data were available, incorporating variables identified as follows.

Number of skier visits: This was provided by the cableway company and represented the number of people attending the ski area for all or part of a day. The cableway was occasionally closed because of strong winds or high avalanche risk. On the morning of a day when the avalanche danger level rises to 3 or higher, an inspection and meeting to decide on closure is held by local residents and guides, without representatives of the cableway company. In the case of closures, the number of skiers was 0; therefore, we excluded 52 such days over the 5 seasons. We also excluded 6 days of exceptional attendance because of local events (eg Derby de La Meije in early April).

FIGURE 3 Average ratio of ticket sales by month per decade (1980/81–2022/23).



Avalanche risk assessment data: The Avalanche Risk Assessment Bulletin for the Oisans massif by Météo-France provides data for 3 independent variables: avalanche risk, fresh snow, and weather.

- Avalanche risk is published every evening, with an estimate of the next day's avalanche risk on a scale of 1 to 5. Larger numbers indicate higher avalanche risk.
- Fresh snow is a qualitative categorical variable representing the amount of snowfall at 1800 masl during the previous night and day. It uses 5 modalities: rain, no fresh snow, and 1–10 cm, 11–20 cm, and 21 cm or more of fresh snow.
- Weather conditions in the morning are represented by a categorical variable with 4 modalities: sunny, cloudy, snowy, or rainy.

Months: A categorical variable for months of the season was included; this could take 5 modalities: December, January, February, March, or April. We also included categorical variables for the 5 specific periods we considered in comparison to nonspecific periods: Christmas vacations, winter vacations, spring vacations, weekends, and holidays outside of vacation periods.

Lagged dependent variable: We included skier visits on the previous day as a lagged dependent variable, because several studies on ski areas have shown that skier visits persist over time. For example, Malasevska et al (2015) and Falk et al (2022) showed that past frequentation values have a positive and significant effect.

Before and after the COVID-19 pandemic: To incorporate changes in visitation patterns before and after COVID-19, a dichotomous variable with pre- and post-COVID values of 0 and 1, respectively, was integrated into the analysis. We defined post-COVID as after the 2020/21 season.

In addition, we conducted an interview of approximately 1 hour with the manager of the cableway company on 17

TABLE 1 Distribution of fresh snow/precipitation categories across all days in the study period on which the cableway was open.

Amount of fresh snow/precipitation	Days	%	Cumulative %
Rain	29	5.28	5.28
No fresh snow	350	63.75	69.03
1–10 cm	128	23.32	92.35
11–20 cm	34	6.19	98.54
21+ cm	8	1.46	100.00
Total	549	100.00	

February 2022 to understand the characteristics of the clientele.

Model specification and estimation method

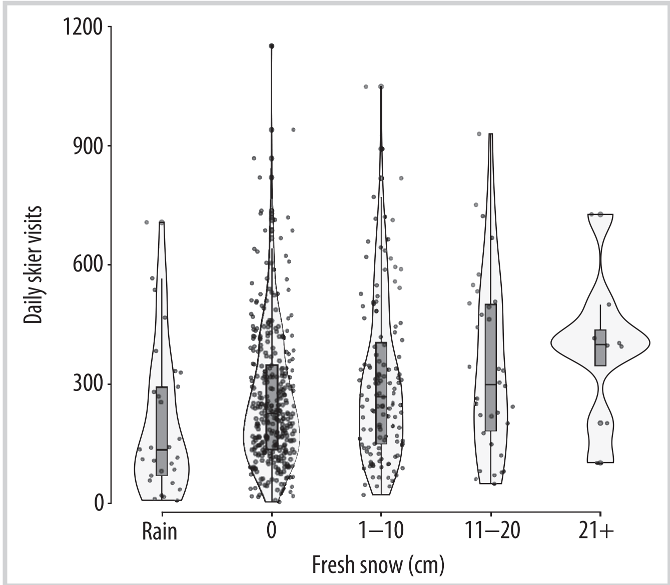
We used a regression model to analyze the relationship between skier visits and the following selected factors:

$$\begin{aligned}\text{Log}(skier\_visit_t) = {} & \phi\text{Log}(skier\_visit_{t-1}) + \beta_1 fresh\_snow_t \\ & + \beta_2 avalanche\_risk_t + \beta_3 post\_covid_t + \beta_4 weather_t \\ & + \beta_5 month_t + \beta_6 specific\_period_t + \varepsilon_t\end{aligned}$$

