Managing Climate Change and Weather Extremes for Nature-based Tourism Organizations in the United States

A dissertation submitted in partial fulfillment
of the requirements for the degree of
Doctor of Philosophy in Environmental Dynamics

by

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May 2022
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Abstract

Weather and climate serve as profound motivators for tourism travels. Much of the United States (US) has experienced a warming trend as well as higher extreme weather frequency, and the trends are projected to be continued. Consequently, the changing climate is expected to have both direct and indirect impacts on tourism decision-making and travel patterns due to the complex relationship between climate, weather, and outdoor recreation. Climate resources capture the integrated effects of varied meteorological variables that interact with humans in different ways and can be categorized along a spectrum of quantifiable values. This dissertation proposed a Camping Climate Index that considers the uniqueness of the nature-based tourism segment interaction with climate variables, as well as explored the impact of climate variability on nature-based tourism organizations in the United States. Chapter 2 used a data-driven method that combines revealed tourists' travel behaviors and multifaceted climate variables to mathematically developed a camping sector-specific climate index. The novel index is validated with 29 for-profit campgrounds across the United States. Chapter 3 examined the feasibility and application of the tourism climate index approach to the nature-based tourism for non-profit organizations in the United States. This study has advanced the understanding of the nuance among the nature-based tourism segments and facilitates the assessment the climate resources for tourism decision-making and sustainable management. Results show that the Camping Climate Index is more predictive of visitation, recreational vehicle camping, and tent camping compared to other indices, though not for all locations or tourism activities. Chapter 4 expand the study scope and explored the climate resources of entire contiguous United States. Climate change analyses have shown signals of either beneficial or adverse change in terms of climate resources for nature-based tourism, as it relates to the warming trend and weather extremes in the United

States. The final chapter provides a discussion of the findings, implications, future research, and conclusions.

Acknowledgements

First and foremost, I would like to thank my advisor Dr. Song Feng, for the continued support, guidance, and intellectual insights through my Grad school. Your kindness and enthusiasm have encouraged me in all the times of my academic research and daily life. I would like to express my sincere gratitude to my co-advisor Dr. Christopher Craig. Your invaluable advice, patience, and quick wit through this journey are deeply cherished. Song and Chris, you both have my sincerest respect as scholars and humans, you have shown me what a good scientist and person should be. I am so grateful for the opportunities you have provided and look forward to our continued research together.

I also would like to thank the other members of my committee, Dr. Jingping Gu, Dr. Steve Boss, and Dr. Lanier Nally. Your feedback and suggestions have been greatly appreciated. Your courses and projects have been inspired me through my research. Many thanks to my friends and colleagues for the continued encouragement and laugher. A special thanks to Chang Liu for your assistance with data collection and programming.

Finally, I would like to acknowledge with gratitude the love and support of my family. I am grateful for my parents, whose love, confidence and support are always with me in whatever I pursue. Importantly, I would like to thank Tianliu Fu for your unconditional love. You all kept me going and made this journey a wonderful time.

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Chapter 2: Ma, S., Craig, C. A., Feng, S., & Liu, C. (2021). Climate resources at United States National Parks: A tourism climate index approach. Tourism Recreation Research, 1-15. (published)

Chapter 4. Ma, S., Craig, C. A., & Feng, S. (2020). Camping climate resources: the camping climate index in the United States. *Current Issues in Tourism*, 1-9. (published)

Chapter 1: Introduction

1.1 Introduction

The anthropogenic forced climate change is a severe challenge facing mankind since entering the 21st century (Hirabayashi et al., 2013; IPCC, 2018). Climate change has altered the frequency and intensity of weather and climate extreme events, including heatwaves, hurricanes, flooding, drought, tropical storms and wildfires (Dutzik & Willcox, 2010; Feng et al., 2017; Gössling et al., 2010), and has presented profound impacts on humans and society (Easterling et al., 2000). The consequences of climate change are expected to have a considerable impact on wide social-economic contexts (Amaru & Chhetri, 2013; Cramer et al., 2018). As growing economic loss has seen linked to the changes in these extremes in recent decades (Hanewinkel et al., 2013; Mechler et al., 2019; Hsiang et al., 2017), it is critical to explore the interactions and the possible impacts of climate change on the natural environment and human activities.

Tourism plays a relevant role in this social-environmental debate. It is known to be one of the major sectors that have a dual relationship with climate and weather (Dube & Nhamo, 2020; Ma & Kirilenko, 2020). Scholars' attention to the tourism industry has continued to increase in the past 30 years. On the one hand, the industry has made important contributions to climate change through greenhouse gas emissions, and on the other hand, due to its strong dependence and sensitivity to climate, global climate change has a profound impact on tourism compared to other economic sectors (UNWTO, 2021; Becken et al., 2020; Nordhaus, 2018). In the context of global climate change, changes in the quality of the environmental resources, both directly and indirectly, affect the development of tourism. The tourism industry also makes a significant contribution, especially due to the transportation (passenger transport) and infrastructure construction (accommodation), to greenhouse gas emissions, which remains the most influential and harmful source of the anthropogenic induced climate change (IPCC 2014).

Nature-based tourism is the fastest growing segment of tourism industry, which involves excursions to national parks and wilderness areas. The demand for nature-based tourism activities has continuously increased in recent years due to the social-economic conditions and the real desire of people to connect with nature (O'Neil et al., 2015; Craig et al., 2021). According to the Pacific Asia Travel Association (PATA, 2015), nature-based tourism is the fastest growing tourism sector nationally and globally. Nature-based tourism takes place in a wide range of locations that are often closely linked to the natural environment. The changes in the climate, especially local climatic conditions have a potential impact on the nature-based tourism businesses and the traveler's experiences. Likewise, as one of the contributors to the build-up of greenhouse gases (GHGs), tourism is recognized as a significant activity with a range of economic, social and environmental consequences. Such links between nature-based tourism and climate change are widely acknowledged by the key scholars in both the climate and tourism industry. The interconnection between climate change, weather events, and nature-based tourism is demonstrated in figure 1.

Recent study claimed that camping is equivalent to nature-based tourism (Filipe et a., 2020). Camping, a type of nature-based tourism that the participants stay away from home to spend one or more nights in a natural setting in pursuit of enjoyment provided by the nature environment, received less attention in tourism research compared with other tourism segments, though it's gaining worldwide popularity. It is estimated that more than 41 million people engaged in backyard, tent or RV camping throughout in the United States each year from 2006 to 2018. The 2019 North American Camping Report found that the popularity of camping has exploded in the past five year, and that the future for camping appears secure, with large increases in camping interest among every young generation, including the emerging Generation Z (those born between 1995 and 2005). Even during the most desperate period for tourism due to Covid-19, as shutdowns, cutbacks and other coronavirus-related troubles led legions of Americans to stay away from hotels and airports, numbers increased at many public and private campgrounds in the United States (California State Parks reservation system, April 2020).

However, in the ongoing debate on the causes and consequences of climate change, scientific production that focus on the camping tourism sector is minor (Craig, 2020; Grimm et al., 2018). The research on some particular markets, such as sun, sea and sand (i.e., beach) tourism or winter sports (i.e., ski) tourism is expanding since the past decade (Bigano et al., 2006; Scott et al., 2016; Airey & Tribe, 2007), while there still remains limited research that empirically explores the relationships between camping, weather and climate change (for an exception see Craig, 2019; Craig & Feng, 2018; Hewer et al., 2015; Ma et al., 2020). In addition, it is widely accepted that in situ studies are needed to understand tourism demand due to unique characteristics of origin, destination, and situation (Crouch, 1995; Witt & Witt, 1995). Inquiry into tourism demand is complicated when considering weather and climate change. Thus, my focus of inquiry is on the dynamic interactions between camping (a salient segment of nature-based tourism), weather, and climate change.

Given the complexity of the problem to address the amenity role of climate, this dissertation concentrates on the nature-based tourism with camping specific – one that is clearly linked with amenity resources attributed to the atmospheric environment. There are several reasons for camping that fulfill the requirement. First, camping recreation is an activity that takes place in natural settings and therefore the human body is directly exposed to atmospheric elements (O'Neill et al., 2015; Lawton et at., 2017), which reinforce the impact of the climate and weather conditions to the human activity. The second reason is from the data collection standpoint. The campers normally choose the available camping sites to implement the activity, i.e., the national parks and/or the corporate-owned campsites. Therefore, sample populations can be observed readily as the corporation recorded the data, and the climate information of the campsites can be retrieved given the spatial and temporal information to represent the ambient environmental conditions. Third, camping has experienced significant growth as the best means possible to connect to the purer natural world while received disproportionate research attention compared with other tourism sectors.

According to the North American Camping Report (2019), the percentage of campers who camp three or more times annually has increased by 72% and about 7 million new campers were added in the US since 2014. Moreover, it's economic contribution to the tourism sector continuously to grow. With the over 40 million Americans who go camping each year, the camping contributes not only generally to the US economy, but specifically to the nature-based tourism economy, which according to the US Department of Commerce's Bureau of Economic Analysis represents 2.2 percent of the US Gross Domestic Product (2019). Given the huge and ever-increasing significance of camping sector, the relative dearth of the study in this territory is astounding. The draw on the camping study under the changing climate is inescapable.

The overarching goal of this dissertation is to better understand how climate change, climate variability, and weather extremes are related to and influence the nature-based tourism. This dissertation aims to gain a clearer understanding of how the changing climate impact the ever-growing tourism economic sector, and how the management strategy can be implemented to alleviate the risks and take advantage of the opportunities. The Resource-based Theory related to resource value, scarcity, competence and capability are examined. Chapter 2-4 explored the interrelationships between weather, climate, and nature-based tourism from meso to macro level. The remainder of the introduction will discuss the nature-based tourism, weather and climate information for nature-based tourism, theory application, objectives and the rationale for compiling chapter 2-4.

1.2 Literature review

Below, the current understanding and methodology approach regarding the interactions among climate change, weather extremes, and nature-based tourism will be discussed, followed by the application of resource-view of nature-based tourism in a theoretical framework.

1.2.1 An overview of nature-based tourism

Nature-based tourism, a general class of tourism, can be defined as the simple ‘temporary migration of people to what they understand to be a different and usually ‘purer’ environment (Wilson, 1992). Boo (1990) uses the title ‘eco-tourism’ as synonymous with ‘nature tourism’ in her major study of Latin America and defines it as “traveling to relatively undisturbed or uncontaminated natural areas with the specific objective of studying, admiring and enjoying the scenery and its wild plants and animals, as well as may existing cultural manifestations”. Smith and Eadington (1992) suggest that the disillusionment of the traditional form of mass tourism and the many problems it has triggered have forced people to propose an "alternative tourism" agenda in the past few decades. Broadly speaking, Smith and Eadington define this emerging form of tourism as "tourism that is consistent with the value of nature, society, and community and which allows both landlords and guests to enjoy positive and valuable interaction and shared experiences." This market broadly encompassing outdoor recreational activities (e.g., camping, hiking, cross-country skiing) undertaken in natural settings in which the individual recreation activity or the quality of the visitor experience depends on and/or is enhanced by the natural environment (Eagles et al., 2001, Wearing & Neil., 2009). Torn (2006) believes that growth in this market has 'increasingly concentrated on pristine environments and protected areas.' Despite the complexity implicit in this array of terms, a useful starting point is a relatively simple definition:

> Nature-based tourism is primarily concerned with the direct enjoyment of some relatively undisturbed phenomenon of nature.

There have been some discussions on the different definitions and features between nature-based tourism and ecotourism. Some authors have used the two terms synonymously (Valentine, 1993; Dolnicar, 2006; Fletcher, 2019; Lee et al., 2018; Xiaobo & Xiaoying, 2020), other literature, however, described the fundamental differences and interrelationships between them. For instance, Weaver (2001) consider ecotourism a subset of nature based-based tourism, while Buckley (1994, 2002) view ecotourism as an intersection of different forms of tourism including nature-based tourism. There has been some research dedicated to understanding the characteristics of tourists visiting ecotourism and nature-based tourism areas. Ecotourism and nature tourism include visiting natural attractions, but they differ in their intentions and activities (Handriana & Amara, 2016; Orams, 1995). Ecotourism involves responsible travel, caring about protecting the environment and respecting the culture of local residents. Nature tourism only refers to visiting scenic spots, especially to enjoy the beauty of nature. The purpose and activities of nature-based tourism are different from ecotourism. Nature-based tourism includes visiting natural attractions with geographic or biological characteristics, which are particularly attractive to the tourist market. Some common natural attractions in tourism include jungles, rivers, deserts, beaches, caves and cliffs, as well as the unique flora and fauna of these places (birds, reptiles, plants, etc.). Therefore, the fundamental difference between ecotourism and nature tourism is that the purpose of ecotourism is to protect nature while the purpose of nature-based tourism is for individual to enjoy the quality time in nature.

Engagement in nature-based tourism present essential benefit to individuals, communities, and contribute to sustainability (Winter et al., 2020). Numerous works showed the positive spillover effect of nature-based outdoor experiences to the participants. Stress level dropped significantly after recreating outdoors in less than two hours (Hull & Michael, 1995). Various leisure activities in nature settings are found to be the key factor in promoting the health and life satisfaction among Western migrants (Kim et al., 2019). Particularly, the ability to practice social distancing while performing physical activities during the pandemic effectively released post-traumatic stress symptoms (Dominski & Brandt, 2020). Callado et al. (2015) find the frequency of contact with nature and the frequency of activities engaged while in the nature affecting children's engagement in pro-environmental behaviors. Specifically, Callado et al. (2015) pointed out encouraging youngsters' active environmental attitude towards nature-based activities is essential for the future of the planet. College students who camp in natural areas frequently were physically stronger and placed more environmental responsibility (Lawrence, 2012). The survey results from national scenic trail users indicate the experience of nature have a significant positive relationship with environmental attitudes and actions to support funding in environment related issues (Kil, 2016). Other works found that there is an important relationship between adult's environmental attitudes, recreational motivations, outdoor experiences and environmentally responsible behaviors (Lin et al., 2020; Li et al., 2015; Høyem, 2020). Those studies suggested the relationships between the time spend in nature-based tourism and the desirable outcome for promoting sustainability.

Nature-based tourism are growing three times faster than the tourism industry in general (Fredman & Tyrväinen, 2010; Margaryan & Fredman, 2017). Reports frequently described the rapid growth in nature-based tourism as one of the fastest growing sectors of the world's largest industry and add increasingly significant weight to the economy. Balmford et al. (2009) conducted a robust trend analysis that have a broad geographical coverage in 20 countries located at six continents from 1992 to 2006, and the results supported the visitation is generally growing in the nature-based tourism and indicated a pervasive shift towards this sector in most less developed nations. Eagles (2001) suggests that for many countries nature-based tourism 'is an important component of their overall tourism industry'. Whether busy metropolis or remote wilderness, today's nature-based traveler levels the same expectations of the destination – namely, it should meet and exceed their quality expectations during every visit. In terms of global significance, nature-based tourism has been developed continuously and gravitating to more researchers' attention (Rogerson & Rogerson, 2020). Hoffmann et al. (2019) asserts that under the combined effect of the usual pull and push motivation factors, it appears that more and more tourists are gravitating towards leisure and entertainment in nature-based tourism stressing the significance of research in this tourism sector.

1.2.2 Weather and climate in nature-based tourism

Weather and climate are essential elements for nature-based tourism. Global climate change refers to a statistically significant change in the average state of the climate or climate change that lasts for a long period of time (typically 30 years or more) on a global scale. While the weather is the way the atmosphere behaves, mainly with respect to its effect upon life and human activities for a short period of time (minutes to months) on a local scale. Unusual weather is frequently used as a proxy for weather changes expected as climate changes. The climate system is dynamic and varies at all times scales, however, over the past century, the mean temperature has been increased by over 0.5. The distribution of seasonal mean temperature anomalies has shifted toward higher temperatures and that the range of anomalies has increased in the past 30 years (Hansen et al., 2012).

Climate affects tourism critically along with other natural resources such as geography, landscape, and other attractions of the destination (Yu et al., 2009). Climate change is expected to have a continued effect on tourism because climate as a tourism destination resources is made up of the weathers that tourist's experience during visitation (de Freitas, 1990). The weather has been found to have an important role in influencing tourist satisfaction and tourist decision-making processes (Tang et al., 2021; Yu et al. 2009). Although most tourism studies focused on economic perspective (Dwyer et al., 2010; Lin et al., 2019), the climate has been identified as a key driver for tourism and an important destination attribute (Beniston, 2003; Rosselló-Nadal, 2014; Scott, 2011; Scott et al., 2007). Dependent on natural based resources, the nature-based tourism was marked as one of the key economic sectors affected by climate change (IPCC, 2018).

People naturally prefer comfortable weather as the nature-based tourism visitation tends to peak with high environmental performance (Clemente et al., 2020). Therefore, providing appropriate information regards weather suitability for those who attempt to enjoy an outdoor recreational activity becomes vital. Temperature and precipitation were the two most common variables used in tourism-based weather impact studies (Andreas et al., 2012); relative humidity, wind speed, could cover and physiological equivalent temperature (PET) were other meteorological variables measured alongside the temperature. Numerous studies noted that the climate changes induced higher frequency of extreme weather events will have a profound and drastic impact on nature-based tourism (Becken & Wilson, 2013; Cohen et al., 2014; Dogru et al., 2019; Dutzik & Willcox, 2010; Hewer, 2020; Jedd et al., 2018)

The impact of climate change on tourism occurs in diverse channels and different forms. Climate change impacts on tourism are characterized as long-term transformation, ranging from direct impacts such as rising temperature (Koutroulis et al., 2018; Rutty & Scott, 2010; Steiger et al., 2019; Takakura et al., 2019), rising sea levels (Cambers, 2009; Hamilton & Tol, 2007; Hoogendoorn & Fitchett, 2018), loss of snow cover (Diro & Sushama, 2020; Elsasser & Bürki, 2002), or indirect impact, such as the impact on the landscape (Shi & Lan, 2019; Hamilton, 2007), increasing insurance costs and safety concerns (Olya & Alipour, 2015), water shortages (Torres et al., 2019; Sifolo & Henama, 2017; Gough, 2015), biodiversity loss (Ling & Hobday, 2019; Perry, 2011) and damage to assets and attractions at destinations (Atzori et al., 2018; Fang et al., 2017). Climatic and weather conditions also influence the way in which tourists undertake certain activities at the destination (Becken, 2010) and the duration of the activities (Scott & Jones, 2006).

Researchers have widely examined the effects of the key weather conditions on nature-based tourism. For instance, Scott & Jones (2006) examined the influence of weather on the number of rounds played at the Toronto golf courses; Becken (2013) analyzed the impact of weather on scenic flights; Wolff & Fitzhugh (2011) examined the effects of weather on outdoor recreation compared to commuting. Rutty & Scott (2015, 2016) explored the weather resilience, ideal and unacceptable climatic conditions for beach users from varied demography background.

Adverse response of tourists to increasing temperature and precipitation were discovered at Khaoyai National Park (Pongkijvorasin & Chotiyaputta, 2013). The weather conditions were also used to investigate visitors' willingness to pay for trips at Alpine National Parks in the United States (Richardson & Loomis, 2005) and Lisbon region (Clemente et al., 2020) in an attempt to predict future recreation demand. The involvements of outdoor activities are found to be predictable from the weather conditions (Wolff & Fitzhugh, 2011).

Buckley & Foushee (2012) analyzed the historical average monthly temperature of the United States national parks and the number of parks visits from 1979 to 2008 and found that the parks have experienced a warming trend, the timing of the peak attendance in 2008 was 4 days earlier than 2007. In addition, they emphasized the importance of climate change assessments to assess the impact of warming on park seasonality and tourists' arrivals. Using a contingent valuation method to measure the effects of weather on net willingness to pay (WTP), Richardson & Loomis (2017) estimated a 4.9% and 6.7% increase in recreation benefits under two climate change scenarios at the Rocky Mountain National Park in Colorado. Existing impact assessments in the tourism and climate change literature also indicate that the expected warming trend in global temperature will increase the number of park visitations and extend the park's operation season in Canada (Hewer & Gough, 2019; Hewer et al., 2018; Matthews et al., 2019; Scott et al., 2007), the northern United States (Fisichelli et al., 2015; Ma et al, 2020), the alpine region (Richardson & Loomis, 2005).

Seasonality has been a common and persistent feature as one of the main challenges of tourism's viability (Qiang, 2020; Rutty & Scott, 2016). Seasonality in tourism is a regular and predictable cycle of visitation across a year. Studies have shown that the fluctuation of tourist flows changes across seasons and time intervals (Turrion Prats, 2017), and it is believed that climatic and institutional factors determine the tourism seasonality (Xie, 2020; Duro & Turrion., 2019; Butler, 2001; Baron, 1975). Hadwen et al. (2011) has found that climate was the principal force driving the seasonal patterns of visitation activities in equatorial, tropical, desert, grassland, and temperature regions, while visitation to alpine and subalpine regions is mainly driven by a series of complex natural and institutional factors. Qiang (2019) matched seasonal factors and tourism climate index and found that climate still regulates recurrent tourism fluctuations though less dominant in cultural destinations. Other socio-economic parameters included in this research were income, education, age, and the presence of an international airport, all of which had a positive effect on tourism (Kim, Park, Lee, et al., 2017; M. Rutty & Scott, 2013; Michelle Rutty & Scott, 2015, 2016).

1.2.3 Theory Application: resource-view of nature-based tourism

1.2.3.1 A Natural-Resource-Based View

The resource-based view (RBV) is a managerial framework used to determine the strategic resources a firm can exploit to achieve sustainable competitive advantage. It considers the company's capabilities and resources, which are bundled in a unique way to give the company its core competitiveness. The main performance factor for a company is the owning and operation of "core" resources and competencies. The core competencies can bring company competitive advantage if they are valuable, rare, inimitable, and irreplaceable (Barney et al., 2001; Wernerfelt, 1995; Lockett & Morgenstern., 2009). However, the traditional strategic model does not address how the constraints of the natural environment affect the company's ability to generate a competitive advantage through its operations. Thus, Stuart Hart (1995) developed a framework that underlying the role of the natural environment to the three driving forces for a firm's long-term growth. The Natural Resource-Based View (NRBV) works on the principle that the company's competitive advantage is fundamentally determined by its relationship with the natural environment. The approach has been used in tourism and may also be a guiding light for tackling relationship issues within destinations (Marsat, 2015). Tourism resources that are shared with other uses vary greatly, in both natural and cultural fields. Being able to identify them as potential resources, evaluate them and use them as tourism assets, maintain them or even create them and manage them, are a competency that may be "core" under the Natural-Resource-Based View.

