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Climate change and the future of the Olympic Winter Games: athlete and coach perspectives

Daniel Scott [a,b,c], Natalie L. B. Knowles [a], Siyao Ma [d], Michelle Rutty [e] and Robert Steiger [f]

[a]Department of Geography and Environmental Management, University of Waterloo, Waterloo, Canada; [b]School of Hospitality and Tourism Management, University of Surrey, Surrey, UK; [c]Western Norway Research Institute, Sogndal, Norway; [d]Environmental Dynamics Program, University of Arkansas, Fayetteville, USA; [e]Department of Environment, University of Waterloo, Waterloo, Canada; [f]Department of Public Finance, University of Innsbruck, Innsbruck, Austria

ABSTRACT
The International Olympic Committee recognizes the risks climate change pose to the Games and its responsibility to lead on climate action. Winter is changing at the past Olympic Winter Games (OWG) locations and an important perspective to understand climate change risk is that of the athletes who put themselves at risk during these mega-sport events. A survey of 339 elite athletes and coaches from 20 countries was used to define fair and safe conditions for snow sports competitions. The frequency of unfair-unsafe conditions has increased over the last 50 years across the 21 OWG host locations. The probability of unfair-unsafe conditions increases under all future climate change scenarios. In a low emission scenario aligned to the Paris Climate Agreement, the number of climate reliable hosts remains almost unchanged throughout the twenty-first century (nine in mid-century, eight in late century). The geography of the OWG changes radically if global emissions remain on the trajectory of the last two decades, leaving only one reliable host city by the end of the century. Athletes expressed trepidation over the future of their sport and the need for the sporting world to be a powerful force to inspire and accelerate climate action.

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Introduction

Every aspect of society will be impacted by global climate change and sport is no exception. There is limited, but increasing, evidence on the interconnections between sport and climate change (Bernard et al., 2021; Deloitte Sports Business Group, 2021; Dingle & Stewart, 2018; Edgar, 2020; Goggins et al., 2018; Goldblatt, 2020; Knowles et al., 2020; Orr, 2020; UNFCCC, 2018). Sports infrastructure (e.g. Steiger et al., 2019), organizations (e,g., Dingle & Stewart, 2018; Orr & Inoue, 2018), events (e.g. Knowles & Scott, 2020; Orr & Inoue, 2018; Rutty et al., 2014; Scott et al., 2018), and participation and athlete development (e.g. Falk & Hagsten, 2017; Steiger et al., 2019) are and will increasingly be impacted by the regional manifestations of the changes in climate. Many aspects of sport (infrastructure, events, team/player travel, sport tourism) are also highly carbon intensive (e.g. Barker et al., 2014; Formula 1, 2019; NHL, 2020; Triantafyllidis et al., 2018; Wicker, 2019; Wynes, 2021) and will be impacted by climate policies like national and sub-national carbon pricing and emission reductions targets (particularly for transportation and buildings) (Scott &

CONTACT Daniel Scott daniel.scott@uwaterloo.ca
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Gossling, 2021). There remain significant knowledge gaps to understand the relationship between sport and climate change in order to advance pathways towards low carbon and climate-resilient sport that align with the Paris Climate Agreement. The direct and indirect implications of climate change impacts and responses by governments, business, sporting organizations, and fans for the global sports tourism market, which some estimate could reach over US$1800 billion by 2030 (Allied Market Research, 2021), remain largely unexplored.

Recognizing the emerging impacts of climate change on sport and the responsibility of the sporting world to take action on climate change, the United Nations, in collaboration with diverse sports organizations like the International Olympic Committee (IOC), International Federation of Association Football (FIFA), World Rugby, Formula 1, and nearly 300 other organizations of varying sizes (entire leagues to individual teams and events), launched the *Sports for Climate Action Framework* in 2018 (UNFCCC, 2018). The overarching goal of the framework is to reduce GHG emissions related to sports (including its events and related travel of participants and spectators) consistent with science-based targets set out in the Paris Climate Agreement (holding global warming to 1.5°C above pre-industrial era) and for sport to become a unifying tool to advance climate literacy and action among global citizens. Signatory organizations commit to (1) incorporate climate change comprehensively into their business strategy (e.g. operations, events, procurement, infrastructure, communications), (2) measure the emissions associated with their organization and events, and develop a strategy to achieve 'climate neutrality' (in 2021 this was updated to the specific climate goals of reducing emissions 50% by 2030 [from 2019 baseline] and net-zero no later than 2050 – IOC, 2021a), (3) collaborate to reduce knowledge gaps related to sport and climate change, share best practice on climate adaptation and mitigation, and promote climate literacy globally, (4) promote lower emissions and sustainable supply chains (including shifts to low carbon transport), and (5) promote climate literacy and advocate for climate action through diverse media channels, athlete ambassadors, and across all fan interactions. To promote transparency and credibility of this collective action by the global sporting community, signatories are to report annual progress from 2021 onwards to maintain signatory status.

The IOC and the Olympic Games have made a visible transition toward sustainability in the last two decades. The IOC suffered from a poor record of environmental impacts throughout the 1990s (Ross & Leopkey, 2017; Schmidt, 2018) and responded by adding sustainability as a third pillar of Olympism in 2014 (alongside sport and culture). The development of a sustainability strategy and transparent reporting on its 18 sustainability objectives across its three spheres of responsibility (as an organization, as the owner of the Olympic Games, and as the leader of the Olympic Movement) (IOC, 2021b) have set a standard for sustainability action and disclosure in the sporting world. The effectiveness of this third pillar is debated (Muller et al., 2021).

The IOC has been a leading force in the development of the *Sports for Climate Action Framework* and the more recent 'Race to Zero' initiative. The IOC as an organization has one of the most ambitious emission commitments in sports and across all sectors, announcing ahead of the UN Climate Conference in Glasgow (Scotland) that it aims to become 'climate positive' in 2024 by reducing its direct and indirect emissions by 30% and compensating more than 100% of its remaining emissions through the Olympic Forest project (IOC, 2021a). Moreover, as of 2030, the IOC will contractually obligate each Organising Committee for the Olympic Games (i.e. host city) to be climate positive. All host cities before 2030 have committed to be climate neutral, with the 2024 Olympics in Paris aiming to be the first climate positive Games.

While the IOC has acknowledged that no sport can escape the impacts of climate change, it has done less to assess physical climate risks and advance adaptation strategies across the organization and host cities (Ross & Orr, 2021; Scott et al., 2015). As the premier global sport mega-event with complex scheduling to fulfil worldwide media coverage within the official duration of 16 days, the summer and winter Olympic Games have often been affected by anomalous and extreme weather over its nearly 100-year history (Rutty et al., 2014). Most recently, the Tokyo Games were impacted by extreme heat and heavy rains of Tropical Storm Nepartak (reaching 35°C with 70%

humidity on some days) that some studies had warned could affect outdoor events and put athlete and spectator safety at risk (Kosaka et al., 2018). Documenting the long history of weather impacts and weather risk management strategies developed for the Olympics since the 1920s, Rutty et al.'s (2014) review of the official post-Games reports (1924–2010) from the host Organizing Committees to the IOC, highlighted poor weather as one of the greatest challenges faced. Sochi, Russia in 2014 was the warmest city ever to host the Olympic Winter Games (OWG), exemplified these impacts with media headlines proclaiming, 'temperatures turn organizer's plans to slush' and 'weather conditions cause problems with crashes' (Scott et al., 2018). Higher crash and injury rates, especially among snow sports athletes (Olympians and Paralympians), were partially attributed to higher ambient temperatures and lower quality snow conditions (Jones, 2021).