where t denotes time; $skier\_visit_t$ represents the dependent variable; $skier\_visit_{\{t-1\}}$ represents skiers' attendance during previous periods, capturing the influence of past trends and patterns; $fresh\_snow_t$ refers to snowfall measured during the day and night; $weather_t$ represents the forecasted weather; $avalanche\_risk_t$ represents the estimated avalanche risk of the day; $month_t$ represents the current month; $specific\_period_t$ captures whether the current day is in a specific period; $post\_covid_t$ indicates whether the season is in a post-COVID period; β_0 to β_6 are the regression coefficients, representing the expected change in skier visits associated with each respective independent variable, and ε represents the error term, accounting for unobserved factors and random variations in skier visits that are not explained by the independent variables. We applied a natural logarithm transformation to the visit variables relating to skiers and past skiers to address potential heteroscedasticity or nonlinear relationships between the variables. This transformation was intended to stabilize the variance and allowed the regression coefficients to be interpreted as approximate percentage changes in skier visits.

We used the statistical software STATA (v15.1) to estimate the regression model coefficients with the ordinary least squares (OLS) estimator, which minimizes the sum of the squared residuals to obtain parameter estimates. Following OLS regression model estimation, we conducted several diagnostic checks to assess the validity of the model's assumptions and evaluate the reliability of the estimated results. (See Narayan 2003 for more information regarding the diagnostic tests to model tourism demand.) We used robust standard errors to avoid an autocorrelation or heteroscedasticity bias in our estimates. We assessed the presence of unit roots in the dependent variable using the augmented Dickey–Fuller test (Dickey and Fuller 1979).

FIGURE 4 Violin plot of skier visits according to amount of fresh snow. The width of each violin represents data density, while the central box plot indicates the interquartile range and median.



Model misspecification was tested using the Ramsey regression specification error test (Ramsey 1969).

Results

Descriptive results

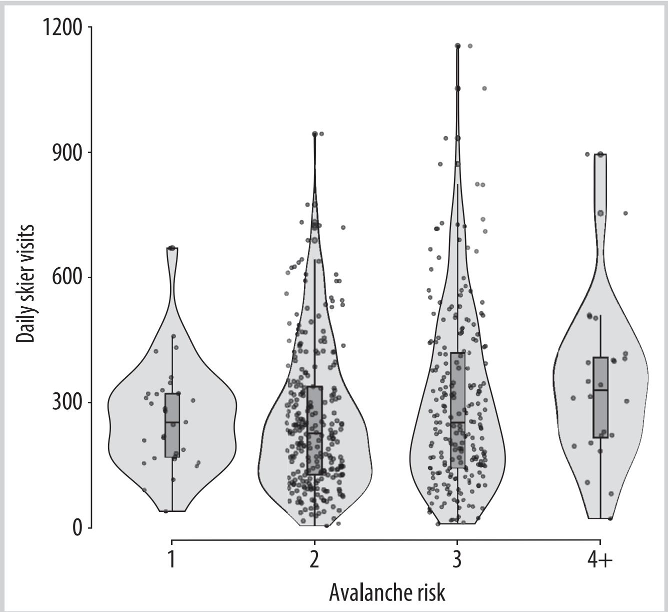
From 2017/18 to 2022/23, skier visits in La Grave were highly variable as the seasons progressed, and they did not follow a clear trend. They were similar for the winters of 2017/18 and 2018/19, with 35,287 skiers during the 111 open days in 2017/18 and 35,786 skiers during the 119 open days in 2018/19 (Figure S1, *Supplemental material,* https://doi.org/10.1659/mrd.2023.00032.S1). The winter of 2020/21 had the lowest numbers, 25,071 skiers for 75 days, because of the COVID-19 pandemic, which shortened the season. The post-COVID seasons of 2021/22 and 2022/23 were similar, with 28,770 skiers during the 123 open days in 2021/22 and 26,905 skiers during the 122 open days in 2022/23. The number of skier visits remained fairly low (around 27,800) compared with the pre-COVID winters (around 34,500). On average, skier visits were higher in February and March than at the beginning or end of the season (Figure S2, *Supplemental material,* https://doi.org/10.1659/mrd.2023.00032.S1) and higher on weekends and Fridays than during the rest of the week (Figure S3, *Supplemental material,* https://doi.org/10.1659/mrd.2023.00032.S1).

Table 1 shows the distribution of fresh snow days on which the cableway was open. On 63.8% of the days, there was no fresh snow. There was rain on 5.3% of the days, and large amounts of snow (≥21 cm) occurred on only 1.5% of the days.

