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Winters too warm to skate? Citizen-science reported variability in availability of outdoor skating in Canada

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Key Messages

- Citizen scientists have contributed thousands of reports of skating conditions in Canada.
- Variability in reported "skateability" is evident across 10 Canadian cities and the temperature-skating relationship varies across Canada.
- Climate modelling scenarios suggest significant declines in opportunities for outdoor skating across Canada.

Outdoor ice-skating is an important cultural pastime in many northern regions. Recent studies forecast declining availability of outdoor ice-skating as a result of warming temperatures. Using data on outdoor rinks collected from a citizen science project called RinkWatch, we compared skating conditions to temperature data for 10 cities across Canada, over two winter seasons. We find there is observable variance in the temperature-skating relationship regionally, and from one year to the next. By combining this data with daily temperature simulations based on the Intergovernmental Panel on Climate Change A2 emissions scenario, we projected the number of skating days by the year 2090 to decline on average by 34 percent in Toronto and Montreal, and 19 percent in Calgary. The results suggest that impacts of a warming climate on future outdoor skating opportunities will exhibit regional variability. Our report further highlights that below-freezing average temperatures do not necessarily provide outdoor ice suitable for skating.

Keywords: climate change, citizen science, forecasting, ecosystem services, Canada

Les hivers sont-ils trop chauds pour patiner? La science citoyenne fait état de la variabilité de la possibilité de patiner en plein air au Canada

Le patin à glace en plein air compte parmi les principaux passe-temps culturels dans de nombreuses régions nordiques. Des études récentes prévoient que le réchauffement des températures diminuera probablement la possibilité de pratiquer le patin à glace en plein air. À partir des données obtenues sur des patinoires en plein air grâce au projet de science citoyenne appelé RinkWatch, nous avons établi une comparaison entre les conditions des patinoires et les données de température dans dix villes canadiennes et ce, pendant deux saisons d'hiver. Une variation de la relation entre le patinage et la température a été observée tant à l'échelle régionale qu'entre les années. En combinant ces données avec des simulations quotidiennes de la

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température sur la base du scénario d'émissions A2 du GIEC, nous estimons que le nombre de jours de patinage d'ici l'an 2090 diminuera en moyenne de 34 % à Toronto et à Montréal, et de 19 % à Calgary. Il existe donc une variabilité régionale des effets du réchauffement climatique sur la pratique du patinage en plein air à l'avenir. Notre rapport met également en évidence que des températures moyennes au-dessous du point de congélation ne se traduisent pas nécessairement par des conditions de glace appropriées pour le patinage en plein air.

Mots clés : changements climatiques, science citoyenne, prévisions, services écosystémiques, Canada

Introduction

Ice-skating has been practiced by populations in northern regions for at least 3,000 years (Formenti and Minetti 2007). Recreational ice-skating became a popular pastime in Europe in the sixteenth century, in the heart of the "Little Ice Age," and was later introduced to North America by European migrants (Kivinen et al. 2001). Outdoor ice-skating is today a popular and culturally significant recreational activity for people across the world's northern latitudes. Sheets of ice that are sufficiently hard and strong enough for skating can thus be seen as an important ecosystem service (Brammer et al. 2015). Outdoor skating is most commonly practiced on natural water bodies where the surface layer has frozen to a sufficient thickness to support the skaters' weight safely, or on skating rinks made by deliberately flooding flat areas, typically done in backyards, parks, and other open spaces.

Two recent studies have suggested that the ecosystem service of skateable ice is threatened by warming temperature trends associated with anthropogenic climate change. Damyanov et al. (2012) found that the annual period when air temperatures are sufficiently cold to create outdoor rinks by flooding (the outdoor skating season, or "OSS") has been declining across Canada since the 1950s. The authors attained these results using a standard measure to define the length of the OSS (i.e., the earliest and latest occurrences of three consecutive days with average temperatures of −5 °C) and applying it to historical weather station data from across Canada. Brammer et al. (2015) combined data from 1970 to 2014 on the number of annual days of operation of Ottawa's Rideau Canal Skateway, (claimed to be the world's largest outdoor skating rink) with the Intergovernmental Panel on Climate Change (IPCC) A2 future climate scenario to predict a one-week shortening in the Skateway's OSS by 2040.

While it is reasonable to assume that warming temperatures will indeed lead to fewer future opportunities for outdoor skating, the relationship between temperature and ice rink conditions is more complicated than it appears. Future projections require considerably more empirical data about skating participation and actual ice conditions than were available to the authors of the aforementioned studies, which in one case used data from a single rink with unusual physical and operational characteristics (Brammer et al. 2015), the other using no rink data at all (Damyanov et al. 2012).