Climate change risks to the Olympic mega-events and associated international tourism (Gaudette et al., 2017; Vierhaus, 2019) have also been examined, with the ability to hold some outdoor events reliably and safely at previous Games locations questioned. Of the 645 cities in the Northern Hemisphere examined by Smith et al. (2016), between 92.5% and 98.5% would not meet the requirements to safely hold the marathon event and would not be a suitable host for the summer Olympics (in July and August) in the late twenty-first century under a high emission climate change future. Scott et al. (2018) similarly found that climate change would alter the geography of the Winter Olympic Games over the twenty-first century. In a low emission future consistent with a successful Paris Agreement, only 13 of 21 previous host locations (all in the Northern Hemisphere) would remain reliable for snow sports competitions in the 2050s and 12 in the 2080s. The impact of a high emission scenario was far more pronounced, reducing the number of climatically reliable locations to 10 in the 2050s and 8 in the 2080s. The prognosis for the Paralympic Winter Games, which occur in March after the Olympics, was far worse.

As we plan for the future of the Olympic Winter Games under accelerating climate change, an important perspective that has been missing from the limited research is that of the most important stakeholders – the athletes themselves. Olympic events seek to showcase the skills of the world's greatest athletes on a world stage. Athletes risk serious injury as they race 160 km per hour down a steep slope, throw tomahawks in a superpipe or complete complex aerials 20 metres in the air. Studies of injury rates are not only higher at the winter versus summer Games, but also the last three OWGs had the highest injury incidence rates recorded among Olympic/Paralympic alpine skiing/snowboarding/freestyle athletes (55% higher versus other OWGs) (Derman et al., 2016, 2019; Jones, 2021). Olympic venues and governing sporting organizations must ensure safe and fair conditions where athletes feel comfortable pushing the limits of human performance. Scott et al. (2018) recommended future climate risk assessments included as part of OWG bid process (and other elite snow sports events and venues) utilize climatic thresholds specified by sporting federations and their athletes and coaches/trainers. Ross and Orr (2021) similarly recommended new research to better define 'environmental boundary conditions' for safe sports training and competition, including monitoring the change in these conditions to inform mega-event planners (particularly those that select future locations many years in advance).

This study provides novel insight into climatic thresholds for sport and tourism, and builds on our previous analyses on the future of the Olympic Winter Games in a warmer world (Scott et al. 2018) by incorporating the unique perspectives of elite international snow sport athletes and coaches. Based on these participant-defined conditions needed for safe and fair OWGs, we examine how the likelihood of these conditions has and will continue to change at the locations of past Games. The paper has three objectives: (1) An online survey of international athletes (including many former and aspiring Olympians) and coaches from across Olympic snow sports disciplines was used to inform the development of climatic indicators for the conditions that are most impactful for creating unfair and unsafe competitions at the OWGs; (2) climate station data is then used to examine how the probability of climatic conditions that support peak performance have evolved between the 1950s–1960s and 2000s–2010s at the 21 locations that the OWG has been held; (3) Future scenarios of climate change, including a low emission scenario (RCP 2.6) consistent with the successful achievement of

Paris Agreement targets and a high emission scenario (RCP 8.5) representative of a continuation of the current emission growth trajectory, were then used to examine which past OWG hosts could reliably provide the climatic conditions that athletes/coaches require for safe and fair competition.

Methods

International athlete and coach survey

An online survey (hosted on the University of Waterloo Qualtrics survey platform) with open- and close-ended questions was used to gain insight into international athletes' and coaches' climate preferences for competition in the following snow sports: Alpine Skiing, Nordic Skiing, Freestyle Skiing, Ski Jumping/Nordic Combined, Alpine Snowboarding, and Freestyle Snowboarding. To complete the survey, respondents were required to be former or current participants at international level competitions including the Federation International de Ski (FIS – the world governing organization for ski and snowboard events) world-ranked events, continental cup events (e.g. Europa Cup, Nor Am Cup), World Junior or U21/U23 Championships, X-Games Competitions, World Cup, World Championships, and the Olympic Winter Games. The survey was available in all three official languages of FIS and three of four official languages of the IOC (English, French, German), receiving research ethics clearance by the University of Waterloo Office of Research (October 2020) and was open from November 2020 to August 2021. Athletes and coaches were initially recruited through personal networks, national sporting organizations (e.g. Canada Winter Games, German National Ski Team), and international non-profit organizations engaged in winter sport (e.g. Protect Our Winters). Supporting a snowball technique, participants were then asked to share the survey anonymously with their teammates, coaches, and competitors in other countries. A total of 339 elite level winter snow sport athletes and coaches from 20 countries participated in the survey.

Participants were asked to rank a series of climatic conditions (e.g. fog, fresh powder snow, chemically treated snow, icy surface, wind) and adaptation strategies (e.g. cancelled training runs, delayed start times) on a five-point Likert scale from unacceptable to ideal for peak performance, safety, and fairness. Because of the known importance of temperatures for athlete/equipment performance and snow conditions (Breitschadel et al., 2010; Fauve et al., 1999; Gilgien et al., 2018; Guisado, 2017; Pellegrini et al., 2021; Sandsund et al., 2012; Wagner & Horel, 2011), the survey also asked participants to identify the ideal temperature range for competition in their sport followed by the thresholds that would define the unsafe and unfair conditions. Open-ended responses to all questions were also invited and responses were coded and analysed following Newing's (2010) process of letting themes emerge through inductive reasoning.

Climate data and climate change scenarios

Historic winter (December–February) climate data were obtained for stations closest to OWG competition sites from the World Meteorological Organization and, where necessary, national meteorological organizations. Daily temperature and precipitation data were obtained for the periods of 1950–1969 and 2000–2019 to examine contemporary change, as well as 1981–2010, which is the baseline period for the climate change scenarios developed for the Coupled Model Intercomparison Project Phase 5 (World Climate Research Program, 2013). Snow depth data was produced using the SkiSim2 model, incorporating natural snowfall and advanced snowmaking capacity. The model has been used to examine climate change and ski operations in nine countries (e.g. Fang et al., 2019; Scott et al., 2019a, 2019b; Steiger & Scott, 2020) and at the 21 OWG hosts (Scott et al., 2018). The model was validated at each climate station using historic snow depth data. Temperature data were adjusted using lapse rates to the elevation of the finish line where skiing events were held at each host location.

Multi-model ensemble climate change scenarios (temperature and precipitation for the winter months of December–February) for each of the OWG hosts were obtained from the Coupled Model Intercomparison Project Phase 5 (World Climate Research Program, 2013), which provided analysis of global climate models used to prepare simulations for the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (Taylor et al., 2012). A mid- and late-century future are explored, with 2041–2070 referred to as '2050s' and 2071–2100 referred to as the '2080s'. Two future emission scenarios are examined, including a low emission RCP 2.6 scenario, which is representative of a future consistent with success Paris Climate Agreement targets, and a high emission RCP 8.5 scenario, which is representative of a continuation of current global emission trajectory. Under the low emission pathway (RCP 2.6), February temperatures at the past host cities/regions are projected to increase by an average of 1.9°C by the 2050s and 2.7°C by the 2080s, while under the high emission pathway (RCP 8.5), more substantive warming of 2.1°C (2050s) and 4.4°C (2080s) is projected. The monthly climate change scenarios were downscaled to the daily scale at the climate stations representing each OWG location using the LARS stochastic weather generator (Semenov & Barrow, 1997; Semenov & Stratonovitch, 2010).

Results

Athlete-coach defined fair and safe competition conditions

Athletes and coaches were asked to rate on a Likert scale (ideal, good, neutral, poor, unsafe) the influence of 23 weather conditions (including temperature, snow quantity, snow type and consistency, wind, rain, and fog) and associated responses by event organizers (including cancelled training runs, delayed start times, shorter courses, chemically treated snow, and poor course preparation) on competition outcomes. The mean rating of the influence of each factor on peak performance, fairness, safety, and an overall average impact are displayed in Figure 1.

