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ADVANCED REVIEW

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Impacts of climate change on organized sport: A scoping review

Madeleine Orr[1] | Yuhei Inoue[2,3] | Russell Seymour[4] | Greg Dingle[5]

[1]The Institute of Sport Business, Loughborough University London, London, UK

[2]Manchester Metropolitan University Institute of Sport, Manchester, UK

[3]Sport Policy Unit, Department of Economics, Policy and International Business, Manchester Metropolitan University, Manchester, UK

[4]The British Association for Sustainable Sport, Reading, UK

[5]Department of Management and Marketing, La Trobe University, Melbourne, Australia

Correspondence
Madeleine Orr, The Institute of Sport Business, Loughborough University London, UK.
Email: m.orr@lboro.ac.uk

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Abstract

The relationship between sport and the environment has been primarily examined to understand how sport impacts the natural environment. However, as the influence of climate change has become more apparent, there is a need to establish a systematic understanding of the impacts of climate change on the operations of sport. The aim of this review is to take stock of existing literature on climate change's impacts on organized competitive sport entities, with further attention paid to their adaptation efforts. A scoping review was conducted to identify relevant studies published between 1995 and 2021. After evaluating more than 2100 publications, we retained 57 articles and analyzed them to answer the research questions: (1) What evidence is available regarding the impacts of climate change on the operation of organized competitive sport entities? (2) What is known from the literature about the measures taken by organized competitive sport entities to adapt to the impacts of climate change? Our analysis yielded five major themes: (1) Heat impacts on athlete and spectator health; (2) heat impacts on athlete performance; (3) adaptive measures taken in sport; (4) suitability of various cities for event hosting; and (5) benchmarking and boundary conditions. This review reveals that there is evidence of some climate change impacts on sport, but the literature reflects only a small share of the global sport sector. Equally, much remains to be understood about the nature of adaptation.

This article is categorized under:

- Assessing Impacts of Climate Change > Evaluating Future Impacts of Climate Change

KEYWORDS

athlete performance, climate adaptation, climate change, health impact, sport

1 | INTRODUCTION

Sport is a global commodity (Ziakas & Beacom, 2018) with an estimated annual market value of US$750–840 billion (Sports Value, 2020; The Business Research Company, 2020). As one of the most universal aspects of popular culture with audiences and participants of billions of people worldwide (Miller et al., 2001), it is also recognized to be a "major contributor to economic and social development" (United Nations, 2020, para. 1). Sport has a unique capacity to influence people and impact whole economies through its largest events (Flyvbjerg & Stewart, 2012), with measures such as contribution to gross domestic product (GDP), media rights revenue, and sporting goods sales ranging from dozens to hundreds of billions of dollars per year (Andreff & Szymanski, 2006).

The historic relationship between sport and the natural environment begins at the origins of nearly every sport. Most sports were borne of interactions between humans and their environment. Surfing came out of indigenous cultural practices in Polynesia (Warshaw, 2010), golfing emerged in the rolling hills of Scotland (Browning, 2011), and cross-country skiing was borne of survival needs in the winter months in Scandinavia and Eastern Europe (Huntford, 2009). From these origins of unique human-nature interactions evolved the controlled and codified sports facilities we rely on today. However, until recently, the conditions of the natural environment surrounding these facilities were taken for granted (Orr & Inoue, 2019), and the impacts of possible changes to the natural environment were ignored (McCullough et al., 2020).

Sport and the natural environment have a bidirectional relationship. Sport impacts the natural environment and is impacted by the natural environment (McCullough et al., 2020; Orr & Inoue, 2019). Far more research has examined the impacts of sport on the environment (e.g., waste production, emissions) and efforts to mitigate these (via sustainability initiatives and fan engagement campaigns), than environmental impacts on sport (Dingle & Stewart, 2018; Orr & Inoue, 2019). The paucity of empirical work about the possible and actual consequences of climate change for sport is surprising given its global significance, combined with the clear vulnerability of certain sports due to their climate-exposed outdoor settings and climatic demands, for instance ski organizations or golf courses (Orr & Inoue, 2019).

The phenomenon of climate change, its urgency, increasing severity, and associated impacts are well-established (IPCC, 2014, 2018). Researchers in disciplines such as atmospheric sciences, oceanography, ecology, geology, and geography have provided abundant evidence that "earth's climate is being affected by human activities" (Oreskes, 2018, p. 1686), and this scientific consensus about climate change informs estimates of future climate impacts. As a consequence of the potentially devastating consequences for more vulnerable populations, such as Small Island Developing States (Hoegh-Guldberg et al., 2018), it is argued that over the next two decades, a rapid global transition to sustainable development is necessary (Rogelj et al., 2018).

However, what remains unclear for the sport sector, as in many other sectors, is how best to respond (Orr & Inoue, 2019). Further, a systematic understanding of the nature and extent of climate change's impacts on sport is lacking, as the research examining climate change and sport has been disjointed and published in journals as diverse as the disciplines of the researchers, including sport medicine (Nybo et al., 2020), climate research (Grundstein et al., 2013), and tourism (Scott et al., 2015). For the latter, Steiger et al. (2019) discussed that research on climate change and ski tourism has reached the diversification phase, where there is a wide array of research questions and interdisciplinary collaborations to understand the impacts of climate change on ski tourism. This is an advancement from the growth phase, where the number and scope of relevant studies expanded significantly, as well as the earliest pioneering phase, where only a small number of studies addressed the topic (Steiger et al., 2019). Yet, there has been no focused attempt to illustrate the state of research in relation to climate change's impacts on organized sport (e.g., sport competitions and organizations that operate them). In this regard, one recent review examined the literature on climate change impacts for physical activity and health behaviors (e.g., walking, recreational cycling; Bernard et al., 2021) and provided a strong foundation on which this present review builds.

The aim of this review article is to take stock of existing literature on the impacts of climate change on organized competitive sport entities (e.g., organizations, teams, events, venues, athletes), with further attention paid to their adaptation efforts. A widely recognized definition of sport offered by Guttmann (2004) comprises three components: (1) competition, (2) physical activity, and (3) structures underpinned by rules or laws. As such, we specify organized competitive sport in this study to comply with that definition and differentiate our subject from recreational physical activities (e.g., jogging, going for a walk, unstructured forms of play), and tourism (e.g., the practice of traveling for business or leisure), which have received substantially more attention in the climate vulnerability and adaptation literatures (e.g., Bernard et al., 2021; Steiger et al., 2019).

The rationale for our focus on sport consists of four parts. First, it has global cultural and symbolic significance. Global-level sport events, such as the Olympic and Paralympic Games and the FIFA World Cup, dominate media attention, are prime sites for celebrating and demonstrating national prowess (Miller et al., 2001), and connect billions of people. At the youth, amateur, scholastic, and masters levels of sport, participation numbers are high: a meta-analysis of global sport participation studies, which included studies representing 47 countries, found a consistent pattern of participation in sport (e.g., swimming, running, soccer) among children and adults (Hulteen et al., 2017). Second, it is economically significant. For example, professional sport competitions (e.g., National Football League, Major League Baseball, National Basketball Association [NBA], European football [soccer] leagues) are an entertainment business that generates billions of dollars in economic activity (Szymanski & Kuypers, 1999), with some estimates indicating that expenditures for participation in youth and amateur sport competitions are even larger (Milano & Chelladurai, 2011). Third, the social benefits of sport participation and spectatorship are increasingly recognized by governments, such as those in Japan and the United Kingdom, which recognize the physical and mental health benefits in addition to the social cohesion benefits of sport. These governments thus have incorporated sport mandates into funding schemes for education, new infrastructure (e.g., public sports facilities; Bergsgard et al., 2019), and high performance (e.g., fielding Olympic team; Green, 2007). Finally, sport is in a bi-directional relationship with the natural environment, as we noted earlier. Direct greenhouse gas emissions can be generated by sport participation, sport-related travel, and facility operations (Wicker, 2019), and indirect emissions occur through a reliance on other emissions-intensive industries (e.g., aviation, electricity generation, sporting goods manufacturing). At the same time, organized sport exhibits degrees of climate vulnerability at the organizational, team, athlete, and facility levels (Orr & Inoue, 2019).

The remainder of this article is organized as follows. The next section introduces a structured review approach we employed to find relevant studies concerning climate change's impacts on organized competitive sport. Then, we present the results of our review based on descriptive and thematic analyses. This is followed by a critical assessment of the current state of literature on sport and climate change, and conclusions summarizing the key findings of this review and directions for future research.

