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# A Review of the Effects of Climate Change on Visitor Use in US Public Lands and Waters

Cyclists in Yellowstone National Park
NPS / JACOB W. FRANK

# A review of the effects of climate change on visitor use in US public lands and waters

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## Abstract

Climate change is affecting recreational visitor use in U.S. public lands and waters, causing changes to visitation levels, timing of trips, activity participation, and visitor safety. This report reviews the literature on how climate change is influencing visitor use in the United States and how visitor use may be affected in the future. Our goal is to provide the current state of the literature for managers of public lands and waters and provide foundational information for the development of a climate change vulnerability assessment methodology for visitor use within the National Park Service (that may be applicable to other federal lands and waters). Specifically, we investigate how seven different climate change factors may affect visitor use on public lands and waters. These factors consist of increasing temperatures; flooding, drought, and increased variability of precipitation; decreasing snowpack and earlier spring runoff; wildfires, smoke, and air quality; coastal hazards: hurricanes and sea level rise; harmful algal blooms (HABs); and zoonotic and vector-borne disease. The current research indicates that these factors are already affecting visitors to public lands and waters and continued effects in the future are likely as the climate warms. Additionally, we summarize existing research on how visitors to U.S. public lands and waters are adapting to climate change. Throughout the review, we note where there are substantial gaps in the literature and more research would help managers respond to the effects of climate change on visitor use.

## Acknowledgments

This report benefitted from feedback provided by Bret Meldrum, Rose Verbos, and Koren Nydick from the National Park Service, and Eric White from the USDA Forest Service. Thanks to the National Park Service Climate Change Response Program for funding to support this research.

## List of Acronyms

**HAB:** Harmful Algal Bloom

**NP:** National Park

**NPS:** National Park Service

# 1. Background and objectives

Visitation to public lands and waters generally has increased in recent decades both in the United States and globally, with U.S. federal lands and waters seeing over 800 million annual visits (in 2015) and the U.S. National Park Service (NPS) system receiving over 300 million annual visits (in all years between 2015 and 2023, with the exception of Covid-19 related disruptions in 2020 and 2021) (Balmford et al. 2015, Leggett et al. 2017, National Park Service 2024a). Many different factors affect both visitation and visitor use in public lands and waters (Bergstrom et al. 2020), and the effects of climate change on visitor use is now a major consideration for managers both in the United States and globally (Fisichelli et al. 2015, Pröbstl-Haider et al. 2021, Rutty et al. 2022, Steiger et al. 2022). The overall goal of this report is to better understand the current literature on the effects of climate change on visitor use in public lands and waters in the United States. The large majority of visits to NPS units and other federal public lands and waters such as national forests and national wildlife refuges are considered "recreation visits," which include outdoor recreation activities like hiking and backpacking, but also activities like scenic driving and exploring visitor centers and museums. Key definitions related to visits, visitor use, and visitor use management can be found below. Throughout this report, we use the term "visitor use" to refer specifically to people visiting public lands and waters for recreational purposes (rather than for business or other purposes), consistent with the definition.

Definitions of terms related to visitor use used throughout this report:

- **Visits** represent the entry of any person, except agency and service personnel, onto lands or waters administered by the agency, while a **visitor** represents an individual who generates one or more visits (National Park Service 2024c).
- **Recreation visits** are generated by visitors using the park "as a park" and exclude non-recreation visits, which are visitors using park territory, roads, and facilities for their own convenience or as a part of their occupation (National Park Service 2024c, b).
- **Visitor use** refers to human presence in an area for recreational purposes, including education, interpretation, inspiration, and physical and mental health (Interagency Visitor Use Management Council 2016).
- **Visitor experience** is the perceptions, feelings, and reactions that a visitor has before, during, and after a visit to an area (Interagency Visitor Use Management Council 2016).
- **Visitor use management** is the proactive and adaptive process for managing characteristics of visitor use and the natural and managerial setting using a variety of strategies and tools to achieve and maintain desired resource conditions and visitor experiences (Interagency Visitor Use Management Council 2016).
- **Off-season** represents the months in which visitation is the lowest for a particular park or unit. **Peak season** or **high-use season** refers to consecutive months in which visitation is highest, while **shoulder season** refers to months around the peak season(s) that have higher visitation than the off-season but lower than the peak season. Parks can have more than one

peak season or shoulder season (e.g., some desert parks may have two peak seasons in the spring and fall) and some parks may not experience seasonal patterns of visitation (e.g., some monuments or memorials in urban areas).

Climate change is causing rising temperatures and increased variability in temperature and precipitation patterns, both of which directly affect visitors. Definitions related to terms such as climate and climate change can be found below. Increasing temperatures and changing precipitation patterns also have cascading effects on the frequency and intensity of droughts and floods, wildfires, and hurricanes (USGCRP 2023a). These changes affect natural and cultural resources as well as infrastructure in public lands and waters (Fatorić and Seekamp 2017, Monz et al. 2021). All of these factors affect visitor use; for example, visitors may change the location they visit, the timing of their trips, activity participation, or desired experiences and enjoyment (Hand et al. 2018). Figure 1 depicts ways in which the effects of climate change considered in this review are affecting visitor use, and how those changes can affect operations of public lands and waters, although it is not intended to be comprehensive of all climate-related effects.

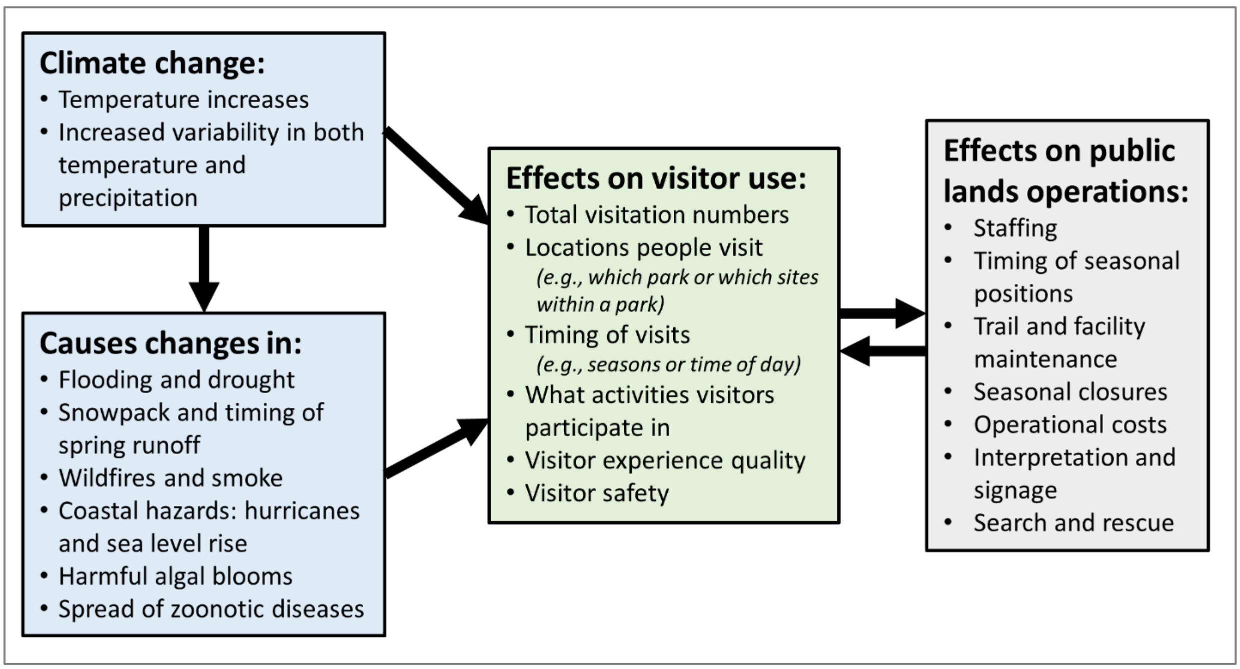


**Figure 1.** A conceptual diagram of how climate change is affecting visitor use in public lands and waters, and how changes to visitor use can affect operations of public lands and waters. NPS

Definitions related to climate and climate change used throughout this report:

- **Climate** refers to the average weather patterns or trends for a region over a period of many years; components usually include seasonal patterns of temperature, precipitation, wind, relative humidity, etc. Climate "normals" are the averages of climate variables for (typically) a 30-year period (National Park Service 2021).

- **Climate change** is a change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forces, or to persistent anthropogenic changes in the composition of the atmosphere or in land use (definition from National Park Service, 2021; paraphrased from IPCC 2007).
- **Vulnerability assessment** is an evaluation of the extent to which a system is susceptible to harm from direct and indirect effects of climate change, including variability and extremes. Vulnerability is often based on measures of exposure and sensitivity with consideration for the adaptive capacity of living organisms (definition from National Park Service, 2021; paraphrased from Rockman et al. 2016).

Any changes to visitor use have the potential to influence park management and operations (Manning 2022, Miller 2022). For example, increased visitation outside of high-use seasons may require seasonal visitor centers or other facilities to open earlier in the year, or a shift in the timing or length of seasonal staffing. These changes could be challenging to accommodate without advanced planning and budgeting that would be needed for any shifting staffing needs. Higher visitation in the off-season or shoulder seasons could also pose a threat to vegetation and wildlife in certain locations because quieter times can be critical for certain species (e.g., having lower visitation during nesting or breeding seasons) (Coombes et al. 2008). Changing visitation patterns could thus necessitate management actions such as seasonal closures or increased signage to protect resources (Coombes et al. 2008). Social science research on changing patterns of visitor use and how conditions may affect visitor experiences could benefit the development of strategic and defensible decisions to manage visitor use (Cahill et al. 2018).

Public land managers and other nature-based tourism suppliers (e.g., outfitters, guides) are already noticing the effects of climate change on visitors (e.g., Lamborn and Smith 2019, Horne et al. 2022, Smith et al. 2024). For example, in a coastal destination, tourism suppliers perceived significant effects of climate change, including increasing visitation, shifts in the seasonality of visitation, and increasing fire risk (Horne et al. 2022). However, for park managers and planners to effectively plan for and adapt to changing climate conditions, there is a need for information about how climate change may affect the system—including visitor use. Previous research and review papers have found the effects of weather and climate change on visitor use vary by recreational activity type (Hewer and Gough 2018, Pröbstl-Haider et al. 2021, Miller et al. 2022, Wilkins and Horne 2024) and by location or geographic context (Brice et al. 2017, Verbos et al. 2018, Steiger et al. 2022). However, we are not aware of any studies to date that have reviewed the literature through the lens of climate change vulnerability. We therefore focus on what existing research tells us about how different climate drivers such as temperature and precipitation, but also wildfires, flooding, hurricanes, and other climate change factors may affect visitor use in public lands and waters. We also review existing research on how visitors are already adapting to climate change effects. As such, this literature review is the first of its kind to be organized around the three key components of climate change vulnerability—exposure, sensitivity, and adaptive capacity—in the context of visitor use on public lands.

The overall goal of this report is to better understand the current literature on the effects of climate change on visitor use in public lands and waters in the United States in order to inform the development of a vulnerability assessment methodology. We aim to assess what factors could be considered when developing a climate change vulnerability assessment related to visitor use, as well as gain insights into how to measure and quantify the three dimensions of vulnerability (exposure, sensitivity, and adaptive capacity) for visitor use. As detailed information on the climate exposure of parks is already available (National Park Service 2024d), we focus on the sensitivity and adaptive capacity of visitors in this review. This future vulnerability assessment methodology would focus on NPS units, but would likely be applicable to other federal lands and waters that are facing many of the same climate change factors and effects on visitor use. The scope of this review spans beyond NPS lands and includes research from a variety of public lands and waters contexts. The specific objectives of this review are: (1) to better understand the current literature on how climate change affects visitor use on U.S. public lands and waters and how visitors are adapting, (2) to identify where there are gaps in the literature regarding climate change and visitor use in the United States, and (3) to inform future climate change vulnerability assessments for visitor use management on public lands and waters.