1.2.3.2 Environmental externality framework

Externality theory focused on how the cost or benefit that affects a third party that didn't choose to incur that cost or benefit. An externality is frequently defined to occur whenever a decision variable of one economic agent enters into the utility function (or production function) of some other agent (Heller & Starrett, 1976). According to Griffin & Steele (1986), externality exists when "the private calculation of benefits or costs differs from society's valuation of benefits or costs".

Climate change can be described as a non-tourism-related externality. In the chaos model of tourism, McKercher (1999) argues that some non-tourism-related externalities have the potential to plunge tourism into chaos, precipitating rapid change. Climate change is undoubtedly likely to affect tourism in this way, as has already been demonstrated by the way climate variability and extreme weather events adverse effect on tourism today and have done so in the past. This suggests that the key role of internalizing the externality by tourism agents. With a vested interest in maintaining a stable tourism system, it is critical to work proactively to avoid, ameliorate, or at least delay the major changes in the climate system.

1.2.3.3 Dynamic General Equilibrium Framework

General equilibrium theory attempts to explain the behavior of supply, demand, and prices in a whole economy with several or many interacting markets, by seeking to prove that the interaction of demand and supply will result in an overall general equilibrium (Hahn, 1980). The computable general equilibrium models assist in tracing the effects of a single element alteration to the entire economic sector. Solaymani (2015) used a general equilibrium model framework to investigate the impact of climate change policies on the Malaysian economy and the transportation sector. Under the general equilibrium framework, Willenbockel (2012) explored the potential impacts of a number of extreme weather event scenarios on food production and prices. From the demand side consideration, outdoor recreation participation will only occur if the potential participant perceives the climate the be suitable because recreation is an activity that individuals freely engage for personal leisure and voluntarily proceed from individual's free choice. De Freitas (2003) argued the voluntary participation nature of tourism implies the tourist's participation will decrease as discomfort and dissatisfaction increase. Thus, satisfaction affects participation, which can be taken as a measure of demand for the climatic resource, the so-called demand factor. De Freitas (2003) further identified the climate or weather circumstances to which the recreationist or tourist may react or respond are (1) conditions anticipated by the tourist and (2) on-site weather. These are collectively referred to as human responses to weather and climate. They can be identified and assessed using "demand indicators".

From the supply side consideration, the factor endowment theory holds that countries are likely to be abundant in different types of resources. In economic reasoning, the simplest case for this distribution is the idea that countries will have different ratios of varied resources. Factor endowment theory is used to determine comparative advantage. The changing environment posted certain and uncertain risks and opportunities for destinations' future climate resources to some extent; thus, the location’s climate resources endowment will shift accordingly. As one of the major resources supply, the past, present, and future redistribution of nature-based tourism can be assessed.

1.3 Methodological Approach

Researchers have widely examined the effects of the key weather conditions on nature-based tourism. Temperature and precipitation were the two most common variables used in tourism-based weather impact studies (Andreas et al., 2012; Scott et al., 2008); relative humidity, wind speed, could cover and physiological equivalent temperature (PET) were sometimes measured alongside the temperature. In terms of assessing climate as a resource for tourism, Scott et al. (2008) identified three different types of preferred climate studies on preferred climate for tourism. The first of these three is the expert-based tourism climate preferences approach. In this domain, three different research tools have been identified: minimum requirements (defined by tourism professionals), weather types and tourism climate index. The second method to identify the climate perceptions of tourists is via a stated preference. Tourist perceptions and preferences are critical in shaping tourism development at a destination. This approach uses both in situ and ex-situ constructs and is gaining increasing popularity in the academic literature. The third type of method to investigate the tourism climate research was referred to as the tourists revealed climate preferences. These studies use the actual tourism visitation data with the matched climate information data to determine the statistical relationships between the climate condition and the actual behavior (willingness to visit) of the tourists.

However, the methodology that was used to quantify the climate resources for tourism is not without criticism, and the lack of closer assessment of this relationship at the individual locations in the United States is astounding. In the face of climate change and massive tourism growth in the states, the tourism industry will encounter either risks or opportunities that yet to explore. In addition, the examination of climate change and weather extremes impact on the camping industry has not well established in the literature the extent to which how the profound effect of the overall climate suitability played in determining the camping decisions and the changing favorable camping season. The non-linearity human response to different weather stimuli and the complexity of social-geographical interactions in nature-based tourism posed challenges to establish a generalize climate index for tourism. Moreover, despite the extensive application around the globe, many indices developed in the tourism context have only been empirically validated with a few tourism destinations in a limited climate system coverage. As such, the three manuscripts presented in this dissertation addressed those knowledge gaps and advanced the knowledge in tourism meteorology field.

The three chapters presented in this dissertation applied a metric-based assessment of climate and tourism in line with the latter approach. The main strength associated with this approach is its objectivity, in that it measures the influences of climate on tourists based on the aggregate tourists' behavior such as visitation/occupation number and is not based on subjective expert-based judgment or what tourists stated (Hewer, 2020; Ma et al., 2020).

The methods utilized in this study are novel. First, it integrated approaches from climatology, biometeorology, econometrics, management, and geography to advance the understating of the interactions of natural-resources (i.e., climate and weather) and tourism organizations. Second, empirical relationships between tourism revealed behavior (i.e., camping occupancy and visitation counts) and climate conditions were established by using a series of quantitative analysis. Third, it is the first study to examine the climate resources for tourism in the contiguous United States. Fourth, daily climate variables are utilized throughout the three manuscripts, which overcame the coarse resolution of monthly data being criticized in the literature.

1.4 Research goal and objectives

The overall goal of this dissertation is to advance the knowledge of human-environment interactions in nature-based tourism in the contiguous United States. In particular, it aims to facilitate the climate resources assessment for nature-based tourism and improve the understanding of the potential climate change impact on camping industry by integrating climate, social and environmental dimensions in a quantitative framework. To achieve the goal, three main objectives were established, associated with each following chapter.

Objective 1. Develop a specific camping climate index (CCI) for nature-based tourism.

Task 1.1 Quantify the relative significance of weather parameters that affecting tourists' comfort and identify the threshold values for the weather extreme events.

Task 1.2 Validate the CCI with the other climate indices for tourism in assessing the climate resources for tourism.

Objective 2. Measure the climate resources at United States National Parks using the tourism climate index approach.

Task 2.1 Examine the performance of different tourism climate indices in assessing the climate resources for nature-based tourism activities in the US National Parks.

Task 2.2 Analyze the historic long-term trends for climate resources, visitation, and camping at non-profit US National Parks.

Objective 3: Analyze the spatial and temporal distribution of climate resources for nature-based tourism in the United States.

Task 3.1 Compute state-level seasonal Camping Climate Index to establish the overall climate suitability across the contiguous United States.

Task 3.2 Apply trend analysis to estimate the impact of climate change on the climate resources at the state-level in the United States.

1.5 Outline of Dissertation

This dissertation mainly consists of two manuscripts that are published (Chapter 2 and Chapter 4) and one manuscript that is under review (Chapter 3) in peer-reviewed academic journals. Collectively, the purpose of these three manuscripts is to achieve the overall goal of this research topic, as well as address the three specific objectives of this research. These three manuscripts are supported by the introduction (Chapter 1) that outlines the problem contexts, reviewed the literature, identified the methodological approach, goals, and objectives of this study. Each peer-reviewed manuscript (Chapter 2 – Chapter 4) includes specific literature reviewed and discussion pertaining to the study. The summary and conclusion section (Chapter

5) summarized the research findings, discussed the implication and future research, and drew concluding remarks about the contribution of this study to the society at broad.

Chapter two is the in-depth exploration of the methodological approach to examine the climate resources for nature-based tourism. The manuscript is entitled “The Camping Climate Index (CCI): The development, validation, and application of a camping-sector tourism climate index” and has been published in the *Tourism Management* journal. This manuscript developed a camping-specific climate index that uses a data-driven method that accomplishes task 1.1 and tasks 1.2 to address objective 1. This novel camping climate index works by assigning a daily score for thermal comfort and sunshine hours combined with a punishment mechanism triggered by extreme weather. The index transforms the non-linear relationship between tourist behavior and weather conditions to a linearly expressed ranking system to easily quantify the integrated effects of weather on tourism. This study advances our understanding of the mechanism and magnitude through which the overall weather conditions affect tourism planning and provide the campsite managers and tourism seekers with a useful tool for future climate resources assessment and decision making.

Chapter three is an empirical extension built upon chapter 2 that provides further discussion of the climate index approach to assess the climate resources at the United States National Parks. The manuscript is entitled “Climate resources at United States National Parks: A tourism climate index approach” and is currently under review in the Tourism Recreation Research journal. In this study, the applicability of four focal climate indices, including the Tourism Climate Index (TCI), the Holiday Climate Index – urban and beach (HCI), the Optimized Index for Tourism, and the Camping Climate Index (CCI), are closely examined in the United States National Parks that accomplish task 2.1 and task 2.2 to address the research objective 2. This study provides a rich description of the varied climate indices in tourism, as well as the discussion of the applicability within or beyond its natural design. Using a multiple indices inter-comparison approach, this study advances our understanding of the changes of climate resources in the United States National Parks in the past half a century and provides related information for re-evaluating the valuable climate resources at the National Parks. These comparisons suggested that the CCI, in general, is better than other indices in explaining the temporal variations of park visitation in these national parks.

Chapter four is the last manuscript of this dissertation that explores the macro-level distribution and re-distribution of camping climate resources in the United States. The manuscript is entitled "Camping climate resources: the camping climate index in the United States" and has been published in Current Issues in Tourism journal. This study quantifies state-level seasonal camping climate resources for the 48 contiguous United States and its nine climate regions from 1984 to 2019 using the empirically tested Camping Climate Index (CCI). Findings reveal that 1) temporally, ideal camping days are increasing an average of 20 days over the study period with the most improvement occurring in the summer where camping demand is at its height; and 2) spatially, mid-latitude, and higher altitude regions are the beneficiaries of the changing climate in terms of a higher percentage of ideal camping days gained. As the first to explore the camping climate resources across the contiguous United States, this study advances our understanding of the large-scale climate change impact on the nature-based tourism industry and described a practical tool for mapping the potential change under the projected climate change to the globe.

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Chapter 2: Ma, S., Craig, C. A., & Feng, S. (2020). The Camping Climate Index (CCI): The development, validation, and application of a camping-sector tourism climate index. *Tourism Management*, *80*, 104105. (published)

2.1 Abstract

Camping is a nature-based tourism activity where individuals spend one or more night away from home in an outdoor setting. Inherent in the definition are time and space, as well as exposure to natural elements such as weather or extremes. This study introduces the novel Camping Climate Index (CCI) to explore the impacts of weather and climatic variability on camping occupancy and optimal camping conditions. Daily meteorological data for 29 for-profit camping locations is analyzed and matched with daily camping occupancy data for the tent, recreational vehicle, and cabin categories. The CCI is empirically validated for camping behaviors compared to other tourism indices including the Tourism Climate Index and Holiday Climate Index. This study is the first to create an index using observed camping occupancy data for the three categories of camping matched with daily weather data that also captures the overriding effects of extreme/adverse weather events.

Chapter 2: The Camping Climate Index (CCI): The development, validation, and application of a camping-sector tourism climate index

2.2 Introduction

Climate change has resulted in shifting seasonality, changing weather trends, and intensified extreme weather conditions (Reidmiller et al., 2018). Camping, the largest outdoor tourism sub-sector in the United States (Outdoor Industry Association, 2017), is particularly vulnerable to these changes warranting exploration. Researchers have examined the effects of weather and climatic variability for nature-based tourism across multiple activities including national park visitation (Hewer, Scott, & Gough, 2015), beach visitation (Lithgow, Martinz, GallegoSilva, & Ramirez-Vargas, 2019; Matthews, Scott, & Andrey, 2019), camping occupancy (Craig, 2019), and winter sports (Scott, Abegg, Pons, & Aall, 2017). Researchers have also used webcams to observe the effect of weather on nature-based tourism activities including park attendance during peak periods (Ibarra, 2011) and nar- row periods during the day (Moreno, Amelung, & Santamarta, 2008). Nature-based tourism includes activities that occur in the natural envi- ronment away from one's home (Laarman & Durst, 1987; Tkaczynski, Rundle-Thiele, & Prebensen, 2015; Valentine, 1992). The consequences of climate change are expected to continue to have a considerable impact on outdoor tourism activities including camping and park visi- tation (Craig, 2019; Go€ssling, Hall, Peeters, & Scott, 2010; Katircioglu, Cizreliogullari, & Katircioglu, 2019; Koutroulis, Grillakis, Tsanis, & Jacob, 2018). While some climate change consequences can be cata- strophic (e.g., natural disasters), others such as warming trends or shifts in seasonality create additional opportunities for outdoor activities, however. This is particularly true for the nature-based tourism activity camping (Craig, 2019; Hewer et al., 2015). Accordingly, we propose the empirical exploration of the temporal and spatial impacts of weather and climatic variability on the three categories of camping: tent, recre- ational vehicle (RV), and cabin.

The Camping Climate Index (CCI) is introduced, empirically tested, validated, and applied as a method to quantify the short- and long-term effects of weather and climatic variability for camping. Camping is an activity where individuals travel away from home to spend a night or more outdoors in a natural setting (Hewer et al., 2015). Camping is unique compared to other tourism activities because it is an outdoor activity itself, is an overnight accommodation, and is closely related to other outdoor activities including hiking, water sports, and site-seeing (Caim Consulting Group, 2019; Craig, 2019). In fact, a recent survey indicates that "campers are continuing to make strong connections be- tween camping and other outdoor recreation activities, considering them to be one in the same" (Caim Consulting Group, 2019, p. 4). The number of active campers grew 4% from 2014 to 2018 to include 78.8 million households (Caim Consulting Group, 2019), and camping has an annual economic impact of approximately $167 billion (Outdoor In- dustry Association, 2017). Considering the size and trajectory of the camping sector, the CCI can help camping organizations, both for-profit and non-profit, better understand the economic impacts of weather, climatic variability, and climate change.

Accordingly, the CCI addresses four gaps in the nature-based tourism literature by (1) introducing a camping sector index, (2) empirically testing relationships between weather variables and actual outcomes (i. e.., camping behaviors), (3) independently integrating extreme/adverse weather events into an index, and (4) empirically capturing seasonality using multiple methods. The remainder of this section will provide an overview of the relevant literature, followed by materials and methods, results and analysis, calculations, and discussion sections.

2.2.1 Climate change, weather, and camping

Climate change has altered the frequency and intensity of weather and extreme weather events, including heat waves, hurricanes, flooding, drought, tropical storms, and wildfires (Dutzik & Willcox, 2010; East- erling et al., 2000; Feng, Trnka, Hayes, & Zhang, 2017; Lithgow et al., 2019; Poumad�ere, Mays, Le Mer, & Blong, 2005; Tippett, Lepore, & Cohen, 2016). The term weather refers to short-term conditions (days to months), climatic variability to mid-term to long-term conditions (months to years), and climate change to long-term conditions (de- cades). The frequency and intensity of extremes in recent decades is linked to increasing economic losses in addition to the loss of lives (Mechler, , Bouwer, , Schinko, , Surminski, , & Linnerooth, 2019; Cor- onese, Lamperti, Keller, Chiaromonte, & Roventini, 2019; Hanewinkel, Cullmann, Schelhaas, Nabuurs, & Zimmermann, 2013; Tol, 2009). With the close spatial proximity to the natural environment, nature-based tourism activities are a vulnerable and highly sensitive economic sector (Dogru, Marchio, Bulut, & Suess, 2019; Hambira et al., 2020; Rutty & Scott, 2013; Verbos et al., 2018). Although weather conditions are only one of the factors linked to tourism destination choices, they are often the primary consideration.

Significant relationships between weather, climatic variability, climate change, and nature-based activities have been established by a number of researchers (e.g., Becken, 2010; Craig, 2019; Craig & Feng, 2018; Fisichelli, Schuurman, Monahan, & Ziesler, 2015; Hewer, Scott, & Fenech, 2016; Kim, Park, & Lee, 2017; Lithgow et al., 2019; Wilkins, de UriosteWeiskittel,&Gabe,2017).Scott,Go€ssling,andHall(2012) contended that warming trends may move climatically suitable areas for activities such as camping to higher latitudes or altitudes. Conversely, medium to low latitude destinations may see shifts because of individual preference for temperate regions and extreme weather avoidance. Shifting seasonality has also occurred, where conditions conducive to nature-based activities in the fall and spring meteorological seasons in the United States have increased (Monahan et al., 2016). Changing conditions are not inherently negative to camping, however. Shifting climate-derived weather and seasonality trends highlight the potential positive (i.e., opportunities) and negative (i.e., threats) impacts that changing conditions can have depending on spatial location.

2.2.2 Tourism resources and previous indices

Early work in tourism climatology was strongly influenced by Mieczkowski (1985) who developed the Tourism Climate Index (TCI) to investigate the impact of weather and climate on general tourism ac- tivities. The tourism index approach pioneered by Mieczkowski (1985) considered three climate resources: thermal, physical, and aesthetic. The thermal resource considers the perceived thermal sensations and com- fort based on the atmospheric conditions including temperature and relative humidity. The physical resource considers the existence of specific meteorological elements such as precipitation and windspeed. The aesthetic resource considers the scenic comfort based on prevailing synoptic conditions such as sunshine hours. Through these three re- sources, weather conditions influence the demand for or satisfaction from nature-based activities (De Freitas, 2003). The development of the CCI builds on previous tourism indices – both general and activity-based – in Canada (Matthews et al., 2019), Europe (Perch-Nielsen, Amelung, & Knutti, 2010; Scott, Rutty, Amelung, & Tang, 2016), Mediterranean (Amelung & Viner, 2006; Ameglung et al., 2007), Australia (Amelung & Nicholls, 2014), Asia (Fang & Yin, 2015; Kubokawa, Inoue, & Satoh, 2014), the Middle East

(Roshan, Yousefi, & Fitchett, 2016), and globally (Amelung & Viner, 2006; Mieczkowski, 1985). Specifically, the CCI will empirically and longitudinally evaluate weather, climatic variability, and camping occupancy relationships across the United States.

2.2.3 Tourism index gaps

As Matthews et al. (2019) and others have noted, the TCI and its variations are not without limitation thus creating gaps in the literature that need to be addressed. Several criticisms of tourism climatology studies using indices were they were too broad, lacked empirical testing with high resolution observational data, were reliant on subjective criteria, and were not validated against behaviors (Craig, 2019; De Freitas, 2003; Hewer et al., 2015; Matthews et al., 2019; Scott et al., 2016). This section highlights four key gaps in the literature that the CCI will address.

First, there is a need for indices that adapt more narrowly to tourism sectors (Matthews et al., 2019). It is not sufficient to assume consistency of desired climate resources across all tourism activities. For instance, (Grillakis, Koutroulis, Seiradakis, & Tsanis (2016)) noted that different nature-based tourism activities (e.g., camping versus alpine skiing) require different climatic conditions. Scott, Gossling, and De Freitas (2007) conducted a study supporting this assertion, finding that perceived optimal climatic conditions differed based on spatial location and activity. Statistical differences in climate preferences based on socio-demographic factors and place of origins across tourism sector have also been recorded (Rutty & Scott, 2015; Rutty & Scott, 2013). Despite a fairly wide body of research in tourism climatology related to nature-based tourism (Amelung & Nicholls, 2014; Amelung, Nicholls, & Viner, 2007; Fang & Yin, 2015; Lise & Tol, 2002; Perch-Nielsen, 2010; Roshan et al., 2016; Scott, McBoyle, &

Schwartzentruber, 2004), how- ever, the literature on camping is scarce (Brooker & Joppe, 2013). The CCI will address this gap by explicitly exploring camping by category.

Second, there has been insufficient empirical testing for indices using observed tourist behaviors (Craig, 2019; Hewer et al., 2016). For instance, the weather variable rating schemes of the TCI and its variations were subjective, as they were based on the authors' opinions and were not empirically tested using observed behaviors (De Freitas, Scott, & McBoyle, 2008; Gomez-Martín, 2007; Perch-Nielsen, 2010; Scott et al., 2016; Matthews et al., 2019). In and ex situ studies have assessed tourist perceived weather preferences to evaluate the importance of weather for outdoor tourism activities and to empirically validate indices (Denstadli, Jacobsen, & Lohmann, 2011; Dubois, Ceron, Go€ssling, & Hall, 2016; Jeuring, 2017; Rutty & Scott, 2010; Rutty & Scott, 2013; Scott, Gossling, & De Freitas, 2008). However, these studies and resultant indices did not empirically match individual perceptions and behaviors with observed weather conditions. Building on the work of Rutty and Scott (2010, 2013, 2015, & 2016), Scott et al. (2016) incorporating survey evidence from tourists into the ratings and weightings for the Holiday Tourism Index (HCI). This approach is rational, but the reliability of the surveys to determine the weather thresholds (i.e., conditions unsuitable for tourists) need to be further tested. For instance, recent camping studies found inconsistencies be- tween self-reported weather thresholds and actual camping behaviors (Craig, 2019; Craig & Feng, 2018). Accordingly, this study will explore empirical relationships between camping occupancy behaviors and weather variables to assess the appropriate weather variable rating scheme and index rating for camping.