2 | METHODOLOGY

We used a scoping review method (Arksey & O'Malley, 2005; Peters et al., 2020) to identify studies to be included for our review. Scoping reviews are a type of structured research synthesis intended to map key concepts or existing evidence especially for an emerging research field (Dowling et al., 2020; Peters et al., 2020). As with a systematic review, scoping reviews follow predefined procedures to identify and analyze related studies (Peters et al., 2020). Examples include the development of a priori review protocols, identification of explicit and transparent search strategies, and use of standardized forms to extract data from reviewed studies. However, unlike a systematic review, scoping reviews do not involve the appraisal of the quality of evidence from each reviewed study, thus enabling researchers to consider and analyze a wide range of sources for their review (Peters et al., 2020). As the impact of climate change on organized competitive sport is a relatively new research topic, no comprehensive understanding exists regarding the extent and nature of evidence that has been produced in the literature. This early stage of research development accords with the rigorous yet inclusive nature of a scoping review (Arksey & O'Malley, 2005).

A nine-step scoping review methodology advanced by the Joanna Briggs Institute (Peters et al., 2020) guided our scoping review. The first step was to define research questions for the review (Peters et al., 2020). Based on the overall aim of the current review as presented in the Introduction, we developed the following questions:

> Research Question 1: What evidence is available regarding the impacts of climate change on the operation of organized competitive sport entities?
>
> Research Question 2: What is known from the literature about the measures taken by organized competitive sport entities to adapt to the impacts of climate change?

In the second step, we used these questions to determine inclusion criteria (Peters et al., 2020). Specifically, we included articles that explicitly examined the impacts that climate change has on organized competitive sport entities (e.g., organizations, teams, events, venues, athletes). That is, the article had to focus on a climate hazard or impact, link the impact to climate change (e.g., a focus on extreme heat, with an explicit mention of climate change as cause or exacerbating factor), and examine a subject that falls within the remit of organized competitive sport. These inclusion criteria led us to exclude articles in which authors: (a) did not make direct reference to climate change concepts (e.g., climate change, climate impacts, global warming), (b) examined the impacts of sport on climate change or the natural environment only (e.g., sustainability initiatives), and (c) focused explicitly on physical activity in general or recreational sport contexts.

It was beyond the scope of this review to attribute environmental conditions to climate change without the original study authors drawing that link. Attribution of individual weather events or disasters to climate change (IPCC, 2018) is complex and requires an evaluation of "the relative contributions of multiple causal factors to a change or event with a formal assessment of confidence" (p. 547). Although attribution is important for the development of effective mitigation and adaptation efforts, and the collation of research in any given area (Rosenzweig & Neofotis, 2013), including sport, it is not a step that can be taken post-hoc with limited and inconsistent information presented. Hence, the inclusion criteria required the article to make direct reference to climate change. We note that not all climate changes are hazardous and as such, we endeavored to include a range of search terms that would capture all types of climate changes that may have an impact on organized sport, whether these pose risks or opportunities.

Following the suggestions of Peters et al. (2020), we reviewed both academic journals and gray literature (e.g., government reports, research reports) to identify articles (encompassing published and unpublished materials) to be included. In addition, for both published and unpublished articles, we included not only empirical articles but also nonempirical articles, such as conceptual papers, reviews, and commentaries, if they referred to relevant empirical evidence as provided by other studies. For database searches, the search period was set between January 1995 and July 2020. In addition, through supplemental searches as described below, we considered articles published until May 2021. We retained only articles with English full-text copies for our review.

The third step involved developing an a priori review protocol to illustrate the planned approach to searching for and selecting articles as well as analyzing data extracted from retained articles (Peters et al., 2020). In this step, we identified search terms used for database searches (see Appendix A) and selected two main databases to find relevant studies: Web of Science (WOS) and SPORTDiscus. The two databases were selected to search for articles published by authors in a range of academic disciplines (WOS), and in sport-related disciplines (SPORTDiscus). These databases were specifically chosen because they represent the primary stores of sport research, and the subject of this review is explicitly focused on organized competitive sport. Both indoor and outdoor sports were included in the search criteria. We also chose to supplement these databases in three ways. First, we reviewed the first 500 sources as sorted by relevance in Google Scholar (de Sherbinin et al., 2019) to identify gray literature that would not appear in the academic databases. For this Google Scholar search, generic search terms "sport and climate change" were chosen to capture a wide array of related materials. Second, we examined the references list of each article identified from the databases to identify additional articles to be included for our review (Arksey & O'Malley, 2005). Third, we reached out to our professional networks to ask for the recommendation of other articles that may be relevant to the scope of our review (Vaughan et al., 2019). In our protocol, we further specified types of information that would be extracted from each included article as well as procedures for analyzing the extracted information (see further discussion about data extraction and analysis below).

In the fourth and fifth steps, we searched for potential articles by following the protocol and selected a final set of articles to be included (Peters et al., 2020). We first conducted an article search using WOS and SPORTDiscus in August 2020 and identified 1916 articles from the former and 335 articles from the latter. We used Endnote reference software to identify duplicates between the two databases and retained 2143 independent articles for the article selection process. Then, following Peters et al. (2020) methodology, three individuals from the research team engaged in a pilot article process in which they independently reviewed a random sample of 25 full-text articles and provided their evaluation of which article should be included in the scoping review based on the inclusion criteria. This process led to 100% agreement among the three reviewers, indicating a clear consensus about the article inclusion and exclusion within the research team.

The pilot testing was followed by the screening of the titles and abstracts of all 2143 articles by the first member of the research team to exclude articles that were clearly unrelated to the topic of our scoping review. Through this initial screening, 2023 articles were excluded, leaving the remaining 120 articles for a subsequent full-text review. The full-text copies of the 120 articles were then reviewed by two members of the team, and when disagreements occurred between them, a third member of the team reviewed the focal articles and made the final decision for inclusion/exclusion. This process led to retaining 36 articles for the scoping review from the two databases. In addition, the additional Google Scholar search process yielded eight more articles for inclusion, and through the review of reference lists of the retained articles, we found two articles that met the inclusion criteria. Finally, the consultation with our professional networks enabled us to identify 11 additional articles and white papers. For all supplementary sources, we retained articles only when at least two members of the team supported their inclusion.

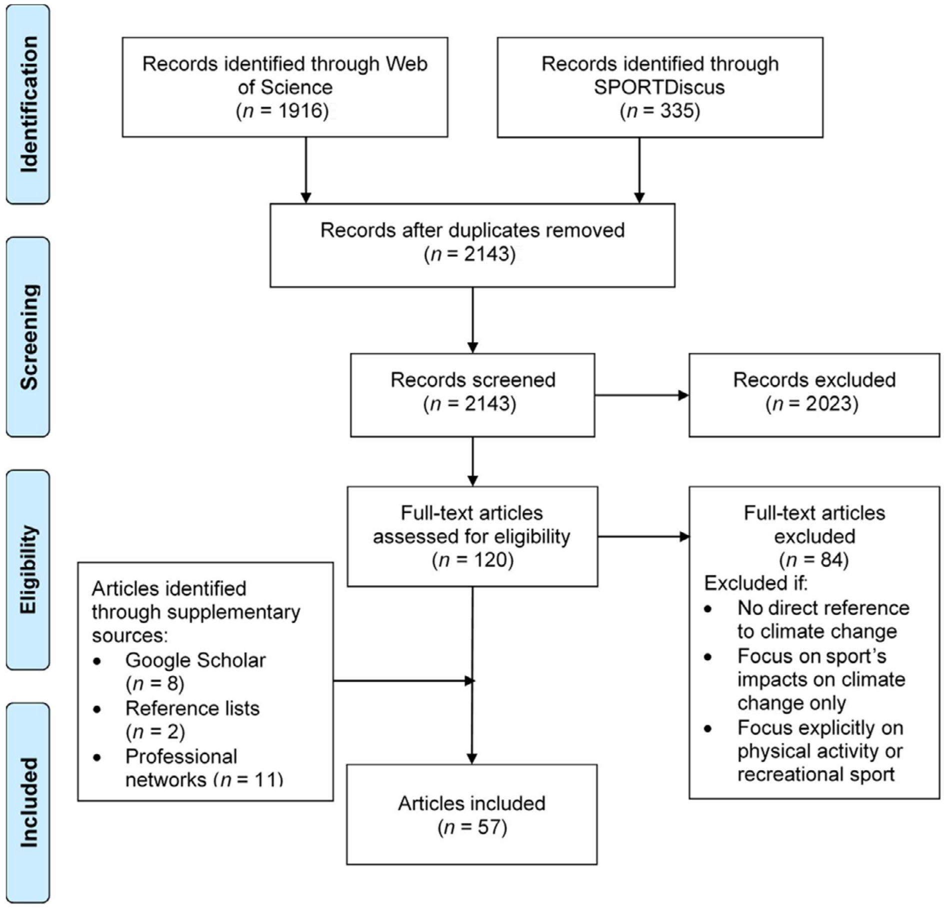

FIGURE 1 Flowchart diagram illustrating the article search and selection process. Adapted from Moher et al. (2009)

Figure 1 illustrates the entire article search and selection process we employed to find relevant articles. Based on this process, we retained 57 articles for our scoping review and analyzed them to answer the research questions. Following the last four steps of the Peters et al. (2020) methodology, we began our data analysis by extracting relevant information from each article and compiling the information in a charting form (i.e., an Excel document used to summarize the findings for each article along a set of predetermined dimensions: Step 6), analyzing the extracted data (Step 7), presenting the results that correspond to the research questions (Step 8), and summarizing—and drawing conclusions from—the evidence to address the overall aim of the scoping review (Step 9). As for specific data analysis procedures, we first conducted descriptive analyses to offer numerical summaries of the reviewed articles and map existing evidence in relation to the research questions. Next, we performed a thematic analysis to provide narrative accounts of the literature (Arksey & O'Malley, 2005). The results of these analyses are presented next.