We operate a citizen science project called RinkWatch (www.rinkwatch.org), which invites people from across North America who maintain outdoor skating rinks to identify the location of their rinks on an interactive website map and then report the "skateability" of their rinks throughout the winter. We aim to collect daily information from participants, and offer the capability to report observations for days in the previous week in order to reduce non-reporting bias for non-skating days. Over the first two years of the project (winters 2012–13 and 2013–14) 10,866 skating condition observations were entered from 961 rinks across Canada and the United States (US); these data are freely available to download from the website. Our long-term objective is to track inter-annual changes and spatial variability in outdoor skating and compare these with observed climate trends. However, we are also able, in the near term, to use these data to comment on the relationship between projected changes in daily temperature and the suitability of ice rinks for skating.

Methods

Location-specific data used in our study were drawn from the RinkWatch project database. RinkWatch participants log in to the project website and report on a daily basis whether their rink is skateable or not given the current weather. Daily records for 10 selected Canadian cities were aggregated and classified as skateable or not skateable depending on the proportion of reported conditions (i.e., majority rule). This masks some intra-city variability in skating conditions that were not considered important for the scale of the analysis reported here. Cities were selected on the basis of having a consistent time series of submissions. Data were extracted for each day from January 1 to April 30 in 2013 and 2014 to match the dates used by Brammer et al. (2015) who found the coldest 100 days to be the best predictor of skating season length and number of skating days. Daily mean temperature data were downloaded from Environment Canada for corresponding periods at a central weather station in each of the selected cities, and used as the sole independent variable in skateability models.

As skateability was represented as a binary variable for each day, for each city, logistic regression was used to relate mean temperature to the probability of skating for each city. The logistic regression model represents a linear function between the log odds of skating and the independent variable, mean daily temperature. The global model was therefore of the form

$$p(\mathrm{Y}_i = 1) = \frac{\exp(\beta_0 + \beta_1 Mean.Temp_i)}{1 + \exp(\beta_0 + \beta_1 Mean.Temp_i)} \quad (1)$$

where $Y_i = 1$ indicates a reported skateable day for day *i*, and β_1 is the parameter of interest, which gives the incremental change in probability of skating for each change in mean daily temperature. We expanded the above model into a random intercept model defined by the city each observation was reported from, such that,

$$p(\mathrm{Y}_{i,j} = 1) = \frac{\exp(\beta_{0\,j} + \beta_1 Mean.Temp_{i,j})}{1 + \exp(\beta_{0\,j} + \beta_1 Mean.Temp_{i,j})} \quad (2)$$

so that model estimates are local for day *i* and city *j*. This formulation allows each city to have a separate baseline (i.e., intercept) level of skateability. Models were fit for both 2013 and 2014 data, resulting in a total of four logistic regression models. All models were fit using the statistical software R (Ihaka and Gentleman 1996), and the lme4 package (Bates et al. 2013) was used to fit the random intercept model.

Projected weather data were obtained from the MarkSim Weather Generator (Jones 2013) using an average of six IPCC general circulation models and the A2 emissions scenario in each the three selected cities (i.e., Toronto, Calgary, and Montreal) analyzed in the study. The MarkSim projections for daily minimum and maximum temperature provide realistic estimates of temperature variability based on a Markov chain-exponential estimation method (Richardson 1981). We obtained daily minimum and maximum for each day for each forecast year (2020 through 2090 at 10-year intervals) for each city. For each year of prediction, 99 replicates of daily temperature were obtained to estimate realistic variability in the changes in temperature in each city. The fitted models were used with each replicate dataset to produce a prediction of the probability of skating based on average daily temperature. The 50 percent threshold was used to classify each day as skateable or not, and the number of skateable days was enumerated for each prediction season. The final forecasts for the number of skateable days were obtained from a weighted average of the 2013 and 2014 random intercept model predictions.

Results

To assess the relationship between air temperature and skateability of ice, we began by extracting skateability data from RinkWatch for 10 Canadian cities for which we have large numbers of participants (Table 1) and compared these with daily temperature data from the nearest Environment Canada weather stations. Variance in ice suitability for skating was positively related to temperature up to a threshold temperature of −3 °C (Figure 1), but this variance is not uniform across locations, nor is it uniform from one year to the next. Almost all cities experienced greater variability in skating conditions in winter 2012–13 than in 2013–14 (i.e., vectors from circles to triangles in Figure 1 mostly point toward the origin) when mean temperatures were lower. Regional effects are evident in the data, as variance changes over the two seasons were similar in cities in the same geographic region (e.g., southern Ontario, western Canada).