Figure 4 shows skier visits based on different amounts of fresh snow. The visits tended to increase with more fresh snow, with the highest number of visits occurring on days with 21 cm or more. Rainy days had the lowest number of visits.

Figure 5 illustrates skier visits based on avalanche risk levels. A notable difference was observed in the distribution of days when La Grave was open across different risk levels:

FIGURE 5 Violin plot of skier visits according to avalanche risk. The width of each violin represents data density, while the central box plot indicates the interquartile range and median.



31 days (5.7%) were classified as risk level 1, 274 days (50.3%) as risk level 2, 216 days (39.6%) as risk level 3, 23 days (4.2%) as risk level 4, and 1 day (0.2%) as risk level 5. Although the average number of visits changed little across risk levels, the variability in visits increased significantly at risk levels 3 and 4.

Empirical results

This section presents the model analysis results. Table 2 shows the estimated coefficients of each independent variable's effect on off-piste skiing demand. The lagged dependent variable (skier visits on the previous day) was statistically significant, with a coefficient of 0.28. It indicates that skier visits on one day moderately influence the number of skier visits on the next day. Because the other variables were categorical, we interpreted the estimates of each variable based on the base level defined for each variable. We observed that the amount of fresh snow positively and significantly affected the number of skier visits compared with days without fresh snow. The intensity of this effect increased with the amount of fresh snow. For example, a day with 11 to 20 cm of fresh snow increased the number of skier visits the following day by 54.5%, compared with a day with no fresh snow, with all other factors being equal. In the case of 21 cm or more of fresh snow, the number of skier visits increased by 121.5%. A day at risk level 2, 3, or 4 was not significantly different from one at risk level 1. These results confirm hypothesis H1 that off-piste skiing demand depends on the availability and amount of fresh powder snow. However, our results oppose hypothesis H2, because high avalanche risk did not affect off-piste skiing demand.

For the weather control variables, we observed that sunny days had a more significant and positive effect on skier visits than cloudy days. In contrast, snowy and rainy days affected the number of skier visits negatively compared with cloudy days. These negative effects were more pronounced on rainy than on snowy days.

Regarding the periods tested in our model, although February and March had significantly more skier visits than December, weekends and holidays had significantly more skier visits than nonspecific periods. This relationship is significant and negative for spring holidays, but not significant for winter and Christmas vacations. On average, skier visits have fallen by 13.6% since COVID-19.

The adjusted R^2 value indicates that our model explains 44.39% of the variance in skier visits to La Grave. Finally, because we used robust standard errors, autocorrelation and heteroscedasticity are not of concern. Therefore, we only conducted diagnostics for a unit root in the dependent variable and for misspecification of the model. Table 3 presents the results of the unit root and misspecification tests. The presence of a unit root in the dependent variable was excluded by the rejection of the null hypothesis of the augmented Dickey–Fuller test, and the misspecification test cannot reject the null hypothesis of missing variables in the model. The results of these tests indicate the reliability of the estimated results.

Discussion

Off-piste skiing demand patterns

The results indicated that an increase in fresh snow at La Grave led to an increase in skier visits. This is similar to the case of Gunstock Mountain Resort in Gilford, NH, USA, described in Hamilton et al (2007), where snowfall had a significant effect on alpine skier attendance. In contrast, it differs from the case of Cannon Mountain Ski Area in Franconia, NH, USA, in the same study, where snowfall did not consistently show a significant effect, as well as the results of 2 ski resorts in Michigan, USA (Shih et al 2009). In La Grave, where off-piste skiing is a key tourism resource (Corneloup 2009; Poulain and Garcia 2024), the skiers seek fresh, deep snow after snowfall. Consequently, the skiers exhibited heightened responsiveness to the prevailing amount of snowfall. Other results were similar to those of other ski resorts: skier visits were higher on sunny days, and skiers visited the previous day (Malasevska et al 2015; Falk et al 2022).

Contrary to hypothesis H2, we determined that avalanche risk did not affect skier visits. Hallandvik et al (2017) showed that users' comprehension of avalanche risk information varies based on their experience level. Engeset et al (2018) showed that comprehension of information can vary depending on which types of avalanche problems are present. We suggest that the choice to visit La Grave for off-piste skiing, even if the avalanche risk is high, is a decision made by the individual and involves a more detailed risk assessment on the day. In addition, previous familiarity with slopes, the presence of ski tracks, and other skiers on the slopes increase skiers' propensity to enter slopes exposed to avalanche risks (McCammon 2004; Furman et al 2010; Marengo et al 2017). La Grave, being an area specializing in off-piste skiing, typically has these factors. Given this specificity of La Grave, we should not generally assume that higher avalanche risks have no impact on off-piste skiing demand. La Grave's unique characteristics may explain this counterintuitive off-piste skiing demand.