# 2. Literature review methodology

We conducted this review as a narrative review (sometimes called a targeted review) rather than a systematic review, as its aim is to provide a comprehensive background on the current state of knowledge, rather than to answer a highly specific or quantitative question (Boell and Cecez-Kecmanovic 2015, Templier and Paré 2015, Paré and Kitsiou 2017). We followed the guidelines for conducting and reporting a narrative review as outlined in Templier and Paré (2015).

## 2.1 Study identification and exclusion criteria

The authors searched for literature related to the effects of climate change on outdoor recreation and visitor use in U.S. public lands and waters. We first searched the database of a prior literature review by the first author related to the effects of weather and climate change on certain recreational activities to identify which of those studies also fit within the scope of this review (Wilkins and Horne 2024). We then searched Google Scholar, Scopus, and Web of Science for additional studies using a variety of search terms. Searches included at least two words or phrases, one related to visitor use (e.g., "outdoor recreation," "park visitation," "visitor use," "nature-based tourism," etc.) and one term related to climate factors (e.g., "flooding," "wildfire," "hurricane," "snowpack," etc.). We added additional studies we were aware of or that we identified by reviewing reference sections of papers already included in the review. Searches were conducted by two authors throughout 2023 and 2024, with the last search occurring on April 24th, 2024.

Given the focus of this review—the effects of climate change on visitor use—we only included studies that contained human dimensions of climate change in public lands and waters; we did not aim to comprehensively summarize the effects of climate change on ecosystems or biophysical processes. Additionally, we limited our search to studies that are based in the United States since this review is intended to inform park and protected area planning and decision-making in the United States. We also did not include studies that only addressed economic effects of climate change on local communities, as this is outside the scope of park management. Although most of the databases we searched tended to return academic journal articles, we did include some reports from credible sources, such as government agencies. Two authors reviewed all identified relevant studies to ensure both agreed that each study was within scope. Although this initial phase of literature searching only focused on studies based in the United States, we later searched for studies outside of the United States to include in the "global insights" sections (described in the following section).

Since this is a narrative review, we did not include every study we found within scope. In instances where there were many papers on similar topics (e.g., the effect of increasing temperatures on visitation), we prioritized papers that were larger in geographic scope (e.g., more than one park or location), that used more recent data, and/or had at least one study site on NPS lands. For topics with few studies (e.g., the effect of hurricanes or sea level rise on visitor use), we included all studies we found that were within scope. In cases where there were many papers on a similar topic, two authors collaboratively discussed which to include or exclude based on these factors.

### 2.2 Review organization and information recorded

After searching the literature, we organized this review around seven climate change factors related to visitor use. These consist of: increasing temperatures; flooding, drought, and increased variability of precipitation; decreasing snowpack and earlier spring runoff; wildfires, smoke, and air quality; coastal hazards: hurricanes and sea level rise; harmful algal blooms (HABs); and zoonotic and vector-borne diseases. These seven factors were chosen based on the known effects of climate change on biophysical processes (summarized in the first paragraph of each section) as well as what was identified during literature searches. Additionally, we only included broad factors that had a minimum of three studies evaluating how each factor affects visitor use in the United States. For example, we searched for additional topics such as increasing extreme events (e.g., wind, hail, lightning) in the literature but did not include these as climate change factors due to the lack of studies on how they affect visitor use. This review was organized around these seven climate change factors, as most studies tended to only focus on one of these factors; however, it is important to acknowledge that each climate change factor is not occurring in isolation, and the combined effects of multiple climate change factors may be different than or greater than any single one.

For each study included in this review, we recorded the following information: bibliometric data (e.g., year, journal title, abstract), climate change factor category (e.g., increasing temperatures, decreasing snowpack and earlier spring runoff, coastal hazards), objectives or research questions, location and setting, the general methods, the type of human-dimensions data used, specific weather or climate variables studied (e.g., maximum temperature, minimum temperature, precipitation, air quality index, particulate matter 2.5, etc.), the time period of historical analyses, temporal unit of analyses (e.g., daily, monthly, seasonal), time period of climate change analyses and scenarios, perceptions of who and what (if the study includes perceptions), the effect on visitors studied (e.g., visitation numbers, activity participation, visitor safety) and the main findings of the paper as they relate to the objectives of this review.

The following review (section 3, papers mentioned under the "literature review results" subsections) includes 63 papers published between 1992 and 2024. About half of the papers (31/63) were published between 2019 and 2024. The number of studies included under each section is as follows: increasing temperatures (11); flooding, drought, and increased variability of precipitation (7); decreasing snowpack and earlier spring runoff (12); wildfires, smoke, and air quality (14); coastal hazards: hurricanes and sea level rise (7); HABs (6); and zoonotic and vector-borne disease (8) (two papers were included in two sections). The full list of papers included in section 3 under the "literature review results" subsections can be found in Appendix 1.

Although the focus of this literature review is how climate change affects visitor use in the United States, for background context we provide a short overview of how climate change has affected biophysical processes in the United States at the beginning of each section. These brief "climate context" sections provide background for the review and are not intended to be comprehensive; for more information on the effects of climate change in the United States and future projections, refer to the fifth National Climate Assessment (Marvel et al. 2023, USGCRP 2023a) or park-specific climate futures for NPS units (National Park Service 2024d). Additionally, although this review is focused on the United States, we include "global insights" sections to provide additional context. These "global insights" sections are not intended to be a comprehensive review of all global literature; rather they aim to highlight key studies from other countries, topics where there is limited research within the United States, or important insights from other locations.

# 3. Effects of climate change on visitor use

## 3.1 Increasing temperatures

**Climate context:** The United States is warming faster than the Earth as a whole, with the continental United States experiencing 1.4°C (2.5°F) of warming since 1970, and Alaska experiencing 2.3°C (4.2°F) of warming since 1970 (Marvel et al. 2023). Lands managed by NPS are warming even faster than the United States in general, due to the locations and high elevations of many parks, with park temperatures projected to increase by 3–9°C (5.4–16.2°F) between 2000 and 2100 under a high emissions scenario (with Alaska expected to have the highest warming) (Gonzalez et al. 2018). In most of the United States, winter is warming faster than summer (Marvel et al. 2023). Warmer temperatures are advancing spring onset on NPS lands (Monahan et al. 2016) while also delaying the onset of autumn and peak fall foliage in parks (Spera et al. 2023). The average number of heatwaves in the United States has doubled since the 1980s, and the average heatwave season has expanded from around 40 days to 70 days (USGCRP 2023b).

**Literature review results:** Temperatures can affect where people decide to visit, as well as the timing of their trips to public lands and waters. Across many federal recreation sites, warmer monthly temperatures were correlated with increases in both trip duration and the total number of recreational trips (Liu 2022). This trend of warmer temperatures increasing monthly visitation is also true at NPS sites (Albano et al. 2013, Fisichelli et al. 2015). However, some studies indicate there is a threshold beyond which visitation decreases. One study found a threshold at an average monthly mean temperature of 25°C (77°F) across many NPS units (when analyzing data from 1979 to 2013) (Fisichelli et al. 2015). Importantly, this threshold is the monthly mean daily temperature averaged over a month and does not represent the specific temperature at which visitors may feel it is too hot. In Utah, a study found that three national parks experienced declines in monthly visitation when the average monthly daily maximum temperature exceeded 25°C (77°F), but two other national parks did not experience visitation declines after this threshold (Smith et al. 2018). This indicates that characteristics of the park (e.g., high elevations, canyons) or characteristics of the visitors or visitor experiences may affect whether or not visitation declines after a threshold, but more research would clarify how temperature thresholds may vary across locations. Due to warming temperatures, visitation is expected to change at 95% of NPS units by the 2050s, with most parks expected to see increased annual visitation as temperatures warm (Fisichelli et al. 2015). In addition to temperatures affecting total visitation numbers, exceptionally hot days may change where visitors travel within a park; for example, visitors may travel to waterbodies or higher elevations to seek cooler temperatures (Wilkins et al. 2021b).

Given that visitation generally increases when it is warmer (up to a point), it is unsurprising that warmer temperatures are leading to changes in seasonal visitation patterns and expanding the peak visitation season in many parks (Fisichelli et al. 2015). Visitation increases are projected to predominately be in the off-season and shoulder seasons, with some public lands possibly seeing declines in summer visitation as temperatures get too hot (Fisichelli et al. 2015, Wilkins et al. 2021a). Figure 2 shows an example of how seasonal visitation patterns have already shifted over the last ten years (2013–2023) at three different Intermountain Region national parks using monthly visitation data from the NPS (National Park Service 2024e). Although all three parks saw increases in annual visitation, these changes differed by season, with all three parks seeing increases in spring, winter, and fall visitation, while summer visitation increased at a slower rate (and decreased substantially in Grand Canyon NP). The peak visitation season across many NPS units is projected to be extended by 13–31 days by the 2050s under climate change (Fisichelli et al. 2015).

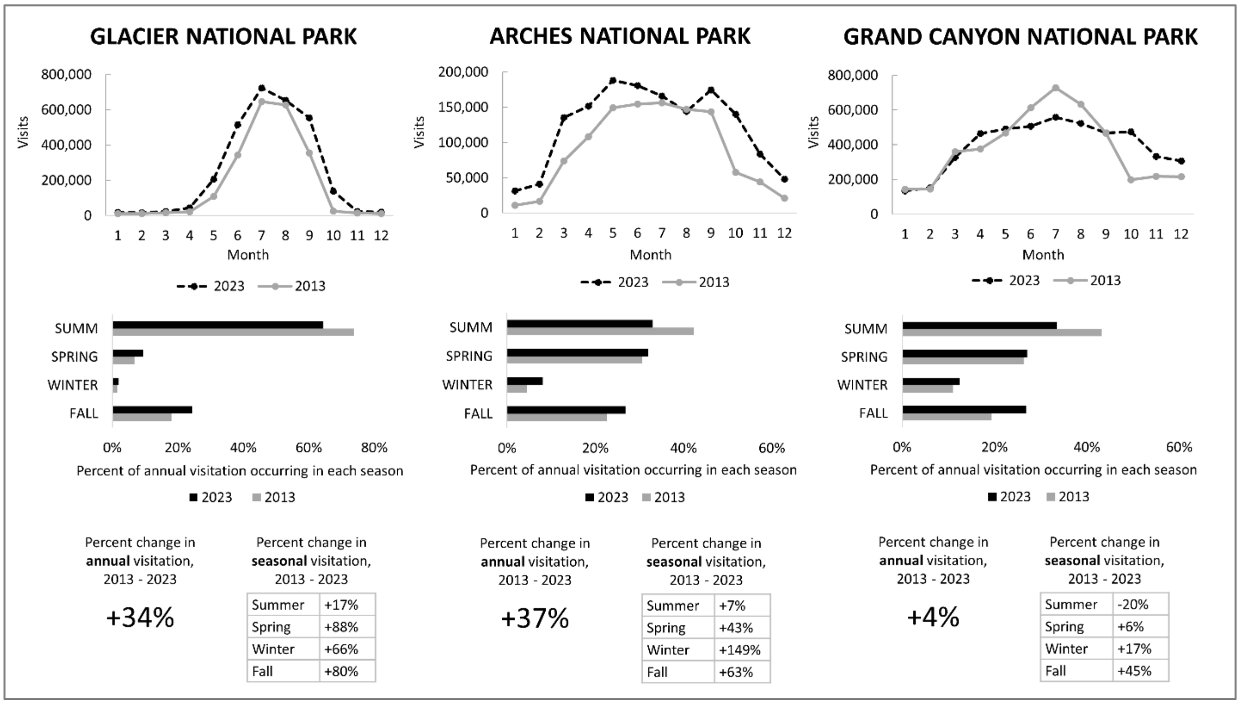


**Figure 2.** An example of how seasonal patterns of visitation have changed at three different national parks from 2013 to 2023. Visitation data from the National Park Service visitor use statistics (National Park Service 2024e). These parks all have different climates; for example, the average monthly maximum temperature (1991–2020) in July was 80°F on the west side of Glacier National Park, 99°F in Arches National Park, and 77–104°F in Grand Canyon National Park (lower on the north rim, hotter within the canyon) (National Oceanic and Atmospheric Administration). NPS