Third, the overriding effects of extreme/adverse thermal (i.e., minimum and maximum temperature) and physical factors (i.e., precipitation and windspeed) are poorly identified. Single weather factors can be pivotal to campers' decision making despite the desirability of other factors. For example, extremely unfavorable temperatures, either too hot or too cold, can overwhelmingly influence camping behaviors depending on camping category (i.e., tent, RV, cabin). Also, heavy rain and strong winds can impact camper occupancy decisions and duration of occupancy. The TCI represents weather conditions by integrating several weather factors into a single index, but it failed to explicitly take extreme/adverse weather events into account. De Freitas et al., (2008) recognized the potential overriding effect of weather extremes and found from survey research that windspeed greater than or equal to 22 km/h or the duration of rainfall for more than half an hour adversely impacted tourism satisfaction. However, these findings were not incorporated into the calculation of the index from the study. The HCI (Scott et al., 2016) addressed overriding effects by assigning equal weights to the thermal and physical resources (both 40%) to lower the index score when extreme/adverse conditions occurred. This allowed the HCI to account for overriding effects within the index, but not independent of the index. Thus, the HCI may not precisely reflect the relative significance of each factors' impact on tourism activities (Hewer et al., 2015; Matthews et al., 2019) due in part to the possibility of favorable con- ditions that can skew the index score when extreme/adverse conditions occur. To address gaps related to overriding extreme/adverse thermal and physical factors, this study will integrate weather thresholds into the CCI independent of the index score calculation.

Fourth, indices have had difficulty capturing seasonality. The seasonal distribution of tourism climate indices and monthly changes in ratings has been analyzed in multiple regions around the world (Amelung & Nicholls, 2014; Amelung et al., 2007; Fang & Yin, 2015; Kubo-kawa et al., 2014; Perch-Nielsen et al., 2010; Scott et al., 2004), however, there remains a salient gap in addressing the change in length of the favorable tourism seasons (for exception see

Monahan et al., 2016; Perch-Nielsen et al., 2010). We will address the gap in capturing favorable or unfavorable shifts in seasonality by using multiple methods to capture the number of optimal camping tourism days by season at 29 locations using the CCI.

In the following, the materials and methods as well as the results and analysis sections will outline the development of the CCI. The calcula- tions section will validate the CCI and present climatic trends across the United States using the CCI.

2.3 Methods and materials

The CCI explores three weather resources: thermal, physical, and aesthetic. Thermal resources were operationalized using thermal com- fort (TC), minimum temperature (Tmin), and maximum temperature (Tmax); physical resources were operationalized using precipitation (P) and windspeed (W); aesthetic forces were operationalized using daily hours of bright sunshine (S). The development of the CCI involves fives steps: (1) Retrieve daily weather variables; (2) Conduct iterative corre- lation to determine weather variable rating scores and thresholds; (3) Run regression analysis to identify the relative significance of individual weather variables; (4) Weight the CCI equation according to findings from regression analysis; and (5) Integrate weather thresholds into the final CCI equation.

2.3.1 CCI data

Daily camping occupancy data (tent, RV, and cabin) for 29 business locations throughout the United States between January 1, 2007 and November 11, 2016 (total 3603 days) were collected. The locations are owned by a large privately held camping corporation. The data repre- sented seven of the nine climate zones in the United States (Feng et al., 2014) including:

Northeast, East Central, Central, Southeast, South, Southwest and West (Fig. 1). No other information is provided about the corporation to maintain confidentiality.

Daily meteorological data was retrieved from January 1, 1997 to December 31, 2017 for the 29 locations analyzed. Daily maximum temperature, minimum temperature, dew point temperature, and precipitation were obtained from Di Luzio, Johnson, Daly, Eischeid, and Arnold (2008) PRISM dataset. Windspeed, cloud cover, and solar radiation were retrieved from the North American Regional Reanalysis dataset (Mesinger et al., 2006). Daily minimum relative humidity was computed using daily mean dew point temperature and daily maximum air temperature, and daily mean relative humidity was computed using daily mean dew point temperature and daily mean air temperature (see Allen, Pereira, Raes, & Smith, 2006). Sunshine hours are an important parameter for camping, but there were no daily sunshine observations available for the focal locations. Therefore, sunshine hours were calculated based on daily incoming solar radiation values (Allen et al., 2006). Table 1 provides a list of variables used in the study and their units, and Table 2 the equations for the three tourism indices used to validate the CCI.

2.3.2 Weather variable rating scores

Iterative correlations were used to determine weather variable rating scores for thermal comfort, sunshine hours, precipitation, and wind- speed (see Table 3). The iterative correlation method makes "the output error between the close-loop system and a reference model uncorrelated with [the] reference signal" (Karimi et al., 2002, p. 418) to maximize model fit. The iterative method can be applied to longitudinal data and has been successfully used to enhance model fit in a variety of contexts including statistics and natural science (Karimi et al., 2002;

Saebo; Pulay, 1993). Rating scores were determined by dividing the range of correlations by 10, where high correlations corresponded to high ratings and low correlations to low ratings. The result was a weather variable rating system from unfavorable (0) to optimal (10). See Table 4 for comparative tourism index rating schemes.

2.3.3 Multivariate regression analysis

Weather variable rating scores were regressed on camping occu- pancy for each category (i.e., tent, RV, cabin). Dummy variables were included for holidays and weekends to detach potential institutional effects that were not weather-related. Dates were only included if the camping locations were open for business. The multivariate regression formula is expressed as:

$$Y_{it} = \alpha_{it} + \beta_1 * TC_{it} + \beta_2 * S_{it} + \beta_3 * W_{it} + \beta_4 * P_{it} + \beta_5 * I_{it} + \varepsilon_{it} \quad (1)$$

Where Y_{it} represents the camping occupancy for three categories (i.e. i = tent, RV and cabin) from January 1, 2006 – November 11, 2017 denoted by t ($t = 3603$). TC_{it} represents the thermal comfort resources (°C); S_{it} represents aesthetic resources (hr); W_{it} and P_{it} represent physical resources (km/hr and mm, respectively); I_{it} is the institutional dummy that was coded one for weekend (Saturday, Sunday) and federal national holidays (United States Office of Personnel Management, 2019), and coded zero for workdays; α_{it} is a constant and ε_{it} is an error term.

The beta regression coefficients computed from equation (1) were used to assess the contributions of each weather variable on the regressed camping occupancy data. Only the beta values significant at $p < 0.01$ were considered for variable weightings. The percentage of each weather variables' beta value was then calculated to represent its relative significance.

Regression results which achieved the highest r^2 values were used to determine the weather resources to include in the final CCI equation.

2.4 Results and analysis

2.4.1 Multivariate regression

The output in Table 5 shows the regression results with coefficient estimations (beta). The parameters indicate one unit increase in weather variable rating score led to a significant change in camping occupancy ($p < .01$ unless designated with ns). Institutional factors (i.e., weekends, holidays) also had a significant positive relationship with camping oc- cupancy in all climate zones.

Variability in camping occupancy explained by weather varied across climate zones. However, similar patterns emerged. Each of the four weather variables (i.e., thermal comfort, precipitation, windspeed, sunshine hours) that captured the three climate resources (i.e., thermal, physical, aesthetic) was rescaled to determine weights for the CCI equation (see Table 6). The aggregate of variables across all climate regions was included when rescaling the final CCI equation. Thermal comfort and sunshine hours were the two most salient contributors regardless of climate zone. The effects of precipitation and windspeed were negligible when relationships were aggregated across climate zones. Therefore, the initial CCI less extreme/adverse events is expressed as:

$$CCI = 0.5 * TC + 0.5 * S \qquad (2)$$

2.4.2 Weather variable thresholds

Extreme/adverse weather events are rare, and the resolution of analysis described above may not be high enough to capture the true effects on occupancy. Therefore, weather variable thresholds were included to account for extreme/adverse weather events. The four threshold variables considered were minimum temperature, maximum temperature, precipitation, and windspeed. Threshold values were determined where the highest correlation between camping occupancy and unfavorable CCI occurred. The definition of “unfavorable” was empirically determined by optimizing the correlation coefficient. CCI was forced to a classification of “unfavorable” (CCI 1⁄4 3Þ when extreme/ adverse weather events were identified. If the calculated value of CCI from equation (2) was below three, the lower value was assigned. For example, if the CCI value calculated using equation (2) was two on a day when an extreme precipitation event occurred (CCI 1⁄4 3), two would be assigned. Values for each of the four threshold values and the final CCI equation are presented in the remainder of this section.

2.4.2.1 Minimum Temperature Thresholds

Minimum temperatures ranged from -5℃ to 15℃ and thresholds were considered using 0.5℃ increments. Weather thresholds occurred at 11℃ for tent camping, 8℃ for RV camping, and 4℃ for cabin camping. As minimum temperatures increased gradually from -5℃ to the thresholds, the correlation coefficient between camping occupancy and CCI from equation (2) increased, meaning the overriding effect for minimum temperature better explained the relationship than the CCI values using equation (2). The optimal minimum threshold value behaved slightly different among camping categories; tent dwellers were less tolerant to low temperatures than RV and cabin campers. The weather threshold value for overriding minimum temperature effects was set at 8℃, the average of the three categories.

2.4.2.2 Maximum Temperature Thresholds

Maximum temperature and camping occupancy demonstrated a positive relationship. The correlation coefficient leveled at 34℃ for all camping categories suggesting temperatures above 34℃ may be considered too hot. This finding is consistent with previous observed temperature thresholds of 35℃ (Hewer et al., 2015) for campers non-discriminant of camping category and from surveys where tourists had a perceived maximum temperature threshold of 32.2℃ (Fisichelli et al., 2015). Thus, the weather threshold value for overriding maximum temperature effects was set at 34℃.

2.4.2.3 Precipitation Thresholds

Weather thresholds for precipitation were examined from 0mm to 30mm using 1mm increments. Precipitation thresholds varied based on camping category. Tent camper thresholds occurred between 2 and 3 mm/day; RV camper thresholds occurred around 20mm/day; cabin camper thresholds occurred around 12mm/day. The aggregate of our results was slightly higher than the previously defined extreme precipitation level of 10mm/day (Frich et al., 2002). The 10mm/day level has also been used in past camping studies to significantly quantify the effects of precipitation (Craig, 2019; Craig & Feng, 2018). Accordingly, the weather threshold value for overriding precipitation effects was set at 10mm/day.

2.4.2.4 Windspeed Thresholds

Windspeed thresholds were explored ranging from 0km/h to 40 km/h at 1km/h increments. The correlation coefficients suggested that windspeed threshold values were about 20km/h for tent campers, 23km/h for RV campers, and 24km/h for cabin campers. The quantitative results were consistent for all camping categories. The weather threshold value for overriding windspeed effects was set at 23km/h, the average of the three categories.

Based on regression analysis and iteration correlations, the final CCI is expressed as:

$$CCI = \begin{cases} 0.5 * TC + 0.5 * S \\ \min(CCI, 3) \ \ if \ \ Tmin < 8℃, or\ Tmax > 34℃, \\ or\ P > 10\text{mm}, or\ W > 23\text{km/h} \end{cases} \qquad (3)$$

2.4.3 CCI and camping occupancy

In general, three insights can be drawn from the observation of CCI and camping occupancy by climate zone depicted in Figure 2. First, camping occupancy demonstrated seasonality no matter zone. Second, camping occupancy was closely linked to the climate resources (i.e., the CCI) in that zone. Third, regional differences existed in terms of the overall suitability for camping. Some zones had higher yearly average CCI (e.g. locations in the Southeast and South), while others had relative lower CCI except for the few peak seasons (e.g. locations in the Northeast).

Specific to climate zones, the Northeast zone experienced peak CCI distributions in the summer season. The CCI scores were consistently higher in summer and lower in winter, a trend that camping occupancy followed. The East Central zone had more attractive CCI distributions for campers during summer months and into the shoulder seasons. The CCI in the Southeast climate zone was generally good or optimal, remaining above 5 for the majority of the year. In the West, the CCI was better in the spring and fall, but was not as variable from season-to-season or throughout the year as other zones. The Central zone demonstrated a similar pattern to the West and East Central zones. Conditions for camping were positive from the onset of spring and lasted until the end of fall in the Southwest zone. In the South zone, camping conditions were suitable throughout much of the year with optimal CCI conditions occurring at various times throughout the spring, summer, and fall seasons. The next section provides calculations relevant to validating the CCI, longer-term climatic trends, and seasonality of optimal camping days by climate zones.

2.5 Calculations

2.5.1 Validating the CCI

The CCI was validated by comparing it to two well established indices and a recent variation: the TCI (Mieczkowski, 1985), the HCI (Scott et al., 2016), and the OPT (Matthews et al., 2019). Table 2 pro- vides the equations for each of the comparison indices. Scores for the three comparison indices and CCI were calculated daily then aggregated monthly to facilitate inter-comparisons. Annual data were subset into four seasons to explore the temporal differences among the indices. Multivariate regression analysis was conducted annually and within seasons, and the r2 values were analyzed to determine variability explained in camping occupancy. As shown in Table 7, the CCI demonstrated an equal or stronger fit than the TCI, HCI, or OPT for 92.3% (12/13) of the significant annual observations. The CCI also demonstrated an equal or stronger fit for 88% (22/25) of the significant observations within season.

2.5.2 Long-term trends

To assess the impact of climatic variability on the suitability for camping tourism for the seven climate zones, the number of optimal days with CCI scores greater than or equal to 7 was calculated for the 29 focal locations between 1997 and 2017. The results are presented in Fig. 3. Overall, the climatic conditions for camping in the contiguous US improved between 1997 and 2017. Five of the seven zones experienced an increase in optimal camping days ranging from an annual increase of 32 days in the East Central zone to an annual increase of 6 days in the Southwest zone. Only the South and Southeast climate zones experienced a decrease in optimal days (18 and 4 days annually, respectively).

2.5.3 Seasonal impact

The climatic trends depicted in Fig. 3 indicated variability in optimal camping days throughout climate zones in the United States. Accordingly, the distribution of optimal camping days by season using the CCI was explored from 1997 to 2017. As depicted in Fig. 4, seasonal variations in climate zones were present.

Generally speaking, the CCI experienced positive changes between 1997 and 2017 as latitudes increased. This benefited locations within the more Northern and Western climate zones across all seasons. The intensified frequency of heat waves and heavy precipitation in the lower to middle latitudes was linked to the decreasing number of optimal days for camping.

A discussion with limitations and future research as well as conclusion sections is provided below.

2.6 Discussion and conclusion

2.6.1 Discussion

Changing climatic conditions will continue to influence opportunities and threats for camping organizations, both for-profit and non- profit. The CCI was developed to quantify these opportunities and threats using three climate resources upon which tourist activities are dependent: thermal, physical, and aesthetic. Specifically, the study developed, validated, and applied the CCI to address gaps in the liter- ature that previous researchers identified pertaining to tourism indices and their respective methodologies (e.g., Craig, 2019; De Freitas et al., 2003; Hewer et al., 2015; Matthews et al., 2019). Encouragingly, the CCI was more predictive for the nature-based tourism activity camping compared to climate indices developed for other tourism sectors. The development of the CCI and findings from the study provide insights into the economic impact of weather, climatic variability, and climate change on the camping sector of tourism.

The CCI addresses the absence of a camping-sector climate index in the tourism climatology literature. Numerous studies have established that weather and climate are intrinsically important for tourism decision-making (Becken, 2010; Scott & Lemieux, 2010; Scott, Lemieux, & Malone, 2011) and that changes in weather patterns (Becken & Wil- son, 2013; Wilkins et al., 2017; Falk, 2014; Olya & Alipour, 2015; Hübner & Gossling, 2012) or the redistribution of climate resources (Rossello-Nadal, 2014; Amelung et al., 2007; Amelung & Nicholls, 2014; Fang, Yin, & Wu, 2017; Fang & Yin, 2015; Lise; Tol, 2002; Perch-Nielsen, 2010; Scott, 2011; Scott et al., 2004) will influence tourism demand. With few exceptions (e.g., Craig, 2019; Craig & Feng, 2018; Hewer et al., 2015; Hewer, Scott, & Gough, 2017; Hewer, Scott, & Gough, 2017b), however, limited research has empirically explored the relationships between camping, weather, climatic variability, and climate change. We addressed this gap by developing a camping-sector index that consid- ered each of the three categories of camping. Furthermore, previous research involved limited locations (e.g., Hewer et al., 2015; Matthews et al., 2019) due in large part to the lack of available observed data. By including daily camping occupancy data for tent, RV, and cabin camping at 29 unique locations across seven climate zones, we were able to overcome this hurdle and provide empirical support for the application of the CCI.

Over the past 10 years researchers conducted in situ studies exploring tourist perceptions and preferences related to weather (e.g., Denstadli et al., 2011; Dubois et al., 2016; Jeuring, 2017; Hewer et al., 2015; Hewer et al., 2017; Hewer et al., 2017b; Matthews et al., 2019; Rutty & Scott, 2010, 2013, 2015, 2016; Scott et al., 2016). The CCI was able to support and extend these studies. For instance, our finding that thermal and aesthetic resources where the two most important resources for camping is consistent with Hewer et al.'s (2015) survey results that comfortable temperatures (i.e., thermal) and sunshine (i.e., aesthetic) are the two most salient contributors to camper satisfaction. We extended the work of Hewer et al. (2015, 2017, 2017b) by using lon- gitudinal camping behavior data (i.e., camping occupancy) matched with observed weather data. We also built on the work of Scott et al. (2016) by validating the CCI with observed camping behaviors rather than surveys. This is important to highlight because recent research demonstrated that actual camping behaviors are not always consistent with perceived tourist perceptions about optimal or adverse conditions (Craig, 2019; Craig & Feng, 2018). For instance, maximum temperatures above previously self-reported acceptable thresholds can have non-significant or positive impacts on camping occupancy.

The use of observed longitudinal camping data was a strength of our study, but it also highlights a potential limitation. We were unable to quantify socio-demographic factors that may have influenced individual camper behaviors. In addition to the changing climatic conditions and weather patterns, socio-demographic factors as well as activity-related descriptive have previously influenced climate resource perceptions for nature-based tourists. For instance, Rutty and Scott (2015) found statistical differences for beach tourists' thermal preferences and perceptions based on gender, age, experience-level, and location type. Specific to camping, Hewer et al. (2017) found statistical differences for perceived ideal and acceptable temperatures based on gender, age, camping experience, distance travelled, camping equipment, and rec- reational activities. Research has empirically demonstrated that younger individuals are more weather tolerant across tourism activities (e.g., Hewer et al., 2017; Rutty & Scott, 2015), which is an opportunity for camping tourism considering that the majority of new campers are under the age of 40 (Caim Consulting Group, 2019). Hewer et al. (2017) also found travel distance and camping duration were positively related to weather tolerance. Younger individuals are camping for longer du- rations; however, they tend to travel shorter distances to camp (Caim Consulting Group, 2019). Previous findings and current trends point to the need for future research that concurrently considers the role of socio-demographic factors, activity-related descriptive, observed behaviors, and observed weather conditions.

There is evidence that changing climatic conditions are contributing to increasingly intense and frequent extreme weather events (Reidmiller et al., 2018) which in turn increase the number of costly and deadly disasters (NOAA, 2020). Weather extremes can adversely impact tourism demand (Becken & Wilson, 2013; Falk, 2014; Rosello, Becken, & Santana-Gallego, 2020) yet "empirical research that confirms or quan- tifies the relationship between disasters and tourism activity is scant" (Rosello et al., 2020, p. 2). Using retrospective time series forecasting, Craig and Feng (2018) found that extreme temperature and precipita- tion events could have an adverse impact on decisions to camp starting on the day of the event and up to 10 days prior to the event. Matthews et al. (2019) also used a data-driven approach for the OPT index using daily aggregate beach visitation data matched with daily weather data. The severity of extreme/adverse weather impact and previous high-resolution findings provide support for the consideration of daily data to examine camping and weather relationships.

Considering the large size of our dataset (from January 1, 2007 through November 11, 2016 for 29 unique locations) the occurrence of extreme/adverse conditions was comparatively rare. Statistical methods such as multivariate regression analysis for such a large dataset does not provide the resolution needed to capture the relationships between extreme/adverse conditions which necessitated the integration of the four thresholds in the final CCI equation, equation (3). This method allowed the CCI to integrate extreme/adverse weather into a scale without inadvertently introducing a cancelling effect.

We also quantified changing seasonality at the 29 camping locations to demonstrate temporal and spatial changes in CCI regionally throughout the United States (Fig. 4). In general, higher latitude locations saw an increase in optimal days regardless of season with three locations experiencing an over 20% increase in ideal days during the spring season. For researchers or practitioners interested in a single camping location or specific region, it may be necessary to explicitly integrate latitude in future studies. For instance, higher latitude (i.e., northern) regions in the study had stronger relationships with thermal climate resources whereas lower latitude (i.e., southern) regions had stronger relationships with aesthetic climate resources (see Table 5 for differences based on climate zone). The summer season saw the largest decrease in optimal days as well as the most modest percentage gains in optimal days. Combined our findings are consistent with Scott and colleagues' assertions that the number of cities in the United States with "excellent" conditions are likely to increase in the winter, decrease in the summer (Scott et al., 2004), and that warming trends will increase desirability of higher latitude locations (Scott et al., 2012). Our findings also support Monahan et al. (2016) research that demonstrated increasing favorable conditions in the spring and fall seasons across the United States.

Ideally, future research could build on this study by exploring the relationships between CCI and an even greater number of spatially diverse for-profit (i.e., business) and non-profit (i.e., governmental) campsites. Approximately 60% of camping nights in the United States occur at non-profit locations (Caim Consulting Group, 2019), yet in the peak summer season popular non-profit campsites have limited va- cancies, higher latitude/altitude campsites have set schedules to close seasonally, and there is no price-response to high-demand holidays or weekends. In fact, campers can purchase an annual national park pass in the United States to book campsites at discounted rates up to six months in advance. For-profit campsites have much more flexibility with demand-based pricing and seasonal openings. Future research should compare the impact of the CCI on for-profit compared to non-profit lo- cations and also explore the economic viability of later season camping in the fall and earlier season camping in the spring at non-profit locations.