TABLE 2 Regression analysis results for factors influencing off-piste skiing.

Independent variable	Coefficient	SE	*t* statistic	*P*
Skier visits (Log) (first lag)	0.2815707	0.0495999	5.68	0***
Fresh snow/precipitation				
Rain	−0.0346638	0.2187055	−0.16	0.874
1–10 cm	0.3762615	0.0685747	5.49	0***
11–20 cm	0.5447301	0.1272681	4.28	0***
21+ cm	1.215456	0.2070146	5.87	0***
Avalanche risk				
Risk 2	−0.109444	0.0752731	−1.45	0.147
Risk 3	0.1040827	0.0848977	1.23	0.221
Risk 4+[a)]	0.2134379	0.1764125	1.21	0.227
Weather				
Rainy	−0.5369286	0.2108238	−2.55	0.011**
Snowy	−0.3934569	0.1008519	−3.90	0***
Sunny	0.4074027	0.0699644	5.82	0***
Month				
January	0.3370368	0.2227226	1.51	0.131
February	0.7220856	0.2334631	3.09	0.002***
March	0.7228202	0.2378272	3.04	0.003***
April	0.433905	0.2472944	1.75	0.08*
Specific period				
Christmas vacations	0.3385028	0.2550309	1.33	0.185
Winter vacations	0.0746278	0.0744303	1.00	0.317
Spring vacations	−0.3954764	0.1295685	−3.05	0.002***
Weekends and holidays	0.2554953	0.064323	3.97	0***
Post-COVID	−0.1358597	0.0616705	−2.20	0.028**
Constant	3.018797	0.2676592	11.28	0***
Number of observations	505			
Adjusted R^2	0.4439			

Note: 0 cm, Risk 1, Cloudy, December, and Pre-COVID serve as baseline categories for the respective variables and are therefore not included in the table.
[a)] Risk 5 appears in only one case and has been combined with Risk 4 for analysis.
***$P < 0.01$; **$P < 0.05$; *$P < 0.1$.

Christmas and winter vacation periods significantly affected ski tourism demand in previous studies (Malasevska et al 2015; Domaines Skiables de France 2023), but this was not the case in La Grave. Moreover, spring vacations negatively affected the skier visits. Conversely, weekends and holidays had a significant positive impact on skier visits. According to our interview with the cableway company manager, La Grave's clientele comprises a significant proportion of local skiers and those residing within a 2-hour radius, such as in Grenoble and Briançon, whereas other nearby resorts depend on vacationers. Bausch et al (2021) suggested a clear impact of weather on the number and duration of short-term trips to alpine destinations, whereas no clear indication existed about the weather playing a significant role in mid- or long-term trips. We believe that the proximity of skiers' residences probably accounted for their heightened sensitivity to the prevailing conditions.

TABLE 3 Results of diagnostic tests.

Diagnostic test	*P*
Unit root test of *skier_visit*	0.0000
Misspecification test	0.1402

Post-COVID negatively affected skier visits in La Grave. This was a different trend from the evolution of skier visits in French ski areas increasing as a whole post-COVID from pre-COVID levels (Domaines Skiables de France 2023). What caused this difference remains uncertain. Post-COVID inflation in France (Plane and Vermersch 2024), might have affected the behavior of La Grave's specific clientele. There are some studies showing changes of tourist flow during and after COVID-19 (Shin et al 2022; Yu et al 2023); however, their findings were derived from macroscale analyses. They could not provide insights into niche tourism for off-piste skiing. Thus, we should consider this in a more localized context. In France, during the closure of ski areas because of the COVID-19 crisis, ski touring, in which skiers climb without ski lifts, gained popularity (Cazé 2021). We suggest that the decrease in skier visits in La Grave resulted from competition between ski touring and lift-accessed off-piste skiing. Even after the restrictions were lifted, skier visits in La Grave decreased—likely because many skiers have continued the habit of ski touring rather than off-piste skiing.

Given the limited data availability, only 5 seasons were analyzed. Further analysis with a larger dataset would be desirable. We used weather forecast data because of the unavailability of observational data. This may have recorded the frequency of skiers' attendance more sensitively than an analysis based on observational data.