3 | RESULTS

3.1 | Descriptive analysis

In the first part of Results section, we report findings from our descriptive analyses to map existing evidence regarding the impacts of climate change on organized competitive sport. These findings cover the following information that provides preliminary answers to our research questions (more specific findings will be discussed in Section 3.2): the publication years of the reviewed articles, study locations, study types and methodologies adopted, climate change impacts examined, types of sport exposed, and whether or not the articles acknowledged sport entities' measures to adapt to the impacts of climate change. A full list of included articles is provided in Appendix B. In addition, Figure 2 shows the

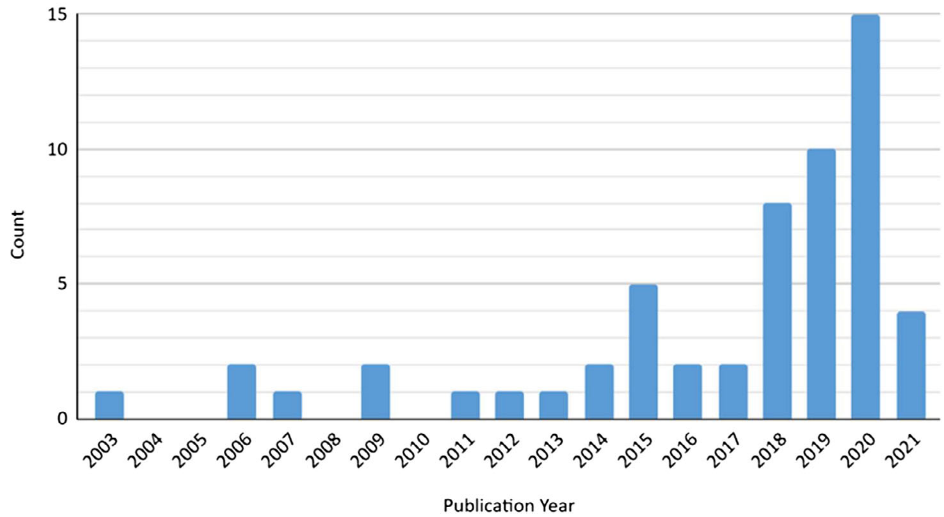

FIGURE 2 Number of reviewed articles published by year

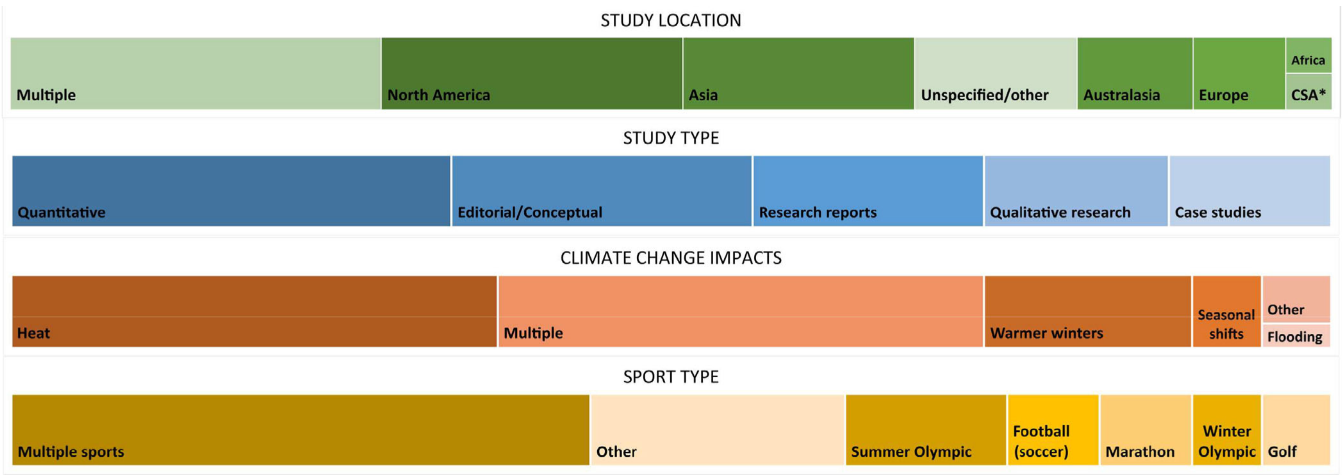

FIGURE 3 Coverage of the literature in relation to four dimensions reviewed. Rectangles are divided proportionally according to the number of articles (out of a total of 57) in a given class. See Appendix B for details of the 57 articles. *Central and South America

number of articles published each year during the search period, while Figure 3 illustrates the coverage of the literature in relation to study locations, study types, types of climate change impacts, and sport types.

3.1.1 | Publication year

Two notable points can be observed regarding publication year. First, while we searched for articles that have been published since 1995, the oldest article identified through our scoping review was from 2003, and it examined the environmental factors which impact upon physical activity and sport participation (Townsend et al., 2003). Then, 2006 saw the publication of two articles, one on the impacts of climate change on the number of rounds played at a golf course in Ontario, Canada (Scott & Jones, 2006) and the other about the effect of seasonal variability on athletic performance and sporting behaviors (Peiser et al., 2006). The dearth of relevant studies published before 2010 ($n = 6$) reinforces our earlier argument that the current research topic is in its infancy, with more research emerging in recent years. Second, a large majority of the studies (46 of 57) have been published since 2015, which coincides with the publication of the Intergovernmental Panel on Climate Change (IPCC)'s Fifth Assessment Report (IPCC, 2014). Indeed, multiple articles referred to this and other reports published by the IPCC to provide the evidence of climate change (e.g., Kellison &

Orr, 2020; Orr, 2020; Scott et al., 2015). This seems to indicate the key role played by the IPCC and its publications in drawing attention to the impact of climate change on organized competitive sport entities.

3.1.2 | Study location

Regarding the study locations examined in the reviewed articles, 16 articles (28.6%) examined two or more world regions and were classified into the "multiple locations" category. North America represented the most studied region ($n = 13$; e.g., Grundstein et al., 2013; Kellison & Orr, 2020). In addition, 10 articles (17.5%) focused on Asian countries, specifically Japan ($n = 9$; e.g., Gerrett et al., 2019; Olya, 2019; Vanos et al., 2019) and Qatar ($n = 1$; Sofotasiou et al., 2015). This interest in the two countries reflected their hosting of the Tokyo 2020 Games (Japan) and the 2022 FIFA World Cup (Qatar). The other regions examined were Australasia ($n = 5$; e.g., Australian Conservation Foundation, 2020a, 2020b; Dingle & Stewart, 2018), and Europe ($n = 4$; e.g., Goggins et al., 2018; Palmer et al., 2014; Visser & Petersen, 2009). We found only one article for each of Africa (Giddy, 2018) and Central/South American countries (Filho, 2014).

3.1.3 | Study type and methodology

About a third of the reviewed articles ($n = 19$) employed quantitative research to investigate the impacts of climate change on organized competitive sport entities. In all of these quantitative studies, authors conducted the analysis of secondary data, such as the wet-bulb globe temperature index (Honjo et al., 2018; Kakamu et al., 2017), finisher times at marathon events (e.g., Gasparetto & Nesseler, 2020), and probability of minimum daily temperatures of ≤0°C (Scott et al., 2015). In addition, 13 articles were classified into the "editorial/conceptual/review" category, which involved the presentation of conceptual arguments and literature syntheses without analyzing primary or secondary data (e.g., Orr & Inoue, 2019). This is followed by research reports ($n = 10$; e.g., Tipton et al., 2019), qualitative research ($n = 8$; Orr, 2021; Rutty et al., 2015), and case studies ($n = 7$; e.g., Dingle & Stewart, 2018).