We next fit two types of models to the data for each season, a global logistic regression model that ignored variability across cities, and a random intercept model that allowed for varying baselines for each city. In both seasons, the varying intercept model outperformed the global model as measured

Table 1
Summary statistics for rinks reporting to RinkWatch in major Canadian cities in the 2013 and 2014 skating seasons. Skateability is the percentage of rink reports to RinkWatch that describe a skateable day.

City	Province	# of rinks	2013 Reports	2014 Reports	Skateability
Toronto (TOR)	Ontario	117	1602	804	62% ±1.94%
Ottawa (OTT)	Ontario	95	1062	1129	76% ±1.79%
Montreal (MON)	Quebec	63	723	462	61% ±2.78%
Kitchener (KIT)	Ontario	55	754	513	56% ±2.73%
Hamilton (HAM)	Ontario	28	513	138	57% ±3.80%
Calgary (CAL)	Alberta	27	262	355	76% ±3.70%
Winnipeg (WIG)	Manitoba	20	286	296	86% ±3.10%
Windsor (WIN)	Ontario	12	104	200	48% ±5.62%
Oshawa (OSH)	Ontario	13	226	201	52% ±4.74%
Saskatoon (SAS)	Saskatchewan	7	227	206	99% ±0.94%

by the AIC (Table 2 - Δ AIC 2013 = +56.2, Δ AIC 2014 = +8.36). Estimates from the global model indicated that in winter 2012–13, for every 1 °C increase in average daily temperature, the odds of skating declined by 34 percent, and by 20 percent in winter 2013–14. The models show that outdoor skating was much more sensitive to temperature in winter 2012–13, when average winter temperatures across Canada were generally milder than in 2013–14. This is evident by considering the probability of skating when temperatures were 0 °C, which was p(skating|temp=0) = 0.37 in 2012–13 and p(skating|temp=0) = 0.59 in 2013–14. The sensitivity of skating to temperature is indicated by the

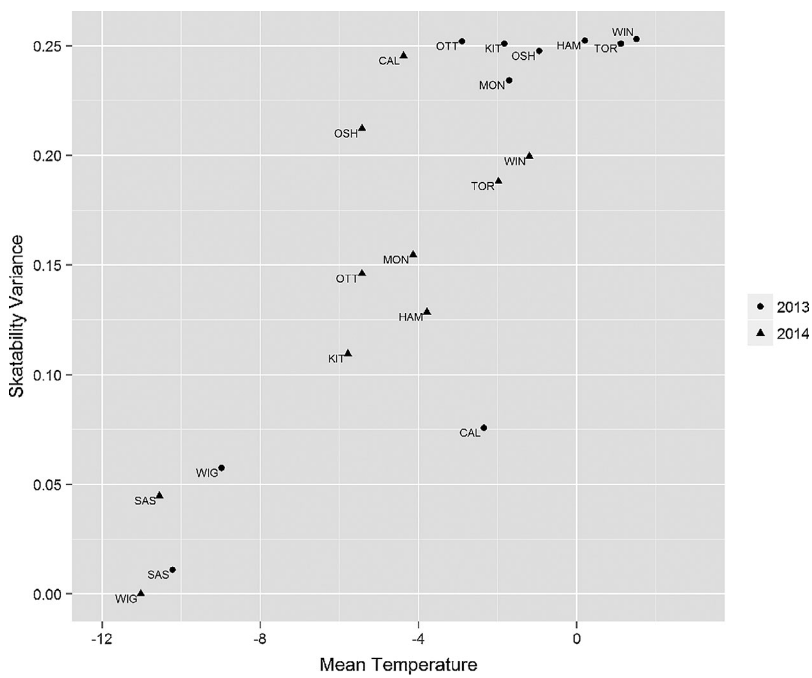

Figure 1
Temperature and skating variability in major Canadian cities in 2013 and 2014 skating seasons.

Table 2
Model diagnostics for average daily temperature and probability of skating. Global and random intercept models for data reported to RinkWatch and Environment Canada daily temperature data, 2013 and 2014.