The majority of significant relationships for the CCI occurred in the spring and fall seasons (see Table 7). The lack of significant relationships in the summer and winter months highlight there may be other factors influencing camping behaviors. Previous researchers suggested that institutional factors (e.g., weekends, holidays) can influence tourist behaviors

(Hewer et al., 2016; Richardson & Loomis, 2004) in much the same manner as weather thresholds can have an overriding effect. Hewer et al. (2016) found that there were significantly more park visi- tors on the weekend than during the week, a trend that became even more pronounced during the shoulder seasons. For the entirety of our matched sample, we observed 31% more tent campers, 19% for more RV campers, and 88% more cabin campers on the weekend. Further, post-hoc correlation analysis demonstrated the CCI had a stronger relationship with weekend occupancy than weekday occupancy for all climate zones and camping types other than RV campers in the south- west (see Fig. 5). This finding highlights the importance of favorable weather conditions for campers making last-minute nature-based tourism decisions regardless of season. Future studies should attempt to capture factors that can influence camping behaviors including shifting weather trends (including desirability of conditions within and between seasons), types of holidays, weekend versus weekday occupancy, advanced reservations, cost of stay, cancellation policies, travel dis- tance, and the length of occupancy (e.g., Brooker & Joppe, 2013; Craig, PetrunFeng, & Kinghorn, 2019; Hall, Gossling, & Scott, 2015; Hewer et al., 2017, 2017b).

Previous research in the United States shows that weather impacts campers differently based on occupancy type. A case study at two lo- cations in the United States empirically demonstrated that weather impacts RV and cabin campers less in the warmer summer months than it does tent campers. Rutty and Scott (2014) discussed how beach tourists can change locations, or create their own micro-climate, at a resort when weather conditions become uncomfortable. RVs and cabins can create an opportunity for campers to create their own micro-climate when climate resources are either not ideal or exceed thresholds. Future research should consider the potential for campers to create micro-climates, and the relationship with this capability relative to weather conditions. Future research should also consider whether or not campsites are at maximum capacity. In the event there are limited va- cancies to camp, this would mask the impact of weather on camping occupancy and also highlight the potential for extreme/adverse weather risks to campers.

2.6.2 Conclusion

Camping is the largest economic sub-sector of outdoor tourism and the characteristics of camping (e.g., overnight stays, natural settings, distance from one's home) make it particularly susceptible to extreme/ adverse weather and changing climatic conditions. The CCI recognized the uniqueness of camping and addressed a salient gap in the literature as the first camping-sector tourism climate index. The approach taken to create and validate the CCI matched daily weather data with daily camping behavior (i.e., occupancy) for the three categories of camping (i.e., tent, RV, cabin). Three key methodological advancements of the CCI include: (1) it was validated using daily camping observations at 29 geographically diverse locations across seven climate zones in the United States; (2) it captured adverse/extreme weather events without introducing a cancelling effect; and (3) it quantified camping climate resources seasonally throughout the United States. These advancements will be useful for those tasked with forecasting future outdoor tourism, weather, and climate change interactions. Missing from the methodology were market-based factors, including socio-demographic factors and other activity-based descriptive such as distance travelled or duration of stay. Building on the CCI, future researchers should strive to integrate market-based factors and descriptive comparable to previously validated climate indices for other tourism sectors. In turn, more robust tourism indices will help nature-based tourism organizations, camping or otherwise, respond to changes in climate resources resulting from future climate change scenarios.

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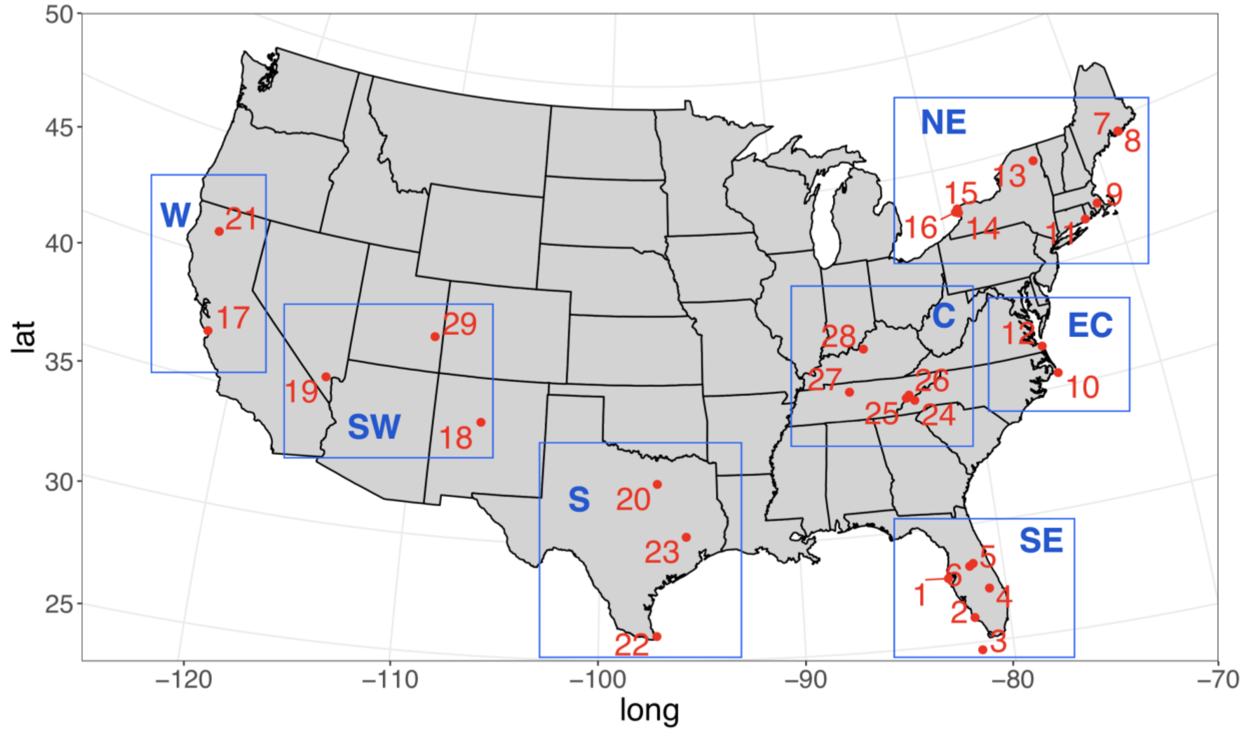
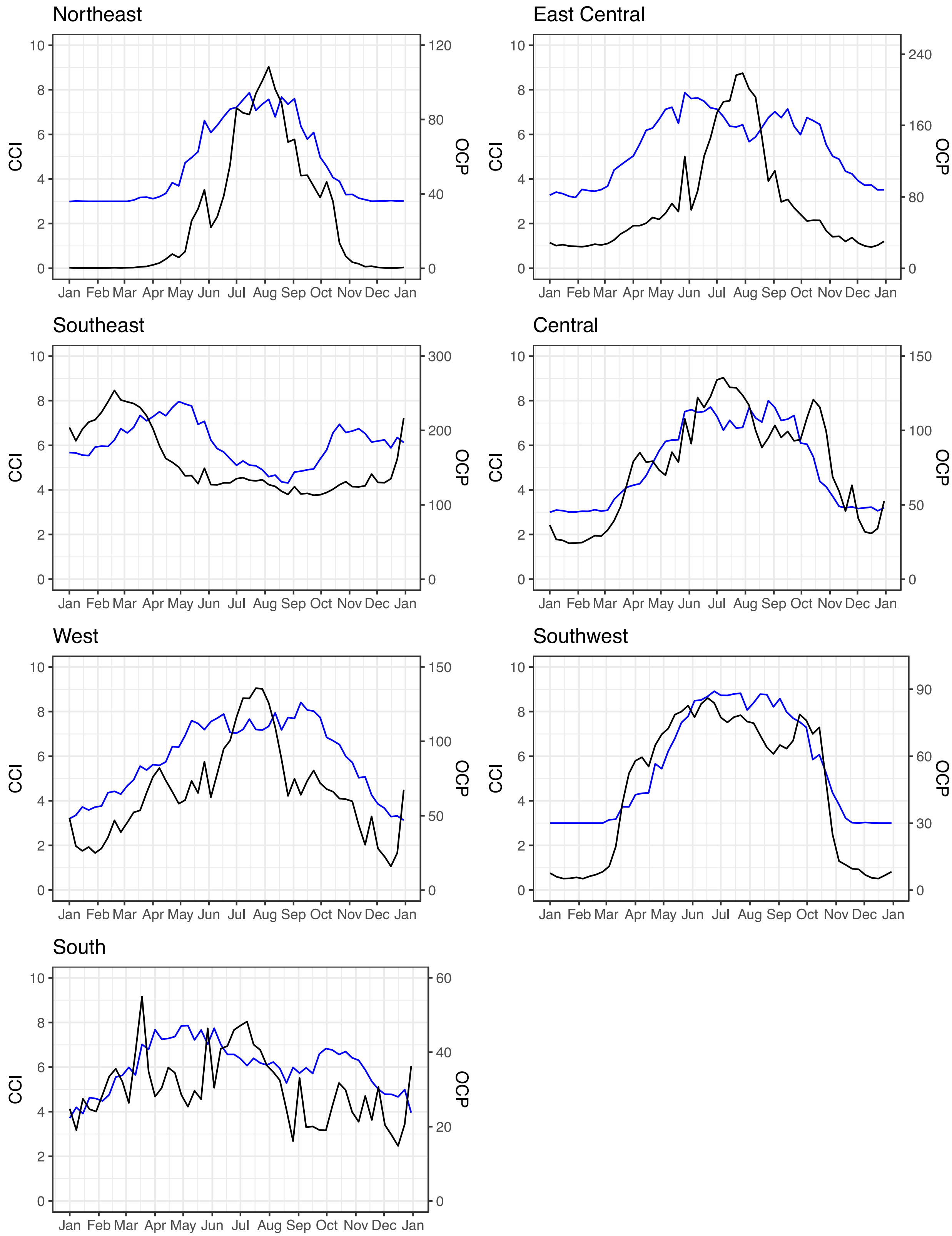
2.8 Figures and Tables

Figure 1. Locations and climate zones for camping businesses.



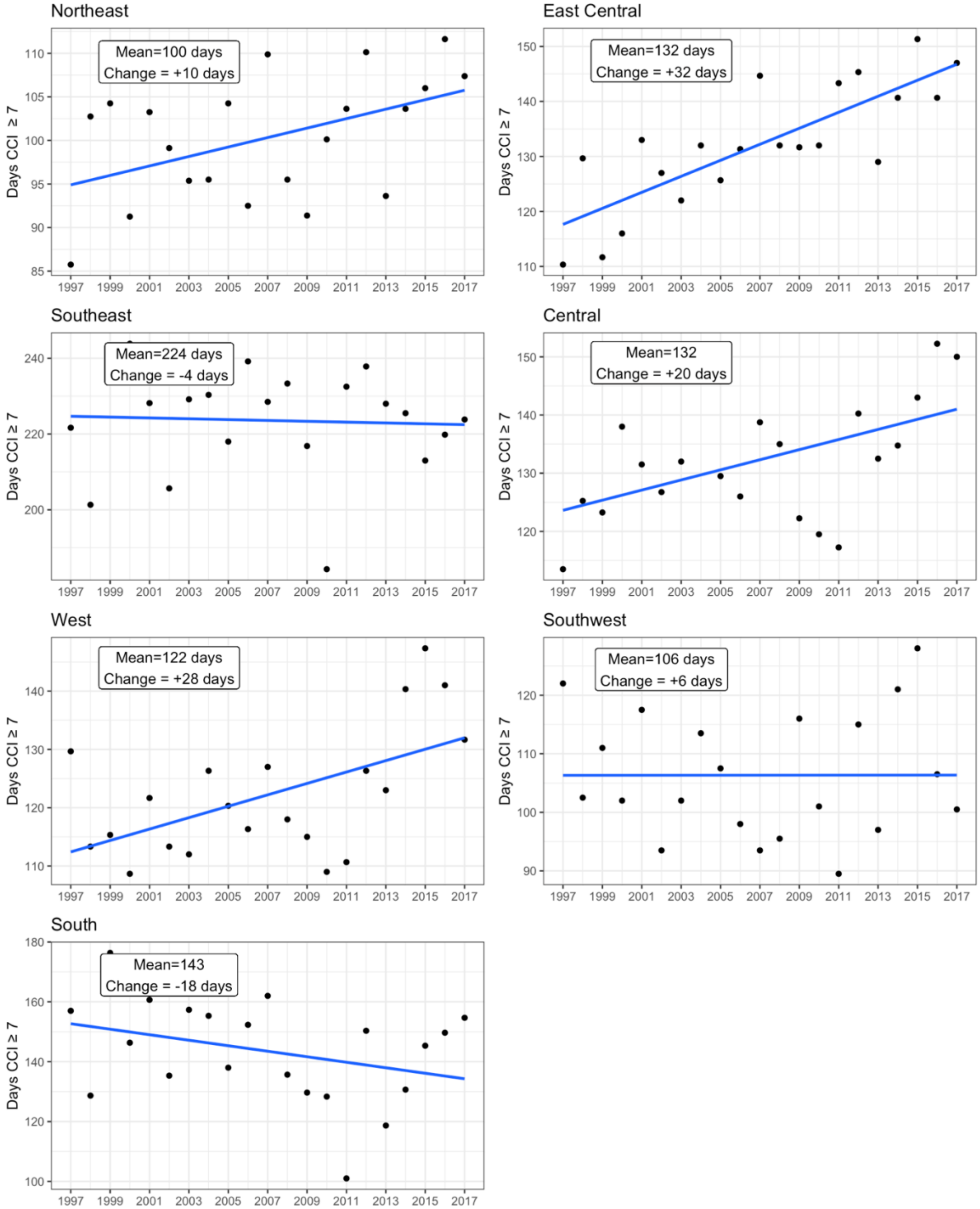
*Note. 29 privately-owned camping businesses throughout the United States in seven climate zones including: Northeast (NE); East Central (EC); Southeast (SE); Central (C); West (W); Southwest (SW); South (S).

Figure 2. Camping occupany and seasonality.



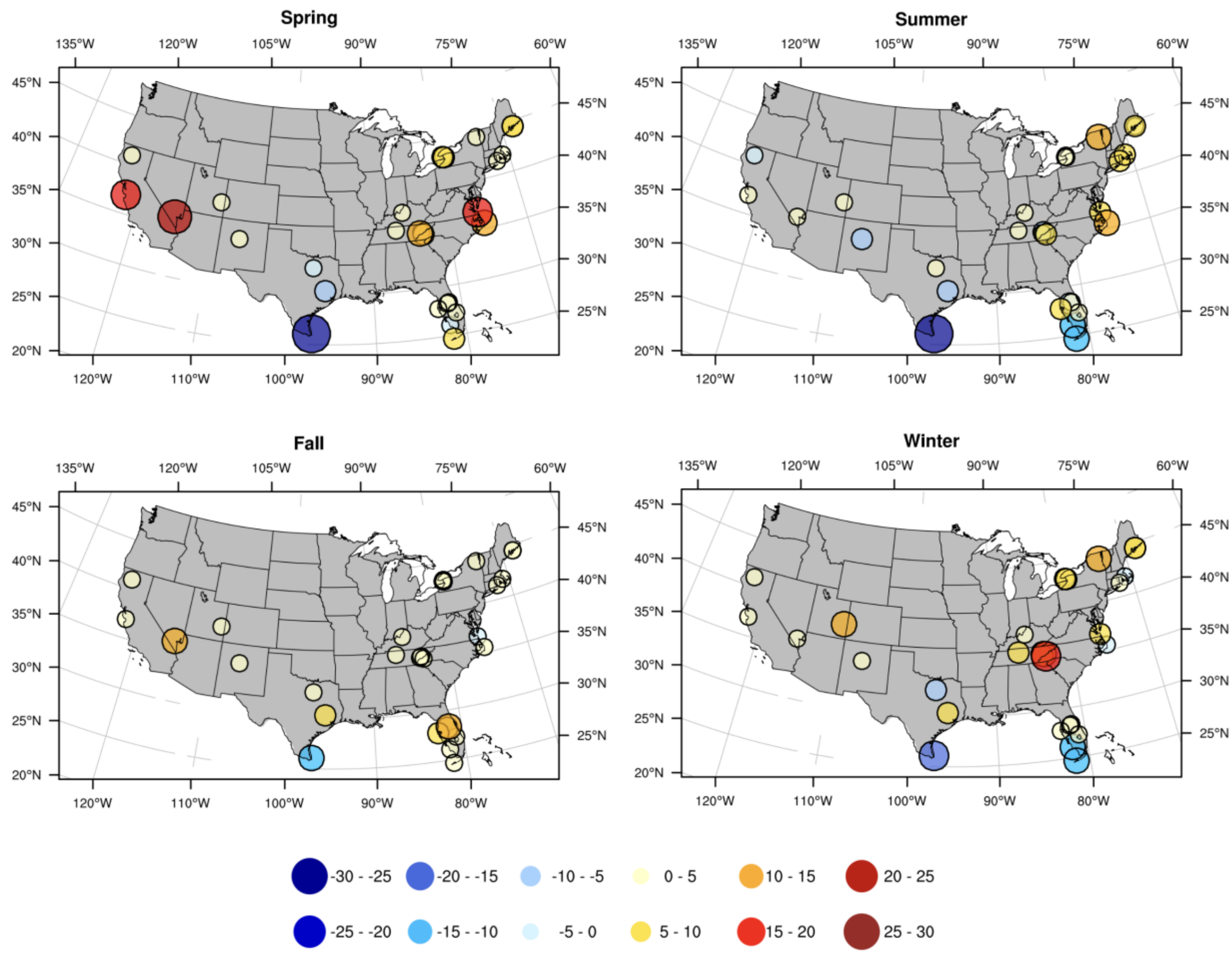
*Note. The black line is the weekly average camping occupancy for all camping categories (OCP) from January 1, 2007 – November 11, 2016. The blue line is the average CCI score. OCP and CCI used seven-day smoothed averages to alleviate impacts of institutional effects for occupancy and extreme weather events for CCI.

Figure 3. Average ideal camping days and change in ideal camping days 1997 – 2017.



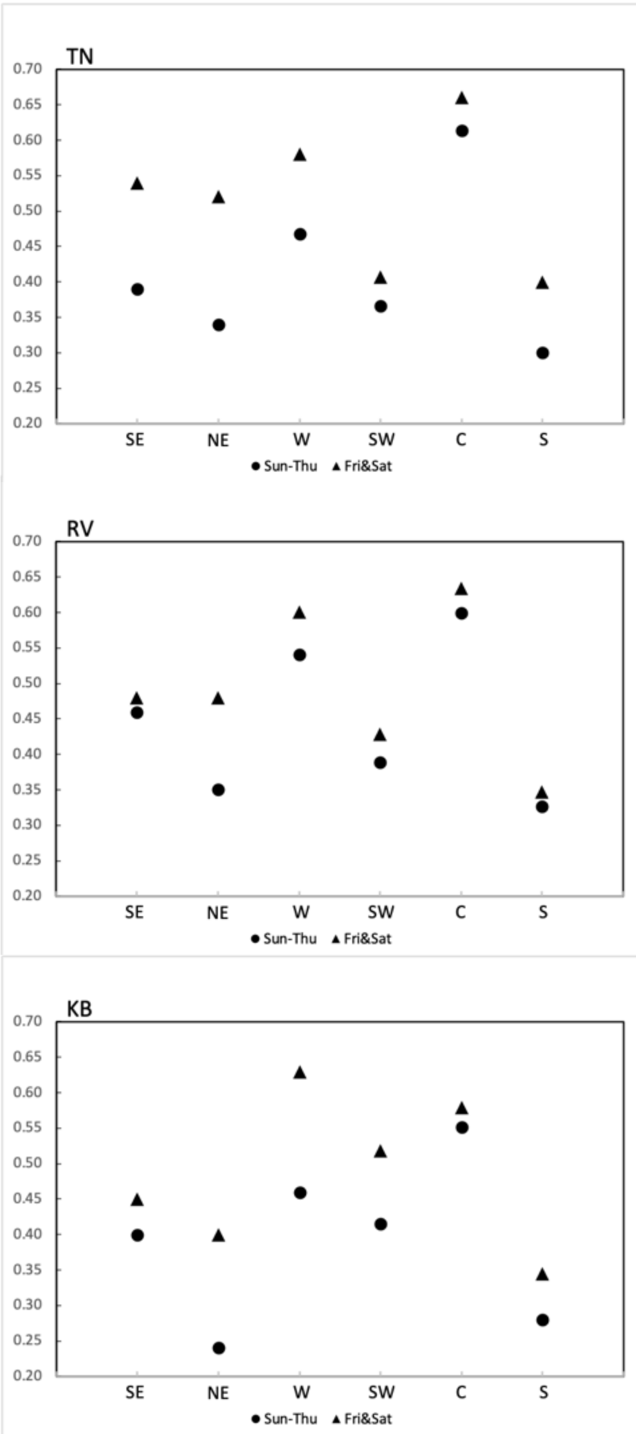
*Note. Figures dictate that average numbers of ideal camping days 1997 – 2017 and the change in ideal camping days 1997 – 2017.

Figure 4. Change in ideal camping days by season 1997 – 2017.



*Note. Values indicate percentage change in ideal camping days 1997 – 2017 for the 29 camping locations.

Figure 5. Correlation between CCI and camping by category for weekends and weekdays.



*Note. Average Friday and Saturday occupancy (TN = 8; RV: 65; KB: 13) and average Sunday through Thursday occupancy (TN = 6; RV = 55; KB = 7) Table 1. Study weather variables

Table 1. Study weather variables.

Sub-index variable	**Initials**	**Climate Resource**	**Units**	**Index**	**Climate variable required**
Daytime Comfort Index	CID	Thermal	Reported as °C	TCI	Maximum temperature (℃) Minimum RH
Daily Comfort Index	CIA	Thermal	Reported as °C	TCI	Mean temperature (℃) Mean RH
Thermal Comfort	TC	Thermal	Reported as °C	HCI, OPT, CCI	Mean temperature (℃) Mean dew point temperature (℃)
Precipitation	P	Physical	Millimeters (mm)	TCI, HCI, OPT, CCI	Precipitation (mm)
Windspeed	W	Physical	Kilometer per hour (km/hr)	TCI, HCI, OPT, CCI	Windspeed (km/hr)
Sunshine hours	S	Aesthetic	Hours (hr)	TCI, CCI	Solar radiation (w/m^2) Location coordinates
Cloud cover	A	Aesthetic	Cloud cover (%)	HCI, OPT	Cloud cover (%)

*Note. CID, CIA and TC are all dimensionless units, but are reported at °C values.