Rising temperatures can also affect activity participation. In general, rising temperatures increase total trips to participate in warm-weather activities, such as camping, biking, and fishing, but decrease total trips to participate in snow-dependent activities, such as skiing or snowmobiling (for a full review on how temperature affects participation by activity, refer to Wilkins and Horne 2024). Across the United States, many more people participate in warm-weather activities compared to activities that depend on snow (Outdoor Industry Association 2023, White et al. 2023a), so visitation will likely increase overall as temperatures rise since losses in visitation from winter activities will likely be offset by gains in visitation from warm-weather activities. However, climate change may also cause conditions for some warm-weather activities to be worse or more variable, such as fishing and water-dependent activities (discussed more in sections 3.2 and 3.3) (Wilkins and Horne 2024). Projections out to 2070 show that higher levels of atmospheric warming would decrease *per capita* participation (meaning the number of people who participate at least once in a year) in activities such as day hiking and mountain biking, but have negligible effects on activities such as camping, viewing nature, and motorized off-road use (White et al. 2023a). However, it is important to note that many factors affect participation beyond warming temperatures and climate change; for example, the declines in per capita participation in day hiking and mountain biking projected due to warming temperatures are smaller than the increases in per capita participation projected due to socioeconomic growth (including increased wealth) (White et al. 2023a).

Finally, warming temperatures and more days with extreme heat have the potential to affect visitor health and safety. In Grand Canyon NP, heat-related illness was significantly related to maximum daily temperatures and humidity (Buttke et al. 2023). In addition to increased heat-related illness in the summer, there is also increased heat risk in the shoulder seasons when more hot days now occur, yet visitors may not be prepared for the heat (Buttke et al. 2023). Under similar rates of visitation but higher temperatures due to climate change, heat-related illness in Grand Canyon NP is projected to increase by 29%–137% by 2100 (compared to 2004–2009 levels) (Buttke et al. 2023). Another study found that the number of days with thermal safety (which represents the meteorological conditions in which it is safe to participate in outdoor recreation and includes temperature, humidity, and solar radiation) decreased in national parks from 1984 to 2019, with the most adverse risk conditions in lower latitudes and in the western United States (Craig 2024). Changes in exposure to extreme heat may be compounded by lack of perceived risks. In Arches NP and nearby Bureau of Land Management lands, visitors' risk perceptions of extreme heat were not found to be higher on warmer days (Goldstein and Howe 2019).

**Global insights:** Similar trends have been found in other countries for how increasing temperatures affect visitor use. For example, reviews of research in Canada and Austria also note shortened seasons for winter recreation but longer seasons for warm weather activities (Hewer and Gough 2018, Pröbstl-Haider et al. 2021). Across global mountainous regions, warming temperatures are generally expected to be favorable for warm weather recreation due to increased season length and fewer cold days; however, other climate impacts such as increased natural hazards are expected to have negative effects (Steiger et al. 2022). In China, researchers found that hiking participation generally increased with warmer temperatures, but declined once daily maximum temperatures exceeded 23°C (73°F), which is a slightly lower threshold than what has been found in the United States (Liu et al. 2021). Importantly, one global study found that the temperature preferences of outdoor recreationists varied by country, with people who live in warmer places preferring higher temperatures when recreating (Linsenmeier 2024). Increasing temperatures can also have other repercussions, such as shifting the timing of pollen, which can affect visitors who have seasonal allergies (Pröbstl-Haider et al. 2021).

**Gaps in the literature**: Additional research on how extreme heat events affect visitor experiences, activity participation, and visitor movement would be beneficial. For example, we are unaware of any research on how activity participation changes on hot days, and if more people or fewer people are participating in water-based recreation when it is particularly hot. Additionally, more research on how extreme heat events affect visitor safety (e.g., number of heat-related illnesses and search and rescue events that are heat-related), and what actions managers could take to help mitigate some safety concerns, would be useful. Finally, there are geographic gaps in the literature, with many studies tending to focus on the Intermountain West; additional research in other areas of the country would be beneficial.

### 3.2 Flooding, drought, and increased variability of precipitation

**Climate context**: As a result of climate change, precipitation events are now more variable and extreme across the United States, causing increasing incidence of flooding (Kunkel et al. 2013, Marvel et al. 2023). Precipitation refers to any form of water released from clouds back to the Earth and includes rain, snow, and hail (U.S. Geological Survey 2019). This section is focused on disturbance-related factors such as flooding and drought, while declining snowpack will be discussed in section 3.3. Projected future changes to total precipitation levels vary by region, with most of the western United States expected to see declines in total precipitation levels, while the northern and northeast United States are projected to see increased precipitation under climate change (Marvel et al. 2023). However, all regions have seen increases in the percentage of rain falling during extreme precipitation events since 1958 (Easterling et al. 2017). On NPS lands specifically, flooding risk is expected to increase in parks in the northern and eastern regions under climate change scenarios but decrease in the southwest (Gergel et al. 2017, Van Dusen et al. 2020). The risk of a flood being a flash flood is increasing due to climate change, with the southwest projected to see the largest increase in flash floods (Li et al. 2022). Due to both increasing variability of precipitation and warmer temperatures, climate change is likely to increase the frequency, severity, and duration of drought events (Payton et al. 2023).

**Literature review results**: Numerous studies evaluated how daily or monthly precipitation levels affect visitation, with precipitation generally decreasing visitation or having no effect on visitation (see Wilkins and Horne 2024 for a review). However, fewer studies examined how precipitation extremes in the form of drought or flooding affect visitor use on public lands. Extreme dry years have variable effects on total annual visits to mountainous NPs in the west, with dry conditions decreasing annual visitation in four cases and increasing visitation in two (Jedd et al. 2018). Similarly, the effect of drought on visitation at NPs in California shows variable effects by park, with some parks seeing increased annual visitation in drought years (e.g., Redwood NP), while other parks experienced no significant changes to annual visitation (e.g., Lassen Volcanic NP, Joshua Tree NP) (Jenkins et al. 2023). However, neither of these studies (Jedd et al. 2018, Jenkins et al. 2023) controlled for other factors that could affect visitation levels, such as temperature or the state of the economy, so more research is still needed on the effect of drought while controlling for other factors. Only two studies evaluated how visitor experiences may be affected by drought (Daugherty et al. 2011, Jedd et al. 2019). State park managers in Nebraska noted that visitor behavior changed as a result of drought; for example, bodies of water were more likely to be busy on dry and hot days, boat docks were more likely to be closed in droughts, and boats were more likely to get stuck during a drought (Jedd et al. 2019).

Some studies have also evaluated how water levels at reservoirs affect visitation. Many boat access sites were found to be unusable at reservoirs in Texas if water levels dropped (e.g., 50% of access sites would be lost with a 2–4 m reduction in water levels below full pool) (Daugherty et al. 2011). Visitation to Lake Mead and Lake Powell increased as reservoir levels increased (with the lowest visitation at very low reservoir levels) (Neher et al. 2013), while visitation to a reservoir in Oklahoma was lower when water levels were either very high or very low (Boyer et al. 2017). Similarly, fishing participation at reservoirs in Mississippi was lower when water levels were very high or very low (Miranda and Meals 2013).

Despite the increasing prevalence and severity of floods across the United States, there is still very limited literature on how floods or very high precipitation affects visitors. No studies that we are aware of investigated how flooding affects visitor use, but a few studies evaluated how above average precipitation or water levels affected total visits. Similarly to drought years having variable effects on annual visitation by park, the same two studies also found variable effects of exceptionally wet years on national park visitation, with some parks experiencing increases in visitation during abnormally wet years (e.g., Channel Island NP), and others seeing decreases in annual visitation (e.g., Sequoia-Kings Canyon NPs) (Jedd et al. 2018, Jenkins et al. 2023). Notably, when visitation is decreased in a park due to an extremely wet year, the visitation decreases are most often occurring in the spring, suggesting this may be attributable to snowpack and access (Jenkins et al. 2023).

**Global insights:** At a national park in South Africa popular for wildlife viewing, researchers found no significant relationship between drought and annual visitation numbers (this study did not control for other factors that affect visitation which could influence results) (Mathivha et al. 2017). However, qualitative interviews with park rangers and tour guides who work in this park revealed that drought can decrease the quality of wildlife-viewing experiences for certain species, although fewer water sources may make wildlife more concentrated in fewer locations and thus easier to photograph (Dube and Nhamo 2020a). In Zimbabwe, park managers and tourism suppliers perceived that droughts had a significant effect on visitation, noting that popular activities such as safaris, water sports, fishing, and boat cruises were brought to a near halt during periods of extreme drought (Dube and Nhamo 2020b). We identified very few studies globally on how flooding is affecting visitor use. In Nepal, increased landslides and flooding from climate change were noted to broadly be a concern for visitor safety (Nyaupane and Chhetri 2009). In South African parks, flooding is a concern for both visitor and staff safety, and park staff noted their biggest concerns with flooding were damage to roads and other infrastructure, increased erosion, and tourist discomfort (Dube et al. 2023).

**Gaps in the literature:** No studies that we are aware of investigate how flooding affects visitor safety, visitor access, or visitor experiences on public lands in the United States. Additionally, more research could help clarify how drought affects visitors, including activity participation (e.g., some activities may be more desirable in drought conditions, while others may be less desirable or impossible in drought conditions). More research could also clarify how flooding and drought may affect trail access and experiences for hikers and mountain bikers. Finally, we did not identify any literature on how flooding or drought affects river-based parks and public lands, including how visitor use on National Wild and Scenic Rivers may be affected.

### 3.3 Decreasing snowpack and earlier spring runoff

**Climate context**: With warmer temperatures, more precipitation is projected to fall as rain rather than snow, and snowpack is likely to melt earlier in the spring, causing earlier spring runoff (Gergel et al. 2017, Payton et al. 2023). For example, in the northeastern United States, warm winters had on average 50 cm less snowfall and 34 more days with no snow cover (Hu and Nolin 2020). Across the western United States, around 90% of snow monitoring sites already show declining snowpack, with the largest declines in the spring (Fyfe et al. 2017, Mote et al. 2018). Additionally, the likelihood of having consecutive years with snow droughts is increasing across the western United States due to climate change, with more variability projected in the timing of peak snowpack each winter (Marshall et al. 2019). In areas of the west, the total water volume from snow is projected to decrease by 25% by 2050, which will affect the amount of spring runoff (Siirila-Woodburn et al. 2021). Additionally, glaciers are retreating due to decreased snow and increased snow melt, which will have variable effects on runoff (Frans et al. 2018, Chang et al. 2023, Huntington et al. 2023).