	Model Term	Estimate	Standard Error
a)	2013 – Global Model – AIC: 727.5, Number of parameters: 2, log likelihood:-363.7		
	Intercept	−0.50	0.101
	Mean Temperature	−0.42	0.027
b)	2013 – Random Intercept Model – AIC: 671.3, Number of parameters: 12, log likelihood: -332.6, change in AIC: 56.2		
	Intercept	−0.38	0.335
	Mean Temperature	−0.44	0.031
c)	2014 – Global Model – AIC 568.2, Number of parameters: 2, log likelihood:-293.8		
	Intercept	0.37	0.112
	Mean Temperature	−0.23	0.0.19
d)	2014 – Random Intercept Model – AIC 559.8, Number of parameters: 12, log likelihood: -276.9, change in AIC: 8.4		
	Intercept	0.49	0.215
	Mean Temperature	−0.23	0.020

magnitude of the coefficient on mean temperature, which for both the global and the random intercept models was larger in magnitude in 2012–13 than 2013–14. The random intercept model revealed that baseline probabilities of skating (i.e., when mean daily temperature $\sim 0\,^{\circ}\mathrm{C}$) varied from 16 percent (Montreal) to 86 percent (Calgary) in 2012–13, and from 40 percent (Calgary) to 70 percent (Toronto) in 2013–14. The variance of the baseline probabilities was larger in 2012–13 (0.038) compared to 2013–14 (0.009), indicating about twice the inter-city variability in skating conditions in 2012–13 compared to 2013–14 (Figure 2). This is further evident in the lower improvement of the random intercept model over the global model in 2013–14 when compared to 2012–13, based on change in AIC. Overall, the results indicate significant year-over-year variability in addition to within-year spatial variability.

We then used these findings to create our own projections for future outdoor skating seasons, employing the same MarkSim weather projection models based on the IPCC A2 emissions scenario used by Brammer et al. (2015). Our variable of interest was the predicted number of skateable days ($p >= 0.5$) in the core January–April skating period for each year from 2020 to 2090, and decadal increments. Final predictions were derived from a weighted average of predictions from our 2012–13 and 2013–14 fitted models. Projections were constrained to three cities (Calgary, Montreal, Toronto) that are geographically dispersed and experience regional differences in climate. In Toronto, the number of skating days between January and April declined from 61 ± 14 days, to 40 ± 15 days in 2090, a change of approximately 34 percent. In Montreal, we forecasted a skating season with 65 ± 13 days in 2020, and 43 ± 13 in 2090, a 34 percent decline. In Calgary, the models predicted similar reductions, though the number of future skating days was higher here, estimated at 86 ± 13 days in 2020, and 70 ± 13 days in 2090, a decline of approximately 19 percent. Figure 3 presents these projections for Calgary (Figure 3a) and Toronto (Figure 3b) along with the range of predictions from 99 replicate scenarios for each time period. In all three cities we see forecasted declines with temperature, however they are not uniform. The models predict that changes in skating season will be more severe in Toronto and Montreal than in Calgary.

Discussion

The reduction in the number of future skating days we project for rinks across Canada is smaller than the reduction projected for Ottawa's Rideau Canal Skateway by Brammer et al. (2015), which is a distinctive skating facility that appears to be less resilient to temperature variation and change. Although the temporal coverage of our data is limited to two skating seasons, the spatial coverage is significant and provides evidence that the severity of the adverse effects of warming temperatures on skating rinks, and the timing of these impacts, will