RH: relative humidity.

Location coordinates: Longitude and Latitude.

All recoded climate variables range from 0 to 10.

Table 2. Comparison tourism index formulas.

Index	Formula
TCI	40% CID + 10% CIA + 20% P + 20% S + 10% W
HCI	40% TC + 20% A + 30% P + 10% W
OPT	75% TC + 15% A + 5% P + 5% W

Table 3. Weather variable ranking scores.

Thermal comfort (TC)		Sunshine (S)		Precipitation (S)		Windspeed (W)	
°C	Rating	Hr	Rating	Mm	Rating	Km/hr	Rating
≥42	0	≥14	10	0	10	[0,2]	9
[34,42]	7	[12,14]	9	[0,0.03]	7	[2,5]	10
[28,34]	10	[9,12]	8	[0.03,4]	4	[5,10]	9
[24,28]	9	[6,9]	4	[4,8]	2	[10,15]	8
[20,24]	8	[4,6]	2	≥8	0	[15,20]	6
[16,20]	7	<4	0			[20,25]	4
[12,16]	6					[25,30]	3
[8,12]	5					[30,38]	1
[4,8]	4					≥38	0
[2,4]	3						
<4	0						

Table 4. Tourism index values and categories.

CCI		TCI		HCI	
Value	*Category*	*Value*	*Category*	*Value*	*Category*
[7,10]	optimal	[80,100]	excellent	[80,100]	excellent; ideal
[5,7]	good	[60,80]	very good; good	[60,80]	very good; good
[3,5]	acceptable	[40,60]	acceptable	[20,60]	acceptable
[0,3]	unfavorable	[-20,39]	unfavorable	[0,20]	dangerous

Note. The OPT index does not provide index categories and thus was omitted from this table.

Table 5. Beta coefficients from multivariate regression results.

TN	*n = 3603 days*						
Climate Zones	**SE**	**EC**	**NE**	**W**	**SW**	**C**	**S**
TC	17.91	4.04	10.86	4.97	5.01	2.87	1.32
S	14.23	3.45	5.77	4.45	4.63	1.45	3.45
P	2.22	0^{ns}	1.27	0.24^{ns}	0.89	0^{ns}	0
W	3.28	1.18	2.36	0.75	0	0.25	0^{ns}
Institutional	18.79	4.57	5.75	3.08	1.12	0.94	1.25
R^2	0.42	0.46	0.66	0.53	0.69	0.61	0.25

RV	*n = 3603 days*						
Climate Zones	**SE**	**EC**	**NE**	**W**	**SW**	**C**	**S**
TC	19.31	38.44	55.56	27.49	18.07	41.17	0^{ns}
S	29.73	37.15	26.03	28.57	13.24	22.67	7.64
P	0.61	2.52	5.73	0^{ns}	0	1.25^{ns}	0
W	6.45	5.44	9.18	0	5.79	5.22	0
Institutional	12.38	30.46	33.62	24.77	3.35	9.54	10.99
R^2	0.28	0.64	0.82	0.47	0.68	0.56	0.28

KB	*n = 3603 days*						
Climate Zones	**SE**	**EC**	**NE**	**W**	**SW**	**C**	**S**
TC	1.87	18.17	20.74	8.33	5.89	9.06	1.06
S	5.74	11.37	6.27	8.18	3.9	7.14	9.74
P	0	0	1.56	0^{ns}	0	0^{ns}	0.34^{ns}
W	0	2.39	2.29	0	0^{ns}	0	0.3
Institutional	8.11	16.92	12.76	12.09	1.67	4.12	9.09
R^2	0.22	0.5	0.72	0.46	0.56	0.33	0.08

Table 6. Relative significant of climatic variables on camping activity.

TN	TC	Sunshine	Precipitation	Wind
SE	48%	38%	6%	9%
EC	47%	40%	0%	14%
NE	54%	28%	6%	12%
W	48%	43%	0%	7%
SW	48%	44%	8%	0%
C	63%	32%	0%	5%
S	28%	72%	0%	0%
US	48%	42%	3%	7%

RV	TC	Sunshine	Precipitation	Wind
SE	34%	53%	1%	11%
EC	47%	44%	3%	6%
NE	65%	22%	5%	9%
W	49%	51%	0%	0%
SW	49%	36%	0%	16%
C	59%	32%	2%	7%
S	0%	100%	0%	0%
US	43%	48%	1%	7%

KB	TC	Sunshine	Precipitation	Wind
SE	25%	75%	0%	0%
EC	57%	36%	0%	7%
NE	67%	20%	5%	7%
W	50%	50%	0%	0%
SW	60%	40%	0%	0%
C	56%	44%	0%	0%
S	9%	85%	3%	3%
US	46%	50%	1%	3%

Table 7. Variability (r2) in occupancy explained by CCI, TCI, HCI, and OPT by climate region.

Annual **n=119 months (from January 2007 to November 2016)**

Climate zones	SE			EC			NE			W			SW			C			S		
Camping category	KB	TN	RV	KB	TN	RV	KB	TN	RV	KB	TN	RV	KB	TN	RV	KB	TN	RV	KB	TN	RV
CCI	0.04	0.06	0.1	0.58	**0.65**	**0.7**	**0.86**	**0.79**	**0.94**	0.59	**0.62**	0.48	**0.62**	**0.83**	**0.67**	0.34	**0.78**	**0.64**	0.29	0.21	0.07
TCI	0.01	0.1	0.2	0.27	0.24	0.31	**0.67**	0.58	**0.76**	0.24	0.5	0.2	0.55	**0.64**	**0.7**	0.12	0.35	0.42	0.27	0.03	0.13
HCI	0.01	0.05	0.1	0.46	0.52	0.58	**0.81**	**0.79**	**0.84**	0.57	0.4	0.34	0.25	0.35	0.21	0.22	**0.62**	0.39	0.06	0.07	0
OPT	0.01	0	0	0.54	0.54	**0.64**	**0.81**	**0.74**	**0.89**	**0.73**	0.47	0.51	0.54	**0.71**	0.57	0.26	**0.76**	0.51	0.1	0.13	0.01

Spring **n=30 months**

Climate zones	SE			EC			NE			W			SW			C			S		
Camping category	KB	TN	RV	KB	TN	RV	KB	TN	RV	KB	TN	RV	KB	TN	RV	KB	TN	RV	KB	TN	RV
CCI	0.07	0.09	0.13	0.52	**0.86**	**0.83**	**0.80**	**0.84**	**0.87**	**0.62**	**0.89**	0.12	0.27	**0.60**	0.50	0.15	**0.68**	0.22	0.33	0.06	0.38
TCI	0.10	0.03	0.30	0.42	0.56	**0.76**	**0.74**	**0.77**	**0.82**	**0.52**	0.47	0.05	0.22	0.59	0.39	0.08	0.41	0.21	0.00	0.00	0.01
HCI	0.00	0.02	0.00	0.37	**0.63**	**0.70**	0.46	**0.50**	0.48	0.31	0.36	0.03	0.00	0.02	0.01	0.05	0.48	0.15	0.24	0.01	0.19
OPT	0.05	0.05	0.00	0.47	**0.70**	**0.75**	**0.79**	**0.80**	**0.87**	0.49	**0.67**	0.07	0.20	**0.62**	0.39	0.05	0.53	0.14	0.08	0.02	0.32

Summer **n=30 months**

Climate zones	SE			EC			NE			W			SW			C			S		
Camping category	KB	TN	RV	KB	TN	RV	KB	TN	RV	KB	TN	RV	KB	TN	RV	KB	TN	RV	KB	TN	RV
CCI	0.07	0.12	0.24	0.13	0.21	0.45	**0.64**	**0.72**	**0.61**	0.02	0.10	0.11	0.01	0.02	0.01	0.08	0.26	0.12	0.16	0.35	0.15
TCI	0.04	0.02	0.10	0.08	0.13	0.26	0.36	0.40	0.35	0.24	0.45	0.45	0.00	0.11	0.02	0.00	0.00	0.03	0.21	0.14	0.14
HCI	0.06	0.02	0.20	0.17	0.10	0.17	0.59	**0.69**	**0.67**	0.24	0.12	0.12	0.00	0.08	0.03	0.01	0.25	0.06	0.02	0.02	0.01
OPT	0.08	0.04	0.20	0.19	0.18	0.31	**0.63**	**0.77**	**0.74**	0.25	0.13	0.12	0.00	0.08	0.04	0.01	0.01	0.00	0.04	0.06	0.20

Fall **n=30 months**

Climate zones	SE			EC			NE			W			SW			C			S		
Camping category	KB	TN	RV	KB	TN	RV	KB	TN	RV	KB	TN	RV	KB	TN	RV	KB	TN	RV	KB	TN	RV
CCI	0.11	0.06	0.09	**0.62**	**0.64**	**0.76**	**0.83**	**0.79**	**0.93**	0.58	**0.67**	0.19	**0.73**	**0.84**	**0.82**	0.37	**0.79**	0.58	0.17	0.19	0.17
TCI	0.01	0.02	0.04	0.42	0.36	**0.65**	**0.73**	**0.72**	**0.85**	0.43	0.23	0.06	**0.61**	**0.71**	**0.74**	0.16	**0.68**	0.3	0.31	0	0.01
HCI	0.04	0.02	0.05	0.44	0.43	0.57	0.59	**0.61**	**0.6**	0.4	0.51	0.07	0.26	0.39	0.24	0.26	0.44	0.09	0.1	0.01	0
OPT	0.09	0.03	0.05	0.46	0.47	**0.66**	**0.75**	**0.74**	**0.87**	0.57	0.52	0.15	**0.6**	**0.76**	**0.63**	0.21	**0.62**	0.2	0.01	0.08	0.02

Table 7. Variability (r2) in occupancy explained by CCI, TCI, HCI, and OPT by climate region. (Cont.)

Winter		**n=29 months**																			
Climate zones		SE			EC			NE			W			SW			C			S	
Camping category	KB	TN	RV	KB	TN	RV	KB	TN	RV	KB	TN	RV	KB	TN	RV	KB	TN	RV	KB	TN	RV
CCI	0.12	0.19	0.19	0.31	0.04	0.07	-	-	-	**0.63**	**0.65**	0.03	0.02	0.09	0.03	0.11	0.14	0.28	0.14	0.23	0.20
TCI	0.20	0.10	0.09	0.00	0.03	0.02	-	-	-	0.28	0.30	0.03	0.02	0.02	0.11	0.00	0.09	0.02	0.21	0.20	0.05
HCI	0.07	0.07	0.14	0.09	0.06	0.03	-	-	-	0.03	0.05	0.04	0.02	0.05	0.03	0.12	0.01	0.00	0.09	0.11	0.01
OPT	0.10	0.11	0.14	0.28	0.00	0.04	-	-	-	0.50	**0.60**	0.06	0.02	0.02	0.07	0.07	0.11	0.21	0.16	0.11	0.01

*Note. Significant relationships ($p < .01$) are denoted by bolded values.

Chapter 3. Ma, S., Craig, C. A., & Feng, S. (2021). Climate resources at United States National Parks: A tourism climate index approach. *Tourism Recreation Research*, 1-15. (published)

3.1 Abstract

Nature-based tourism is beholden to weather, extreme weather, and climate change (i.e. climate resources), though researchers have yet to longitudinally explore the influence of climate resources on United States National Parks for visitation and camping. Accordingly, this study operationalises climate resources at 11 southern United States National Parks using five tourism climate indices including the Tourism Climate Index, Holiday Climate Index (urban and beach), Optimised Index, and Camping Climate Index. Results demonstrate that the Camping Climate Index is more predictive of visitation, recreational vehicle camping, and tent camping compared to other indices, though not for all locations or tourism activities. Results also indicate that between 1981 and 2019 climate resources improved at mid-latitude parks though either declined or moderately improved for parks in arid and tropical locations. Discussion, limitations, and future research directions are provided.

Chapter 3. Climate resources at United States National Parks: A tourism climate index approach

3.2 Introduction

3.2.1 Nature-based tourism and climate variability

Nature-based tourism—the fastest-growing segment of the tourism industry (UNWTO, 2020; Kuenzi & McNeely, 2008)—accounts for 20% of all tourism worldwide (Center for Responsible Travel, 2019) and includes outdoor activities (e.g., camping, hiking, cross country skiing) that either depend upon or are enhanced by the natural environment (Eagles et al., 2001; Wearing & Neil, 2009). Wilson (1992) defines nature-based tourism as the "temporary migration of people to what they understand to be a different and usually 'purer' environment." Nature-based tourism captures the relatively undisturbed phenomenon of nature and activities of nature-based tourists are dependent on weather and climate conditions (Verbos et al., 2018; Wilkins et al., 2018). Weather occurs days to months, climatic variability months to years, and climate change over decades. Both short- and long-term conditions, including shifting seasonality, have a significant impact on tourist motivations (Hewer et al., 2016; Goh, 2012; Li et al., 2018; Ma et al., 2020a; Scott et al., 2019; Scott et al., 2012). For instance, the IPCC (2001) notes "an extended warm-weather recreation season is likely to be economically beneficial" (p. 769). Moreover, the sensitivity of weather and climate impact on nature-based tourism varies depending on different tourism activities, geographic locations, landscapes, and other specific attractions of the destinations (Bigano et al., 2006; Hoogendoorn & Fitchett, 2018; Perch-Nielson, 2010; Salpage et al., 2020; Steiger et al., 2019). Therefore, it is necessary to understand weather and climate resources relevant to tourists to inform destination choice and management.

3.2.2 Camping, COVID, and climate at US National Parks

National parks are increasingly popular globally (Esfandiar et al., 2019) providing easily assessable nature-based tourism and recreation opportunities. In the United States, parks serve as an economic driver where 2019 marked the fifth consecutive year with over 300 million visits resulting in over $41 billion in economic benefits (National Park Service, 2020). Despite the novel coronavirus 2019, the socially distant setting of United States National Parks led to a "booming business" over the summer and into the fall of 2020 (Nathan, 2020). However, with the influx of tourists came safety concerns about accommodations; over twice as many travelers viewed camping as the safest accommodation compared to hotels, resorts, or shared accommodations (e.g., Airbnb) (Cairn Consulting Group, 2020a). With the coronavirus pandemic expected to persist through at least 2022 (Kissler et al., 2020), United States National Parks remain an accessible and viable option for outdoor recreation (e.g., park visitation) and accommodations (e.g., camping).

Regardless coronavirus conditions, a primary determinant of national park tourism and recreation is local weather and climate conditions (Hewer et al., 2017; Monahan et al., 2016). This did not change during the height of the pandemic; favorable weather continued to significantly influence nature-based tourism decisions throughout the United States (Authors, 2020a). United States National Parks are valuable assets, protecting the natural heritage of the country while generating tens of billions of dollars a year, necessitating the need to understand how changing climate resources influence parks (National Park Service, 2020; Gonzalez et al., 2018; Jedd et al., 2018). Recognizing the economic impact of United States National Parks, Rice et al. (2019) used retrospective time series forecasting to determine the best method to forecast camping occupancy. Despite previous studies that quantified the influence of weather and weather extremes on privately-owned campsites (Craig & Feng, 2018), however, Rice et al. (2019) did not include weather in their models. To date, we are unaware of research that explores the influence of weather and climate resources on nature-based tourism for United States National Parks.

Accordingly, we address this knowledge gap using a case study of 11 national parks in the southern United States from 1981 to 2019. Specifically, we utilize a tourism climate index approach to establish the relationship that weather and climate resources share with United States National Park visitation, recreational vehicle (RV) camping, and tent camping. Five tourism climate indices—the Tourism Climate Index (TCI, Mieczkowski, 1985), the Holiday Climate Index (HCI-urban, Scott et al., 2016; HCI-beach, Rutty et al., 2020), an optimized index for tourism (henceforth identified as the Optimized Index; Matthews et al., 2019), and the Camping Climate Index (CCI; Ma et al., 2020a)—are utilized to quantify weather and climate resources at United States National Parks to address the following questions:

Research Question 1: Which index best explains the relationship with park visitation, RV camping, and tent camping at United States National Parks?

Research Question 2: What are the historic long-term trends for climate resources, visitation, and camping at United States National Parks?

In the following, select literature pertaining to the tourism climate index approach will be discussed followed by methods, results, discussion, and conclusion sections.

3.3 Tourism Climate Indices

Climate indices have been around for over 100 years, historically describing thermal conditions (e.g., temperature and humidity) (De Freitas & Grigorieva; 2015). De Freitas (2003) highlighted “a need for a tourism climate index (or indices) that integrates all facets of climate, uses standard data and is objectively tested and verified” (p. 45). Since, climate indices have evolved in the tourism and climatology literatures building on the seminal TCI (Mieczkowski, 1985) to include additional meteorological factors to assess environmental and tourists interactions (Matzarakis, 2007; Agnew & Palutikof, 2006; Gossling & Hall, 2006; Forster et al., 2012). More recently, researchers have also explored the overriding effects of weather extremes on tourism derived from industry expert opinion (Yu et al., 2009), survey revealed preferences (Scott et al, 2016; Rutty et al., 2020), and tourists’ behaviors (Craig & Feng, 2018; Ibarra, 2011; Matthews et al., 2019; Wilkins et al., 2021).

Weather and climate are supply- (i.e., tourism operators) and demand-side (i.e., tourists) resources for the growing nature-based tourism industry (Rogerson & Rogerson, 2020; Scott & Lemieux, 2010) and an index approach has proven useful at quantifying the resources (De Freitas et al., 2008; Matzarakis, 2007; Moore, 2010). The multifaceted nature of weather and the complexity of its interactions with tourists’ destination choices make a climate index approach a viable method to quantify tourism weather and climate resources (Matthews et al., 2019; Dubois et al., 2016). The composite climate indices for tourism consider three aspects of tourists’ weather experiences: thermal, physical, and aesthetic (De Freitas, 2003; De Freitas et al., 2008). The thermal aspect involves individual perceptions about heat or cold according to the atmospheric environment (e.g., temperature, “feels like” temperature, relative humidity). The physical aspect involves the presence of specific meteorological elements, such as precipitation and wind, which directly affect or restrict outdoor activities. The aesthetic aspect is based on the visibility (e.g., hours of sunshine or cloudiness). Indices are comprised of variably weighted weather and climate resources (i.e., thermal, physical, and aesthetic) associated with an index rating system (e.g., 0-10, 0-100) where the primary goal of an index is to capture preferred conditions that broadly represent the overall suitability for tourists.

The practicability of composite climate indices for tourism is derived from non-linear impacts of climate conditions on suitability for tourists. Three approaches have been used to calibrate tourists climate preferences: expert-based, survey-based, and experienced-based (Scott et al., 2008). The five focal indices operationalized here include an expert-based index (i.e., TCI), two survey-based indices (i.e., HCI-urban, HCI-beach), and two experienced-based indices (i.e., Optimized Index, CCI). There are additional indices that may be of use dependent on geography, tourism subsector, or other application (e.g., location desirability), though the study scope is limited to the most widely used indices (i.e, TCI, HCI) and data-driven indices (i.e., Optimized Index, CCI). For instance, the Beach Climate Index (BCI; Morgan et al., 2000) is a survey-based index based on Nordic beach users, though their preferences differ from beach users elsewhere. Another promising index is the Relative Climate Index (RCI; Li et al., 2018), which applies a push and pull framework to assess differences in tourist origins and destinations. The RCI made a theoretical advancement by constructing the relative attractiveness of destinations. However, the RCI utilizes a variation of the TCI, therefore is not operationalized either.

The five indices included in the study are described below:

3.3.1 Tourism Climate Index (TCI)

The seminal tourism climate index— the TCI (Mieczkowski, 1985)—is a general sightseeing, broadly applicable expert-based climate index that has been applied extensively in different regions throughout the world (see supplementary Table 6 for a comprehensive overview of indices). A weakness of the TCI is that it does not include a mechanism to capture the nuances across tourism sectors. Not all tourism sectors respond the same to weather and climate conditions, thus tourism sectoral differences often require tailored indices (Jeuring, 2017; Morgan et al., 2000; Scott et al., 2016). For instance, Rutty and Scott (2015) assert that "beach users hold fundamentally different comfort perceptions and preferences compared to people using urban spaces" (p. 1). The TCI also does not have a mechanism within its component weighting system to capture overriding, extreme conditions. To be fair, Mieczkowski (1985) acknowledged the need for index customization based on tourism subsector, a call that led to the development of the next generation survey-based and experienced-based indices (see Tables 1 and 2 for required weather variables and index formulas).

3.3.2 Holiday Climate Index (HCI) – urban

The HCI-urban (Scott et al., 2016) introduces three modifications to the TCI: (1) sector-oriented on urban tourism, (2) objective rating scale based on surveys and available literature, and (3) recognition of overriding physical factors. The relative significance of climate variables (i.e., component weightings) within the index is derived from tourists stated preferences on surveys and the biometeorology literature. The HCI-urban captures overriding weather effects by assigning equal weights to thermal and physical resources (both 40%) to lower the index rating category when extreme precipitation occurs. Specifically, the lowest rating of physical factors can pull the overall index score from "acceptable" to "unfavorable" (Table 2) regardless of thermal and aesthetics factors. Researchers have used the HCI-urban to quantify weather and climate resources for beach tourism, urban tourism, and general tourism in multiple countries in the northern hemisphere (see supplementary Table 6). There are a few potential weaknesses with the HCI-urban including: (1) the additive method used to aggregate climate factors may not precisely reflect the non-linear, overriding effects of physical factors (De Freitas et al., 2004); (2) survey-based indices may introduce an uncertain response bias (Bigano et al., 2006), and; (3) there have been observed inconsistencies between reported tourists' preferences and actual behaviors (Craig & Feng, 2018; Craig, 2019).