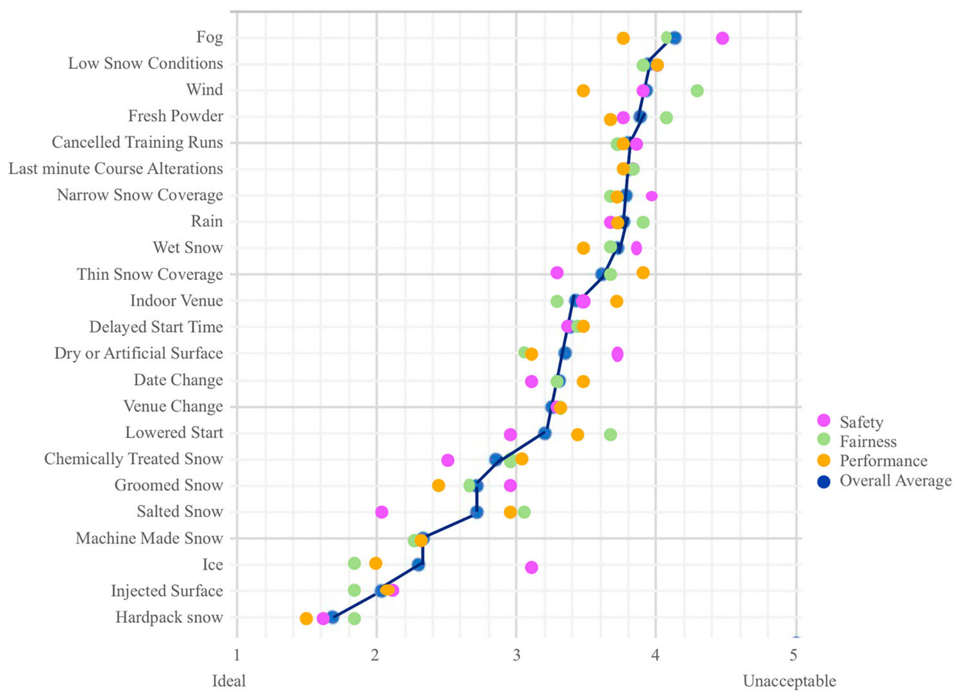

Figure 1. Athlete-coach ratings of conditions that influence competition safety and fairness.

In terms of peak athlete performance, respondents rated hardpack snow, injected surfaces (i.e. injecting the course or jump feature with water ahead of the event so the snow freezes solid overnight), and hard icy surfaces as the most ideal conditions. Low and thin snow coverage were rated the most unacceptable for peak performance, followed closely by fog, narrow snow coverage and rain. Cancelled training runs and last-minute course alterations were also deemed most unacceptable.

The fairest conditions included hardpacked snow, injected surfaces, hard icy snow, and machine-made snow. With the exception of hard icy snow, the same conditions were noted for safety, along with chemically treated and groomed snow. At the opposite end of the rating scale, the conditions considered the least fair for competitions are wind, fog, fresh powder (i.e. ungroomed snow) and low snow. The most unsafe conditions differed slightly, with fog, narrow snow coverage (around the edges of the racecourse or features), wind, and wet snow, followed by cancelled training runs and last-minute course alterations. These ratings were supported by many statements from athletes and coaches, who also observed that adverse snow conditions, athlete heat stress, and equipment failures (e.g. boots flexing too much, visibility reduced from salt spray on goggles) were often caused by warmer temperatures:

> Temperature impacts snow conditions significantly- specifically warm temperatures making snow heavy and unsafe at high speeds. (Downhill, Super G athlete)

> Too warm is the worst because it makes the course super slushy, the speed slows down, and you get a bunch on bomb holes in the landings which are unsafe! (Freestyle athlete)

> Competing in too warm conditions can cause overheating, spiking the heart rate and internal body temp to an unhealthy status, also causing long term damage. (Nordic/Biathlon athlete)

> Too warm: body is too hot – difficult to build tension, tiredness – higher risk of injury … equipment (impacted) in general, but mainly boots get too soft - no proper control over the skis – dangerous! (Slalom athlete)

Recognizing the importance of temperature to fair and safe competitions, athletes and coaches were asked to identify the ideal temperature range for competition in their outdoor winter sport, as well as the temperature range they felt was unacceptable for competition. Figure 2 indicates the percentage of respondents that indicated each temperature (ranging from −25°C to +25°C) is too cold, ideal, and too warm (blue, grey, and orange bars respectively). The threshold temperatures used to define unacceptably cold (blue shading), ideal (green shading), and unacceptably warm (red shading) conditions were based on the majority (over 50% of respondents agreeing). The majority of respondents

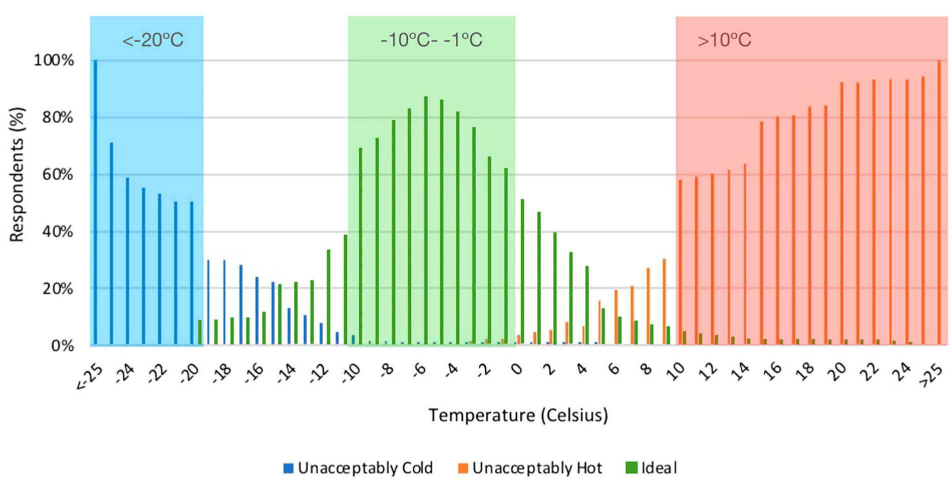

Figure 2. Athlete-coach rating of temperatures for safe and fair competition.

(>50%) indicated temperatures colder than −20°C or warmer than 10°C are unacceptable for safe and fair snow sport competitions, with ideal temperatures between −10°C and −1°C. Respondents noted that although colder temperature usually makes snow conditions more reliable and fair, extreme cold temperatures impede equipment performance (including some safety equipment), as well as negatively impact physical performance which can lead to increased risk of injury. It was noted that International Biathlon Union (IBU, 2021) events cannot compete at temperatures below −20°C, but that no warm weather threshold is similarly codified in rules that govern competitions.

The results from the survey (Figures 1 and 2) were then used to inform the development of four climatic indicators – narrow/low snow, rain, wet snow, and unacceptable temperatures (Table 1). Narrow and low snow were operationalized as days with less than 10 cm of natural snow because it implies that the snowpack in the competition areas would be almost completely machine-made and non-competition terrain rarely has snowmaking coverage (i.e. limited snow coverage in run off and other off course areas). Rain was operationalized as days with greater than 1 mm of rain. The temperature threshold for rain-snow was determined with a precipitation typology analysis of historic climate data at each host location. Wet snow was operationalized as days with maximum temperatures warmer than +5°C, which is based on consultations with ski area managers and snow technician teams in North America and Europe over the last two decades (e.g. Scott et al., 2003; Steiger, 2010; Rutty et al., 2017). Unacceptably warm temperatures are days with daytime maximum temperatures (warmer than +10°C), which is when competitions typically occur, and unacceptably cold temperatures (colder than −20°C).