Impact of climate change and adaptation strategies in La Grave

We considered the likely impact of climate change on off-piste skiing in La Grave. On the demand side, based on our results regarding the importance of fresh snow at the 1800-masl elevation, we suggest that climate change will negatively affect skier visits to La Grave in the future. On the supply side, recent analyses of ski businesses facing climate change have emphasized the adaptive importance of snow management practices, such as grooming and snowmaking (Spandre et al 2019; Berard-Chenu et al 2023). However, snow management practices cannot support off-piste skiing, because this activity seeks fresh, natural snow on unmanaged slopes. Therefore, the challenge of adapting to climate change is even more pronounced for off-piste skiing than for alpine skiing, because off-piste skiing highly depends on natural snow conditions. This is an important insight for the ski area management to consider. Moreover, extreme snowfall, increased by climate change at high elevations (Le Roux et al 2021), can complicate risk management in La Grave. It could heighten the frequent disruption of cableway operations. Hence, we highlight the future vulnerability of La Grave, which relies on off-piste skiing as a major tourist resource.

Facing these situations, a new exploitation plan, replacing the T-bar lift on the glacier with a cableway, is being implemented by the cableway company (Poulain and Garcia 2024). It will enable tourists to reach an elevation of 3600 masl instead of 3200 masl all year, along with the experience of riding the cableway, which will allow them to observe the Girose glacier from above. The project will promote tourism beyond winter, repositioning La Grave as a glacier tourist site (Salim et al 2021). This tourism diversification strategy will strengthen tourism resources in seasons other than winter (George et al 2019). Moreover, the new cableway will be powered by electricity and therefore will reduce carbon dioxide emissions, because the T-bar lift consumes 5000–6000 L of fuel per season (SATG 2020). From the perspective of the cableway company, the development of the glacier zone and its use beyond the winter season will allow some adaptation to climate change.

However, a group of residents called La Grave Autrement has opposed the cableway company's project since 2019 (Poulain and Garcia 2024). The group has expressed its opposition to the new construction plan on the glacier zone. They have criticized the more tourism-dependent future model, which is contrary to La Grave's tradition of maintaining minimal development since the cableway opening. The project could also enhance the destination's international and domestic attractiveness, potentially increasing its carbon footprint because of tourist travel, although not directly emitted by the cableway company. As an alternative, the group proposes removing the existing T-bar lift and constructing a mountain hut at 3200 masl to keep the high mountain environment above this elevation undeveloped (Plas and Virilli 2022). They advocate for the glacier zone to be used for nonfacilitated recreational or educational activities, such as hiking, alpine climbing, ski touring, and scientific tourism.

Our analysis was limited to demand for off-piste skiing in winter, making it difficult to suggest constructive alternatives. The issue of the cableway project represents the 2 climate change adaptation strategies for La Grave, both of which lower dependence on off-piste skiing. This decision also represents a choice for La Grave about the extent to which it will rely on tourism in the future.

Conclusion

In this study, we examined demand patterns for off-piste skiing in La Grave, developing an empirical model based on a 5-year daily time series of skier visits. Our findings revealed a strong, positive, and significant correlation between amount of fresh snow and skier visits. Higher avalanche risk did not deter skier visits, suggesting that individual decision-making and familiarity with the terrain may outweigh perceived risks in the unique setting of La Grave. Off-piste skiing demand was more sensitive to weekends and holidays than to vacation periods. The post-COVID period posed a unique challenge, with skier visits declining despite a general increase in skier visits across French ski areas. We suggest that this decline may stem from the rising popularity of ski touring during the pandemic, which provided an appealing alternative to off-piste skiing.

We confirmed a seasonal shift trend in ticket sales for off-piste skiing from spring to winter since the opening of the cableway in La Grave. Ticket sales have been decreasing in recent years. The current business model, heavily reliant on off-piste skiing and natural snowfall, faces challenges because of climate change. Unlike conventional skiing, which increasingly relies on snow management to adapt, off-piste skiing cannot benefit from such measures. In response, a new cableway plan to enhance summer glacier tourism is under way. However, there is also an opposing movement advocating for an alternative plan that involves removing all artificial structures from the glacier. The issue of the cableway project represents 2 climate change adaptation strategies, both seeking to reduce reliance on off-piste skiing. La Grave appears to be undergoing a transition away from a model heavily dependent on off-piste skiing.

ACKNOWLEDGMENTS

We are grateful to SATG-Téléphériques des Glaciers de la Meije for their cooperation with this research. This work was supported by JSPS KAKENHI (grant numbers 24K21014 and 23K21815) and Bourses France Excellence 2021–2022.