**Literature review results**: Two related factors that have the potential to affect visitor use include 1) decreasing snowpack and 2) snowpack melting earlier in the spring and associated earlier spring runoff. For example, the timing of wildflower blooms and related wildflower viewing visits in mountainous parks depends on the snow disappearance date, which is already occurring earlier due to climate change (Lambers et al. 2021). In Mount Rainier NP, for every 10 days of earlier snowpack disappearance, wildflower blooms arrived 7.1 days sooner and seasonal visitation peaks arrived 5.5 days earlier (Breckheimer et al. 2020). Earlier snowmelt and spring runoff, and increased variability in spring runoff, also affect fishing and boating (Ligare et al. 2012, Lamborn and Smith 2019). In the Yellowstone River watershed, snowpack and spring runoff affect species distributions of fish and the perceived timing of optimal fishing, which increases uncertainty for trip planning and the quality of fishing (Lamborn and Smith 2019). In California's Sierra Nevada mountains, changing snowpack and runoff associated with temperature increases of 2°C are expected to increase the number of boatable weeks per year for whitewater recreation, but decrease the number of boatable weeks under warming of 6°C or higher (Ligare et al. 2012). Both of these studies indicated that, because of earlier spring runoff, the optimal timing to participate in fishing and boating was moving earlier in the spring (Ligare et al. 2012, Lamborn and Smith 2019).

Declining snowpack is also changing the ability to participate in snow-dependent activities, such as cross-country skiing, downhill skiing, and snowmobiling. Almost all locations across the United States are projected to see a reduction in the winter-recreation season length under climate change, with an anticipated 50% or more reduction by 2050 in many locations (Wobus et al. 2017). The effects vary by region, with lower-elevation areas expected to have the largest declines in season length (Wobus et al. 2017). Almost half of Vermont snowmobilers noted a shorter season length, which decreased the time people spent snowmobiling (Perry et al. 2018b). Additionally, per capita participation in cross-country skiing and snowshoeing is expected to decline under climate scenarios by 2070 (White et al. 2023a). For downhill skiing, research has shown that visitation is lower when the snow depth is lower (Hamilton et al. 2007, Shih et al. 2009, Chapagain et al. 2018). Under climate change scenarios (including reduced snowpack), there are projected to be fewer visits to ski resorts on national forests (Chapagain et al. 2018)[1]. Although declining snowpack reduces the season length to participate in snow-based activities, it does increase the season length to participate in warm-weather activities, such as hiking or biking. For example, in Rocky Mountain NP, decreased snowpack resulted in increased visitation (Loomis and Richardson 2006). Declining snowpack may contribute to extended shoulder season length and more visitors in the spring in certain parks (as described in section 3.1).

Changes to snowpack and spring runoff can also affect visitor safety. Avalanches are expected to decrease at lower elevations (due to less snow), but increase at higher elevations; however, human-triggered avalanches may not change because they depend on the number of winter recreationists (Strapazzon et al. 2021). Additionally, avalanches are likely to become even more dangerous as snow densities rise due to climate change, and lower snow cover is more likely to expose terrain roughness and cause blunt trauma (Strapazzon et al. 2021).

**Global insights:** Similar to the United States, decreasing snowpack due to climate change is expected to decrease the season length to participate in snow-dependent activities in many other countries (Hewer and Gough 2018, Steiger et al. 2021, Steiger et al. 2022). Related to decreasing snowpack is decreasing ice and ice thickness. Across the northern hemisphere, the number of days available to safely recreate on frozen lakes will decrease by 17 days with a temperature increase of 2°C (Woolway et al. 2022). This could have implications for visitor safety or visitor experiences in places where people recreate on frozen lakes, including for activities such as ice fishing or dogsledding that require ice to be a certain thickness (Nilsson and Demiroglu 2024). Finally, the effect of retreating glaciers on visitor use is a topic with minimal research in the United States, but significant research in other countries. Decreased snowpack and retreating glaciers can present increased safety concerns for visitors by destabilizing slopes, increasing rockfall, and increasing the possibility of ice or snow collapse (Purdie et al. 2015, Kaenzig et al. 2016, Wang and Zhou 2019). Additionally, almost half of visitors said they would not visit if there were no glaciers present at a site in New Zealand (Stewart et al. 2016), and around 80% of visitors to glaciers in the Alps said a motivating factor was to see the glacier before it disappears (Salim et al. 2023). This is a phenomenon termed “last chance tourism” in which people rush to see certain locations or landscape features before they disappear—often associated with glaciers, coral reefs, and polar bear viewing (Dawson et al. 2011, Groulx et al. 2016, Woosnam et al. 2022).

**Gaps in the literature:** More research could clarify how declining snowpack and earlier melting of snowpack will affect the quality of experiences for visitors who do not participate in activities explicitly dependent on snow. Additionally, more research would be useful to determine how changing snowpack and earlier melting may affect visitors’ trip planning and where visitors are

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[1] When factoring in changing socioeconomic factors such as population growth and a projected wealth increase in the future, a different study projects that both per capita participation and total trips to participate in downhill skiing and snowboarding will increase by 2070. However, this study does not explicitly account for future snowpack declines (White et al. 2023a).

going within a park. If visitor use patterns within a park change due to earlier snowmelt and earlier access to certain locations, it may unexpectedly harm sensitive resources in some locations, such as vegetation or wildlife.

### 3.4 Wildfires, smoke, and air quality

**Climate context**: Due to declining snowpack as well as increased temperatures, the severity, extent, and frequency of wildfires in the western United States has already increased and is projected to increase further (Abatzoglou and Williams 2016, Gergel et al. 2017, Marvel et al. 2023). From 1985 to 2017, the annual area burned by high-severity wildfires in the western United States increased eightfold (Parks and Abatzoglou 2020). Wildfires are also occurring at higher elevations due to reduced snowpack, drier conditions, and warmer temperatures (Ostoja et al. 2023). Increases in wildfires have already brought along increases in wildfire smoke, which can affect areas both near and far from the location of a wildfire (Burke et al. 2021, Ostoja et al. 2023). Wildfire smoke causes a decline in air quality, specifically fine particular matter ($PM_{2.5}$) and ozone precursors, which can affect human health (Ostoja et al. 2023).

**Literature review results**: Active wildfires and related site closures, burn scars, wildfire smoke, and air quality all have the potential to affect visitor use on public lands. Wildfires within 50, 100, and 200 miles of Yellowstone NP were all found to have a negative effect on monthly visitation levels; wildfires also decreased visitation in the following month (Duffield et al. 2013). Similarly, a more recent study found that wildfires from the previous month had a negative effect on visitation to four NPs in Utah (excluding Zion NP, which did not experience changes in visitation due to wildfire) (Kim and Jakus 2019). However, the reduction in peak season visitation was relatively small (1.5% or less for each NP) (Kim and Jakus 2019). When recreational sites were closed due to a wildfire in the Columbia River Gorge, there was little to no visitation at the closed sites, but there was not a resulting increase in visitation at adjacent sites outside the closure area, indicating that some visitors were displaced from the whole area and not substituting nearby sites (White et al. 2023b). This study found that visitation to areas affected by fires rebounded fairly quickly once sites reopened (White et al. 2023b). Finally, in Angeles National Forest, stated preferences of visitors indicated that having a recent forest fire or shrub fire that burned some or all of the plants in the area would have a negative effect on their desire to visit, but older fires would not affect their site choice (Tanner et al. 2022).

In addition to active fires affecting visitors, burn scars may affect recreation for many subsequent years. Half of recreationists visiting wilderness areas one year after a fire said the fire the previous year affected their experience (Love and Watson 1992). Changes to experiences were perceived to be both positive (e.g., improved game habitat, educational benefits) and negative (e.g., diminished scenic values, negative effects to hunting and water quality), with the recent occurrence of a fire to be an important factor in campsite selection for almost half of campers (Love and Watson 1992). Recreationists in the Boundary Waters Canoe Area perceived burned areas to be an interesting landscape feature and burn scars may actually increase the desire to visit an area; however, people who are camping did not want to camp in a recently burned area (Schroeder and Schneider 2010). Similarly, recreationists in the Deschutes River Canyon also thought burn scars were interesting to look at and reported that burn scars did not affect their recreational activities (White et al. 2020).

However, almost half of visitors had previously changed planned camping trips due to wildfire or smoke, and the majority of visitors said the potential for future wildfires and smoke may influence their camping plans (White et al. 2020). Additionally, the number of campsite reservations on National Forests was found to be significantly lower in the one to two years after a fire (Lee et al. 2023). Collectively, these results suggest that burn scars do not negatively affect most visitors but burn scars (as well as active wildfires and smoke) do have a negative effect on camping specifically.

Wildfires produce smoke, which can affect visitors near the fire as well as hundreds of miles away. One study found that wildfire smoke did not significantly affect total monthly visitation at the majority of western NPs, even at high levels of smoke (Clark et al. 2023). Another study concurred that wildfire smoke did not significantly affect monthly visitation at national parks in the Pacific Northwest (although this study did not control for other factors that affect visitation) (Brown et al. 2024). However, both of these studies analyzed monthly visitation and it is possible that smoke affects visitors on smaller time scales (for example, daily or weekly visitation). For camping specifically, the presence of both wildfire and smoke decreased campground occupancy at federally managed campgrounds in the west and caused more cancellations; however, the magnitude of these effects was small, indicating that not many visitors were cancelling their camping reservations due to wildfire or smoke (however, this study could not detect if visitors showed up for their reservations, only whether or not they were cancelling reservations) (Gellman et al. 2022).

Related to smoke, public lands staff across the United States note that air quality in general impacts visitors through three main mechanisms: reduced visibility (which can impair views of scenery), human health, and aquatic recreation (since air quality can also affect water quality and water resources) (Zajchowski et al. 2019). Staff also noticed that some visitors do change their behavior due to air quality, such as by changing locations they visit (Zajchowski et al. 2019). Ozone, which is one type of air pollutant, was found to negatively affect visitation at NPs (Keiser et al. 2018). Air quality can also be a push factor for visitors, meaning that when air quality is bad in cities, more people may be inclined to visit public lands away from the city (Zhang and Smith 2018).

**Global insights**: Although global research on how wildfires and smoke affect visitor use is limited, some studies show similar findings to the United States. A forest fire caused the closure of a national park in Malaysia, which caused many cancelled visits and an 80% drop in hotel occupancy (Suhardono et al. 2024). Wildfires were also found to cause disruptions to tourism activities and damage to infrastructure in coastal South African parks (Chapungu et al. 2024). Around 40% of surveyed Romanian and Serbian people said that recent large fires and flooding events would affect their potential travel to Greece, with some people saying they would not visit disaster affected areas and others saying they would not visit Greece at all (Kovačić et al. 2020). Air quality also affects visitor use in other countries. For example, visitation declined in Chinese parks when air quality was worse; however, 71% of people said they would still visit a park with moderate air pollution (Huang et al. 2023). In Portugal, although some visitors said they would leave the destination if there were to be a bad air quality episode, more visitors said they would avoid the most polluted areas or avoid more tiring physical activities, indicating some visitors may shift activities or locations they visit due to smoke or other air quality concerns (Carneiro et al. 2021).

**Gaps in the literature:** More research could clarify how wildfire smoke affects visitors. Three studies found that total visitation numbers were not substantially affected by wildfire smoke (Gellman et al. 2022, Clark et al. 2023, Brown et al. 2024), but wildfire smoke could be affecting visitors in other ways (e.g., health effects, changing what activities visitors participate in, changing what locations visitors go to within a park, decreasing enjoyment or satisfaction with their visit, etc.). More research related to visitor safety and experiences during active wildfire events could also be beneficial, as well as research on safety concerns after a wildfire event (e.g., the increased prevalence of hazard trees near high visitor use areas could cause additional safety concerns or closures).