Both the athlete-coach defined temperature thresholds and those used to operationalize the wet snow indicator are further supported by the scientific literature on temperature impacts on snow conditions (Guisado, 2017), ski boot stiffness (Colonna et al., 2015), snow sport athlete physical performance (Buhl et al., 2001; Gould et al., 2002; Sandsund et al., 2012), and ski-snow friction and waxing (Wagner & Horel, 2011). Some conditions identified by survey respondents could not be operationalized due to climate data limitations near OWG snow sport competition venues (e.g. fog and snow). The distance between the host city and snow sport venues can be substantial (e.g. the last four OWGs the distance is between 70 and 220 km) given that competitions need to be held in locations with a sufficient range of elevations to support alpine events. So, while host city airport stations include fog and wind conditions, these stations do not approximate the conditions at mountain venues and are therefore not included in the analysis.

Historic and future change in Winter Olympic Games competition conditions

Winter is getting shorter and OWG sites are warming. The IPCC Sixth Assessment (IPCC, 2021) and Special Report on the Ocean and Cryosphere (IPCC, 2019) extensively document the many ways that winter and snow resources are changing in the Northern Hemisphere. A recent study specific to the midlatitudes of the Northern Hemisphere where all the OWGs have been held, found that the onset of winter has shifted, and the average length of winter was three days shorter in the 2000s than in the 1950s (73 days versus 76 days) (Wang et al., 2021). The same study found that climate change will continue to shorten winter to between 56 days (if current policy/pledged emission reductions are achieved) and 53 days (if the current high emission trajectory is maintained) in the 2050s, and alarmingly as low as 27 days (high emission future) by the end of the century.

Table 1. Indicators of unfair and unsafe conditions for snow sports competition.

Athlete-coach identified risk factor	Climate indicator
Narrow (and low) snow coverage	Days with natural snow depth <10 cm
Rain	Days with rain >1 mm
Wet snow	Days with Tmax ≥ +5°C
Unacceptable temperatures	Days with Tmax colder than −20°C or warmer than +10°C

The Winter Olympics have been held in warmer conditions throughout their history. Using historical climate station data (30-year climatologies), the average February daytime temperature of OWG host cities has steadily increased – from 0.4°C at Games held in the 1920s–1950s, to 3.1°C at Games during the 1960s–1990s, and 6.3°C in Games held in the twenty-first century (including the Beijing Games). Looking to the future, under a low emission pathway consistent with successful Paris Climate Agreement targets (RCP 2.6), February temperatures at the past host cities are projected to further increase by an average of 1.9°C by the 2050s and 2.7°C by the 2080s, while under a high emission scenario that maintains current emission trajectories (RCP 8.5), more substantive warming of 2.1°C (2050s) and 4.4°C (2080s) is projected.

Changes in winter conditions at the OWG host locations over the last 50 years have increased the probability of unfair-unsafe conditions. Figure 3 illustrates how the probability of the four indicators of unfair-unsafe conditions have changed between the decades of the 1950s–1960s and the 2000s–2010s. Change in the four indicators has not been uniform, nor has observed change been equal across the 16 host locations (of 21 total OWG hosts) for which complete data for the month of February was available. The least change was observed in the probability of rain and unacceptable temperatures. An increase in the number of rain days (of more than 5%) occurred in only three locations (Squaw Valley, Albertville, Oslo). An increase in the number of days with unacceptable daytime high temperatures (more than 5%) was similarly recorded at three locations (Squaw Valley, Chamonix, and Garmisch-Partenkirchen). Diverse changes were recorded in the incidence of narrow snow conditions, with two locations recording fewer days due to increased snowfall/precipitation between the two periods (Calgary and Cortina d'Ampezzo), four locations experiencing no change (±5%) (Sapporo, Nagano, Albertville, and St. Moritz), and 10 (63%) recording more narrow snow days. Incidences of wet snow is the most widespread unfair-unsafe conditions observed (81% of locations).

The probability of unfair-unsafe conditions at previous OWG host locations is projected to continue to increase under all future climate change scenarios, and dangerously so under high emission scenarios. The athletes and coaches surveyed shared this concern and were almost unanimous (94%) in their fear that climate change will adversely impact the future development of their sport. Figure 4 demonstrates the differential probability of unfair-unsafe conditions across the host locations and how the probability of each of the four indicators changes under future climate change. The Figure compares the percentage of days in February that each of the four indicators of unfair-unsafe conditions occur in the 1981–2010 baseline period and in the 2050s and 2080s (under low and high emissions) at all 21 former/current OWG host locations (organized by continent). Each

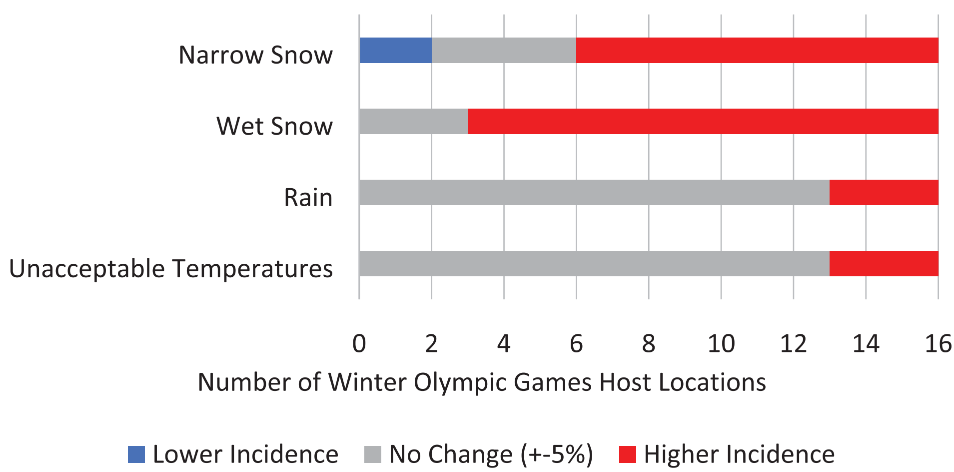

Figure 3. Change in unfair-unsafe conditions between 1950s–1960s and 2000s–2010s.

Note: Five host locations could not be included in this analysis due to insufficient long time series of climate data.

Figure 4. Occurrence of unfair-unsafe conditions under future climate change.