REFERENCES

Bausch T, Cartner WC, Humps A. 2021. How weather conditions affect guest arrivals and duration of stay: An alpine destination case. *International Journal of Tourism Research* 23:1006–1026. https://doi.org/10.1002/jtr.2441.

Beniston M, Farinotti D, Stoffel M, Andreassen LM, Coppola E, Eckert N, Fantini A, Giacona F, Hauck C, Huss M, et al. 2018. The European mountain cryosphere: A review of its current state, trends, and future challenges. *Cryosphere* 12:759–779. https://doi.org/10.5194/tc-12-759-2018.

Berard-Chenu L, Cognard J, François H, Morin S, George E. 2020. Do changes in snow conditions have an impact on snowmaking investments in French Alps ski resorts? *International Journal of Biometeorology* 65:659–675. https://doi.org/10.1007/s00484-020-01933-w.

Berard-Chenu L, François H, Morin S, George E. 2023. The deployment of snowmaking in the French ski tourism industry: A path development approach. *Current Issues in Tourism* 26(23):3853–3870. https://doi.org/10.1080/13683500.2022.2151876.

Brugger H, Etter HJ, Zweifel B, Mair P, Hohlrieder M, Ellerton J, Elsensohn F, Boyd J, Sumann G, Falk M. 2007. The impact of avalanche rescue devices on survival. *Ressuscitation* 75(3):476–483. https://doi.org/10.1016/j.resuscitation.2007.06.002.

Cazé E. 2021. Boom du ski de rando (1/3): l'avenir du marché, vu par les fabricants, détaillants et loueurs. *Montagnes* 12 April 2021. https://www.montagnes-magazine.com/actus-boom-ski-rando-1-3-avenir-marche-vu-les-fabricants-detaillants-loueurs; accessed on 15 July 2024.

Corneloup J. 2009. Système culturel localisé et gestion des stations touristiques. *In:* Ferreol G, Mamontoff AM, editors. *Tourisme et société*. EME editions, pp 122–146. https://shs.hal.science/halshs-00579779; accessed on 15 August 2023.

Dickey DA, Fuller WA. 1979. Distribution of the estimators for autoregressive time series with a unit root. *Journal of the American Statistical Association* 74(366):427. https://doi.org/10.2307/2286348.

Domaines Skiables de France. 2023. *Indicateurs et analyse 2023*. France: Domaines Skiables de France. https://www.domaines-skiables.fr/publications/observatoire/; accessed on 15 July 2023.

Engeset RV, Pfuhl G, Landrø M, Mannberg A, Hetland A. 2018. Communicating public avalanche warnings: What works? *Natural Hazards and Earth System Sciences* 18:2537–2559. https://doi.org/10.5194/nhess-18-2537-2018.

Falk M, Hagsten E, Lin X. 2022. Spatial influence on the distribution of downhill skiers in Sweden. *International Journal of Biometeorology* 68:535–545. https://doi.org/10.1007/s00484-022-02259-5.

Fisher KC, Haegeli P, Mair P. 2022. Exploring the avalanche bulletin as an avenue for continuing education by including learning interventions. *Journal of Outdoor Recreation and Tourism* 37:100472. https://doi.org/10.1016/j.jort.2021.100472.

Freeskier. 2023. Insights, data & more: A closer look at skier participation around the United States. *Freeskier*. 16 February 2023. https://freeskier.com/first_look/insights-data-more-a-closer-look-at-skier-participation-around-the-united-states; accessed on 15 July 2024.

Frühauf A, Anewanter P, Hagenauer J, Marterer N, Kopp M. 2019. Freeriding: Only a need for thrill? Comparing different motives and behavioural aspects between slope skiers and freeride skiers. *Journal of Science and Medicine in Sport* 22(1):44–49. https://doi.org/10.1016/j.jsams.2018.11.002.

Frühauf A, Zenzmaier J, Kopp M. 2020. Does age matter? A qualitative comparison of motives and aspects of risk in adolescent and adult freeriders. *Journal of Sports Science and Medicine* 19:112–120.

Furman N, Shooter W, Schumann S. 2010. The roles of heuristics, avalanche forecast, and risk propensity in the decision making of backcountry skiers. *Leisure Sciences* 32(1):19–37. https://doi.org/10.1080/01490400.2010.510967.

George E, Achin C, François H, Spandre S, Morin S, Veraille D. 2019. Changement climatique et stations de montagne alpines: impacts et stratégies d'adaptation. *Eaux & Territoires* 28:44–51. https://doi.org/10.3917/set.028.0044.