### 3.5 Coastal hazards: Hurricanes and sea level rise

**Climate context**: Coastal destinations are experiencing unique climate-related challenges, such as sea level rise, increasing intensity of hurricanes, ocean acidification, and rising ocean temperatures (Marvel et al. 2023). Sea level along the continental United States has risen by 28 cm (11 in) on average over the last century, with water along the Gulf of Mexico and mid-Atlantic coasts rising faster than along the Pacific coast (Marvel et al. 2023, May et al. 2023). From 2020 to 2050, sea levels in the continental United States are expected to rise by another 28 cm (11 in) on average (Sweet et al. 2022, May et al. 2023). This sea level rise is likely to cause increased severity, frequency, and geographic extent of coastal flooding (May et al. 2023). Additionally, hurricanes are intensifying more rapidly than in the past, leaving people less time to evacuate, and are causing higher storm surges and heavier rainfall, which lead to coastal flooding (Bhatia et al. 2019, Marvel et al. 2023). Increasing ocean surface temperatures have also been linked to higher incidences of coral bleaching and coral disease, which may lead to large reef mortality events (Miller et al. 2009). Finally, oceans are becoming more acidic, caused by the ocean absorbing higher levels of atmospheric carbon dioxide and changing the chemistry of the water, which affects flora and fauna in the ocean (Marvel et al. 2023).

**Literature review results**: Coastal public lands and waters face unique hazards related to climate change, including hurricanes, sea level rise, ocean acidification, and rising ocean temperatures. Stakeholders (e.g., government entities, local businesses, NGOs, residents) in Everglades NP perceived that climate-related impacts such as hurricanes and sea level rise already affect the park (Choe and Schuett 2020). In ten coastal NPS units, the presence of hurricanes decreased visitation during the hurricane season, with higher-category hurricanes leading to the largest visitation declines (Woosnam and Kim 2014). In Acadia NP, visitors indicated that the potential presence of hurricanes in the future would have the largest influence on future decisions to visit the island (Wilkins and de Urioste-Stone 2018). Although visitor safety regarding hurricanes has not been studied in the context of parks specifically, hurricanes do have the potential to affect safety; for example, Hurricane Sandy (category 3, 2012) caused 5,795 hospital admissions and 2,247 emergency department visits in the United States (Limaye et al. 2019). Finally, one of the top ecological concerns residents had after Hurricane Sandy was the erosion of beaches, which are a primary destination for visitors, and related to the capacity of parks to defend from hurricanes and sea level rise (Burger 2015).

Sea level rise has the potential to affect recreationists who visit coastal areas and participate in coastal activities, such as surfing or fishing. On the California coast, the best conditions for surfing occur when water levels are in the middle of the present-day tidal range, with low and high-water levels being less likely to create good surfing conditions (Reineman et al. 2017). As sea levels rise, there will likely be more days in which the water depth creates sub-optimal surfing conditions (Reineman et al. 2017). With sea level rise, beaches are also expected to get narrower, which may deter some shore fishers, who prefer wider beaches (Whitehead et al. 2009). In the future, pier and bridge fishing may become more popular if beaches become less suitable for fishing (Whitehead et al. 2009).

**Global insights:** In the Catalonia region of Spain, sea level rise is projected to decrease the recreational carrying capacity of local beaches down to 83% under normal erosion trends, and under climate change projections, this decrease in carrying capacity could be as low as 53% by 2050 (López-Dóriga et al. 2019). Some beaches in the United States may also experience decreased carrying capacity with sea level rise and erosion. Other coastal-related global literature offered insights into subjects that are affecting some U.S. coastlines and visitor use but were not represented in the U.S. literature, such as ocean acidification and coral bleaching. A survey of experienced scuba divers in Southeast Asia found that participants showed the least awareness towards the effects of acidification on coral reefs, but the most awareness of pollution, overfishing, and melting sea ice (Apps et al. 2023). An Australian survey of visitors to the Great Barrier Reef found that visitor's overall satisfaction with their trip decreased after the mass coral bleachings in 2016 and 2017, and their perceived quality of snorkeling, scuba diving, and wildlife watching also decreased (Curnock et al. 2019). Similarly, coral disease and bleaching were found to be the primary concerns of tourists to the Great Barrier Reef, and 70% of visitors said their top motivation for visiting was to see the reef before it is gone (Piggott-McKellar and McNamara 2017).

**Gaps in the literature:** We are not aware of any studies on how ocean acidification or rising ocean temperatures may affect visitor use in U.S. coastal parks. Additionally, more research would be useful to better understand the timeframe over which hurricanes affect visitation and visitors' experiences in parks, including how this may affect timing of visits and access to visitor services. More research would also be useful on how coastal hazards affect the safety of visitors recreating on public lands. Finally, although we did identify a couple studies on how sea level rise affects visitor use, these studies focused on two specific activities, and more research could clarify how sea level rise may affect visitor use broadly, including in coastal forests.

### 3.6 Harmful algal blooms

**Climate context**: While effects on water quality occur in multiple dimensions, the presence of harmful algal blooms (HABs) in both inland freshwater and marine (saltwater) bodies may pose a direct threat to visitor use and safety (Hand et al. 2018, Miller et al. 2022). Increased nutrients (such as nitrogen and phosphorus) in agricultural, wastewater, and other sources of runoff, as well as increasing water surface temperatures, may lead to excess growth of algae and cyanobacteria in water bodies. In turn, some of these species may produce the toxins associated with HABs (Brooks et al. 2017, Wolf et al. 2017). These toxins can cause severe gastrointestinal and respiratory illnesses and mortalities in humans and other animals (Roberts et al. 2020). Under climate change, mean days with HABs per waterbody are projected to increase (Chapra et al. 2017).

**Literature review results**: A 2019 Centers for Disease Control and Prevention report found that out of the 63 reported human cases of HAB-caused illnesses voluntarily reported during a calendar year, 85% of the case population was exposed to HAB toxins at outdoor recreation areas and parks (Roberts et al. 2020). Reporting is voluntary and, as of 2023, only 16 states were participating in voluntary reporting, indicating that HAB effects on humans are more widespread. One study found that increased HAB scenarios could decrease visitor-days per year to U.S. reservoirs by 1.2 million to 5.3 million by 2090, with larger losses projected under a high emissions scenario and scenarios where HABs could grow linearly (rather than plateau at a certain point). In an analysis of mortality and hospitalization rates for different climate-related events, researchers found that HABs in Florida caused 11,066 hospital admissions and 3,857 emergency department visits in a 4-month period in 2012 (Limaye et al. 2019).

A few studies targeted the perceptions of recreational visitors to beaches and lakes. In a survey of water-based recreationists on Lake Erie, visitors reported that their activities were negatively affected by HABs and other water quality concerns (Ferguson et al. 2018). Another survey of Great Lakes beachgoers found that beach visitors were willing to drive 260 miles on average to avoid a beach with an active HAB warning in effect (Boudreaux et al. 2023). In Florida, where HABs are primarily caused by red or brown algae and dubbed “red tide” events, awareness and knowledge of HAB events were correlated with beach-going visitors being more likely to delay their plans to visit (Morgan et al. 2010).

**Global insights:** Research shows that HABs are also affecting recreationists in other countries. In Austria, a review of climate change impacts on summer and shoulder season activities found that lake bathing and swimming would be significantly affected by HABs, as HABs would pose health risks to visitors and their pets (Pröbstl-Haider et al. 2021). A study in Cornwall, England, found that the presence of HABs would not only hamper recreation activities, such as diving, but would also cause emotional distress, loss of sense of place, and a decline in general well-being among community members (Willis et al. 2018). In Alberta, Canada, recreational park users were less likely to choose a campsite if there was a water quality advisory at the closest water source (Amini et al. 2024). In Quebec, Canada, choice experiments revealed that recreationists value the ability to perform water recreation activities safely, and that they value the water quality and ecological health of recreational waterbodies over their aesthetics, such as visual appeal and odor (L’Ecuyer-Sauvageau et al. 2019). Tourists to Swedish beaches on the Baltic Sea showed high awareness of HAB events, and around a quarter of the sample indicated that they changed their behavior due to HABs (e.g., changed activities or shortened their stays) (Nilsson and Gössling 2013). Lastly, HABs have been a recurrent issue at Italian coastal beaches since the early 2000s, affecting recreational swimming, diving, and even non-swimming coastal recreationists, prompting the creation of HAB management guidelines (Funari et al. 2015).

**Gaps in the literature:** Despite the clear connections between increasing surface temperatures and HABs, there is a lack of literature that includes a defined human dimensions component—although the implications for human health have been well established in biophysical-focused research. The few studies we found were mostly situated in the Great Lakes and Florida, although inland HABs are a known concern for land and water management agencies. More research could help clarify recreational visitor choices related to HABs, short and long-term health impacts to recreationists, and how HABs specifically impact different recreational activities.

### 3.7 Zoonotic and vector-borne diseases

**Climate context**: Zoonotic diseases that can be transmitted back and forth between humans and animals are likely to pose increasing impacts to visitor safety as climate change drivers shift ecological conditions favorably towards the vectors that carry some of these diseases, such as ticks and mosquitos (Beard et al. 2016). These vectors can carry diseases that affect human health, such as Lyme disease (spread through ticks) or West Nile virus (spread through mosquitos) (Harrigan et al. 2014, Monaghan et al. 2015). Increasing temperatures—especially in winter—were significantly correlated with increased West Nile virus incidence rates in seven out of ten National Oceanic and Atmospheric Administration regions, including the northern Rockies and Plains regions (Hahn et al. 2015). Years of drought following high precipitation years were also found to be significant predictors of West Nile virus incidence in the Midwest (Smith et al. 2020).

**Literature review results**: For this section, we included studies that used human medical case-data alongside climate models. Under a high emissions climate scenario, Lyme disease case incidence (the number of human cases) was expected to continue increasing in the Northeast—and temperature shifts were a significantly positive predictor of increased incidence (Couper et al. 2021). In three urban Staten Island parks, human-tick encounters were found to be higher on the edges of trails rather than in open spaces, suggesting that trail users may have higher encounter risk in urban-adjacent areas. Park visitors were also aware of the potential presence of ticks and tick-borne diseases at parks, but most did not perceive high risk for actually encountering ticks (Hassett et al. 2022). In Acadia NP, visitors perceived high future risk from increased presence of ticks and mosquitos due to climate change (De Urioste-Stone et al. 2016). Increasing rates of tick-borne diseases are causes of concern not just for recreation visitors, but for park employees as well. In a survey of Florida Fish, Wildlife, and Parks staff, 75% of staff surveyed said they did not receive any occupational hazard training related to tick-borne diseases, even though the state's rate of reported Lyme disease cases had doubled by 2016 (Donohoe et al. 2018). At Gettysburg National Military Park, 82% of interviewed staff reported Lyme disease to be a serious problem at the park, 6% of participants contracted the disease while employed at the park, and staff were likely to encounter at least one infected tick per hour working outdoors (Han et al. 2014).

Other zoonotic vector-borne diseases such as West Nile virus, dengue fever, and eastern equine encephalitis virus also pose potential impacts to visitor use in a changing climate. The literature for West Nile and dengue viruses in the context of visitor recreation is limited, although a survey of visitors to midwestern urban parks found that tick-borne and mosquito-borne diseases were most likely to impact visitation in the future (Zhang et al. 2024). West Nile virus human case incidence rates have also been shown to be correlated with increasing temperatures during the winter season (Hahn et al. 2015). Eastern equine encephalitis virus, which is also transmitted by mosquitos and carries a 50% fatality rate in human cases, was found to have high risk levels of transmission across equestrian recreational trails at Florida state parks (Downs et al. 2021).