3.1.4 | Climate change impacts

As for the type of climate change impacts examined, 21 studies (36.8%) focused on heat (e.g., Cheung, 2018; Gerrett et al., 2019); whereas nine articles examined the impact of warmer winter and associated snow shortage (Rutty et al., 2015; Scott et al., 2015, 2019), three focused on seasonal shifts associated with climate change (e.g., Scott & Jones, 2006) and one focused on flooding (Palmer et al., 2014). In addition, 21 articles were classified into the multiple category, examining the combinations of climate changes, such as heavier rainfall, drier and hotter summer, and thunderstorms (Goggins et al., 2018); and heat, hurricane risk, and sea level rise (Kellison & Orr, 2020). The final two articles were classified as Other: one study examined water availability and water demand on golf courses under projected future climate conditions (Scott & Jones, 2007), and another documented extreme winds impacting the Cape Town Cycle Tour (Giddy, 2018).

3.1.5 | Sport type

The most common approach, adopted in 25 studies (43.9%), was to examine multiple sport types to consider the impact of climate change on organized competitive sport. This, for example, included baseball and cross-country skiing (Orr, 2020); and swimming, tennis, and cycling (Cheung, 2018). For the remaining 32 studies, the sport types examined in two or more articles were Summer Olympic and Paralympic sports ($n = 7$), Winter Olympic and Paralympic sports ($n = 3$), football (soccer) ($n = 4$), marathon ($n = 4$), golf ($n = 3$), cross-country skiing ($n = 2$), American football ($n = 2$) and cycling ($n = 2$). Additionally, the following sport types were explicitly examined by single articles: pond hockey (Fairley et al., 2015), baseball (Kellison & Orr, 2020), tennis (Australian Conservation Foundation, 2020b), speed skating (Visser & Petersen, 2009), and cricket (Tipton et al., 2019). The 57 studies also span a wide range of sports that reflect an array of accepted parameters of physical activity: intensity (low-to-high), duration (short-to-long), statics (low-to-high), and dynamics (low-to-high) (Mitchell et al., 2005). The vast majority of studies focused on outdoor sports, which is unsurprising given the clearer exposure to weather and environmental factors. The few that included sports that can be played indoors or outdoors, such as tennis, football, and baseball—focused their research on the outdoor spaces

3.1.6 | Acknowledgment of climate adaptive measures

Most studies ($n = 47$; 82.5%) acknowledged adaptive measures that have been (or can be) taken by sport entities to respond to the present and future impact of climate change. Only 10 articles did not refer to the climate change adaptation of these entities (e.g., Edgar, 2020; Grundstein et al., 2013).

3.2 | Thematic analysis

The thematic analysis revealed five dominant themes in the literature: (1) heat impacts on athlete and spectator health, (2) heat impacts on athlete performance, (3) adaptive measures taken in sport, (4) suitability of various cities for event hosting, and (5) benchmarking and boundary conditions. These themes span different levels of sport from industry-level, organization-level (organizations managing sports events), to individual-level (athletes and spectators).

3.2.1 | Heat impacts on athlete and spectator health

With the latest Summer Olympics and Paralympics and FIFA World Cup being hosted in locations that regularly experience extreme heat conditions (Tokyo and Qatar, respectively; Gerrett et al., 2019; Sofotasiou et al., 2015), the potential risks of thermal stress among athletes and spectators were common concerns raised by researchers (Honjo et al., 2018; Kakamu et al., 2017; Olya, 2019; Tipton et al., 2019; Vanos et al., 2019). In the context of organized sport, thermal risks can be defined as the probability of suffering from heat exhaustion or heat illness during play or spectating at sport competitions; these risks depend on both environmental factors (e.g., hot weather) and personal factors (e.g., age, poor physical fitness, health conditions) (Roberts et al., 2021). For athletes and officials on the field, the primary concern is exertional heat illness. This concern served as justification for several studies examining heat exposure along the Tokyo marathon route (Honjo et al., 2018; Vanos et al., 2019), in Tokyo event venues (Gerrett et al., 2019; Oikawa et al., 2021), and in Qatari event venues for the 2022 FIFA World Cup (Sofotasiou et al., 2015). Beyond these two events, thermal stress and thermal comfort were identified as possible risks for athletes in the sports of cricket (Goldblatt, 2020; Tipton et al., 2019), cycling (Australian Conservation Foundation, 2020a), baseball (Kellison & Orr, 2020; Orr, 2020), tennis (Australian Conservation Foundation, 2020b; Goldblatt, 2020; Menzies et al., 2021; Rice et al., 2021), American football (Grundstein et al., 2020; Kerr et al., 2019), and football (soccer; Goldblatt, 2020; Nybo et al., 2020; Tobías et al., 2019). Researchers found that the primary health consequences of thermal stress include heat exhaustion, heat stroke, and hyperthermia (Gerrett et al., 2019; Grundstein et al., 2020; Honjo et al., 2018; Kerr et al., 2019; Oikawa et al., 2021). Due to prolonged exposure (i.e., playing sport outside in hot conditions) and the physical exertion involved in sport, athletes may be at higher risk for experiencing heat-related illnesses compared to spectators or the general population (Brocherie et al., 2015; Olya, 2019).

3.2.2 | Heat impacts on athletic performance

A second point of concern linked to heat, raised in several studies and across different sports and geographic locations, is the potential and actual impact of heat stress on athletic performance (Craig et al., 2016; Nybo et al., 2020; Tobías et al., 2019; Vanos et al., 2019). Tobías et al. (2019) found that at FIFA Men's World Cup events, the number of penalty shoot-outs during the round of 16 is strongly positively correlated ($r = 0.82$) with anomalous high temperatures. Nybo et al. (2020) went one step further and showed that heat, specifically, had detrimental effects on endurance performance of football (soccer) players: in hot temperatures athletes' core body temperatures can rise as much as 1.5°C above normal, putting them within range of a low-grade fever, and sweat loss can decrease by 50%, leading to overheating and slower pace of play. Tipton et al. (2019) raised similar concerns related to heat impacting athlete performance and suggested that the adoption of heat policies is appropriate as a measure not just for protecting the health of the athletes, but also for preserving the competitiveness and quality of play. This concern was echoed in a case study of the Texas Rangers baseball franchise, which proposed a new facility with a roof and air conditioning capacities to address heat (Kellison & Orr, 2020). One important note is that many studies in our review referenced heat exposure research, as it relates to athletic performance (including among game officials). However, the majority of heat exposure studies did not link heat to climate change and thus were not included in this review.

3.2.3 | Adaptive measures taken in sport

Heat policies are advanced in this literature as a possible tool for managing the incidence of heat-related illness among athletes and spectators (Australian Conservation Foundation, 2020a; Grundstein et al., 2013; Grunstein et al., Grundstein et al., 2020). Though not as common as other weather-related policies (e.g., lightning policy; Cheung, 2018), heat policies are adaptive measures that allow sport organizations and sportspeople to respond quickly to high temperatures and protect the health and well-being of athletes and spectators (Grundstein et al., 2013). Heat policies typically include a temperature threshold that triggers a predetermined action, such as a pause for a water break, a change in equipment (e.g., to reduce the number of layers worn; Grundstein et al., 2013), or offering athletes access to a cooling agent (e.g., cooling towel, mist showers; Kakamu et al., 2017).

Some adaptive measures are not linked to any specific hazard, but were proposed as a precaution to overall health and performance issues linked to climate. These include increasing the amount of time afforded to athletes to acclimatize to new climate conditions before competing (Honjo et al., 2018; Nybo et al., 2020) and choosing host cities for competitions based on favorable weather and environmental conditions (Scott et al., 2015, 2019), thereby reducing the need to build new facilities or worry about extreme conditions.

Infrastructural upgrades and equipment changes were also commonly invoked as an adaptive strategy that may help sport organizations to manage the impacts of heat (Kellison & Orr, 2020; Orr, 2020; Sofotasiou et al., 2015), storms (Goggins et al., 2018; Orr, 2020), and sea level rise (Kellison & Orr, 2020). The infrastructural changes differ based on the hazard, but range from adding shade or fans along the course of a marathon route (Vanos et al., 2019), to installing outdoor cooling technologies for open-air stadiums (Sofotasiou et al., 2015), to building brand new facilities (Kellison & Orr, 2020).