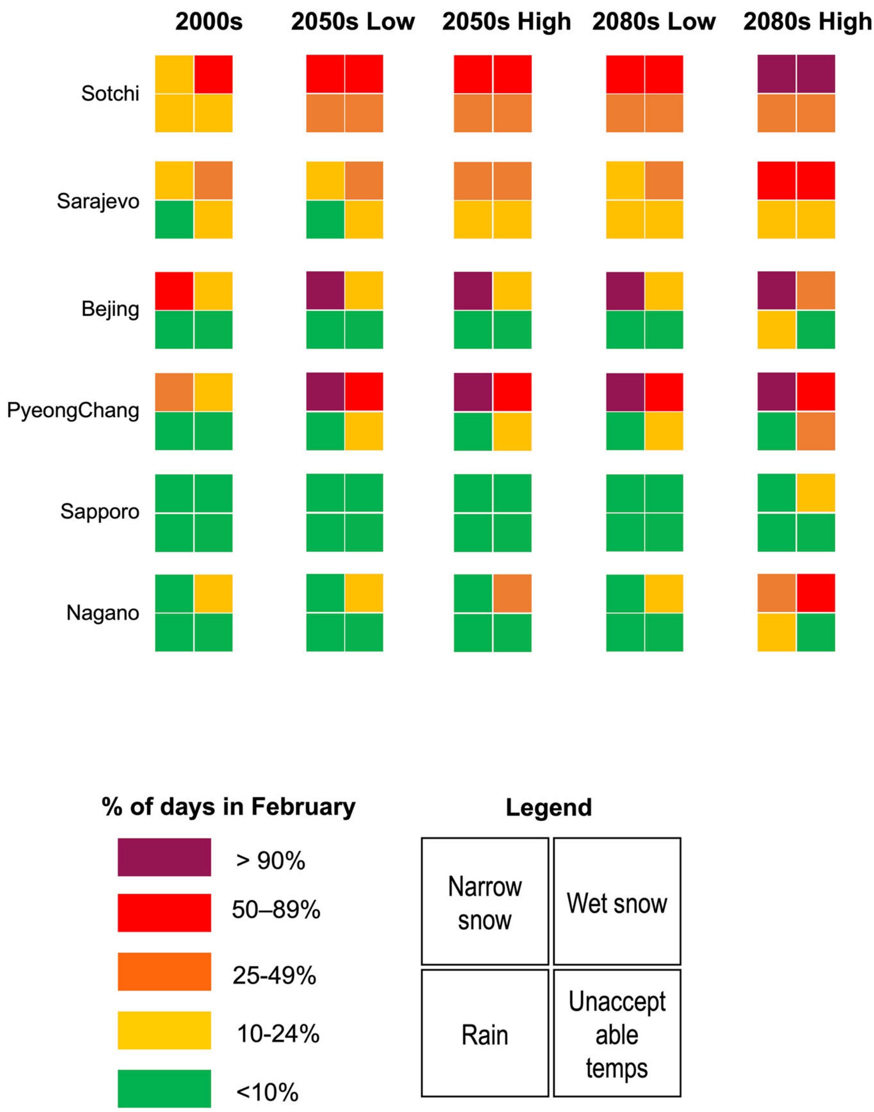

Figure 4. *Continued*

quadrant of each square represents one of the four indicators (see legend). Low risk locations with less than 10% probability of indicator occurrence are shown in green, while high risk locations with a greater than 50% probability are shown in red and purple.

Of the four indicators, rainfall occurs the least often currently and is projected to experience the least change in the future (Figure 4 – lower left quadrants). In the baseline period, only five locations record rainfall on more than 10% of days in February. The probability of rainfall increases at between five and eight locations (under low and high emissions) in the 2050s and six and 12 locations (low and high emissions) in the 2080s. Except for the warmest scenario for late century, most locations continue to have less than 10% of days with rain, posing the lowest risk of impacting future OWG.

As with observed change between the 1950s–1960s and 2000s–2010s, the narrow snow indicator (upper left quadrants) has diverse and bi-directional change projected under future climate change. Continuing its historic trend, Calgary is projected to see fewer days with narrow snow in the 2050s (both low and high emission scenarios) than it experienced in the baseline period because of increased precipitation projected in the region (Figure 4). By mid-century, between nine and 12 locations (low and high emissions) are projected to have narrow snow conditions more often, and as many as seven have a greater than 50% probability of narrow snow (signifying much reduced natural snow). By late century, little additional change occurs in the low emission scenario, but a marked increase occurs in the high emission scenario with 15 of the 21 locations projected to have more than 50% probability of narrow snow (and seven with greater than 90% probability). Only one location in North America (Salt Lake City), Europe (Albertville), and Asia (Sapporo) retain a less than 10% probability of this type of unfair-unsafe condition occurring each day in the high emission 2080s scenario.

Figure 4 also reveals that the probability of wet snow conditions is already much higher than either rain or narrow snow (upper right quadrants). In the baseline period, only two locations have a less than 10% probability of wet snow conditions (Lillehammer and Sapporo) and four already have a greater than 50% probability (Squaw Valley, Chamonix, Garmisch-Partenkirchen, and Sochi). By mid-century, the low emission scenario sees limited change with worsening conditions at only three locations, but much more pronounced change under the high emission scenario, where nine locations exceed the 50% probability of wet snow conditions. The late century sees this dichotomy accentuated, with limited additional change in the low emission scenario and worsening conditions at 18 of the 21 locations (17 of which are projected to exceed a 50% probability of wet snow conditions daily).

The final indicator, unacceptable temperatures (lower right quadrants) for competition, happens relatively rarely in the baseline period (less than 10% occurrence at 15 locations and 10–24% at six locations, mainly in Europe). By mid-century, most locations see limited change (±5%), with four worsening in the low emission scenarios and six in the high emission scenario. Little additional change occurs in the low emission scenario by late century, but under the high emission scenario, nine locations are projected to have substantially higher probability of exceeded the unacceptably high temperatures, with six locations 25–49% of February days (Squaw Valley, Chamonix, Garmisch-Partenkirchen, Innsbruck, Sochi, and PyeongChang).

Discussion

This analysis provides new insights into the Olympic competition conditions preferred by and deemed safe-fair by elite snow sports athletes and coaches. That these conditions are more complex and narrower than those required by novice and recreational snow sports tourists is not surprising. The latter, as provided by ski area managers and snow management technicians, have informed much of the literature on climate change and the ski industry (Steiger et al., 2019), including our own work. The more nuanced indicators of suitable and unsafe-unfair conditions developed in this study advances our ability to assess the risk posed by climate change to the OWG and other elite sports competitions and the associated sport tourism market.

Figure 5 presents the reliability of each of the OWG locations based on the combined probability of exceeding each of the four indicators of fair-safe conditions in each of the timeframes. Hosts are considered reliable if all four indicators occur less than 25% of days in February (i.e. are green or yellow in Figure 4). Hosts are rated marginally reliable if one or more of the unfair-unsafe indicators occur 25%–49% of the time. Locations where one or more of the indicators of unfair-unsafe conditions occur more than 50% of the time are rated unreliable. To reflect the adaptive capacity of advanced snowmaking capacity (and the ability to extend it well outside the designated competition terrain), if narrow snow is the only indicator considered high risk (occurs greater than 50% of days) and all other indicators had less than 25% probability, then the location was rated marginal instead of unreliable.

With this improved knowledge of fair-safe competition requirements, the projected impact of climate change on the ability of previous OWG hosts to reliably deliver the growing snow sports