**Global insights:** The increasing rates of zoonotic diseases, especially those spread by primary vectors such as ticks and mosquitos, are affecting recreation and human health on nearly every continent. In Sweden, tick-borne encephalitis cases have steadily increased in the past two decades, with nearly 300 people contracting the illness in 2011 alone—the highest annual case load for the country at the time (Jaenson et al. 2012). Jaenson et al. (2012) suggest that a number of factors contributed to this case increase, including increasing temperatures and more recreationists exposing themselves to questing ticks through activities such as mushroom and berry picking. In Romania, study participants found more ticks on their persons during the COVID-19 lockdown as compared to 2019, even though outdoor recreation activities decreased (Borșan et al. 2021). Participants reported lower risk perceptions and preventive behaviors during the lockdown, perhaps negating the lower recreation rates (Borșan et al. 2021). A community science study in Scotland found that orienteers (long-distance hiker/runners) were likely to be bitten by a tick at least once every four hours, and bites were more common for orienteers who ran earlier in the day or in woodland areas as compared to pastures (Ribeiro et al. 2023). Lastly, increased presence of ticks at a recreation site could influence whether or not someone decides to visit. In a study of recreationists at a provincial park in Ontario, Canada, 43% of visitors reported that they would be unlikely to return to the park if the amount of tick-borne illnesses increased by 30% (Brady et al. 2022).

Tick-borne diseases are not the only zoonosis of concern globally. A 2017 systematic review linked various zoonotic diseases with adventure recreation travel, including linking leptospirosis (spread to humans through rodent urine) with whitewater sports and spelunking, various tick-borne and mosquito-borne diseases with hiking and trekking, and Ebola virus and rabies with cave recreation (Gundacker et al. 2017). In Malaysia, leptospirosis caused 338 deaths from 2004 to 2012 (Shafie et al. 2021). A survey of visitors to a forest in Malaysia found that visitors had high overall knowledge about the disease, but gaps in knowledge were high when it came to what behaviors could prevent disease transmission (Shafie et al. 2021). Lastly, a survey of equine owners (78% of whom were owners for recreational purposes) in the United Kingdom found that owners had low knowledge of mosquito-borne zoonotic infections, and did not grasp the signs and severity of potential infections (Chapman et al. 2018).

**Gaps in the literature:** There is limited literature that accounts for the human dimensions of zoonotic diseases in public lands and waters. Mosquito-borne viruses, such as West Nile virus, were particularly sparsely populated in the literature. This is primarily due to a lack of long-term surveillance for disease vectors in these landscapes, and low reporting rates—especially in the case of Lyme disease, for which clinical diagnosis can be difficult (Eisen et al. 2013, Buttke et al. 2021). Additionally, more research on how zoonotic diseases affect visitors to public lands and waters would be useful, including visitor awareness, visitor risk perceptions, and case incidence rates.

### 3.8 Summary of the current state of the literature on climate change effects on visitor use

The literature reviewed above shows the complex ways in which different climate-related effects are already affecting visitor use in public lands and waters and how these changes may continue in the future. Studies show that climate change is already affecting total recreation visits, timing of visits, where visitors go, activity participation, visitor experience quality, and visitor safety. Table 1 briefly sums up the literature described in sections 3.1–3.7, including areas where research gaps exist.

**Table 1.** A broad summary of how climate change has affected and may continue to affect different aspects of visitor use in public lands and waters in the United States, based on the current scientific literature (as of summer 2024). Citations can be found in the respective sections in 3.1–3.7.

| Climate change factors | Influence on visitation [A] | Timing of visits | Locations visitors choose to visit | Activity participation [B] | Visitor experience quality | Visitor safety |
|---|---|---|---|---|---|---|
| **Increasing temperatures** | Generally increased visitation at most parks, up to a threshold | Extended season length into shoulder seasons; more winter visitors | Will affect use patterns, likely more visits in comparatively colder parks | Increased participation in warm-weather activities | Would benefit from more research | Increased incidence of heat-related illness in parks |
| **Flooding, drought, & increased variability of precipitation** | Variable effects of extremely dry or wet years by park | Water levels in reservoirs may affect timing of trips (fewer trips with low reservoirs) | Would benefit from more research | Drought decreased participation in water-based activities (boat docks closed) | Drought decreased experience quality for boaters [C] | Would benefit from more research in public lands & waters; generally pose safety concerns |
| **Decreasing snowpack & earlier spring runoff** | Changing; lower visitation if a location focuses on snow-based activities | More visits earlier in spring due to less snowpack and earlier runoff | Will vary, depends on whether visitors want to seek out snow or water for fishing/boating | Decreased participation in snow-dependent activities | Would benefit from more research | Avalanches more dangerous due to higher snow density and exposed terrain |
| **Wildfires, smoke, and air quality** | Fires decreased visitation, but visitation rebounded fast; smoke did not decrease monthly visitation much | Would benefit from more research | Campers preferred to camp in areas not recently burned | Would benefit from more research | Burn scars may increase enjoyment (for people not camping); smoke may reduce views | Would benefit from more research in public lands & waters; generally pose safety concerns |
| **Coastal hazards** | Hurricanes decreased visitation | Would benefit from more research | Would benefit from more research | Sea level rise likely to affect some activities more than others (e.g., surfing, fishing) | Beach erosion may decrease experience quality [C] | Would benefit from more research in public lands & waters; generally pose safety concerns |

[A] The changes in total recreation visits noted here are only due to climate change and do not include other factors that are likely to change visitation in the future, including population growth and increased wealth.

[B] All uses of the term "participation" in this table are referring to the total number of trips changing due to climate change, not necessarily the total number of unique participants or per capita participation. Additionally, these studies often do not factor in other considerations that will also affect number of trips, such as future population change.

[C] Indicates that this statement is based on a single study; all other statements are based on two or more studies. Boxes containing "more research needed" indicate there is limited or poor research on this topic in the United States to make a statement on how it may affect visitor use (although in some cases, there may be intuitive effects on visitors not found in the literature). Other areas may need additional research as well, as sometimes these summary statements are based on a single study or focus on a single activity or topic (e.g., some of the wildfire and smoke related research only focuses on how it affects camping).

**Table 1 (continued).** A broad summary of how climate change has affected and may continue to affect different aspects of visitor use in public lands and waters in the United States, based on the current scientific literature (as of summer 2024). Citations can be found in the respective sections in 3.1–3.7.

| Climate change factors | Influence on visitation [A] | Timing of visits | Locations visitors choose to visit | Activity participation [B] | Visitor experience quality | Visitor safety |
|---|---|---|---|---|---|---|
| **Harmful Algal Blooms (HABs)** | Would benefit from more research | Awareness of HAB events caused visitors to delay timing of trips [C] | Would benefit from more research | Negatively affected water-based activity participation [C] | Negatively affected experiences for water-based recreationists | Can cause gastrointestinal and respiratory illnesses; many human cases are at parks |
| **Zoonotic and vector-borne diseases** | Would benefit from more research | Would benefit from more research | Would benefit from more research | Would benefit from more research | Would benefit from more research | Visitors perceive risks associated with diseases from ticks and mosquitos |

[A] The changes in total recreation visits noted here are only due to climate change and do not include other factors that are likely to change visitation in the future, including population growth and increased wealth.

[B] All uses of the term "participation" in this table are referring to the total number of trips changing due to climate change, not necessarily the total number of unique participants or per capita participation. Additionally, these studies often do not factor in other considerations that will also affect number of trips, such as future population change.

[C] Indicates that this statement is based on a single study; all other statements are based on two or more studies. Boxes containing "more research needed" indicate there is limited or poor research on this topic in the United States to make a statement on how it may affect visitor use (although in some cases, there may be intuitive effects on visitors not found in the literature). Other areas may need additional research as well, as sometimes these summary statements are based on a single study or focus on a single activity or topic (e.g., some of the wildfire and smoke related research only focuses on how it affects camping).

Table 1, and all of the literature summaries in section 3, only summarize the current scientific literature and do not capture assumptions or inferences that can be made based on known prior events. It is worth noting that there are some inferences that can be made despite a lack of support in the literature. For example, we can infer that coastal hazards such as hurricanes and sea level rise will negatively affect visitor safety in U.S. public lands and waters, even if there is not a study that explicitly shows that. For instance, Death Valley NP had a park-wide closure to protect visitor safety in summer 2023 due to flash flooding from a hurricane (National Park Service 2023). Additionally, although not present in the scientific literature, we know that past flooding events have affected visitors in parks. For example, search and rescue crews had to evacuate 60 people out of Capitol Reef NP due to flash flooding in 2022 (Associated Press 2022).

# 4. Visitor adaptation

Existing research has identified a variety of ways visitors are already adapting or coping with some of the effects of climate change. Adaptive capacity is defined as "the ability of systems, institutions, humans, and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences" (IPCC 2022). Coping capacity is similar to adaptive capacity, with a focus on overcoming shorter-term negative conditions. Coping capacity is defined as "the ability of people, institutions, organizations and systems, using available skills, values, beliefs, resources, and opportunities, to address, manage and overcome adverse conditions in the short to medium terms" (IPCC 2022). Coping thus focuses on overcoming negative conditions, while adaptation can include responding to both negative and positive conditions. In section 4.1 we describe coping strategies in outdoor recreation more generally before focusing on visitors' adaptive capacity specifically as it relates to the climate change literature in section 4.2. We focus on the adaptive capacity of visitors to public lands and waters rather than the adaptive capacity of park management or other institutions that facilitate outdoor recreation opportunities.[2] Many of the effects described in section 3 above are intertwined with visitor adaptation (e.g., more visitors in the shoulder seasons indicates visitors are adapting to warmer than usual temperatures by shifting the timing of their trips) and the literature described in section 4.2 gives more explicit examples of how visitors have adapted.

## 4.1 Recreation theory on coping

Although not specific to climate change, the broader literature on coping in outdoor recreation can provide some context for how visitors respond to negative conditions. Coping is part of a theoretical framework in outdoor recreation that incorporates a recreation demand hierarchy (Driver and Brown 1978, Rice et al. 2019, Manning 2022). In this framework, people engage in certain activities (e.g., picnicking, hiking, skiing) in specific areas (e.g., remote lake, visitor center, developed campground) because they have motivations (e.g., risk taking, challenge, family togetherness) to achieve outcomes (e.g., increased self-confidence, improved health, family solidarity) that are known, expected, and valued. In the recreational demand hierarchy framework above, coping occurs when people experience goal interference (Manning 2022); in other words, people cope when they are unable to achieve their desired outcomes. For example, if recreationists wanted to summit a mountain with the desired outcome being increased self-confidence, and the trail they planned to hike was closed due to a wildfire, they could cope by finding a different way to achieve the desired outcome (possibly by finding another challenging hike in the area or engaging in a different challenging activity).

Coping is generally employed in three different forms by recreationists: 1) displacement, 2) product shift, and 3) rationalization (Manning 2022). Displacement includes adapting locations or timing of trips at both small and large scales (also sometimes called "substitution"). Product shift includes both cognitive and behavior adaptations. Cognitively, product shift may result in visitors shifting their

[2] For more information on the adaptive capacity of parks or other institutions, refer to Miller et al. (2022) and O'Toole et al. (2019).

motivations or desired outcomes to align with experienced conditions. Behaviorally, product shift may result in visitors substituting their activity or setting to maintain original motivations and achieve desired outcomes (Shelby and Vaske 1991, Rice et al. 2019). Rationalization is another cognitive coping strategy where people reevaluate negative conditions more favorably (Miller and McCool 2003, Manning 2022). Since recreation is generally self-determined and involves significant investments of time and money, people may rationalize that they were satisfied with their experience to avoid unpleasant cognitive dissonance (in other words, trying to avoid the mental discomfort that comes with having conflicting opinions or behaviors) (Manning 2022).