3.2.4 | Suitability of various cities for sports event hosting

With the growth of sports events in terms of financial investments and participation over time, there is increased pressure from governing bodies, sponsors, fans, and the media for host cities to deliver their events exactly as promised, and on tight timelines (Rutty et al., 2015). As climate change worsens and threatens to disrupt sports competitions (Orr, 2020; Scott et al., 2015, 2019), there is a growing need to proactively assess the potential threats facing host cities so that risks can be minimized through technological adaptations, new facilities, or policy options (some options listed above in Sections 3.2.3); or avoided altogether by changing the host city.

A small body of literature has emerged that focuses on the suitability of various cities to host large sports events, based on the climatic demands of the sports involved (e.g., alpine skiing requires snow and a slope, outdoor summer sports require fair weather but not too hot), the typical climate conditions in the city during the month of the event (e.g., February for the Winter Olympic and Paralympic Games), the available adaptation options (e.g., snowmaking, new facility proposals), and projected changes to local weather in future (Scott et al., 2015, 2019; Smith et al., 2016). The focus of these studies has predominantly been on the Winter and Summer Olympic and Paralympic Games. These provide a useful blueprint for how future researchers could estimate the climate suitability of host cities for other sports events, and based on these studies, if a climate suitability criterion were to be implemented for event hosting, Qatar would most likely be deemed unsuitable for a FIFA World Cup.

Importantly, these early studies demonstrate that, should climate projections be accurate, few cities will be suitable settings in which to host large sport competitions by the end of the century. On the summer sports side, Smith et al. (2016) found that by 2085, only 12 cities in the northern hemisphere will have low-risk summer conditions for sports competitions (i.e., less than 10% chance of temperatures above 26 degrees Celsius). For winter sports, Scott et al. (2015) found that while the 19 former Winter Olympic and Paralympic Games host cities all have a suitable climate in the 1981–2010 period, only 10 or 11 remain climatically viable in the 2050s (low–high-emission scenarios) and as few as six will be viable in the high-emission scenario of the 2080s. These findings suggest that the geography (i.e., northern hemisphere cities) and timing of competition hosting (i.e., July and August for summer competitions, February for winter competitions) may have to change in the future.

3.2.5 | Benchmarking and parameters for safe playing conditions

As an emerging literature, the most consistent thread across the studies is the importance of benchmarking past and current conditions for sport and setting parameters around what is considered safe playing conditions for competition. These parameters, once established through further research centered on the health and safety of players and spectators (Grundstein et al., 2013; Kakamu et al., 2017; Olya, 2019), will impact adaptation requirements and innovation (Dingle & Stewart, 2018; Goggins et al., 2018; Kellison & Orr, 2020; Orr, 2020; Vanos et al., 2019) and the selection of host cities for events (Scott et al., 2015, 2019; Smith et al., 2016). They could also impact the general organizing principles of sport. Though this theme was addressed differently across the articles we reviewed, benchmarking and setting boundary conditions was raised as an implication or a next step in nearly every study.

4 | CRITICAL REFLECTION

In this section, the results of our review are discussed as they relate to the research questions. For each research question, themes are provided to organize the discussion and address the question.

With Research Question 1, we sought to understand the scope of evidence available concerning the impacts of climate change on the operation of organized competitive sport. The results of this review demonstrate that the 57 studies we reviewed collectively reflect an immature stage of development for the research literature. Borrowing the typology developed by Steiger et al. (2019, p. 1345), research on organized competitive sport and climate change between 1995 and 2021 can be characterized as being at a "pioneering phase," with signs that it is beginning a "growth phase." Overall, there is sufficient evidence that climate change hazards are having adverse short-term, and potentially long-term, impacts on climate-exposed sports. This evidence divides across two themes: heat impacts on athlete and spectator health, and heat impacts on athlete performance.

As discussed in Results section, the potential risks of thermal stress to athlete and spectator health were a concern frequently raised by researchers. Thermal stress and thermal comfort were associated with climate change and identified as a higher risk for athletes in a range of climate-exposed sports, and geographic locations ranging from Europe to Asia to North America. Thermal stress phenomena for athletes such as heat exhaustion, heat stroke, and hyperthermia were identified as being a potentially higher risk. For athletes, such thermal stress and illness issues are consistent with exercise physiology research identifying risk factors, mechanisms, and effective interventions in sport, yet this research typically is not directly linked to climate change (e.g., Chalmers, 2017; Gamage et al., 2020).

According to our review, another longer-term challenge is the impacts of climate change, especially extreme heat, on the performance of elite and professional athletes. Several studies linked temperature anomalies to lower endurance performance by athletes, and there is also some evidence of higher skill error potential (e.g., Nybo et al., 2020; Tobías et al., 2019) and more aggressive play (Craig et al., 2016). Although causation of such endurance and skill impacts remain an area requiring further investigation (Tobías et al., 2019), in an era of climate change, there is justification for further physiological and medical research investigating the role of climate change in such impacts. Such studies would provide an important addition to the literature on the impacts of climate change on organized competitive sport. In summary, in relation to Research Question 1, we argue that although the number of studies is to date relatively small, there is sufficient evidence to suggest that climate change is contributing to adverse impacts on the operation of organized competitive sport and these impacts will likely continue for the foreseeable future.

By answering Research Question 2, we sought to develop an understanding of the measures organized competitive sport entities have taken (or can potentially take) to adapt to the impacts of climate change. The results of our scoping review suggest that adaptation to climate change impacts on sport has been happening for nearly a century in some cases (Rutty et al., 2015) and is likely to continue for the future (Orr & Inoue, 2019; Scott et al., 2015). Given the identified heat impacts, responses at the sport organization and events levels, such as heat policies, may be characterized as climate change adaptation (Australian Conservation Foundation, 2020a; Grundstein et al., 2013). In addition to effective heat policies, operational, technical, and geographical adaptations were discussed. Notably, this discussion of climate change adaptations is consistent with wider, nonsport specific research studies in other climate-exposed industrial sectors (e.g., tourism, agriculture, water utilities), where natural resources and/or the health of customers and performance of human resources under extreme heat conditions are an ongoing issue (Amelung & Moreno, 2012; Berkhout et al., 2006).

Given the extent of attention paid to climate change adaptation across the studies we reviewed, it is appropriate to consider what these adaptations mean for the sport sector. First, the adaptations above are principally in response to hot extremes and seasonal changes (e.g., warmer winters, seasonal shifts), with limited attention paid to extreme weather and disasters (cf. Field et al., 2012; Glasser, 2020). While this is perhaps understandable given the consequences of thermal stress and illness for elite and professional athletes, these studies tell us little about the risks posed by disasters, such as storms, cyclones, and floods, and adaptive responses. This is a significant limitation that can be explained in part by the fact that disasters are by nature highly uncertain at a spatial and temporal resolution relevant to sporting infrastructure or events. For that reason, climate change researchers have mainly focused on the potential impacts of associated seasonal changes or temperature records that can be assessed more robustly and over longer periods of time. Nonetheless, as could be seen from Super Typhoon Hagibis, a Category 5 storm (NASA, 2019) that made landfall during the 2019 Rugby World Cup (RWC) in Japan, cyclones (typhoons/hurricanes) have potentially catastrophic impacts on affected locations. While impacts on the 2019 RWC itself were limited to some match cancellations and minor flooding of venues (ABC News, 2019), the disruptive potential that extreme weather and disasters can have on sports events in the long-term can be arguably crucial, and opportunities to examine these climate change impacts should be leveraged in future.

Classifying the climate change adaptations evident in the reviewed studies is an appropriate analytical task. While adaptations were identified, these studies—with the exception of Rutty et al. (2015)—fell short of offering classifications of these adaptations, and opportunities to integrate well-developed nonsport climate change adaptation research literature into analyses were overlooked. While it is beyond the scope of this paper to present a detailed discussion of climate change adaptation literature, existing adaptation typologies offer some insights as to how climate change adaptations for organized competitive sport might be classified now, or in the future. For example, if a risk-based approach (Berkhout, 2012) were adopted, it is arguable that the adaptations identified in the reviewed studies ranged from climate risk "assessment" to climate risk "reduction" strategies, but did not extend to climate risk "sharing" or climate risk "diversification." These adaptation strategies offer avenues for future studies of organized competitive sport and climate change to extend existing knowledge claims. Furthermore, adaptation types (e.g., capacity building, management and planning) developed by Biagini et al. (2014) offer potential for interpreting adaptation in organized competitive sport contexts. In summary, we argue that adaptation to climate change impacts on organized competitive sport has been happening for some time and is likely to continue so for the foreseeable future. In addition, integrating risk-based and/or other nonsport climate change adaptation literature into future sport-climate research can enhance the development, and contribution of, this research to sport organizations and participants.