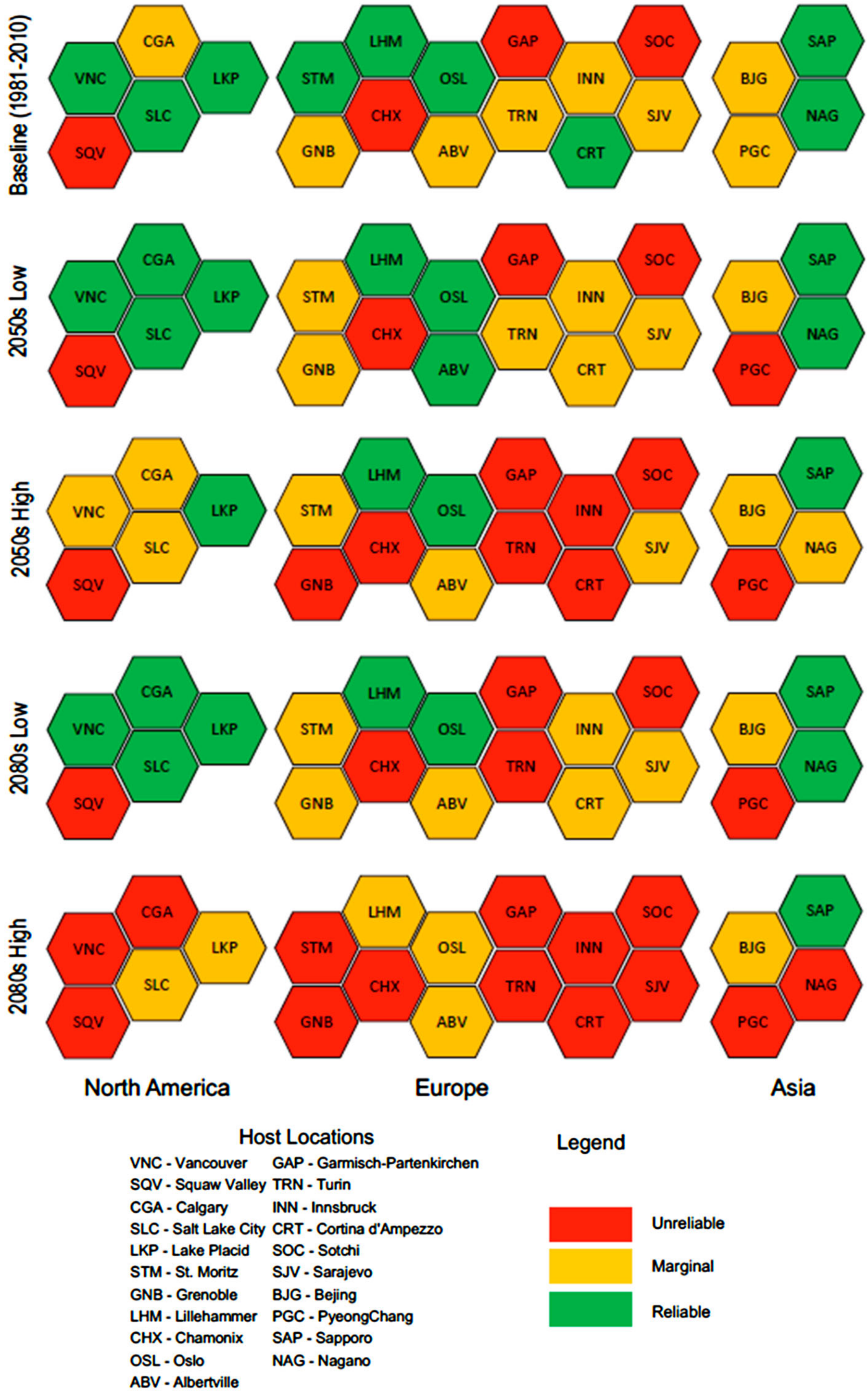

Figure 5. Reliability of OWG hosts for fair-safe snow sports conditions under climate change.

programme is comparatively greater than the study by Scott et al. (2018), particularly under high emission scenarios (Figure 5). In the baseline period, nine locations are rated reliable, and eight considered marginal. Four previous hosts are already considered unreliable (Squaw Valley, Chamonix, Garmisch-Partenkirchen, and Sochi) mainly because of their relatively higher temperatures and the wet snow conditions these temperatures create. Positively, under the low emission scenario that is aligned to a successful Paris Climate Agreement, the number of reliable hosts remains almost unchanged throughout the twenty-first century (nine in the 2050s, eight in the 2080s). The high emission pathway results in a very different outcome for the ability to reliably deliver fair and safe conditions for snow sports at OWG locations. By mid-century the number of reliable hosts declines to four (Lack Placid, Lillehammer, Oslo, and Sapporo) and by the end of the century only one location remains reliable (Sapporo), which compares with 12 and eight locations considered reliable under a similar high emission climate change scenario for the 2050s and 2080s by Scott et al. (2018).

The new insights into conditions deemed safe-fair by elite snow sports athletes and their coaches also represent a contribution to advancing the codification of competition guidelines by international sports organizations more clearly, particularly with respect to warmer temperatures, snow conditions, and the responses of event organizers. Athletes and coaches were clear that more needs to be done to protect the safety of athletes. As one responded stated, 'Athletes should feel empowered and comfortable expressing concerns or fears of injury in these conditions versus being pushed to continue through them'. The importance of consulting and codifying revised competition guidelines and the leadership of international sporting organizations was further underscored in statements by another athlete, emphasizing that although there is ' … risk that comes with competing in those temperatures and the effects on the body/mind … Who's going to qualify for the [Olympic] games and then sit it out?'

As snow sports conditions become more challenging in a warmer world, international sports organizations have a heightened duty of care to protect athletes from themselves. The competitiveness of elite athletes means they will often put themselves at physical and mental risk to compete. The very drive to compete and 'stay in the game' was a critical consideration in the development of concussion protocols in many professional sports (Emery et al., 2017). Sport's governing organizations should consult widely with coaches and athletes to further refine conditions that are safe for competitions. The IOC should subsequently require future bids to include more advanced analysis of the probability of these unsafe conditions and strategies to mitigate them.

Conclusion

The Olympic Games unite the world in a celebration of sport and like many forms of cultural heritage, are put at risk by accelerating climate change. The findings make it clear that projected climate change will reduce the reliability of past/current OWG hosts to provide fair and safe conditions for the growing number of snow sports in the Olympic programme over the course of the twenty-first century. The geography of the OWG in the future will change under all climate change scenarios; radically so if global emissions remain on the trajectory of the last two decades. The much more moderate impacts associated with low emission pathways consistent with the net-zero 2050 targets of the Paris Climate Agreement proffer yet another reason to support the rapid decarbonization of the global economy. Athletes and coaches expressed trepidation over the impact climate change will have on the future development of their sport. As one athlete emphasized, 'Our sports are going to end unless there is serious change in the world'.

The growing threat climate change poses to the OWG and sport more broadly cannot be resolved by the IOC, sporting organizations, and athletes and coaches alone, it requires a society-wide response to this grand challenge. In their survey comments, athletes and coaches emphasized that international sporting organizations, like the IOC, are the most responsible and influential in the sports community for leadership on climate change. The highly influential sporting community and its celebrity athletes are a potentially powerful force to unite, inspire, and accelerate change required for one of the most important societal transitions in history.

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ORCID

Daniel Scott http://orcid.org/0000-0001-7825-9301
Natalie L. B. Knowles http://orcid.org/0000-0002-5605-5954
Siyao Ma http://orcid.org/0000-0003-4111-0145
Michelle Rutty http://orcid.org/0000-0002-4567-7766
Robert Steiger http://orcid.org/0000-0002-1752-6450

References

Allied Market Research. (2021). Sports tourism market: Global opportunity analysis and industry forecast 2021–2030. *Sport Tourism Market*. https://www.alliedmarketresearch.com/sports-tourism-market-A13076

Barker, D., Barker-Ruchti, N., Wals, A., & Tinning, R. (2014). High-performance sport and sustainability: A contradiction of terms? *Reflective Pract*, *15*(1), 1–11. https://doi.org/10.1080/14623943.2013.868799

Baroghi, F., Ribeiro, P., & Lourenco, J. (2021). Experts' opinions about the sustainability impact intensity of the Olympics in Rio de Janeiro. *Journal of Urban Planning and Development*, *147*(1). https://doi.org/10.1061/(ASCE)UP.1943-5444.0000618

Bernard, P, C., Kingsbury, G., Baillot, C., Romain, A., Molinier, A. J., Gadais, V., & Dancause, T., & Dancause, K.N. (2021). Climate change, physical activity and sport: A systematic review. *Sports Medicine*, *51*(5), 1041–1059. https://doi.org/10.1007/s40279-021-01439-4

Boykoff, J., & Mascarenhas, G. (2016). The Olympics, sustainability, and greenwashing: The Rio 2016 summer games. *Capitalism Nature Socialism*, *27*(2), 1–11. https://doi.org/10.1080/10455752.2016.1179473