### 4.2 Visitor adaptation to climate change

Multiple studies have used visitor surveys to better understand how visitors are coping with and adapting to climate change (e.g., Seekamp et al. 2019, Hestetune et al. 2020, McCreary et al. 2020). Although visitors to public lands and waters are both coping with and adapting to various climate-related effects, throughout this section we use the term "adapt" to represent both adaptation and coping mechanisms, since not all shifts in behavior are necessarily responding to negative conditions. For example, visitors choosing to visit earlier in the spring due to favorable temperatures could represent adapting to a perceived positive condition (longer season length).

In line with the recreation theory described in section 4.1, visitors can adapt their behavior to a changing climate by adjusting the locations they visit, the timing of their trips, what activities they participate in, or their behavior once on-site (McCreary et al. 2019, Seekamp et al. 2019, McCreary et al. 2020). For example, visitors can change the locations they visit either by choosing a different park entirely (e.g., visiting a mountainous park or more northern park during a hot summer) or by visiting alternative locations within a park (e.g., going to a waterbody or higher elevation area during a particularly warm day). Visitors can change the timing of their trips either by visiting earlier in the day on hot days, or by planning ahead and visiting in a different season to avoid times of the year that might be exceptionally warm or have wildfire danger. For example, at Vermont state parks, over a third of visitors said they would move to more northern parks or higher elevations if daytime temperatures were to increase, and just under a third of visitors said they would visit earlier or later in the season (Perry et al. 2018a). This review demonstrates that many visitors are not employing adaptive strategies in isolation, and sometimes may consider a variety of adaptive strategies.

Visitors also have the option to change the activities they participate in (one form of product shift, as described in section 4.1). For example, going for a hike rather than snowshoeing in a low snow year, or biking rather than rafting if there is a drought and water levels are not sufficient for rafting. Visitors can further adapt their behavior, for example by carrying more water and salty snacks or by wearing lightweight clothing that provides sun protection on hot and sunny days. One-fifth of summer visitors to the North Shore of Lake Superior said that they adapted to changes by buying new gear or technology and changing the activities they participated in; however, these adaptation strategies were much more common in the winter, with over three-fourths of winter visitors using these strategies (McCreary et al. 2019).

The adaptation strategies visitors are most likely to use will vary somewhat by location and visitor profile. For example, on the North Shore of Lake Superior less than 5% of visitors indicated they would adapt to a climate change scenario by changing the timing of their trips, but around one-fifth of visitors said they would change where they visit on the North Shore or the activities they engage in (Hestetune et al. 2020). For some visitors, changing the timing of trips may be challenging if they are scheduling trips around winter or summer breaks. In contrast, about a third of visitors to Vermont state parks intended to change the timing of their trips based on future climate scenarios (Perry et al. 2018a). Additionally, some groups of visitors may be more sensitive than others; for instance, over half of downhill skiers say they have already changed the timing of their trips, the locations they visit, and the activities they participated in due to warm temperatures and low snowpack (Dawson and Scott 2010).

Visitors' adaptive capacity depends on a variety of factors, including the purpose of their visit, the number of activities they participate in and their level of specialization, available alternative site options, their level of knowledge or experience with the area, and the sociodemographic characteristics of visitors themselves (McCreary et al. 2019, Delie and Dietsch 2024). For example, if the purpose of someone's visit is to participate in fishing, they may be more constrained in which coping mechanisms they employ once they are at their destination if they are seeking a fishing opportunity in particular. Furthermore, if the visitor is very specialized in fishing and is looking for certain fishing conditions, it makes adaptation even more challenging. Conversely, visitors whose trip purpose is to experience the park without engaging in a specific activity would have more options to adapt by changing locations within the park or their activity choice. Visitors with high destination loyalty or place attachment are less likely to substitute locations altogether (Wilkins and de Urioste-Stone 2018, McCreary et al. 2020). For sociodemographic characteristics, visitors' home location and income both affect what adaptive behaviors they engage in (Seekamp et al. 2019). For example, in North Carolina's Outer Banks, in-state residents were more likely to substitute locations that were also in-state, while out-of-state residents were more likely to substitute locations out-of-state (Seekamp et al. 2019). In Vermont, local snowmobilers were more sensitive to climate change conditions than non-locals and more likely to decrease their total number of trips in response (Xiao et al. 2020). Additionally, visitors with lower incomes or more limited transportation options may be unable to change the locations they intend to visit (Winter et al. 2020). Finally, visitors' knowledge of the situation also affects their ability to adapt. For example, beach-going visitors in Florida who had knowledge of HAB events were more likely to delay their plans to visit (Morgan et al. 2010).

Despite the ability of some visitors to adapt by changing their behavior, not all visitors who have the capacity to adapt will choose to change their behavior. As described by recreation coping theory (see section 4.1), some visitors may choose to adapt by using rationalization instead. For example, visitors participating in water-based recreation on Lake Erie were more likely to employ cognitive coping strategies for HABs and other water quality concerns (such as convincing themselves that the quality of water is fine despite alert notices), rather than changing their behavior (Ferguson et al. 2018). In studies that found many visitors will adapt or have already adapted their recreation due to climate change, there were also many visitors who indicated they have not or will not adapt their behavior (given the adaptation options provided on a survey) (e.g., McCreary et al. 2019, Hestetune et al.

2020). Additionally, even if visitors do adapt their behavior, adaptation measures may have varying effects on the quality of visitors' experiences.

Although this review provides ample evidence of visitors' adaptive capacities in a changing climate, it also provides cautionary examples that this adaptive capacity is limited. If certain settings—such as glacial alpine areas, cold and clean water, or areas with continuous snow coverage—that are required to engage in certain activities or achieve certain outcomes become scarce or unavailable, substituting locations or changing the timing of trips may no longer be a viable strategy. Furthermore, visitor characteristics may create inequities in the amount of adaptive capacity visitors can employ, which may create an extinction of experiences and a lack of benefits for certain activities, user types, and population segments. Visitors are more likely to substitute locations, timing, or activities if they have a perceived choice in their adaptive strategies (Iso-Ahola 1986). As climate change forces the need for these adaptations, the impact on outdoor recreation and the visitor experience is yet to be determined.

# 5. Discussion

Collectively, the studies included in this review show the many ways that climate change is already influencing visitor use in U.S. public lands and waters. This review demonstrates how seven different climate change factors are already impacting visitor use in terms of total recreation visits, timing of visits, locations visitors choose to visit, activity participation, quality of experience, and visitor safety. In addition, the studies reviewed above indicate how visitors are already starting to adapt to and cope with various climate change effects. As such, this review provides insights into various components of climate change vulnerability that could inform future visitor use vulnerability assessments. For example, this study highlights seven ways that visitor use is exposed to the effects of climate change and summarizes what is known about the consequences of those effects. This review also highlights existing knowledge about visitor adaptive capacity, which is an important third dimension of vulnerability (McDowell Peek et al. 2022).

Many of the conclusions drawn from this review are context specific. For example, we know that visitor use will change with increasing temperatures, but how it will change depends on the current climate at the park. Parks that are already hot will likely see decreased visitation in the summer and increased visitor safety concerns with extreme heat, while parks that have a relatively cool climate may see increased visitation year-round as temperatures warm. In addition to the current climate of parks being an important factor, visitor profiles—including what activities they participate in and how far they travel to get to the park—will influence how much climate change affects visitors and their capacity to adapt. As a result, there is no “one size fits all” answer to many questions about how climate change will affect visitors to public lands and waters, and the context of each location needs to be considered.

In addition to results being context dependent, future projections for visitation or participation rates are dependent on more than just climate change. However, the majority of studies discussed in this review that projected visitation changes into the future only included changes due to climate change and did not account for other socioeconomic conditions that are projected to change. For example, by 2070 the United States is expected to have a larger population and a higher Gross Domestic Product, both of which can affect recreation visitation numbers (White et al. 2023a). In some cases, projected visitation declines due to warming temperatures may be negated in the future due to population growth. For future projections by activity that include changing socioeconomic conditions, refer to White et al. (2023a).

This review highlights substantial gaps in existing research on the vulnerability of visitor use to climate change. Perhaps most importantly, many of the studies only investigated a single topic (e.g., the effect of increasing temperatures on visitation), yet different effects do not occur in isolation. The combined effect of multiple climate-related stressors may be more severe than any single effect alone, and this has consequences for visitors’ abilities to adapt (Lawrence et al. 2020, Monz et al. 2021). For instance, visitors trying to plan a trip may consider increasing temperatures, increasing risk of wildfire smoke, and the presence of a drought—and all these factors together may deter visiting a location in late summer, even if any one of the factors in isolation may not change behavior. There may also be interacting or cascading effects of different climate-related events on visitor safety and experience quality, or the negative effects of one climate event may be cancelled out by the positive effects of another climate event on visitor use. For example, a study in England found that under sea level rise, future visitation to beaches would slightly decline, but these small declines would be entirely offset by much larger increases in visitation expected from warmer temperatures (Coombes et al. 2009). Despite the challenge of accounting for multiple climate-related effects, research on synergistic and cascading climate change factors could clarify more precisely how climate change is affecting visitor use.

### 5.1 Gaps in the literature

This review highlights many gaps in the literature, as detailed in section 3 and summarized in Table 1. The literature shows that increasing temperatures and decreasing snowpack affect the timing of visits (e.g., more visitors earlier in spring), but it is unclear how other factors such as flooding, wildfire and smoke, coastal-related hazards, or HABs may influence the timing of visits. Overall, there is a lack of information on how zoonotic and other vector-borne diseases will affect visitor behavior, despite multiple studies indicating visitors do perceive zoonotic diseases to be a threat in certain locations. There is also sparse literature on the effect of wildfire smoke on visitor behavior and experiences, despite wildfire smoke now being a common summer occurrence in the western United States. Additionally, more research on all topic areas could clarify how climate change affects visitor safety. Although there are some studies on this, more research to determine how visitor safety will be affected across many locations would be beneficial. Lastly, we did not include extreme events such as high wind, hail, lighting, and tornadoes as a category in this review because we could not find any literature on how these factors are affecting visitor use in United States public lands and waters. However, we can assume that increased prevalence of any of these extreme events would pose a threat to visitor safety and likely make certain locations or seasons less desirable to visit in. More research in all of these areas would help managers better prepare for changing visitor use under climate change.

While we chose to focus on seven particular climate change factors, there are other topics that could affect visitors' sensitivity that may be important considerations in certain regions. For example, increasing rates and geographic spread of pests and invasive species are linked to several factors, some of which are related to climate change. For example, various species of bark beetle can cause widespread fungal blight in large stands of trees, which can affect aesthetics and visitor experiences (Sumner & Lockwood, 2020). These fungal blight events are becoming more common as more temperate winters caused by climate change lead to decreased winter die-off of bark beetles (Fettig et al. 2022). Topics such as bark beetles may be important in some public lands and waters, while other invasive species may be of higher concern in other places. Understanding the effects of invasive species and pests may require searching for individual species names depending on what is of high concern for the region.