We also argue that there is room for some optimism around climate change adaptation that has emerged from our review. The good news is that the literature consistently shows that, at some scales, adaptation is not only possible for organized competitive sport, but that heat impacts of climate change can be adequately managed. Specifically, the worst impacts of heat (i.e., heat-related illnesses among athletes and spectators) can be avoided altogether with some adaptation efforts such as scheduling changes and the provision of additional cooling or shade options (Gerrett et al., 2019). In addition, a thorough assessment of potential host cities' climate suitability (Scott et al., 2015, 2019; Smith et al., 2016) before selecting a sport competition site could serve as a viable strategy for alleviating detrimental impacts from extreme heat. Nevertheless, further research is required to determine which thresholds are most appropriate, and which interventions will be most effective if global average temperatures in years to come are at the higher end of estimates. It is worth noting here that caution must be exercised when determining which adaptive measures to adopt, to avoid those adaptive measures which might become environmentally burdensome and thus counter-productive to any sustainability-oriented efforts of the organization. This was precisely the challenge that organizers of the FIFA 2022 World Cup in Qatar sought to solve, as efforts to deliver outdoor air conditioning at stadiums introduced challenges with regard to the costs and environmental impact of the adaptive measure (Sofotasiou et al., 2015). There is, as yet, little research in the sport sector addressing the tensions that can arise between adaptation efforts and sustainability commitments.

Moving beyond the foci of Research Question 1 (climate change impacts) and Research Question 2 (adaptation to climate change), the studies we reviewed tended to focus on sporting competitions, most notably those at the global level: Summer and Winter Olympic and Paralympic Games and the FIFA World Cup. This is likely a reflection of the magnitude of these events, both in terms of logistical requirements and media and public interest (thus attracting academic interest), along with the climatic conditions that prevail at the recent and next host cities or countries; Tokyo, Beijing, and Qatar respectively. For any sports event, the safety of athletes, spectators, and staff ought to be paramount, and climate change represents an increasing risk. Yet, the risk also exists at smaller events and in league play, and at the lower levels of sport, where the medical facilities and responses may be more limited. Further, research is needed for training programs in sport, which occupy the majority of athletes' and coaches' time. Similarly, sport governing bodies and leagues in each country should be looking toward academic researchers to provide sound information to inform future planning and policies in their sports.

While our review demonstrates that organized competitive sport and climate change research is at an early stage of development, there is great scope for growth. Despite the 27-year window stretching back to 1995, the first relevant article included was not published until 2003 (Townsend et al., 2003). Climate change sensu stricto has been a research discipline for many years. However, it is revealing that the link between sport and climate change has not been actively researched, as reflected by an absence of strong publication record, until the last 10 years. This likely reflects a number of issues, including a lack of awareness about climate change impacts by the sport sector in general, a lack of connection between sports academics and climate researchers, and journal editorial policy that has likely not linked the two areas as being of interest. More than 80% of the reviewed studies have been published since the IPCC Fifth Assessment Report (2014), and nearly two-thirds (37 of 57) have been published in the last 4 years (2018–2021). This is when the influence of the Paris Climate Change agreement would have been present, most visibly through the United Nations' Sport for Climate Action Framework. The small number of sport and climate studies is consistent with research in the disciplines of business and management demonstrating that academic journals, especially the most prestigious ones, can be slow to respond to climate change (Goodall, 2008; Linnenluecke et al., 2013).

Based on the findings and the centrality of adaptation efforts, we argue that some adaptations, including the implementation of heat policies, will change aspects of the game that event managers will have to take account of, such as managing spectators during heat breaks, especially when they may also be feeling the effects of increased heat. It is necessary that event managers understand and track potential future climate change hazards by way of risk assessment procedures, and proactively adopt strategies that protect athlete, staff, and spectator health and safety and the quality of play.

It is important to note that the overwhelming majority of research on the topic has been carried out on sports that are performed outdoors and are thus climate-exposed. For sports performed indoors, sport stadia typically provide a protective effect that is less available to climate-exposed sport. However, we argue that indoor sport still has potential climate vulnerabilities. As noted by Wicker et al. (2013), extreme weather and disasters, such as extreme rainfall and flash flooding, has already resulted in damage to the interiors of community sport facilities in Australia. Another example can be found in the poor air quality inside Sacramento's Golden 1 Center, the home arena of the Sacramento Kings of the NBA, during the devastating 2018 wildfires in California, which forced a game cancelation (Holleran, 2018). We therefore argue that the potential for climate change disruption to indoor organized competitive sport entities (e.g., NBA, youth hockey leagues) cannot be discounted.

Furthermore, athletes and their coaches must be increasingly aware of and actively seek information on all climate risks, particularly heat, and how these can negatively impact their health and performance, so that they can advocate for themselves (Orr & Inoue, 2019). National sport governing bodies and international sport federations can provide education opportunities to athletes and coaches and look to their relevant sport and sustainability bodies in their countries (if available), or internationally, for information.

The growth of the academic literature over the last few years reflects a number of other trends including the increasing political and public awareness of climate change, and the growth in visibility (media coverage) of climate issues in sports media, which has increased consistently since 2017 (Orr & Muehlbauer, 2020). We argue that this is also reflected in the slow, but recently increasing, growth of membership organizations, including the British Association for Sustainable Sport (established in the United Kingdom in 2010), the Green Sports Alliance (established in the United States in 2010), and the Sports Environment Alliance (launched in 2015 in Australia and New Zealand), that support sport industry leaders to adopt more sustainable practices to mitigate environmental impacts and to adapt their events to predicted climate change and other sustainability issues.

While not the focus of this review, it is worth noting that a fast-growing body of literature has emerged to examine and facilitate progress toward climate change mitigation efforts within the sport sector (as summarized by McCullough et al., 2016). Due to the dependency on natural conditions to produce safe and competitive sport experiences, and the increasing unreliability of such conditions due to climate change, some athletes have called for the sport sector (and other athletes) to be more outspoken on climate issues (BBC, 2020; Protect Our Winters, 2020). Others call on sport organizations to engage in climate action and environmental stewardship because of its "innate" (McCullough et al., 2020, p. 6) and "intrinsic" (Sartore-Baldwin & McCullough, 2018, p. 392) value, no matter how severely they are impacted by the outside environment. In the United States, this sentiment was enshrined by the Obama Administration in 2016 as part of the launch of Green Sports Day in 2016 (Stone, 2016). At the international level, the International Olympic Committee (IOC, 2017) and the United Nations Framework Convention on Climate Change's Sport for Climate Action Framework (UNFCCC, 2018) further encourage climate action and education in the sport sector. Based on these pressures, and the interests of their communities, many sport organizations have begun engaging in climate action, for example by reducing their own emissions or building new facilities to the standards such as the Leadership in Energy and Environmental Design standard and the Building Research Establishment Environmental Assessment Method. Others have also worked to raise awareness of climate issues among their fans and participants, inspiring others to follow their lead (Casper et al., 2017, 2020; Inoue & Kent, 2012). These developments provide evidence to suggest that sustainability is advancing in the sport sector and that sport organizations are becoming more proactive in assessing and managing climate issues (McCullough et al., 2020; Orr & Inoue, 2019). Using their "unique" (Inoue & Kent, 2012, p. 417) status in society and their large platforms, many sport organizations have begun contributing to the fight against climate change (Atkinson, 2016; McCullough et al., 2020; Sartore-Baldwin & McCullough, 2018), though the precise outcomes of these efforts are understudied. There is also the risk that some mitigation efforts are the subject of greenwashing. Researchers should continue to investigate the impacts of climate change on sport to fill the gaps identified in this literature review, while taking into account the efforts made by sports entities to engage in climate change mitigation efforts (McCullough et al., 2020).

5 | CONCLUSIONS

There is no shortage of opportunity to study climate impacts on sport. What was immediately striking from the review process was the relatively limited volume of literature available that met the scoping review criteria. Put simply, not enough studies examined the impacts of climate change on competitive, climate-exposed sport. This is puzzling because scientific climate change research has a long history dating back over 150 years (Oreskes & Conway, 2010), and at least a decade ago climate change moved beyond the realm of climate science to become a genuinely *multidisciplinary* issue (Grieneisen & Zhang, 2011). Since the 1990s, climate change has been a major research focus of the natural sciences, professions and applied sciences. In addition, while the humanities and social sciences more generally have been slower to shift attention to climate change (Grieneisen & Zhang, 2011), growing multidisciplinary research has been evident. However, the 57 studies we reviewed collectively suggest that multidisciplinary collaboration involving sport is still at a very early stage.