Breitschadel, F., Klein-Paste, A., & Sveinung, L. (2010, June). Effects of temperature change on cross country ski characteristics. *Procedia Engineering*, *2*(2), 2913–2918. https://doi.org/10.1016/j.proeng.2010.04.087

Buhl, D., Fauve, M., & Rhyner, H. (2001). The kinetic friction of polyethylene on snow: The influence of the snow temperature and the load. *Cold Regions Science and Technology*, *33*(2–3), 133–140. https://doi.org/10.1016/S0165-232X(01)00034-9

Colonna, M., Matteo, M., Nicotra, M., Gioia, C., De Bon, F., Farella, E., & Giovanelli, D. (2015). Thermo-formable materials for Ski boots for improved comfort and performance. *Procedia Engineering*, *112*(2015), 128–133. https://doi.org/10.1016/j.proeng.2015.07.187

Deloitte Sports Business Group. (2021, April). *A sporting chance/The role of sport in mitigating climate change*. https://www2.deloitte.com/content/dam/Deloitte/be/Documents/technology-media-telecommunications/deloitte-be-sbg-the-role-of-sport-in-mitigating-climate-change.pdf

Derman, W., Runciman, P., Jordaan, E., Schwellnus, M., Blauwet, C., Webborn, N., Lexell, J., van de Vliet, P., Kissick, J., Stomphorst, J., Lee, Y., & Kim, K. (2019). High incidence of injuries at the Pyeongchang 2018 Paralympic Winter Games: A prospective cohort study of 6804 athlete days. *British Journal of Sports Medicine*, *54*(1), 38–43. https://doi.org/10.1136/bjsports-2018-100170

Derman, W., Schwellnus, M. P., & Jordaan, E. (2016). High incidence of injury at the Sochi 2014 Winter Paralympic Games: A prospective cohort study of 6564 athlete days. *British Journal of Sports Medicine*, *50*(17), 1069–1074. https://doi.org/10.1136/bjsports-2016-096214

Dingle, G., & Stewart, B. (2018). Playing the climate game: Climate change impacts, resilience, and adaptation in the climate-dependent sport sector. *Managing Sport and Leisure*, *23*(4–6), 293–314. https://doi.org/10.1080/23750472.2018.1527715

Edgar A. (2020) Sport and climate change. *Sport, Ethics and Philosophy*, *14*(1), 1–3. https://doi.org/10.1080/17511321.2020.1694601

Emery, C. A., Black, A. M., Kolstad, A., Martinez, G., Nettel-Aguirre, A., Engebretsen, L., Johnson, K., Kissick, J., Maddocks, D., Tator, C., Aubry, M., Dvorak, J., Nagahiro, S., & Schneider, K. (2017). What strategies can be used to effectively reduce the risk of concussion in sport? A systematic review. *British Journal of Sports Medicine*, *51*(12), 978–984. https://doi.org/10.1136/bjsports-2016-097452

Falk, M., & Hagsten, E. (2017). Climate change threats to one of the world's largest cross country skiing races. *Climatic Change*, *143*(1–2), 59–71. https://doi.org/10.1007/s10584-017-1992-2

Fang, Y., Steiger, R., & Scott, D. (2019). The impact of climate change on ski resorts in China. *International Journal of Biometeorology*. https://doi.org/10.1007/s00484-019-01822-x

Fauve, M., Rhyner, H., Schneebeli, M., & Ammann, W. (1999). *Optimal preparation of Alpine Ski Runs*. WSL Swiss Federal Institute for Snow and Avalanche Research.

Formula 1 (F1). (2019). *Countdown to Zero*. F1 Sustainability strategy. https://corp.formula1.com/wp-content/uploads/2019/11/Environmental-sustainability-Corp-website-vFINAL.pdf

Gaudette, M., Roult, R., & Lefebvre, S. (2017). Winter Olympic Games, cities, and tourism: A systematic literature review in this domain. *Journal of Sport and Tourism*, *21*(4), 287–313. https://doi.org/10.1080/14775085.2017.1389298

Gilgien, M., Reid, R., Raschner, C., Supej, M., & Holmberg, H. (2018). The training of Olympic Alpine Ski racers. *Frontiers in Physiology*, *9*, 1772. https://doi.org/10.3389/fphys.2018.01772

Goggins, D., Goldsmith, C., Grogan, C., Marsh, J., & Smith-Thomas, B. (2018). *Game changer: How climate change is impacting Sports in the UK*. The Climate Coalition and The Priestley International Centre for Climate. https://static1.squarespace.com/static/58b40fe1be65940cc4889d33/t/5a85c91e9140b71180ba91e0/1518717218061/The+Climate+Coalition_Game+Changer.pdf

Goldblatt, D. (2020). *Playing against the clock: Global sport, the climate emergency and the case for rapid change*. Rapid Transition Alliance, UK. https://www.rapidtransition.org/resources/playing-against-the-clock/

Gould, D., Greenleaf, C., Chung, Y., & Guinan, D. (2002). A survey of U.S. Atlanta and Nagano Olympians: Variables perceived to influence performance. *Research Quarterly for Exercise and Sport*, *73*(2), 175–186. https://doi.org/10.1080/02701367.2002.10609006

Guisado, R. (2017). *The effects of warm temperatures on skiing and snowboard safety*. Expert Presentation, International Society for Skiing Safety; Innsbruck Austria.

Intergovernmental Panel on Climate Change (IPCC). (2019). Summary for policymakers. In H.-O. Pörtner, D.C. Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, K. Mintenbeck, A. Alegría, M. Nicolai, A. Okem, J. Petzold, B. Rama, & N.M. Weyer (Eds.), *IPCC Special Report on the Ocean and Cryosphere in a changing climate*. https://www.ipcc.ch/srocc/chapter/summary-for-policymakers/

International Biathlon Union (IBU). (2021). *Events and competition rules, version 2021*. Adopted by the 1998 IBU Congress with amendments by the 2020 Congresses. https://res.cloudinary.com/deltatre-spa-ibu/image/upload/nuzknw5thqfxq25jimm4.pdf

International Olympic Committee (IOC). (2021a). *IOC to be climate positive in 2024*. Retrieved January 21, 2021, from https://olympics.com/en/news/ioc-to-be-climate-positive-in-2024

International Olympic Committee (IOC). (2021b). *Sustainability*. Retrieved December 14, 2021, from https://olympics.com/ioc/sustainability

IPCC. (2021). Climate change 2021: The physical science basis. In Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, & B. Zhou (Eds.). *Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press.

Jones, G. (2021). *Winter Paralympic athletes challenged with injuries too*. American Orthopaedic Society for Sports Medicine. https://sa1s3.patientpop.com/assets/docs/252285.pdf

Knowles, N., & Scott, D. (2020). Media representations of climate change risk to ski tourism: A barrier to climate action? *Current Issues in Tourism*, *24*(2), 149–156. https://doi.org/10.1080/13683500.2020.1722077

Knowles, N., Scott, D., & Steiger, R. (2020). Winter sport and climate change. In G. Dingle & C. Mallen (Eds.), *Sport and environmental sustainability* (1st ed). Routledge. https://doi.org/10.4324/9781003003694-8

Kosaka, E., Iida, A., Vanos, J., Middel, A., Yokohari, M., & Brown, R. (2018). Microclimate variation and estimated heat stress of runners in the 2020 Tokyo Olympic Marathon. *Atmosphere*, *9*(5), 192. https://doi.org/10.3390/atmos9050192

Muller, M., Wolfe, S., Gaffney, C., Gogishvili, D., Hug, M., & Leick, A. (2021). An evaluation of the sustainability of the Olympic Games. *Nature Sustainability*, *4*(4), 340–348. https://doi.org/10.1038/s41893-021-00696-5

Newing, H. (2010). *Conducting research in conservation: Social science methods and practice*. Routledge.