Haegeli P, Haider W, Longland M, Berdmore B. 2010. Amateur decision-making in avalanche terrain with and without a decision aid: A stated choice survey. *Natural Hazards* 52:185–209. https://doi.org/10.1007/s11069-009-9365-4.

Hallandvik L, Andresen MS, Aadland E. 2017. Decision-making in avalanche terrain: How does assessment of terrain, reading of avalanche forecast and environmental observations differ by skiers' skill level? *Journal of Outdoor Recreation and Tourism* 20:45–71. https://doi.org/10.1016/j.jort.2017.09.004.

Hamilton LC, Brown C, Keim BD. 2007. Ski areas, weather and climate: Time series models for New England case studies. *International Journal of Climatology* 27:2113–2124. https://doi.org/10.1002/joc.1502.

Lagneux B. 2019. Isère: deux stations ont dépassé le million de journées-skieurs. *Le Dauphine Libéré* 28 April 2019. https://www.ledauphine.com/isere-sud/2019/04/28/isere-deux-stations-ont-depasse-le-million-de-journees-skieurs; accessed on 15 July 2024.

Langford R, Haegeli P, Rupt R. 2020. *How Much Recreational Exposure to Avalanche Terrain is There? An Overview of Possible Approaches for Monitoring Winter Backcountry Use for Public Avalanche-Warning Services*. Report prepared for Per-Olov Wikberg, Mountain Safety Council/Swedish Environmental Protection Agency. Zurich, Switzerland: Zurich University of Applied Sciences. https://digitalcollection.zhaw.ch/handle/11475/25350; accessed on 15 July 2024.

Le Roux E, Evin G, Eckert N, Blanchet J, Morin S. 2021. Elevation-dependent trends in extreme snowfall in the French Alps from 1959 to 2019. Projection of snowfall extremes in the French Alps as a function of elevation and global warming level. *Cryosphere* 15:4335–4356. https://doi.org/10.5194/tc-15-4335-2021.

Malasevska I, Haugom E, Gudbrand L. 2015. Modeling and forecasting alpine skier visits. *Tourism Economics* 22(3):669–679. https://doi.org/10.5367/te.2013.0366.

Malterud L, Engelsrud G, Vereide V. 2021. "Super stoked girls": A discourse analysis of girls' participation in freeride skiing. *Journal of Adventure Education and Outdoor Learning* 23(1):74–87. https://doi.org/10.1080/14729679.2021.1950557.

Mannberg A, Hendrikx J, Johnson J, Hetland A. 2021. Powder fever and its impact on decision-making in avalanche terrain. *International Journal of Environmental Research and Science* 18(18):9496. https://doi.org/10.3390/ijerph18189496.

Marengo D, Monach MG, Micel R. 2017. Winter recreationists' self-reported likelihood of skiing backcountry slopes: Investigating the role of situational factors, personal experiences with avalanches and sensation-seeking. *Journal of Environmental Psychology* 49:78–85. http://dx.doi.org/10.1016/j.jenvp.2016.12.005.

Matiu M, Crespi A, Bertoldi G, Carmagnola CM, Marty C, Morin S, Schöner W, Cat Berro D, Chiogna G, De Gregorio L, et al. 2021. Observed snow depth trends in the European Alps: 1971 to 2019. *Cryosphere* 15:1343–1382. https://doi.org/10.5194/tc-15-1343-2021.

McCammon I. 2004. Heuristic traps in recreational avalanche accidents: Evidence and implications. *Avalanche News* 68(1):19–24.

Narayan PK. 2003. Tourism demand modelling: Some issues regarding unit roots, co-integration and diagnostic tests. *International Journal of Tourism Research* 5(5):369–380. https://doi.org/10.1002/jtr.440.

Parrilla JC, Font AR, Nadal JR. 2007. Accommodation determinants of seasonal patterns. *Annals of Tourism Research* 34(2):422–436. https://doi.org/10.1016/j.annals.2006.10.002.

Plane M, Vermersch G. 2024. Inflation: Reemerging in France. *Revue d'économie financière* 153:99–118.

Plas S, Virilli. 2022. *Demain la montagne. 101 initiatives de transition*. Boulogne, France: Glènat.

Poulain M, Garcia PO. 2024. Negotiating the climatization of the glacial stratum. A study of La Grave cable car third section development project. *Journal of Alpine Geography* 112(1):75–85. https://doi.org/10.4000/rga.12875.