The relative paucity of studies investigating organized competitive sport and climate change might be explained, in part, by the siloed nature of academic research, as sport researchers stick to sports and may not necessarily feel they have the expertise or authority to attribute the phenomena they study (e.g., impacts of heat, storms or shorter winters on sport) to climate change. There are also several sport medicine studies that examine athletic performance under varying conditions (e.g., cold, hot, extreme wind) that do not attribute these circumstances to climate change nor introduce climate change as a possible exacerbating factor of future inclement conditions. Consequently, much research that is salient to the subject but not specific regarding links to climate change was excluded from the review (e.g., Donnelly et al., 2016; Gossling et al., 2008; Herdt et al., 2018; Watanabe et al., 2017). This finding and its implications point to the importance of interdisciplinary research teams, the potential for sport researchers to take advantage of recent advances in the field of extreme-event attribution (Bellprat et al., 2019; Swain et al., 2020), and increased communication and collaboration between disciplines to advance climate research in sport moving forward.

This review introduces themes that, given the sport calendar for the next few years, will continue to be front-of-mind. This is particularly true for climate hazards like extreme heat which can have direct impacts on athlete health and performance and will be critically important as large sports events are being hosted in warm climate locations such as Qatar (FIFA World Cup in 2022), Australia (FIFA Women's World Cup in 2023), and Mexico (FIFA World Cup in 2026). However, this is also true for national-level climate-exposed professional sport competitions (e.g., National Football League, Major League Baseball, Major League Soccer, Indian Premier League cricket, English Premier League, Super Rugby) and their women's counterparts (e.g., National Women's Soccer League, Frauen-Bundesliga, FA Women's Super League, W-League soccer, ITF Women's World Tennis Tour), as well as amateur sport competitions. From the extant research literature, very little is known about the specific climate change impacts on these competitions. Future research opportunities are abundant in these contexts. Equally, future research opportunities include organized competitive sport and climate change in African and Central/South American settings where to date there is little to no research of location-specific impacts, and/or adaptation responses.

Another theme that will likely only continue to attract research attention in the coming years is adaptive options which can reduce the negative impacts of climate change (Orr & Inoue, 2019), and setting parameters around what is considered safe playing conditions at each of the youth, amateur, elite, and professional levels of sport. As sport organizations grapple with the changing environmental conditions, a continued research focus on adaptation is likely. Adaptation developed in nonsport literature such as incremental options (Tàbara et al., 2019) and transformational options (Termeer et al., 2017) will be critically important to shaping adaptation efforts.

Despite the various implications and future research directions as we presented above, the major limitation of our review is that it included a relatively small number of studies for its analysis. Only 57 studies met our review criteria, and these studies were limited temporally, with the first study not published until 2003, as well as geographically, with many studies confined to a small number of regions and sports events. An additional limitation of this study was the exclusion of air quality and other weather-related challenges (e.g., "tornado") from the search criteria. Thus, some caution about knowledge claims for this area will be needed until a larger and more robust research literature is available. Future reviews might also broaden the search terms to include topics like air quality to capture a larger number of studies, or include articles that address heat impacts, or disasters, even without direct reference to climate change. It is also important to note that the scoping review methodology employed in this article does not involve quality assessment of reviewed evidence (Peters et al., 2020). Hence, a future synthesis of the literature—when more relevant studies are published—would require adopting a systematic review to offer more definitive insights into the impacts of climate change on organized competitive sport.

In conclusion, the aim of this review was to develop a clearer understanding of the impacts of climate change on organized competitive sport entities, with further attention paid to adaptation efforts taken by these entities. Our review reveals that there is evidence of some climate change impacts, but this reflects only a small share of the global sport sector; the literature on this topic is still nascent. Equally, while there is evidence of adaptation, much remains to be understood about the nature of this adaptation, and the limits to this adaptation. Opportunities for multidisciplinary research collaboration are abundant and may yield important insights. It is our hope that the insights from this scoping review will help future researchers contribute to a better understanding of climate change impacts on sport and facilitate improved management practices with the ultimate aim of the apex-level of sport becoming genuinely sustainable.

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AUTHOR CONTRIBUTIONS
Madeleine Orr: Conceptualization (lead); data curation (equal); formal analysis (equal); methodology (supporting); project administration (equal); writing – original draft (lead); writing – review and editing (equal). **Yuhei Inoue:** Conceptualization (supporting); data curation (equal); formal analysis (equal); methodology (lead); project administration (equal); writing – original draft (supporting); writing – review and editing (equal). **Russell Seymour:** Conceptualization (supporting); data curation (supporting); formal analysis (supporting); writing – original draft (supporting); writing – review and editing (equal). **Greg Dingle:** Conceptualization (supporting); data curation (supporting); formal analysis (supporting); writing – original draft (supporting); writing – review and editing (equal).

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Data sharing is not applicable to this article as no new data were created or analyzed in this study.

ORCID
Madeleine Orr https://orcid.org/0000-0002-3478-3686
Yuhei Inoue https://orcid.org/0000-0002-1983-6217

Russell Seymour https://orcid.org/0000-0002-1696-3165
Greg Dingle https://orcid.org/0000-0003-0931-6303

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APPENDIX A.: SEARCH TERMS USED FOR DATABASE SEARCHES

The two sets of search terms below are connected by the AND operator for the database searches.

1. "Sport*" or "athlete*" or "coach" or "Olympic*" or "Paralympic*" or "Stadium" or "Stadia" or "FIFA World Cup" or "National Football League" or "NFL" or "National Basketball Association" or "NBA" or "Major League Baseball" or "MLB" or "Major League Soccer" or "MLS" or "National Women's Soccer League" or "NWSL" or "Women's National Basketball Association" or "WNBA" or "PGA" or "Ladies Professional Golf Association" or "LPGA" or "Tour de" or "Grand Slam" or "FIS" or "Association of Volleyball Professionals" or "AVP" or "World Surf" or "World Athletics" or "FINA" or "FIBA" or "Cricket World Cup" or "ICC World Cup" or "ICC T20 World Cup" or "Indian Premier League" or "Rugby Union" or "Rugby League" or "Australian Football League" or "English Premier League" or "La Liga" or "Bundesliga" or "Ligue 1" or "UEFA Champions League" or "Serie-A" or "J-League" or "A-League" or "FA Women's Super League" or "W-League" or "Nadeshiko League" or "Frauen-Bundesliga" or "Women's League" or "Rugby World Cup" or "Six Nations Rugby" or "Rugby Championship" or "Super Rugby" or "National Rugby League" or "Women's Rugby League" or "Japan Golf Tour" or "Sunshine Tour" or "Ladies European Tour" or "Ladies Asian Golf Tour" or "ALPG Tour" or "ATP World Tour" or "ITF Women's World Tennis Tour" or "National Collegiate Athletic Association" or "NCAA" or "Abbott Series" or "Super Bowl" or "race"
2. "Climate change" or "Global warming" or "Extreme weather" or "Climate impact" or "Storm" or "Hurricane" or "Typhoon" or "Cyclone" or "Natural Disaster" or "Thermal stress" or "Extreme Heat" or "Heat Wave" or "Bush Fire" or "Fire" or "Flood" or "Drought" or "Snow" or "Sea Level"

APPENDIX B.: ARTICLES INCLUDED IN REVIEW

Author(s) and year	Pub online[a]	Journal or publisher	Study location	Type of study	Type of climate hazard	Sport	Season	Is adaptive capacity discussed?
Australian Conservation Foundation, 2020a	2020	Australian Conservation Foundation, Monash University	Australasia	Research Report	Heat	Cycling	Summer	Yes
Australian Conservation Foundation, 2020b	2020	Australian Conservation Foundation	Australasia	Research Report	Heat	Tennis	Summer	Yes
Brocherie et al., 2015	2015	Climate	Multiple	Editorial/ Conceptual/ Review	Multiple	Multiple	Unspecified	Yes
Bruce, 2009	2009	The David Suzuki Foundation	North America	Research Report	Warmer winter/ Snow shortage	Multiple	Winter	Yes
Cheung, 2018	2018	International Journal of Sports Physiology and Performance	Multiple	Editorial/ Conceptual/ Review	Heat	Multiple	Combinations	No
Craig et al., 2016	2016	Journal of Sport and Health Science	North America	Quantitative	Heat	American Football	Combinations	Yes
Dingle, 2020	2020	Sport and Environmental Sustainability: Research and Strategic Management (Routledge)	Unspecified/Other	Qualitative	Multiple	Multiple	Combinations	Yes
Dingle & Mallen, 2020	2020	Managing Sport & Leisure	Multiple	Case studies	Multiple	Multiple	Combinations	Yes
Dingle & Stewart, 2018	2018	Managing Sport and Leisure	Australasia	Case studies	Multiple	Multiple	Combinations	Yes
Edgar, 2020	2020	Sport Ethics and Philosophy	Unspecified/ Other	Editorial/ Conceptual/ Review	Multiple	Multiple	Unspecified	No
Fairley et al., 2015	2015	Sport Management Review	North America	Case studies	Warmer winter/ Snow shortage	Pond hockey	Winter	Yes