NHL. (2020). *NHL Sustainability Report 2018*. http://sustainability.nhl.com/report/#!/innovate/reducing-emissions

Orr, M. (2020). On the potential impacts of climate change on baseball and cross-country skiing. *Managing Sport and Leisure*, *25*(1), 1–14. https://doi.org/10.1080/23750472.2020.1723436

Orr, M., & Inoue, Y. (2018). Sport versus climate: Introducing the climate vulnerability of sport organizations framework. *Sport Management Review*, *22*(4), 452–463. https://doi.org/10.1016/j.smr.2018.09.007

Pellegrini, B., Sandbakk, O., Stoggl, T., Supej, M., Ortenblad, N., Schurer, A., Steiner, T., Lunina, A., Manhard, C., Liu, H., Ohtonen, O., Zoppirolli, C., & Holmberg, H. (2021). Methodological guidelines designed to improve the quality of research on cross country skiing. *Journal of Science in Sport and Exercise*, *3*(3), 207–223. https://doi.org/10.1007/s42978-021-00112-6

Ross, W. J., & Leopkey, B. (2017). The adoption and evolution of environmental practices in the Olympic Games. *Managing Sport and Leisure*, *22*(1), 1–18. https://doi.org/10.1080/23750472.2017.1326291

Ross, W., & Orr, M. (2021). Predicting climate impacts to the Olympic Games and FIFA Men's World Cups from 2022 to 2032. *Sport in Society*, https://doi.org/10.1080/17430437.2021.1984426

Rutty, M., Scott, D., Johnson, P., Steiger, R., Pons, M., & Vilella, M. (2017). Using ski industry response to climatic variability to assess climate change risk: An analogue study in Eastern Canada. *Tourism Management*, *58*, 196–205. https://doi.org/10.1016/j.tourman.2016.10.020

Rutty, M., Scott, D., Steiger, R., & Johnson, P. (2014). Weather risk management at the Olympic Winter Games. *Current Issues in Tourism*, *18*, 10. https://doi.org/10.1080/13683500.2014.887665

Sandsund, M., Saursaunet, V., Wiggen, O., Renberg, J., Faerevik, H., & van Beekvelt, M. (2012). Effect of ambient temperature on endurance performance while wearing cross-country skiing clothing. *Euro Journal of Applied Physiology*, *112*(2), 3939–3947. https://doi.org/10.1007/s00421-012-2373-1

Schmidt, R. (2018). *The carbon footprint of the games – International climate change law and the Olympics*. Symposium on the Olympics and International Law. https://www.cambridge.org/core/services/aop-cambridgecore/content/view/0387DED9FA41AB026660514406896B84/S2398772320000719a.pdf/div-class-title-the-carbon-footprint-of-the-games-international-climate-change-lawand-the-olympics-div.pdf. https://doi.org/10.1017/aju.2020.71

Scott, D., Gössling, S. (2021) Destination net-zero: What does the International Energy Agency roadmap mean for tourism? *Journal of Sustainable Tourism*. https://doi.org/10.1080/09669582.2021.1962890

Scott, D., McBoyle, G., & Mills, B. (2003). Climate change and the skiing industry in southern Ontario (Canada): Exploringthe importance of snowmaking as a technical adaptation. *Climate Research*, *23*, 171–181.

Scott, D., Rutty, M., & Steiger, R. (2015). Climate change and the future of the Winter Olympic Games. *Journal of Olympic History*, *276*(1), 52–61.

Scott, D., Steiger, R., Dannevig, H., & Aall, C. (2019a). Climate change and the future of the Norwegian Alpine Ski industry. *Current Issues in Tourism*, *23*(19), 2396–2409. https://doi.org/10.1080/13683500.2019.1608919

Scott, D., Steiger, R., Knowles, N., & Fang, Y. (2019b). Regional Ski tourism market risk to climate change: An inter-comparison of Ontario (Canada), Quebec (Canada), and the Northeast USA. *Journal of Sustainable Tourism*, *28*(4), 568–586. https://doi.org/10.1080/09669582.2019.1684932

Scott, D., Steiger, R., Rutty, M., & Fang, Y. (2018). The changing geography of the Winter Olympic and Paralympic Games in a warmer world. *Current Issues in Tourism*, *22*(11), 1301–1311. https://doi.org/10.1080/13683500.2018.1436161

Semenov, M. A., & Stratonovitch, P. (2010). Use of multi-model ensembles from global climate models for assessment of climate change impacts. *Climate Research*, *41*(1), 1–14. https://doi.org/10.3354/cr00836

Semenov, M., & Barrow, E. (1997). Use of a stochastic weather generator in the development of climate change scenarios. *Climatic Change*, *35*(4), 397–414. https://doi.org/10.1023/A:1005342632279

Smith, K., Woodward, A., Lemke, B., Otto, M., Chang, C., Mance, A., Balmes, J., & Kjellstrom, T. (2016). The last summer Olympics? Climate change, health, and work outdoors. *The Lancet*, *388*(10045), 642–644. https://doi.org/10.1016/S0140-6736(16)31335-6

Steiger, R. (2010). The impact of climate change on ski season length and snowmaking requirements in Tyrol, Austria. *Climate Research*, *43*(3), 251–262.

Steiger, R., & Scott, D. (2020). Ski tourism in a warmer world: Increased adaptation and regional economic impacts in Austria. *Tourism Management*, *77*, 104032. https://doi.org/10.1016/j.tourman.2019.104032

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

Taylor, K. E., Stouffer, R. J., & Meehl, G. A. (2012). An overview of CMIP5 and the experiment design. *Bulletin of the American Meteorological Society*, *93*(4), 485–498. https://doi.org/10.1175/BAMS-D-11-00094.1

Triantafyllidis, S., Robert, J., & Kaplanidou, K. (2018). Carbon dioxide emissions of spectators' transportation in collegiate sporting events: Comparing on-campus and off-campus stadium locations. *Sustainability*, *10*(1), 1–18. https://doi.org/10.1175/BAMS-D-11-00094.1

United Nations Climate Change Conference (UNFCCC). (2018). Sports for climate action framework. *Conference of the Parties to the United Nations Framework Convention on Climate Change*. Katowice, Poland.

Vierhaus, C. (2019). The international tourism effect of hosting the Olympic Games and the FIFA World Cup. *Tourism Economics*, *25*(7), 1009–1028. https://doi.org/10.1177/1354816618814329

Wagner, W., & Horel, J. (2011). Snow surface temperature on cross country ski racing courses. *Cold Regions Science and Technology*, *66*(1), 11. https://doi.org/10.1016/j.coldregions.2010.12.003

Wang, J., Guan, Y., Wu, L., Guan, X., Cai, W., Huang, J., Dong, W., & Zhang, B. (2021). Changing lengths of the four seasons by global warming. *Geophysical Research Letters*, *48*(6). https://doi.org/10.1029/2020GL091753

Wicker, P. (2019). The carbon footprint of active sport participants. *Sport Management Review*, *22*(4), 513–526. https://doi.org/10.1016/j.smr.2018.07.001

World Climate Research Program. (2013). *CMIP5 – coupled model intercomparison project phase 5 –overview*. http://cmip-pcmdi.llnl.gov/cmip5/

Wynes, S. (2021). COVID-19 disruption demonstrates Win-Win climate solutions for major league sports. *Environmental Science & Technology*, *55*(23), 15609–15615. https://doi.org/10.1021/acs.est.1c03422