3.3.3 Holiday Climate Index (HCI) – beach

The HCI-beach, an update to the HCI-urban, was proposed by Scott et al. (2015) and the index was validated by Rutty et al. (2020). The HCI-beach is tailored to beach tourism where its component weights and sub-ratings are informed by surveys among coastal tourists over a decade. There are two differences between the HCI-beach and HCI-urban. The first is that the HCI-beach updated weights to reflect that cloudiness is a more salient factor than thermal factors for beach activities (i.e., aesthetic factors 40%, thermal comfort 20%). The HCI-beach also adjusted the sub-index rating system of the HCI-urban to reflect that beach tourists prefer warmer temperatures. That is, 30 °C is rated 10 for the HCI-beach compared to 6 and 7 in TCI and HCI-urban, respectively. Like the HCI-urban, the HCI-beach maintains a 40% rating for physical components (i.e., precipitation and wind) to capture overriding effects. The HCI-beach has the same potential weaknesses as the HCI-urban.

3.3.4 Optimized Index

Matthews et al (2019) adopted a new mathematical optimization (i.e., the Optimized Index) approach based on daily park beach visitation data in Ontario Canada. The data-driven process defines the sub-index weighting and rating systems by using an optimization routine to achieve the highest fit (r^2) between observed weather and reported visitation data. The mathematical regression results suggest thermal comfort is the dominant factor (75%) for park beach visitation while sunshine and cloud cover (i.e., aesthetic) are moderated factors (15%) and precipitation (5%) and wind speed (5%) are minor factors. The Optimized Index underscores the predictability of a high temporal resolution, data-driven approach compared to expert- and survey-based approaches. Because the Optimized Index was validated in Ontario Canada for beach visitation, a potential weakness is its generalizability to other geographies and activities.

3.3.5 Camping Climate Index (CCI)

The CCI was empirically validated at 29 for-profit campsites across the United States with matched daily weather and occupancy data from 2007 to 2016 (Ma et al., 2020a). Iteration correlation and multiple linear regression were used to determine component weights, sub-ratings, and threshold levels for overriding effects. Results demonstrate thermal comfort and aesthetic factors are of equal importance (50%) for camping. Critical threshold values were identified independently of the weighted index, finding that thermal and physical thresholds (i.e., minimum temperature, maximum temperature, extreme precipitation, high wind) are inversely impact overall suitability of conditions. In other words, the index forces conditions to the "unacceptable" category if a threshold is exceeded. The CCI requires higher temporal resolution data (at least daily) to capture and punish weather extremes, a unique characteristic compared to other indices. Comparable to the Optimized Index, a potential weakness is generalizability to other geographies and non-camping activities.

3.4 Methods and materials

3.4.1 Study area and tourism data

The study area consists of 11 parks in the southern United States. As shown in Figure 1, the parks are representative of four main climate classifications (henceforth referred to as climate regions): tropical, temperate, subtropical, and arid (Feng et al., 2014). Table 3 provides the park name, climate sub-classifications, and coordinates. The parks at the subtropical and temperate climate regions are grouped together as the “warm” region because the six parks analyzed are located along the climate classification boundaries and demonstrate similar park visitation patterns in terms of seasonality. Monthly data was retrieved from the National Parks Service (2020) from 1981 to 2019 for recreational visits, RV camping, and tent camping. Visits represent the number of individuals who enter the parks and camping occupancy is based on the number of individuals at the campsites. For detailed counting procedures, please see National Park Service (2020).

3.4.2 Climate indices and data

The five tourism climate indices calculated in the study are TCI (Mieczkowski, 1985), HCI-urban (Scott et al., 2016), HCI-beach (Rutty et al., 2020), the Optimized Index (Matthews et al., 2019), and CCI (Ma et al., 2020a). The required daily meteorological data for each index (see Table 1) was retrieved at the 11 national parks from January 1, 1981 to December 31, 2019. Maximum temperature, minimum temperature, dew point temperature, and precipitation were obtained from the PRISM dataset (Di Luzio et al., 2008). Windspeed, could cover, and solar radiation were retrieved from the North American Regional Reanalysis dataset (Mesinger et al., 2006). Relative humidity was calculated from dew point temperature and air temperature. Each index rating system is defined differently, therefore we rescaled all the indices from 0 (unfavorable) to 10 (excellent) for comparison purposes (see Table 2).

3.4.3 Time series and analysis

There are three time series explored for each index including park visitation, RV camping, and tent camping (a total of 15 matched time series). It is possible that the three time series will increase over time because of the expansion of the nature-based tourism industry. Thus, to ensure the statistical properties of the time series did not change over time, we applied the Augmented Dickey-Fuller (ADF) test using the "tseries" package in R. In the event nonstationary data was detected, an order differencing technique was applied. Daily climate index scores were averaged to monthly means to correspond with the monthly park data.

To answer *Research Question 1*, which index best captures the relationship with park visitation, RV camping, and tent camping, cross-correlations were calculated to measure the similarity between the five index scores and parks data (i.e., visitation, RV camping, tent camping) as a function of the displacement of one relative to the other.

To answer *Research Question 2*, what are the climate resource, visitation, and camping trends at United States National Parks, long-term trends for each index were first calculated and mapped. Next, monthly arrivals for park visitation, RV camping, and tent camping as a percentage of annual totals were mapped alongside each index (i.e., TCI, HCI-urban, HCI-beach, Optimized Index, and CCI) to demonstrate seasonal variations for each time series sorted by climate region. Two-sided chi-square testing were also utilized to demonstrate seasonal variance for each index.

3.5 Results

3.5.1 Climate indices performance

To begin, cross-correlation was applied to the stationary time series to measure how index scores are numerically associated with park visitation, RV camping, and tent camping (see Table 4 for results sorted by tourism type and climate region). The hyphen sign in the table indicates there were no observations of the corresponding tourism type. The TCI outperformed for three sites in the arid and warm regions; the HCI-urban outperformed for three sites in the tropical and warm regions; the HCI-beach outperformed for three sites in the tropical and warm regions; the Optimized Index outperformed for nine sites in the tropical and warm regions, and; the CCI outperformed for 11 sites across the tropical, warm, and arid climate regions. When considering all scenarios (i.e., type of tourism and climate region), the CCI demonstrated the strongest overall performance. Curiously, the HCI-beach and the Optimized Index were negatively related to park visitation, RV camping, and tent camping at some locations in the arid climate region (Table 4).

3.5.2 Historic long-term trends

To quantify the long-term trend in climate suitability, "excellent" index ratings described in Table 3 were aggregated annually to form the 39-year time series sorted by the 11 United States National Parks (see Figure 3). All indices described an increased number of "excellent" days at locations for the mid-latitude, warm (include subtropical and temperate) climate region. Surrounded by the Appalachian mountain range, the Shenandoah and Great Smoky Mountain National Parks (sites 4 and 5) experienced the most improvement. In the low-latitude, tropical climate region, the indices delineate similar trends but in the opposite direction of the warm region where the number of "excellent" days declined. However, the trend is not as salient for the CCI. Interestingly, the trend among indices is inconsistent for the arid climate region, a region characterized as "hot, sometimes extreme hot summers and warm to cool winters with minimal precipitation" (Peel et al., 2007, p. 1636). In the arid region, no conclusive trend was detected for TCI and HCI-urban, the HCI-beach and the Optimized Index moderately improved, and the CCI declined.

To assess long-term trends in seasonality, the five climate indices were sorted by main Koppen-Trewartha climate regions (i.e., tropical, warm, arid) and graphed relative to the monthly percentage of park visitation, RV camping, and tent camping (see Figure 4). Overall, the climate indices resemblance to the seasonal patterns indicates a strong relationship with combined park arrivals with exception of two indices in the arid climate region: the HCI-beach and the Optimized Index scores are out of phase with park visitation, RV camping, and tent camping during summer months. Notably, the monthly CCI scores on average are lower than TCI and HCI score for all climate regions.

The tropical climate region represents a relatively homogenous atmospheric condition throughout the year (Feng et al., 2014). Comparably, the distribution of park visitation is relatively stable throughout the year and corresponds closely with climate index trends. The peak season for RV camping is December through March (91%) and for tent camping December through April (72%). The warm climate region demonstrates the most well-defined seasonality with minimal park visitors or campers in the winter months (December – February) corresponding with "unfavorable" index ratings. The majority of park visitation (52%), RV camping (55%), and tent camping (61%) corresponds to summer (June – August). In the arid region, park visitation closely resembles the most popular form of camping throughout the year;

January through April is the peak season for RV camping (54%) and March through June (50%) for tent camping. As shown in Figure 5, in the arid region the TCI is most closely with RV camping whereas the CCI trends most closely with park visitation and tent camping.

To compare the seasonal variability in the tropical, warm, and arid regions, the variance of daily TCI, HCI-beach, HCI-urban, Optimized Index, and CCI scores were calculated (see Table 5). The findings show the seasonal variation of expert-based and survey-based index scores (i.e., TCI, HCI-urban, and HCI-urban) is substantially less than the data-driven indices (i.e., Optimized Index and CCI). The seasonal variations of the Optimized Index is dominated by thermal factors (75%); the constant high temperature in the warm and arid climate regions led to a low index variation in summer, and the temperature shifts within seasons led to high index variations in the spring and fall. The CCI has a high variance in the tropical classification regardless of season due to (1) smaller temperature and sunshine hours ranges and (2) frequent overriding, extreme precipitation events. For the warm classification, the variance of CCI is low in winter where the CCI score remains constantly low, and high in shoulder seasons (spring and fall) in the mid-latitude regions because weather conditions fluctuate frequently during the transitional seasons. For the arid classification, however, the CCI variance is highest in summer due to frequent overriding, extremely hot days corresponding with “unfavorable” conditions (CCI ≤ 3) for tourists.

3.6 Discussion and Conclusion

According to Garth (2020), “Outdoor recreation—camping, hiking, biking, boating, fishing, wildlife watching and more—was social distancing before it had a name” (par. VII) which is largely attributable to the rebound in nature-based tourism and recreation with loosening coronavirus travel restrictions (Authors, 2020b; Gossling et al., 2020; Nathan, 2020; Rice et al., 2020). In fact, results from a national survey in September 2020 by Cairn Consulting Group (2020b) reveal "camping continues to experience a strong rebound with its ability to meet travelers' desire to experience the outdoors with natural social distancing" (p. 2). Prior to the pandemic, United States National Parks were an economic catalyst with hundreds of millions of visitors yearly and billions of dollars contributed to the US GDP (National Parks Service, 2020). This performance is attributable to the increasing popularity of camping and other nature-based forms of recreation and tourism (Cairn Consulting Group, 2019; Fieger et al., 2019). What makes nature-based tourism resilient to a pandemic—the socially distant, natural outdoor setting—also makes it susceptible to weather, extreme weather, and climate change. Thus, we sought to quantify weather and climate resources at United States National Parks by (1) determining which tourism climate index best describes the relationship with park visitation, RV camping, and tent camping and (2) establishing the long-term trends for and relationships between climate resources, park visitation, RV camping, and tent camping. The results of this study speak directly to the tourism climate change knowledge disconnect "between academic knowledge outputs and practical and political knowledge needs" (Loehr & Becken, 2021, p. 1).

Below, research question findings as well as limitations and future research are discussed followed by a conclusion section.

3.6.1 Index performance

Research Question 1 sought to determine which tourism climate index—TCI, HCI-urban, HCI-beach, the Optimized Index, or CCI—is more appropriate to explain relationships between climate resources and the United States National Parks outcomes of park visitation, RV camping, and tent camping for geographically distinct climate regions. Results demonstrate that the experienced-based, data-driven indices (i.e., Optimized Index and CCI) generally outperformed the expert-based (TCI) and survey-based indices (HCI) for park visitation and camping behaviors (see Figure 2). For all observations, the CCI outperformed at more parks for visitation (55%), RV camping (36%), and tent camping (46%) (see Figure 2).

However, the fact the CCI did not outperform other indices by a greater margin, particularly for camping, highlights the importance of utilizing multiple indices or index customization based on geographic region and tourism activity (Rutty & Scott, 2015). For instance, higher temperatures are characteristic for the arid climate region. Thus, a possible explanation for the superior performance of the TCI—an index that does not capture the overriding effects of temperature—for RV camping is that characteristics of RVs (e.g., air conditioning) result in lower tourist sensitivity to high temperatures. The Optimized Index also demonstrated geographic effects, where it performed comparable to the CCI in the warm climate region, the same region where the index was validated in Ontario Canada. Further, the HCI-beach weightings were derived from beach tourists' preferences, and outperformed other indices for tent camping at the only two locations where significant results emerged in the tropical climate region (Table 4). Results for the HCI-beach suggest that beach seekers are more resilient to higher temperatures and swift, intense precipitation events likely due to the late-afternoon cooling effect in tropical regions (Rutty & Scott, 2015; Rutty & Scott 2014; Rutty & Scott, 2013).

An example of significant underperformance also emerged for HCI-beach and the Optimized Index in the arid climate region. The persistent low precipitation levels characteristic of the arid climate region contribute to high HCI-urban and HCI-beach values throughout the year and in some cases HCI-beach has inadvertent inverse relationships with park outcomes. For example, the correlation between HCI-beach and RV camping at the two arid park locations is negative (i.e., r = -.59 and -.24; see Table 4). Conversely, the HCI-urban has less tolerance to high temperatures and thus the index scores are lower than HCI-beach in the summer. For the Optimized Index, thermal comfort is heavily weighted leading to high scores in the summer that are inverse to visitor and camping patterns in the arid climate region.

3.6.2 Long-term trends

Research Question 2 asks about the long-term trends for climate resources, visitation, and camping at United States National Parks. Figure 3 shows that the mid-latitude region (i.e., warm climate region) experienced the most improvement in climate resources as quantified by each index from 1981 to 2019. Conversely, we observed either a decline or a moderate improvement (dependent on index) in the tropical and arid climate regions. The shifting patterns of climate resources—both favorable and unfavorable dependent on climate region—are consistent with previous studies on global (Mieczkowski, 1985), continental (Scott et al., 2004), and national (Fisichelli et al., 2015; Ma et al., 2020a,b) geographic scales. Our results empirically support the assertion that climate change is unequally impacting the re-distribution of climate resources dependent on climate region and other characteristics (e.g., altitude) (Diffenbaugh & Burke, 2019; Ma et al., 2020a; Kilungu et al., 2019).

Pertaining to the HCI-beach, it is important to note that the index improvement in the arid climate region should not be interpreted as improving climatic conditions. The improvement is due to: (1) the weighting scheme where thermal comfort (i.e., mean temperature and dew point temperature) and aesthetic (i.e., cloud cover) factors are heavily weighted (60%) and (2) a rating system that is skewed to a higher score because of low relative humidity throughout the year. The unbalanced weighting and the contribution of dry air (i.e., low relative humidity) also explain why the HCI-beach is notably out of cycle with the TCI, HCI-urban, and CCI in the arid climate region from May to September (Figure 4).

Another index trend is related to variability, particularly in the warm and arid climate regions. Thermal comfort is a large contributor to both the Optimized Index and CCI, weighted at 75% and 50%, respectively. In turn, the data-driven indices (i.e., Optimized Index and CCI) exhibit higher seasonal variation (1) in the warm regions where the climate is characterized by four distinct meteorological seasons and (2) in arid regions where the climate is characterized by large daily and seasonal temperature ranges (Feng et al., 2014) (Figure 4). Conversely, the thermal weights are lower for HCI-urban (40%) and beach (20%) due to the heavier weightings on precipitation (30%) to capture overriding psychical conditions resulting in less variation.

Visitation and camping at United States National Parks are trending upwards throughout the study period with overall visits increasing from over 238 million in 1981 to over 327 million in 2019 (National Parks Service, 2020). The growth corresponds with increasingly favorable tourism climate index scores across much of the US—particularly in mid-latitude regions and above—with more improvement experienced in the spring and fall meteorologic seasons (see Figure 3 and also Ma et al., 2020b). Monahan et al. (2016) documented the earlier onset of spring at mid- to high-latitude parks, and Fisichelli et al. (2015) predicted future visitation growth at mid- to high-latitude parks in the spring and fall due to warming temperatures. Our findings support this assertion for mid-latitude locations, where climate resources, visitation, and camping were improving and in sync (Figure 4). Using monthly mean temperature, however, Fisichelli et al. (2015) were not able to capture short-term variations to traveler experiences, in particular how park visitors reacted when the 25°C mean temperature threshold they reported was exceeded.

The use of monthly data by Fisichelli et al. (2015) was necessitated by availability of matched parks visitation data. While the geographic scale (i.e., 340 locations) helps to establish general relationships between park visitation and shifting of favorability climatic resources (e.g., mean monthly temperatures), higher temporal resolution data is needed to assess geographically dispersed intermonth interactions between tourists and weather thresholds (Ma et al., 2020a; Wilkins et al., 2021; Yu et al., 2009). The need for higher resolution data is heightened due to the increased pace of climate change and increased frequency of both thermal (e.g., high temperature) and physical (e.g., extreme precipitation or wind) overriding conditions that inequivalently impact certain geographies (Monahan et al., 2016; Reidmiller et al., 2018; Wilkens et al., 2021). For instance, using daily social media posts from 2006 to 2018 Wilkins et al. (2021) established maximum temperature thresholds for visitor centers at 110 parks locations across 14 climate regions ranging from 21.0° C to 37.1° C. Without daily data, such threshold levels cannot be identified. Though the climate indices in this study were aggregated to monthly means to match with the monthly visitation and camping data, short-term extremes were still captured because more frequent extreme weather events within a month lead to lower monthly scores. Thus, in the tourism climatology context, monthly data derived from daily data represent a higher temporal resolution than monthly data.

3.6.3 Limitations and Future Research

This study provides a novel exploration of United States National Parks as the first known to assess the interrelations between nature-based tourism (i.e., visitation and camping), weather, and climate using a tourism climate index approach, though it is not without limitation. The first limitation is the use of monthly park visitation and camping occupancy data which necessitated aggregating daily climate indices to monthly to match datasets. Parks tourists travel usually lasts from a few days to one or two weeks. Though, monthly data do not clearly capture the daily variations in tourists' behaviors, nor do they capture other factors such as weekends, natural effects (e.g., hurricanes, foliage), or institutional effects (e.g., holidays). Ideally, we could have used daily visitation and camping data. Higher resolution visitation and camping data are needed to conduct analysis to better understand daily weather variability and also the impact of anomalously extreme weather events, however, the availability of such data remains a challenge (Craig, 2019; Hewer et al., 2016), particularly for national parks in the United States. Future researchers should strive to curate spatially diverse datasets that track daily visitation and camping behaviors in addition to other nature-based tourism outcomes of interest (e.g., hiking traffic, fishing permits).

Partially overcoming challenges of monthly data, the CCI demonstrates more variability (Table 5) during peak parks tourism seasons (spring, summer, fall) due to its ability to capture daily overriding temperature, precipitation, and wind events (i.e., frequency of overriding events forces monthly scores lower). Further, in the warm climate zone the Optimized Index demonstrated more variability in spring and fall. Further, Craig and Feng (2018) found that weather conditions can have leading effects on camping behaviors (i.e., occupancy). In other words, expectation of weather (e.g., based on forecasts) within a week or two can significantly influence future nature-based tourism behaviors. With increased accuracy in forecasting, the deviation from expectation and actual weather conditions is lowering (Scott & McBoyle, 2007). The expected weather can then be captured as actual conditions the month travel occurs. Future researchers should consider comparing differences in weather expectations and actual weather conditions.

Another limitation is the potential influence of institutional (i.e., societal factors) seasonality and natural seasonality not easily captured by climate indices (i.e., ecological factors other than climate change or weather) (Butler, 2001; Hadwen et al., 2011). The correlation between parks outcomes and the monthly indices might be inflated due to institutional effects such as weekends, holidays, distance traveled, or advanced booking. Or, the correlation between parks outcomes may not be as strong as one would expect based on the favorability of weather or climate conditions. For instance, the average fall CCI in Florida (i.e., tropical climate region) from 1984 to 2019 is good (CCI=6), a better score than all other states represented in our sample of parks (Ma et al., 2020b). However, visitation and camping are comparatively low in the fall (see Figure 4) corresponding with the Atlantic Ocean hurricane season, a socio-ecological factor difficult to clearly capture using a monthly index approach. Irrespective backward or forward analysis, future researchers and research models should consider how both non-natural (socio-economic, institutional) and/or natural (climate and weather conditions, extreme events, other ecological factors) effects influence tourist flows.

Lastly, the comparison of sector specific indices highlights strengths and weaknesses of each index and reveals an opportunity to advance the development of tourism indices more broadly. For instance, the CCI underperformed the TCI for RV camping in the arid regions and HCI-beach for tent camping in tropical regions suggesting that the extreme threshold values, as well as component sub-ratings, are likely different based on climate region and type of nature-based activity. We suggest that future researchers should more closely examine threshold values for adverse events. In turn, future iterations of indices should be refined dependent on nature-based activity and geographic location to quantify unique thresholds to overriding weather effects.

3.6.4 Conclusion

Climate indicators for tourism have evolved over the past four decades to better represent the nonlinear, multifaceted nature of climate resources. Scott et al. (2016) acknowledged that different types of nature-based tourism require different climate considerations and developed the HCI to address key limitations of the seminal TCI (Mieczkowski, 1985) including: crude climate input resolution, subjectivity, preclusion of extreme weather impact, and a unified application for distinct tourism segments. Rutty et al. (2020) further refined the HCI based on beach tourists' perceived preferences. Matthews et al. (2019) introduced a data-driven approach to mathematically optimize an index, and to remove human subjectivity from component weightings and ratings. Developing the CCI, Ma et al. (2020a) expanded the scope of Matthews et al. (2019) to camping where index ratings were punished for daily extreme, overriding thermal (i.e., high and low temperatures) and physical (e.g., heavy precipitation, high wind) events. Contributing to the further advancement of tourism climate indices, this study is the first known to utilize the index approach to explore the relationships that weather, climatic variability, and climate change (i.e., climate resources) share with three US National Park tourism and recreation outcomes: visitation, RV camping, and tent camping.