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Author(s) and year	Pub online[a]	Journal or publisher	Study location	Type of study	Type of climate hazard	Sport	Season	Is adaptive capacity discussed?
Falk & Hagsten, 2017	2017	Climatic Change	Europe	Quantitative	Warmer winter/ Snow shortage	Cross-country skiing	Winter	Yes
Filho, 2014	2014	International Journal of Climate Change Strategies and Management	Central and South America	Editorial/ Conceptual/ Review	Multiple	Football (Soccer)	Summer	No
Gasparetto & Nesseler, 2020	2020	Frontiers in Psychology	North America	Quantitative	Heat	Marathon	Fall	Yes
Gerrett et al., 2019	2019	Frontiers in Physiology	Asia	Quantitative	Heat	Summer Olympic and Paralympic Sports	Summer	No
Giddy, 2018	2018	International Journal of Festival and Event Management	Africa	Qualitative	Other (Extreme winds)	Cycling	Fall	Yes
Goggins et al., 2018	2018	The Climate Coalition, Priestly International Centre for Climate	Europe	Research Report	Multiple	Multiple	Combinations	Yes
Goldblatt, 2020	2020	The Rapid Transition Alliance	Unspecified/Other	Research Report	Multiple	Multiple	Combinations	Yes
Grundstein et al., 2013	2013	Climate Research	North America	Quantitative	Heat	Multiple	Combinations	No
Grundstein et al., 2020	2020	Journal of Science and Medicine in Sport	North America	Quantitative	Heat	Multiple	Combinations	Yes
Honjo et al., 2018	2018	International Journal of Biometeorology	Asia	Quantitative	Heat	Marathon	Summer	Yes
Hosokawa et al., 2019	2019	International Journal of Biometeorology	North America	Research Report	Heat	Multiple	Combinations	Yes
James, 2011	2011	Journal of Sports Engineering and Technology	Unspecified/Other	Editorial/ Conceptual/ Review	Multiple	Multiple	Combinations	Yes
Jurbala & Mallen, 2020	2020	Sport and Environmental Sustainability: Research and Strategic Management (Routledge)	Unspecified/Other	Editorial/ Conceptual/ Review	Multiple	Multiple	Summer	Yes

Author(s) and year	Pub online[a]	Journal or publisher	Study location	Type of study	Type of climate hazard	Sport	Season	Is adaptive capacity discussed?
Kakamu et al., 2017	2017	Environmental Health and Preventative Medicine	Asia	Quantitative	Heat	Summer Olympic and Paralympic Sports	Summer	Yes
Kellison & Orr, 2020	2020	International Journal of Sports Marketing and Sponsorship	North America	Case studies	Multiple	Baseball	Summer	Yes
Kerr et al., 2019	2019	Environmental Health Perspectives	North America	Quantitative	Heat	American football	Combinations	Yes
Knowles et al., 2020	2020	Sport and Environmental Sustainability: Research and Strategic Management (Routledge)	Multiple	Empirical/ Conceptual/ Review	Warmer winter/ snow shortage	Multiple	Winter	Yes
Matzarakis et al., 2018	2018	Atmosphere	Asia	Qualitative	Heat	Summer Olympic and Paralympic Sports	Summer	No
Matzarakis et al., 2019	2019	Atmosphere	Asia	Quantitative	Multiple	Summer Olympic and Paralympic Sports	Summer	No
Menzies et al., 2021	2021	The Climate Institute	Australasia	Research Report	Multiple	Multiple	Combinations	Yes
Miller-Rushing et al., 2012	2012	PLoS One	North America	Quantitative	Heat	Marathon	Spring	No
Nybo et al., 2020	2020	British Journal of Sports Medicine	Multiple	Editorial/ Conceptual/ Review	Heat	Football (Soccer)	Unspecified	Yes
Oikawa et al., 2021	2021	BASIS	Asia	Research Report	Heat	Summer Olympic and Paralympic Sports	Summer	Yes
Olya, 2019	2017	Current Issues in Tourism	Asia	Quantitative	Multiple	Multiple	Summer	Yes
Orr, 2020	2020	Managing Sport and Leisure	Multiple	Qualitative	Multiple	Multiple	Combinations	Yes
Orr, 2021	2021	Managing Sport and Leisure	Multiple	Qualitative	Multiple	Multiple	Combinations	Yes

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Author(s) and year	Pub online[a]	Journal or publisher	Study location	Type of study	Type of climate hazard	Sport	Season	Is adaptive capacity discussed?
Orr & Inoue, 2019	2018	Sport Management Review	Multiple	Editorial/ Conceptual/ Review	Multiple	Multiple	Combinations	Yes
Orr & Kellison 2020	2020	Managing Sport and Leisure	Multiple	Editorial/ Conceptual/ Review	Multiple	Multiple	Combinations	Yes
Orr & Schneider, 2018	2018	Journal of Sport and Tourism	North America	Quantitative	Warmer winter / Snow shortage	Cross-country skiing	Winter	Yes
Palmer et al., 2014	2014	Civil Engineering	Europe	Case studies	Flooding	Multiple	Summer	Yes
Peiser et al., 2006	2006	International SportMed Journal	Unspecified/Other	Editorial/ Conceptual/ Review	Seasonal shifts	Multiple	Combinations	Yes
Rice et al., 2021	2021	Climate Council	Australasia	Research Report	Multiple	Multiple	Combinations	Yes
Rutty et al., 2015	2014	Current Issues in Tourism	Multiple	Qualitative	Warmer winter / Snow shortage	Winter Olympic and Paralympic Sports	Winter	Yes
Scott & Jones, 2006	2017	Journal of Leisure Research	North America	Case studies	Seasonal shifts	Golf	Summer	Yes
Scott & Jones, 2007	2007	The Canadian Geographer	North America	Quantitative	Seasonal shifts	Golf	Summer	Yes
Scott et al., 2018	2018	Journal of Sustainable Tourism	North America	Qualitative	Other (Water availability)	Golf	Summer	Yes
Scott et al., 2019	2018	Current Issues in Tourism	Multiple	Quantitative	Warmer winter/ Snow shortage	Winter Olympic and Paralympic Sports	Winter	Yes
Scott et al., 2015	2014	Current Issues in Tourism	Multiple	Quantitative	Warmer winter/ Snow shortage	Winter Olympic and Paralympic Sports	Winter	Yes
Smith et al., 2016	2016	The Lancet	Multiple	Quantitative	Heat	Summer Olympic and Paralympic Sports	Summer	Yes
Sofotasiou et al., 2015	2014	Sustainable Cities and Society	Asia	Case studies	Heat	Football (Soccer)	Spring	Yes

Author(s) and year	Pub online[a]	Journal or publisher	Study location	Type of study	Type of climate hazard	Sport	Season	Is adaptive capacity discussed?
Tipton et al., 2019	2019	BASIS, University of Leeds, University of Portsmouth	Multiple	Research Report	Multiple	Cricket	Combinations	Yes
Tobías et al., 2019	2019	Revista Internacional de Ciencias del Deporte	Multiple	Quantitative	Heat	Football (Soccer)	Summer	Yes
Townsend et al., 2003	2003	Journal of Science and Medicine in Sport	Unspecified/Other	Editorial/Conceptual/Review	Multiple	Multiple	Combinations	No
Vanos et al., 2019	2018	Science of the Total Environment	Asia	Quantitative	Heat	Marathon	Summer	Yes
Visser & Petersen, 2009	2008	Climatic Change	Europe	Editorial/Conceptual/Review	Warmer winter/Snow shortage	Speed skating	Winter	No
Wu et al., 2020	2020	Atmosphere	Asia	Quantitative	Heat	Summer Olympic and Paralympic Sports	Summer	Yes

[a] Pub Online indicates the year an article was published online. As journals are increasingly publishing articles online ahead of publishing a print version, this column was intended to elucidate when the article was first publicly available.