Despite certain areas having an abundance of literature, some of the literature may be a bit outdated as both temperatures and extreme events have continued to increase over the last decade (Marvel et al. 2023, U.S. Environmental Protection Agency 2023), which in turn is already changing visitor behavior in many locations (as demonstrated in this review). For example, one of the largest-scale studies to investigate the relationship between temperature and park visitation used data from 1979 to 2013 (Fisichelli et al. 2015); this study had important implications and it would be useful to see if and how projections for visitation have changed when including the last decade of climate and visitation data. Although it is likely many of the same overarching trends would be the same (e.g., most parks seeing visitation increases under climate change), some of the nuance and variation by park could be important for park planning. Another study investigated how seasonality (particularly timing of spring visitation) had changed in NPs using data from 1979 to 2008 (Buckley and Foushee 2012). This was another important study, but it is likely these findings would not be the same today if the most recent 15 years of data were included, given that there have already been many noticeable climate change effects over the last 15 years. For example, that study found seasonality had not changed from 1979 to 2008 in many parks, but the decade from 2012 to 2021 was the warmest decade on record (U.S. Environmental Protection Agency 2023), so it is possible some parks may have started to show seasonality changes since 2008. Even in topic areas that are relatively well covered (e.g., the effect of temperature on visitation or seasonality of visits), there is a need to repeat similar analyses to update information based on more recent data and trends.

Existing literature focuses almost exclusively on how climate change affects outdoor recreation. However, visitor use management on public lands and waters is a much broader endeavor wherein managers must also consider how climate change effects on visitor use intersect with park staffing, infrastructure, and resources. As such, more research could help clarify the complex relationships between climate change, visitor use, and broader park management.

Finally, there are places where public land and water managers have already noticed changes that are not well documented in the scientific literature. For example, a recreation manager in North Carolina was quoted in the media as noting how flooding and increased variability of precipitation has affected the conditions of trails, which affect mountain biking (Igelman 2022). Yet this type of climate change effect was not found in our literature review, and it is unknown if the experience of this manager is indicative of a larger trend. Future research that aims to document and synthesize the effects managers are seeing on-the-ground would be a useful complement to this body of work. There are also inferences that could be drawn despite a lack of scientific studies documenting the effects. For instance, although we did not identify any scientific studies on how flooding, drought, or coastal hazards such as hurricanes and sea level rise affect visitor safety in public lands and waters, it is intuitive that all these factors are going to negatively affect visitor safety. Future research looking at evidence such as park closures, infrastructure damage, and visitor evacuations that have been reported in the news or by federal agencies (e.g., Associated Press 2022, Siegler and Cope 2022, National Park Service 2023) could improve our understanding of how extreme events such as flooding, hurricanes, or other events are impacting infrastructure and visitor use. For example, in 2021 there was a landslide caused from a thawing rock glacier in Denali National Park and Preserve, which cut off a section of road and limited visitor access for multiple years (Huntington et al. 2023). Events like these provide important information on the effects of climate change on visitor use, but are often not well documented in scientific studies.

### 5.2 Management implications

This review provides insights into how climate change is already affecting visitors and will continue to do so in the future. It also examines how visitors are already changing their behavior due to climate change and how visitor behavior may continue to change into the future. All of these changes have the potential to affect park management, as shown by Figure 1. For instance, the changing seasonality of visitation may require additional staffing, shifted timing of seasonal staff, extended open periods for facilities, or increased signage and interpretation to protect sensitive resources. Increasing temperatures, more days with extreme heat, and increased frequency and intensity of flash flooding may require more search and rescue operations as well as more signage to warn visitors about the dangers of heat and flooding in parks. Visitors changing the locations they visit may shift which trails and facilities require the most maintenance.

As described in section 4, visitor adaptive capacity is generally high, and research has shown that visitors are already changing the places they visit, the timing of trips, and the activities they participate in due to climate change. However, visitor use management systems may struggle to adapt to the shifts in visitor use and timing that are driven by climate change. For instance, if visitation is growing substantially in shoulder- and off-seasons in a park, the traditional approach of employing seasonal staff for a short summer period may no longer be effective for visitor use management.

There are situations in which visitor adaptation may not be possible depending on the visitor's desired outcomes. For example, if a visitor planned a trip in advance to a certain location to participate in cross-country skiing, but there was not any snow on the ground during their trip, adaptation would not be possible unless the visitor can still achieve their desired outcomes by switching to an activity that does not rely on snow. Finally, the increased prevalence and severity of extreme events such as floods and wildfires may make it challenging for visitors to adapt when there may be little to no warning before the event. Although visitors could choose to generally plan trips outside of peak fire or flooding seasons (in areas where they are concerns), it is impossible to plan when and where events like wildfires or flash floods may occur in advance.

While this review confirms that climate change is already affecting visitor use in myriad ways, it also highlights a pressing need to better understand how the changes noted in the literature are actually affecting park resources, infrastructure, staffing, and management decisions. Future research could include manager perspectives to better understand how climate change effects on visitor use are impacting park operations and identify the information that managers need for planning and decision-making.

# 6. Conclusion

This report summarizes 63 studies on how visitor use is being affected by climate change in the United States, as well as key insights from other countries. The studies demonstrate that climate change is already affecting visitors to public lands and waters, and there is evidence that visitor use is affected by varying factors in different locations. Specific effects related to climate change that managers need to be aware of include increasing temperatures, flooding and drought, decreasing snowpack and earlier spring runoff, wildfire and smoke, coastal hazards, HABs, and zoonotic diseases. Managers will increasingly need to consider how those climate change effects relate to visitation numbers, timing of visits, visit location choice, activity participation, visitor experience quality, and visitor safety. The summary of existing research in this review provides baseline information about the climate context (exposure), sensitivity of visitors, and adaptive capacity of visitors that can be considered in future visitor use management climate change vulnerability assessments. However, this review also highlights key gaps in the literature that will need to be addressed to develop robust methods for managing the effects of climate change on visitor use in public lands and waters.

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# Appendix 1. Studies included in this review

This appendix provides a list of all studies on the effects of climate change on visitor use in U.S. public lands and waters that were included in the “literature review” sections within section 3 (excluding papers cited in the “climate context” and “global insights” sections) (Table 2).

**Table 2.** A list of all studies of the effects of climate change on visitor use in U.S. public lands and waters included in the “literature review” sections within section 3 (excluding papers cited in the “climate context” and “global insights” sections).

| Topic area cited in this review | Authors | Title | Year | Journal or outlet title | DOI |
|---|---|---|---|---|---|
| Increasing temperatures | Albano, C.M.; Angelo, C.L.; Strauch, R.L.; Thurman, L.L. | Potential effects of warming climate on visitor use in three Alaskan national parks | 2013 | *Park Science* | No DOI |
| Increasing temperatures | Buttke, D. E.; Raynor, B.; Schuurman, G. W. | Predicting climate-change induced heat-related illness risk in Grand Canyon National Park visitors | 2023 | *Plos one* | https://doi.org/10.1371/journal.pone.0288812 |
| Increasing temperatures | Craig, C.A. | Climate Resource View (CRV): A case of thermal safety at United States national parks | 2024 | *Journal of Outdoor Recreation and Tourism* | https://doi.org/10.1016/j.jort.2024.100737 |
| Increasing temperatures | Fisichelli, N.A.; Schuurman, G.W.; Monahan, W.B.; Ziesler, P.S. | Protected area tourism in a changing climate: Will visitation at US National Parks warm up or overheat? | 2015 | *Plos one* | https://doi.org/10.1371/journal.pone.0128226 |
| Increasing temperatures | Goldstein, K.; Howe, P.D. | Dry heat among the Red Rocks: Risk perceptions and behavioral responses to extreme heat among outdoor recreationists in southeastern Utah | 2019 | *Journal of Extreme Events* | https://doi.org/10.1142/S2345737620500049 |
| Increasing temperatures | Liu, P. | The effect of temperature on outdoor recreation activities: Evidence from visits to federal recreation sites | 2022 | *Environmental Research Letters* | https://doi.org/10.1088/1748-9326/ac5693 |
| Increasing temperatures | Smith, J.W.; Wilkins, E.; Gayle, R.; Lamborn, C.C. | Climate and visitation to Utah’s ‘Mighty 5’ national parks | 2018 | *Tourism Geographies* | https://doi.org/10.1080/14616688.2018.1437767 |
| Increasing temperatures (citation also appears in decreasing snowpack) | White, E.M.; Askew, A.E.; Bowker, J.M. | Outdoor recreation and wilderness | 2023 | *U.S. Department of Agriculture Forest Service publication* | http://doi.org/10.2737/WO-GTR-102-Chap11 |
| Increasing temperatures | Wilkins, E.J.; Chikamoto, Y.; Miller, A.B.; Smith, J.W. | Climate change and the demand for recreational ecosystem services on public lands in the continental United States | 2021 | *Global Environmental Change* | https://doi.org/10.1016/j.gloenvcha.2021.102365 |

**Table 2 (continued).** A list of all studies of the effects of climate change on visitor use in U.S. public lands and waters included in the "literature review" sections within section 3 (excluding papers cited in the "climate context" and "global insights" sections).

| Topic area cited in this review | Authors | Title | Year | Journal or outlet title | DOI |
|---|---|---|---|---|---|
| Increasing temperatures | Wilkins, E.J.; Horne, L. | Effects and perceptions of weather, climate, and climate change on outdoor recreation and nature-based tourism in the United States: A systematic review | 2024 | *PLOS Climate* | https://doi.org/10.1371/journal.pclm.0000266 |
| Increasing temperatures | Wilkins, E.J.; Howe, P.D.; Smith, J.W. | Social media reveal ecoregional variation in how weather influences visitor behavior in U.S. National Park Service units | 2021 | *Scientific Reports* | https://doi.org/10.1038/s41598-021-82145-z |
| Flooding, drought, and increased variability of precipitation | Boyer, T.A.; Melstrom, R.T.; Sanders, L.D. | Effects of climate variation and water levels on reservoir recreation | 2017 | *Lake and Reservoir Management* | https://doi.org/10.1080/10402381.2017.1285375 |
| Flooding, drought, and increased variability of precipitation | Daugherty, D.J.; Buckmeier, D.L.; Kokkanti, P.K. | Sensitivity of Recreational Access to Reservoir Water Level Variation: An Approach to Identify Future Access Needs in Reservoirs | 2011 | *North American Journal of Fisheries* | https://doi.org/10.1080/02755947.2011.559846 |
| Flooding, drought, and increased variability of precipitation | Jedd, T.M.; BhattacharyA, D.; Pesek, C.; Hayes, M.J. | Drought impacts and management in prairie and sandhills state parks | 2019 | *Journal of Outdoor Recreation and Tourism* | https://doi.org/10.1016/j.jort.2019.02.003 |
| Flooding, drought, and increased variability of precipitation | Jedd, T.M.; Hayes, M.J.; Carrillo, C.M.; Haigh, T.; Chizinski, C.J.; Swigart, J. | Measuring park visitation vulnerability to climate extremes in U.S. Rockies National Parks tourism | 2018 | *Tourism Geographies* | https://doi.org/10.1080/14616688.2017.1377283 |
| Flooding, drought, and increased variability of precipitation | Jenkins, J. S.; Abatzoglou, J. T.; Wilkins, E. J.; Perry, E.E. | Visitation to national parks in California shows annual and seasonal change during extreme drought and wet years | 2023 | *PLOS Climate* | https://doi.org/10.1371/journal.pclm.0000260 |
| Flooding, drought, and increased variability of precipitation | Miranda, L.E.; Meals, K.O. | Water levels shape fishing participation in flood-control reservoirs | 2013 | *Lake and Reservoir Management* | https://doi.org/10.1080/10402381.2013.775200 |
| Flooding, drought, and increased variability of precipitation | Neher, C.J.; Duffield, J.W.; Patterson, D.A. | Modeling the influence of water levels on recreational use at lakes Mead and Powell | 2013 | *Lake and Reservoir Management* | https://doi.org/10.1080/10402381.2013.841784 |
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