Study findings suggest that the CCI is the most predictive index overall, but not universally for all geographic locations and parks outcomes. We suggest that one of two approaches can be used to resolve inconsistencies in index performance when considering spatially dispersed tourism locations: (1) the use of multiple indices to determine best fit or (2) index customization based on geographic location and tourism activity. Mid-latitude United States National Parks locations are benefiting from more favorable climatic conditions where climate resources improved from 1981 to 2019. During the same period, however, climate resources either declined or only moderately improved for parks located in arid and tropical regions. The continued growth of tourism throughout the United States National Parks system suggests that while climate resources are an important consideration when predicting future visitor flows, other ecological (e.g., hurricanes, fall foliage) effects, societal-driven institutional effects (e.g., holidays), and individual-level socio-economic factors should be included in forecasting models.

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3.8 Figures and Tables

Table 1. Required weather variables for indices

Sub-index	**TCI**	**HCI-urban**	**HCI-beach**	**Optimized Index**	**CCI**
Thermal	Maximum temperature (°C)	Mean temperature (°C)	Mean temperature (°C)	Mean temperature	Maximum temperature (°C)
	Minimum temperature (°C)	Dew point temperature (°C)	Dew point temperature (°C)	Dew point temperature (°C)	Minimum temperature (°C)
	Minimum relative humidity				Mean temperature (°C)
	Mean relative humidity				Dew point temperature (°C)
Physical	Wind speed (km/h)	Wind speed (km/h)	Wind speed (km/h)	Wind speed (km/h)	Wind speed (km/h)
	Precipitation (mm)	Precipitation (mm)	Precipitation (mm)	Precipitation (mm)	Precipitation (mm)
Aesthetic	Solar radiation (w/m2)	Cloud cover (%)	Cloud cover (%)	Cloud cover (%)	Solar radiation (w/m2)

Note. Daily sunshine hours were calculated from solar radiation (Allen et al, 1998).

Table 2. Tourism index formulas and ratings

Index	Formula	Category			
		Excellent	**Good**	**Acceptable**	**Unfavorable**
TCI	40%CID + 10%CIA + 20% P + 20%S + 10% W	[8,10]	[6,8]	[4,6]	≤4
HCI-urban	40%TC + 20%A + 30%P + 10%W	[8,10]	[6,8]	[4,6]	[0,4]
HCI-beach	20%TC + 40%A + 30%P +10%W	[8,10]	[6,8]	[4,6]	[0,4]
Optimized Index	75%TC + 15%A +5%P +5%W	[8,10]	[6,8]	[4,6]	[0,4]
CCI	50% TC + 50%S, min(CCI,3) if Tmin<8°C, or Tmax>34°C, or P>10mm, or W>23km/h	[7,10]	[5,7]	[3,5]	[0,3]

Note. CID = Daytime Comfort Index (scaled -40 to 100; Mieczkowski, 1985); CIA = Daily Comfort Index (scaled -40 to 100; Mieczkowski, 1985); P = precipitation; W = windspeed; TC = Thermal Comfort (Scott et al.., 2016); S = bright sunshine hours (i.e., solar radiation; Allen et al.., 1998); A = % day with cloud cover; Tmin = minimum temperature; Tmax = maximum temperature.

Figure 1. Koppen-Trewatha Climate classifications for focal US National Parks (adopted from Feng et al.., 2014)

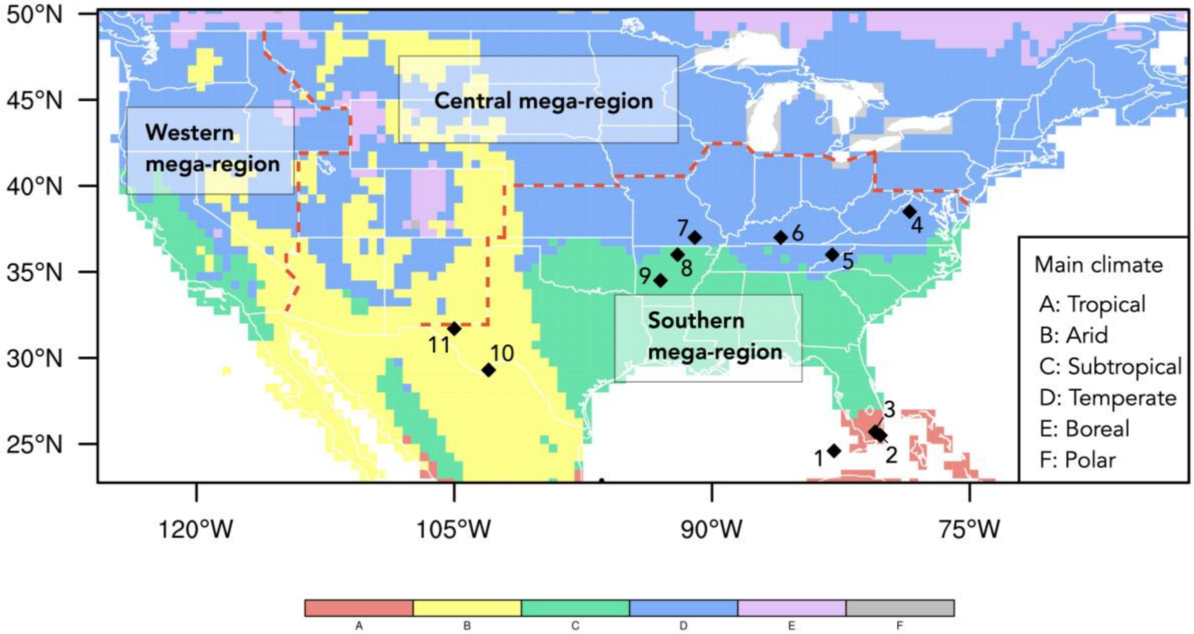


Table 3. Focal US National Parks, climate sub-classifications, and coordinates

Sites	National Parks	Koppen-Trewartha classification	Coordinates	
			Lon (°W)	**Lat (°N)**
1	Dry Tortugas (FL)	Tropical (A)	-82.9	24.6
2	Biscayne (FL)	Tropical (A)	-80.2	25.5
3	Everglades (FL)	Tropical (A)	-80.5	25.7
4	Shenandoah (VA)	Warm/Temperate (D)	-78.5	38.5
5	Great Smoky Mountain (TN)	Warm/Temperate (D)	-83.0	36.0
6	Mammoth Cave (KY)	Warm/Temperate (D)	-86.0	37.0
7	Ozark National Scenic Riverway (MO)	Warm/Temperate (D)	-91.0	37.0
8	Buffalo National River (AR)	Warm/Subtropical (C)	-92.0	36.0
9	Hot Spring (AR)	Warm/Subtropical (C)	-93.0	34.5
10	Big Bend (TX)	Arid (B)	-103.0	29.3
11	Guadalupe Mountain (TX)	Arid (B)	-105.0	31.7

Table 4. Cross-correlations between indices, park visits, RV camping, and tent camping

Category	Indices	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9	Site 10	Site 11
Park Visitation	TCI	0.47	0.73	0.26	0.41	0.63	0.30	0.59	0.17	0.54	-0.15	0.03
	HCI-urban	0.11	0.46	0.64	0.68	0.58	0.43	0.56	0.58	0.25	0.04	0.00
	HCI-beach	0.17	0.57	0.77	0.68	0.81	0.47	0.64	0.63	0.27	-0.07	0.10
	Optimized Index	0.31	0.68	0.82	0.74	0.86	0.58	0.46	0.77	0.16	-0.17	-0.08
	CCI	0.50	0.76	0.78	0.79	0.89	0.56	0.63	0.72	0.42	0.29	0.29
RV	TCI	-	-	0.35	0.72	0.55	0.55	0.15	0.32	0.30	0.65	0.67
	HCI-urban	-	-	0.43	0.74	0.63	0.64	0.34	0.52	0.27	0.20	0.19
	HCI-beach			0.37	0.64	0.74	0.58	0.62	0.73	0.28	-0.59	-0.24
	Optimized Index	-	-	0.24	0.75	0.80	0.71	0.66	0.77	0.37	-0.50	-0.06
	CCI	-	-	0.49	0.78	0.80	0.72	0.61	0.77	0.49	0.36	0.37
Tent	TCI	0.02	0.37	0.51	0.81	0.51	0.46	0.11	0.46	0.11	0.42	0.40
	HCI-urban	0.20	0.33	0.60	0.92	0.72	0.54	0.54	0.65	0.57	0.29	0.55
	HCI-beach	0.04	0.37	0.63	0.80	0.80	0.79	0.70	0.64	0.56	-0.14	0.35
	Optimized Index	-0.02	0.28	0.36	0.89	0.85	0.86	0.72	0.71	0.66	0.00	0.49
	CCI	0.12	0.32	0.47	0.92	0.85	0.87	0.66	0.75	0.61	0.45	0.62

Note. Statistics are reported at the $p < .05$ significance level. Non-significant values are bolded.

Figure 2. Comparative performance for indices for all observations

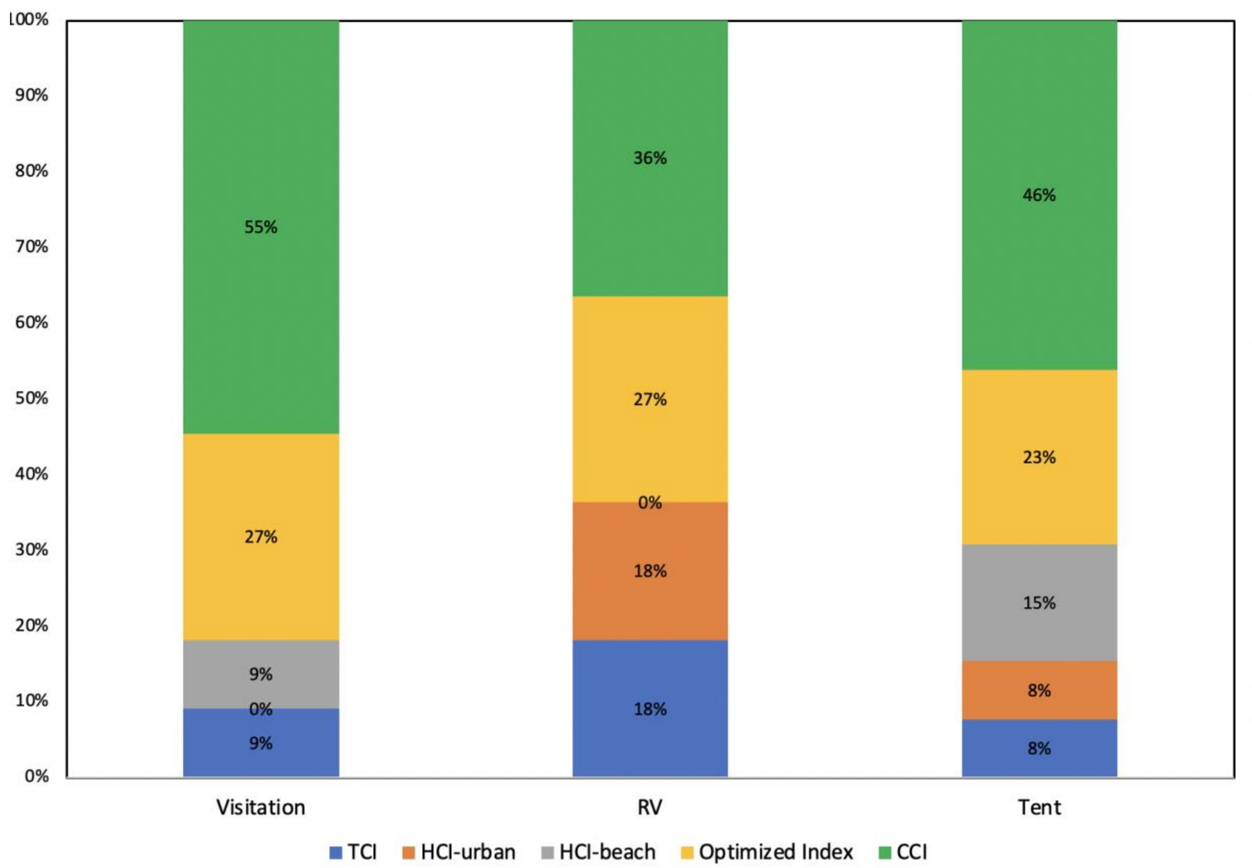
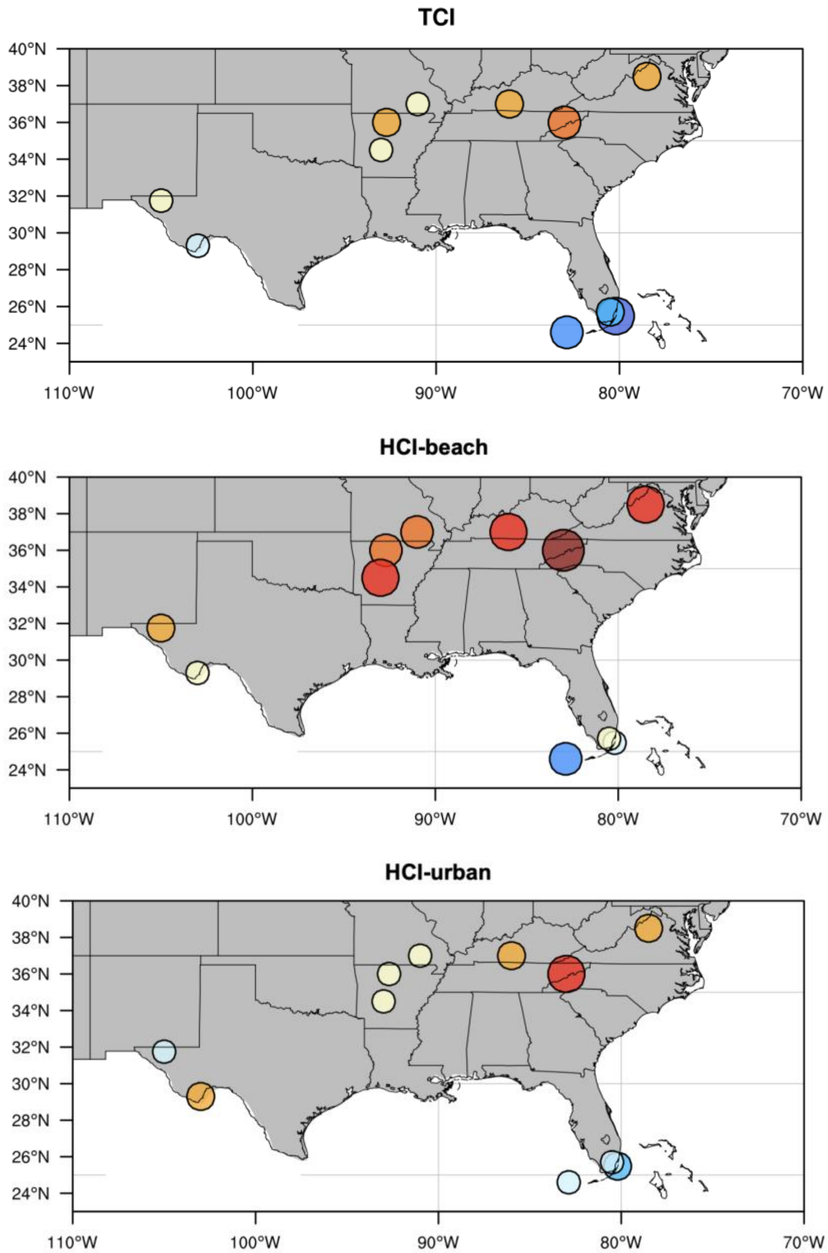


Figure 3. Changes in “excellent” climate resources: CCI days from 1981 to 2019



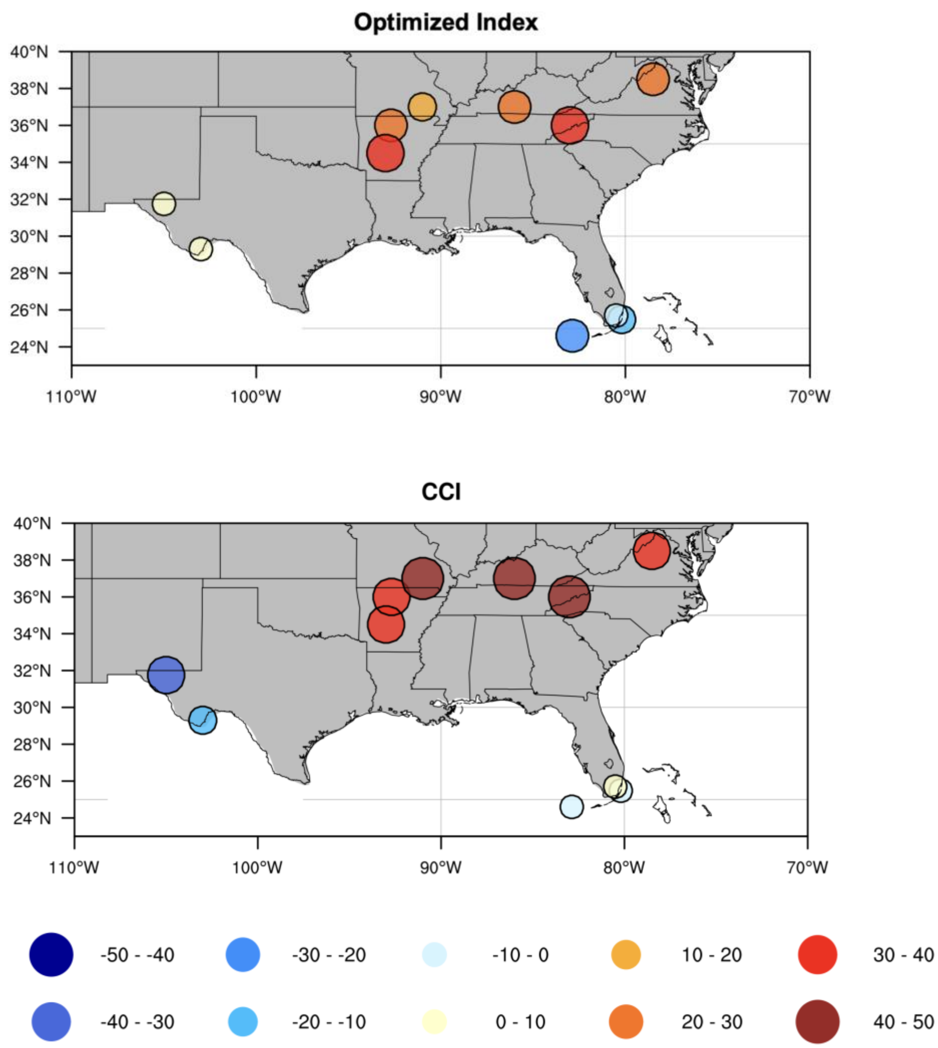
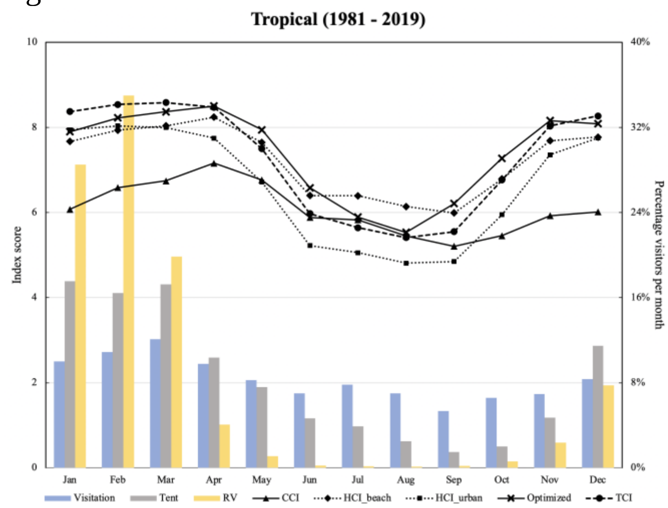
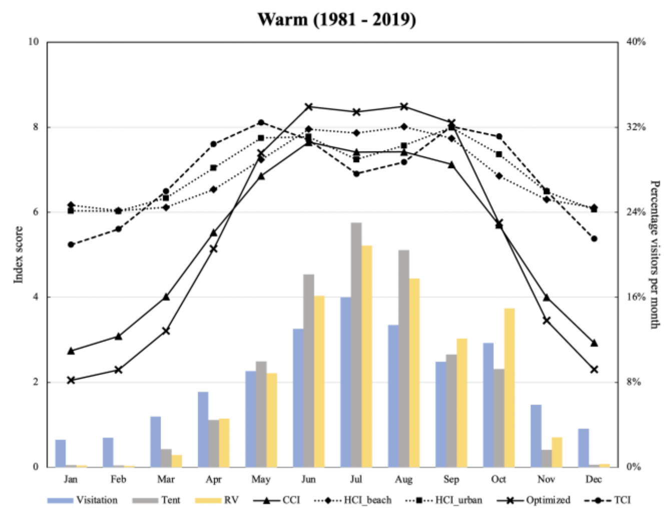

Optimized Index
40°N
38°N
36°N
34°N
32°N
30°N
28°N
26°N
24°N
110°W
100°W
90°W
80°W
70°W
CCI
40°N
38°N
36°N
34°N
32°N
30°N
28°N
26°N
24°N
110°W
100°W
90°W
80°W
70°W
-50 - -40
-30 - -20
-10 - 0
10 - 20
30 - 40
-40 - -30
-20 - -10
0 - 10
20 - 30
40 - 50

Figure 4. Index comparison for park visits, RV camping, and tent camping sorted by climate region





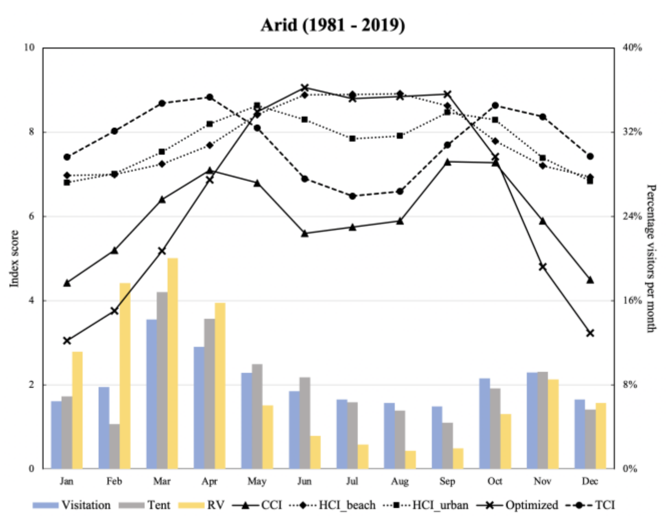


Table 5. Tourism index rating seasonal variance

	Tropical					**Warm**					**Arid**				
	TCI	HCI-urban	HCI-beach	Optimized Index	CCI	TCI	HCI-urban	HCI-beach	Optimized Index	CCI	TCI	HCI-urban	HCI-beach	Optimized Index	CCI
Winter	0.98	1.01	1.18	1.36	2.20	1.30	0.66	1.29	1.31	0.90	1.53	0.32	0.66	1.28	1.51
Spring	1.21	1.40	1.35	0.62	2.68	1.27	0.86	1.21	2.87	2.10	0.67	0.40	0.49	1.80	2.49
Summer	0.81	0.75	1.08	1.34	1.38	1.04	0.88	0.70	0.31	1.57	0.61	0.34	0.35	0.17	4.28
Fall	1.47	1.58	1.54	1.50	1.79	1.27	0.79	1.21	2.39	1.65	1.08	0.58	0.72	1.88	2.26

Note. Index rating units (1-10) are reported at the $p < .05$ significance level.