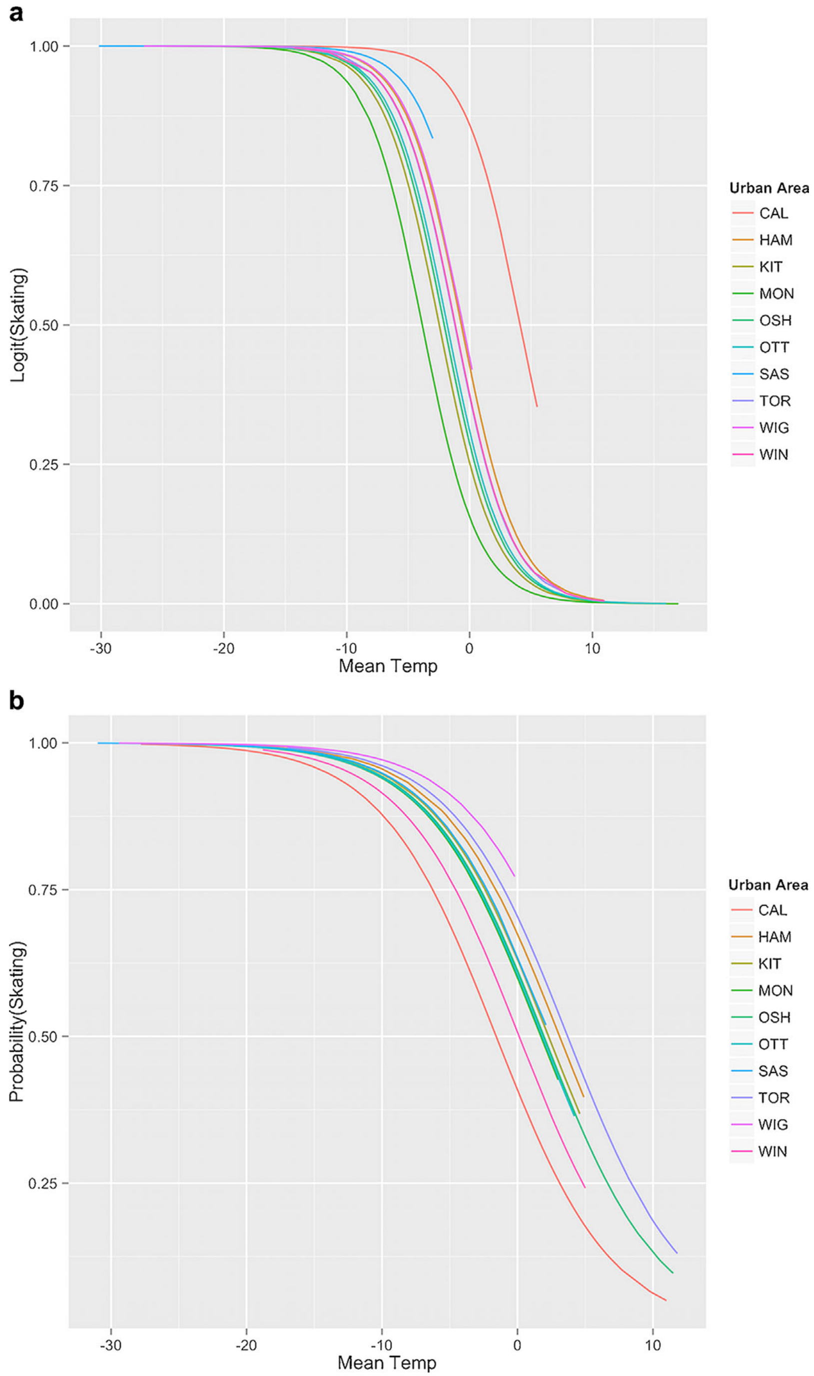

Figure 2
Model predictions of the probability of skating relative to mean daily temperature for (A) 2013 and (B) 2014 skating seasons.