Pröbstl-Haider U, Richens H, Türk S. 2019. *Winter Tourism: Trends and Challenges*. Wallingford, United Kingdom: CABI.

Ramsey JB. 1969. Tests for specification errors in classical linear least-squares regression analysis. *Journal of the Royal Statistical Society: Series B (Methodological)* 31(2):350–371. https://doi.org/10.1111/j.2517-6161.1969.tb00796.x.

Rupf R, Haegeli P, Karlen B, Wyttenbach M. 2019. Does perceived crowding cause winter backcountry recreationists to displace? *Mountain Research and Development* 39(1):9–17. https://doi.org/10.1659/MRD-JOURNAL-D-18-00009.1.

Rupf R, Stäuble A. 2018. Monitoring methods of winter backcountry recreation in a wildlife sanctuary. *In:* Elliott CR, Dumanski J, Pushparajah E, Latham M, Myers R, editors. *Evaluation for Sustainable Land Management in the Developing World*. IBSRAM [International Board for Soil Research and Management] Proceedings 12, Vol 2. Bangkok, Thailand: IBSRAM, pp 253–278. https://mmv.boku.ac.at/refbase/files/rupf_reto_stauble_adrian-2018-monitoring-methods-winter-backcountry.pdf; accessed on 15 July 2024.

Salim E, Gauchon C, Ravenel L. 2021. Seeing the ice. An overview of alpine glacier tourism sites, between post- and hyper-modernity. *Journal of Alpine Research* 109(4):99–107. https://doi.org/10.4000/rga.8383.

SATG [Société d'Aménagement Touristique de la Grave]. 2020. *F09320P0027: réalisation du troisième tronçon des téléphériques des glaciers de la Meije*. Marseille, France: Direction régionale de l'environnement, de l'aménagement et du logement de Provence–Alpes–Côte d'Azur. https://www.paca.developpement-durable.gouv.fr/f09320p0027-realisation-du-troisieme-troncon-des-a12502.html?lang=fr; accessed on 15 July 2024.

Shih C, Nicholls S, Holecek DF. 2009. Impact of weather on downhill ski lift ticket sales. *Journal of Travel Research* 47(3):359–372. https://doi.org/10.1177/0047287508321207.

Shin H, Nivalau JL, Kang J, Sharma A, Lee H. 2022. Travel decision determinants during and after COVID-19: The role of tourist trust, travel constraints, and

attitudinal factors. *Tourism Management* 88:104428. https://doi.org/10.1016/j.tourman.2021.104428.
Spandre P, François H, Verfaillie D, Pons M, Vernay M, Lafaysse M, George-Marcelpoil E, Morin S. 2019. Winter tourism under climate change in the Pyrenees and the French Alps: Relevance of snowmaking as a technical adaptation. *Cryosphere* 13:1325–1347. https://doi.org/10.5194/tc-13-1325-2019.
Steiger R, Scott D, Abegg B, Pons M, Aall C. 2019. A critical review of climate change risk for ski tourism. *Current Issues in Tourism* 22(11):1343–1379. https://doi.org/10.1080/13683500.2017.1410110.
Tøstesen G, Langseth T. 2021. Freeride skiing: Risk-taking, recognition, and moral boundaries. *Frontiers in Sports and Active Living* 3:564–579. https://doi.org/10.3389/fspor.2021.650564.
Tremper B. 2013. *Avalanche Essentials: A Step-by-Step System for Safety and Survival*. Seattle, WA: Mountaineers Books.
Truong J, Bulota M, Desbiens AL. 2020. Historical trends in alpine ski design: How skis have evolved over the past century. *Proceedings* 49:135. https://doi.org/10.3390/proceedings2020049135.
Vanat L. 2022. *2022 International Report on Snow & Mountain Tourism: Overview of the Key Industry Figures for Ski Resorts.* Geneva, Switzerland: Laurent Vanat. https://de.cdn-website.com/64e34689550d402aa147af5bbc27524d/files/uploaded/RM-world-report-2022.pdf; accessed on 15 July 2024.
Yu L, Zhao P, Tang J, Pang L. 2023. Changes in tourist mobility after COVID-19 outbreaks. *Annals of Tourism Research* 98:103522. https://doi.org/10.1016/j.annals.2022.103522.

Supplemental material

FIGURE S1 Violin plot of skier visits depending on the season.
FIGURE S2 Mean of skier visits by month.
FIGURE S3 Mean of skier visits by weekday.

Found at: https://doi.org/10.1659/mrd.2023.00032.S1.