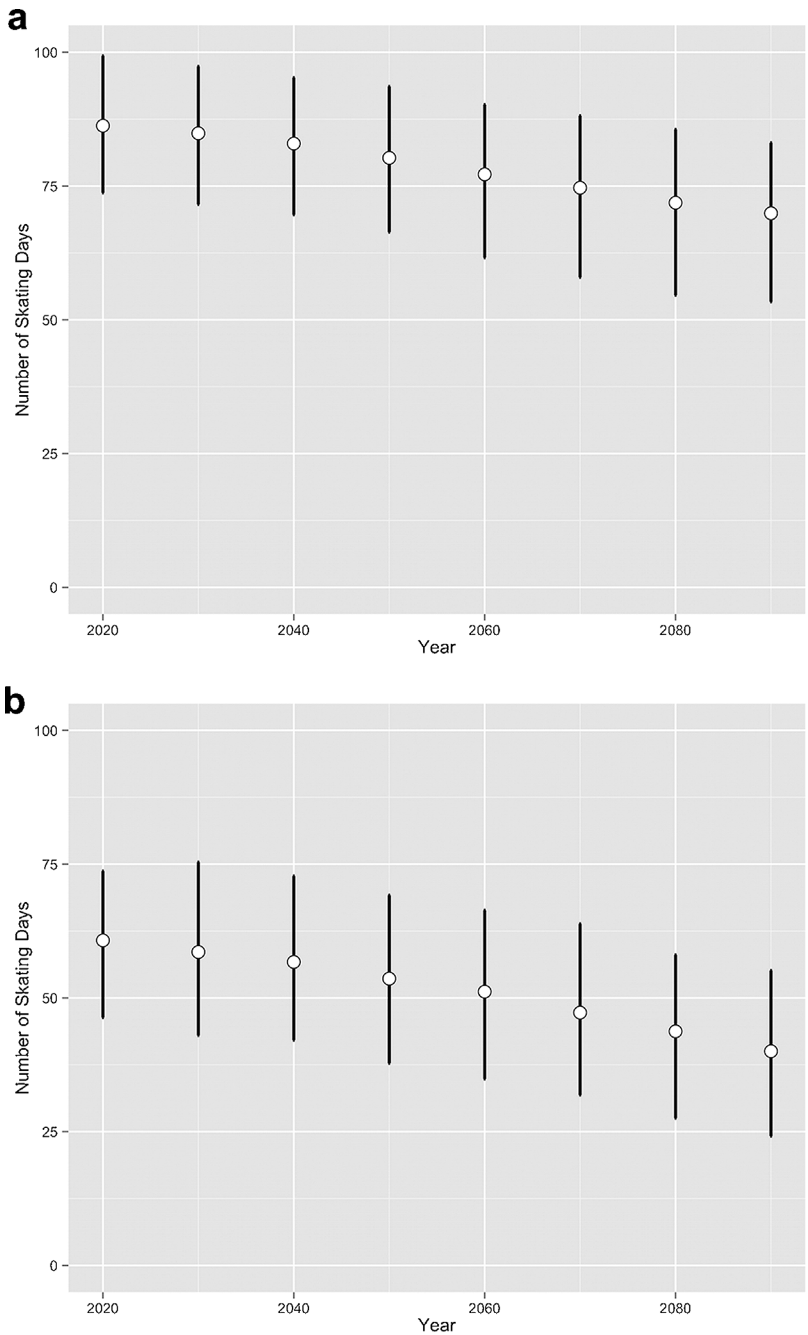

Figure 3
Model predictions of the number of skateable days in (A) Calgary and (B) Toronto. These models are projected from 2020 to 2090 based on daily average temperature projections from the MarkSim Weather Generator under the IPCC A2 scenario using an ensemble modelling approach and a 50% probability threshold.

vary across locations. The regional patterns of variance found in our results are consistent with those reported by Damyanov et al. (2012) which observed that skating season lengths and start dates have been most affected in the Prairies and Southwest parts of Canada.

Due to the nature of the citizen science data driving the models, there are some hidden uncertainties likely impacting our results. Firstly, we did not explicitly incorporate temporal dependence into the model. While we investigated alternative model formulations that were time-oriented (e.g., Markov models), we decided that due to the strong dependence of skating on temperature, temporal dependence would be subsumed within that relationship. This limits our analysis in that we do not investigate within-year temporal relationships that could be important indicators of use. For example, it would be instructive to identify the pattern of freeze-thaw cycles each season and how that relates to participants' likelihood of both skating (i.e., is a rink perceived to be unskateable regardless of the temperature after a certain number of freeze-thaw events), as well as the likelihood of reporting skating conditions at all. This hints at a second and more important limitation in the analysis, in that there may be variability in reporting depending on the skating conditions (or even anticipated/forecasted weather). For example, after a week of unskateable conditions there could be a drop in temperatures, but many people will have given up on outdoor skating by that point. For instance, in the first week of March 2014 in Calgary, the average mean daily temperature was −19.4 °C, and the following week the average rose to 3.9 °C, reaching 9.8 °C on March 12. This melt event, given the time of year, likely impacted skating behaviour more so than if it had happened earlier in the season. By the last week of March, the average temperature had dropped to −11.7 °C, however reports to RinkWatch from Calgary were all but limited to one user reporting conditions by April, many of which included non-skateable reports even though temperatures were lower than −10 °C. Identifying the perceived end to the season relative to the availability of outdoor skating given temperatures remains to be explored in more detail.

Our findings highlight an important consideration with respect to the ecosystem service of skateable ice. There is clearly a temperature window where sub-freezing conditions exist but outdoor skating is not possible, falling generally between −5 °C and 0 °C. As average winter-month temperature regimes across large parts of northern North America and Eurasia warm into this window over the course of the coming century, growing numbers of people will experience winters that are cold and icy, but not cold or icy enough to skate. More detailed analysis of RinkWatch data will require detailed examination of intra-city variation, user-submission patterns over time and in relation to temperature, and perhaps additional factors related to outdoor skating such as neighbourhood characteristics or presence of other recreational facilities. We will continue to use RinkWatch's citizen science-generated data to monitor the condition of this culturally important ecosystem service on an ongoing basis, making the raw data available to all.

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