Supplementary Table 6. Overview of tourism climate indices and applications

Study region	Tourism Sector	Temporal Scale	Source
Tourism Climate Index (1985)			
Global	General	Monthly	Mieczkowski (1985)
UK and Mediterranean	Beach/3S	Monthly	Morgan et al. (2000)
United Kingdom	General	Quarterly	Maddison (2001)
North America	General	Monthly	Scott et al. (2004)
Mediterranean	General	Monthly	Amelung & Viner (2006)
Tehran	Urban	Monthly	Roshan et al. (2009)
Spain	General	Monthly	Hein et al. (2009)
Northwest Iran	General	Daily	Farajzadeh & Matzarakis (2009)
Europe	General	Daily	Perch-Nielsen et al. (2010)
South Caucasus	General	Monthly	Amiranashvili et al. (2014)
Puerto Rico	Beach	Daily	Mendez-Lazaro et al. (2014)
Australia	General	Monthly	Amelung & Nicholls (2014)
Japan	General	Daily	Kubokawa et al. (2014)
China	General	Monthly	Fang & Yin (2015)
South Africa	General	Daily	Fichett et al. (2016)
Iran	General	Monthly	Roshan et al. (2016)
Iran	General	Monthly	Nasabpour et al. (2017)
Lesotho	Mountain	Monthly	Noome & Fitchett (2019)
Egypt	Beach	Daily	Mahmoud et al. (2019)
Tibet, China	General	Monthly	Zhong et al. (2019)
Zimbabwean	Nature-based tourism	Daily	Mushawemhuka et al. (2020)
Holiday Climate Index (HCI-urban, 2016)			
Europe	Urban and Beach	Daily	Scott et al. (2016)
Turkey	General	Daily	Ozturk & Goral (2018)
Iran	General	Daily	Mahtabi & Taran (2018)
Iran	Beach	Daily	Hejazizadeh et al. (2019)
Optimized Index for Tourism (2019)			
Canada	Beach	Daily	Mathews et al. (2019)
Holiday Climate Index (HCI-beach, 2020)			
Caribbean	Beach	Daily	Rutty et al. (2020)
Mediterranean	Urban and Beach	Daily	Demiroglu et al. (2020)
China	Beach	Daily	Yu et al. (2020)
Camping Climate Index (CCI, 2020)			
The United States	Camping	Daily	Ma et al. (2020a,b)

Chapter 4. Ma, S., Craig, C. A., & Feng, S. (2020). Camping climate resources: the camping climate index in the United States. *Current Issues in Tourism*, 1-9. (published)

4.1 Abstract

Camping is the largest sub-sector of outdoor tourism, is growing in popularity, and is increasingly accessible to a diverse population of new campers. An outdoor accommodation and form of recreation, camping is especially susceptible to extreme weather and climate change. Though, camping research remains underrepresented in the tourism and tourism climatology literatures. Accordingly, this study quantifies seasonal camping climate resources for the 48 contiguous United States and its nine climate regions from 1984 to 2019 using a newly developed Camping Climate Index (CCI; Ma et al., 2020). The CCI is unique compared to other tourism climate indices (e.g., Tourism Climate Index and Holiday Climate Index) because it captures the overriding effects of daily extreme weather conditions. Findings demonstrate that ideal camping days are increasing an average of 20 days over the study period with the most improvement occurring in the summer where camping demand is at its height. The improvement is also closely related to favorable conditions in the shoulder seasons (i.e., fall and spring) where mid-latitude and higher altitude locations are the beneficiaries of a higher percentage of ideal camping days. Implications, future research directions, and limitations are provided.

Chapter 4. Camping climate resources: the camping climate index in the United States

4.2 Introduction

Camping—the largest sub-sector of outdoor tourism (Outdoor Industry Association, 2017)—continues to increase in popularity in the United States. Between 2014 and 2018 the number of camping households increased by 7.3 million and the number of campers taking three or more trips increased by 72% (Cairn Consulting Group [CCG], 2019). The interest in camping is present across age groups and income brackets (CCG, 2019; Hewer et al., 2017; Outdoor Foundation, 2019). For instance, in 2018 56% of new campers were Millennials (born between 1981 to 1997), 44% of new campers were 40 or older, and 47% of camping household incomes were less than $50,000 (CCG, 2019). There was a 22% increase in Millennial campers from 2015 to 2018, though camping trends have not substantially changed based on income (CCG, 2019).

The expanded range of accommodation options increases the accessibility for travelers to camp. For example, new forms of camping such as glamping and van life are of interest to experienced and new campers (CCG, 2019). CCG (2019) defines glamping as "staying in unique accommodations with enhanced services and amenities" and van life as "a form of adventure tourism that involves a van that is livable and self-sustained" (p. 44). Shared economy (e.g., rvshare.com) and equipment rental (e.g., rei.com/rentals) options have also lowered cost barriers making camping accessible to a wider audience. However, camping remains underrepresented in the tourism literature (Rogerson & Rogerson, 2020; Rice et al., 2019) despite its economic impact, popularity, and accessibility.

Like other tourism segments, camping is influenced by safety, environmental setting, and climatic conditions (Scott & Lemieux, 2010). Present-day, the most salient safety concern for camping, shared (e.g., Airbnb), and traditional (e.g., hotel) accommodations is the novel coronavirus 2019 (COVID-19) where travelers prefer locations without communal spaces that facilitate social distancing (Author, 2020a; Author, 2020b; CCG, 2020; Dolnicair & Zaire, 2020; Hong et al., 2020). Many campsites were able to remain open due to outdoor, natural settings that provide ample distance from others (Centers for Disease Control [CDC], 2020; Gossling et al., 2020). Also, campsites that closed due to travel restrictions in the United States were among the first locations to re-open as restrictions loosened (CDC, 2020). Within a COVID and post-COVID-19 environment, camping is well-positioned for growth as demand for domestic accommodations and outdoor recreation improves (Dubois, 2020; Gossling et al., 2020; Rice et al., 2020).

The natural setting that makes camping a safer accommodation during a pandemic also underscores its sensitivity to climatic conditions (Author, 2018; Author, 2019a; Brooker & Joppe, 2013; Hewer et al., 2017; Ma et al., 2020; Rice et al., 2019). Ma et al. (2020) note that "shifting climate-derived weather and seasonality trends highlight the potential positive (i.e., opportunities) and negative (i.e., threats) impacts that changing climatic conditions can have depending on spatial location" (p. 2). Positive impacts include improved camping conditions in the spring and fall, longer shoulder seasons (i.e., spring and fall), and improved conditions with increasing latitude and altitude (Ma et al., 2020; Monahan et al., 2016; Scott et al., 2012). Negative impacts include dangerous extreme weather trends (e.g., hurricanes, drought, extreme precipitation, extreme heat) in peak seasons and/or at popular camping destinations (Author, 2019b; Reidmiller et al., 2018). In fact, "climate related impacts are expected to result in decreased [outdoor and/or seasonal] tourism revenue in some places and, for some communities, loss of identify" (Reidmiller, 2018, p. 32). Camping's reliance on weather and vulnerability to extreme weather events necessitates an understanding of the impact of regional and changing climatic conditions on the $150 billion sector (Rice et al., 2019).

Yet, to-date, there have been no tourism climatology studies to quantify camping climate resources across the entirety of the contiguous United States. Thus, we utilize the newly developed Camping Climate Index (CCI; Ma et al., 2020) to quantify the climate resources for camping. The climate index approach has been widely applied in tourism climatology to quantify climate resources for tourism around the world capturing the multifaceted nature of weather variables that interact with tourist decisions (e.g., Amelung & Nicholls, 2014; Matthews et al., 2019; Mieczkowski, 1985; Per-Nielsen et al, 2010). The index approach involves weights and ratings where weights indicate the relative importance of each climate resource and ratings provide a score for the overall climate desirability. Though, there are several key limitations with previous indices that the CCI addresses.

Critical limitations of the seminal index—the Tourism Climate Index (TCI; Mieczkowski, 1985)— include subjectivity of climate resource weights and ratings, low temporal resolution, and the inability to recognize overriding effects of extreme events. Scott et al. (2016) highlighted the need to tailor indices for specific tourism segment yielding the HCI-beach (i.e., Holiday Climate Index) and HCI-urban indices. A key advancement of the HCI is that it tested the climate resource weights and ratings based on in-situ traveler surveys and evidence-based research. Yet, the HCI represents the proportional impact of each climate resource using an additive approach that does not capture the influence of extreme weather events on tourist decisions. The optimized index (Matthew et al., 2019) is the first data-driven index that used mathematical optimization to determine climate resource weights and ratings which proved its efficiency in predicting beach visitation. Matthews et al. (2019) recognized that extreme weather can have a significant impact on tourists when a key threshold is surpassed, however, thresholds were not expressed in the optimized index.

The CCI (Ma et al., 2020) provides three key advancements over prior indices that make it particularly well-suited for camping and other outdoor tourism activities. First, the CCI utilizes a novel method (i.e., iteration correlation) to determine optimal climate resource weights and ratings that removes rater subjectivity, including tourist surveys. This is important because previous research shows there can be discrepancies between tourist perceptions about climate resource desirability and outdoor tourism behaviors (Author, 2018). Second, the CCI was empirically validated using high-resolution, daily camping occupancy data matched with daily weather data at 29 spatially dispersed campsites in United States over a nine-year span. The CCI is the first known climate index that focuses on camping and compared to the two most widely adopted tourism climate indices—the TCI (Mieczkowski, 1985) and HCI (Scott et al, 2016)—demonstrates better predictability for camping occupancy (Ma et al., 2020). And third, the CCI theoretically and empirically captures the overriding extreme weather impact within the index calculation formula to indicate when thresholds are surpassed. The ability to mathematically force the index score to unfavorable overcomes a limitation of previous indices that "overrate" rainy or windy days (De Freitas et al., 2008).

The remainder of the article includes methods, results, and discussion sections.

4.3 Measures and Methods

The CCI integrates three climate resource facets that are relevant to tourists' comfort level with the natural environment, which are thermal comfort, aesthetic quality, and physical impact (Gomez-Martin, 2005). Six climate variables were retrieved to operationalize the three facets (see Table 1). Each climate variable interacts with human outdoor activity in a different fashion. De Freitas et al. (2008) noted that thermal and aesthetic facets describe the physiological sensation of the human body, and at certain thresholds, the physical facets override thermal and aesthetic conditions. As outlined by Ma et al. (2020), thermal comfort and sunshine hours (i.e., aesthetic quality) represent physiological and psychological states of comfort approximately equally for camping occupancy. Extremes create overriding effects despite physiological and/or psychological states. Thus, the value of the CCI is forced to an "unfavorable" classification (3 or less) if an overriding effect is detected for thermal comfort (i.e., maximum or minimum temperature) or physical impact (i.e., precipitation or windspeed). See Ma et al. (2020) for a full explanation of the CCI.

To ensure data input consistency, daily weather data from 1984 to 2019 with a half degree resolution was obtained from NASA (2020) for the variables in Table 1. Half degree spatial resolution is sufficient to cover each state in the contiguous United States. This dataset was derived from the Modern-Era Retrospective Analysis for Research and Applications, version 2 (MERRA-2, Gelaro et al, 2017). Compared to other high-resolution climatic reanalysis datasets and observations this dataset is of high quality (Gelaro et al., 2017; Reichle et al., 2017). A total of 3,264 grid cells for the 48 contiguous United States were analyzed. The 36 years daily CCI scores were calculated for each 0.5 gird cell and then grouped into state-level means for the four meteorology seasons to represent similar seasonal traits (see Figure 2 and Table 1). Next, the number of ideal days, or those with CCI scores of 7 or greater, were aggregated both seasonally and annually to form a time series from 1984 through 2019 for each grid cell. Grid cells were then grouped into the nine climate regions. Climate regions demonstrate comparable weather and climate trends (Karl & Koss, 1984) and allow for more generalizable, macro-level assessment of camping climate resources.

4.4 Results

4.4.1 Seasonal state-level mean CCI

State-level mean CCI scores demonstrate a strong spatial distribution pattern among the four seasons in the contiguous United States (see Figure 1 and Table 2). In spring, the CCI scores range from 4.5 (Acceptable) in Maine to 7.4 (Optimal) in South Carolina. In summer, the CCI scores range from 5.6 (Good) in Florida to 7.6 (Optimal) in Nevada. In fall, the CCI scores range from 4.2 (Acceptable) in Connecticut to 6.2 (Good) in South Carolina. In winter, the CCI scores range from 3.0 (Unfavorable) in several states in the north to 5.5 (Good) in Florida. Notably, all states were classified as having "good" to "optimal" climate resources for camping in summer, while all states except Florida and South Carolina were classified as having "unfavorable" to "acceptable" climate conditions in winter. In general, the climate conditions become more desirable from north to south during the spring and fall shoulder seasons.

4.4.2 Seasonal climate region CCI trends

Changes in the number of ideal days from 1984 to 2019 (n = 36 years) were calculated for the nine climate regions. Figure 2 shows the seasonal trends and Table 3 the annual trends. The regional results highlight three primary contributions. First, the number of ideal camping days is increasing across the United States over the past three decades. Second, there are regional differences in levels of CCI improvement. For instance, the CCI improved by 40 days from 1984 to 2019 in the Southwest region, a region characterized by high altitudes in the Rocky Mountains as well as increasing latitudes into Colorado and Utah. In the South and Southeast regions, regions characterized by a humid subtropical climate, the CCI improved by only six and seven ideal camping days, respectively ($p > .10$). In other words, there has been no significant change in ideal camping days in the regions. And third, summer experienced the most improvement in the ideal camping days whereas there was no or minimal improvement in the winter.

4.5 Discussion and Conclusion

4.5.1 Discussion

This study explores the climate resources and changing climate suitability for camping in the United States over the past three decades. Quantifying camping suitability is important because climate resources are the primary concern for nature-based tourists when choosing destinations (Wilkins et al., 2018). The index approach integrates climate resources, or variables, into a single product that accommodates a comparable quality analysis across space (i.e., 48 states in nine climate regions) and time (i.e., 36 years). The 36-year study period is long enough to rule out short-term weather variations and reach a statistically significant trend as a function of time (Crate & Nuttall, 2016; Feng & Fu, 2013). Using a camping sector specific climate index—the Camping Climate Index (CCI; Ma et al., 2020)—we demonstrate a differentiated spatial distribution of climate resources for camping and an improvement for camping conditions across the United States.

Encouragingly for the camping sub-sector of tourism, seven of the nine climate regions saw significant improvement accounting for an average improvement of 20 ideal camping days over the 36-year study period. Most of the improvement in ideal days occurred in summer (see Figure 2) coinciding with the current highest camping demand season (Craig, 2019; Rice, 2019;

Hewer et al., 2017; Jeuring, 2017). Conversely, the overall poor climate conditions for camping during winter marked the weakest improvement in the number of ideal days change. The early onset of spring and warmer temperatures extending into fall contribute to prolonged shoulder seasons (Monahan et al., 2016; Reidmiller et al., 2018) and subsequently improved camping conditions.

When considering the CCI across dispersed geographic regions, mid-latitude locations are the beneficiaries of a higher percentage of ideal CCI days. Mid-latitude locations account for a relatively high proportion of "good" CCI conditions especially in the shoulder seasons, thus a moderate increase in the overall index performance could lead to significant categorical advancement to "optimal." Regionally, there are also different temporal and spatial distributions. For instance, locations in the northern climate regions experienced greater seasonal CCI fluctuations (mean seasonal CCI ranged from "unfavorable" to "optimal") than the southern states (mean seasonal CCI ranged from "good" to "optimal" in Florida) (Figure 1). Extremes are also of concern regionally. Warming in recent decades has caused more heat waves, heavy downpours, and other weather extremes (Reidmiller et al., 2018), all of which could adversely affect camping climate resources. The CCI accounts for these impacts. Because the south and southeast United States are exposed to these extremes more often than other regions (Reidmiller et al., 2018), and the CCI empirically captures the extreme weather events within the formula, the increasing frequency of these extremes lead to weaker trend in the ideal camping days (Table 3).

Climate change (i.e., changes that occur over decades) will have a long-term impact on the suitability of nature-based tourism (Reidmiller et al., 2018), and as demonstrated here can be quantified using the CCI. Climate change interacts with ideal climate conditions in a variety of ways, including increased temperature (which disproportionally favors higher latitude and altitude regions) and extreme weather conditions (which disproportionally impact mid-latitude locations). As such, study findings demonstrate that changing climatic conditions represent both opportunities and threats for camping and other outdoor tourism activities beholden to the natural environment.

4.5.2 Implications, Future Research, and Limitations

On average, climate change in the United States positively influences the camping tourism sub-sector. With additional ideal CCI days across the contiguous United States, the amount of desirable camping destinations is increasing; the nine climate regions all demonstrated some level of ideal camping day improvement over the past four decades, meaning that camping operational seasons have gradually prolonged over time. New camping opportunities are more obvious in some regions (e.g. Southwest, Central, Northwest, Northeast) while less obvious in others (e.g. South, Southeast) creating potential competition among destinations. Knowing that many national park campgrounds in the United States cannot add additional occupancy to preserve the natural environment (Rice et al., 2019), the need to understand camping climate resources is heighted. For instance, there are more opportunities at the beginning and end of the camping season where conditions are increasingly more favorable but campgrounds are not at maximum capacity due to institutional factors such as summer holiday (Author, 2019a; Hewer et al., 2017; Ma et al., 2020; Monahan et al. 2016).

Campsites also face threats including traveler health concerns (e.g., COVID-19) as well as extreme weather conditions. Travelers are expressing a preference for non-communal spaces like private bathrooms and natural, outdoor space (CCG, 2020; Hong et al., 2020). Emerging trends in camping (e.g., glamping, cabin camping, shared economy) provide alternative accommodations that can address health concerns by providing private space and social distance (Author 2020a,b; Dubois, 2020). Further, these alternative accommodations can also provide amenities (e.g., air conditioning, covered structures) to help overcome comfort and safety concerns related to increasing extreme weather events (e.g., heat, precipitation).

Though novel, the study is not without limitation. CCI was captured at the state and climate region resolution to provide more generalizable results. However, considering varying geographic distinctions in the United States, the findings may not be accurate for location-based campsites. Using a location-based approach will allow future researchers consider campground characteristics such as latitude and altitude. When taking a more resolute approach, it may become necessary for future researchers to modify the CCI to more accurately rate and weight local climate resources. Further, case studies that explore weather and camping outcomes (e.g., occupancy) can also highlight individual campsite characteristics (e.g., Author, 2019a, b; Hewer et al., 2017). Because the CCI explicitly includes overriding, extreme weather conditions, researchers should also consider exploring the application of the CCI to other outdoor tourism and recreation activities (e.g., park visitation, sightseeing, hiking) around the world.

4.5.3 Conclusion

Camping—an outdoor accommodation, form of recreation, and the largest sub-sector of outdoor tourism—continues to grow in popularity among a diverse population of experienced and new campers. Despite recent setbacks stemming from COVID-19, camping is positioned as a widely accessible and safe alternative to traditional accommodations and other recreational forms that are not as socially distant. Climate resources are closely related to past and future outcomes for camping and other closely related forms of nature-based tourism and recreation, though, to-date researchers have not seasonally quantified climate resources for camping across the contiguous United States. Camping climate resources were operationalized using the Camping Climate Index (Ma et al., 2020) where results indicate improvement in camping climate resources across the United States in the summer and in the shoulder seasons due to the early onset of spring and warmer temperatures extending into the fall. Over the 36-year study period, climate change improved the desirability of camping across the United States. The improved desirability should be viewed with caution, however, as changing climatic conditions have also created salient threats due to increases in heat waves, heavy downpours, and other weather extremes.

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4.7 Figures and Tables

Table 1. CCI weather variables.

Sub-index variable	Initials	Units	Climate variable required	Variable weight
Thermal Comfort [T]	TC	°Celsius (C)	Mean temperature (℃) Mean dew point temperature (℃)	50%
Sunshine hours [A]	S	Hours (hr)	Solar radiation (w/m^2) Location coordinates	50%
Maximum Temperature [T]	Tmax	°C	Maximum temperature (°C)	CCI ≤ 3 if Tmax > 34°C
Minimum Temperature [T]	Tmin	°C	Minimum temperature (°C)	CCI ≤ 3 if Tmin < 8°C
Precipitation [P]	P	Millimeters (mm)	Precipitation (mm)	CCI ≤ 3 if P > 10mm
Windspeed [P]	W	Kilometer per hour (km/hr)	Windspeed (km/hr)	CCI ≤ 3 if W > 23km/hr

Note. [T] = thermal resources, [A] = aesthetic resources, [P] = physical impact; CCI = .5*TC + .5S where CCI ≤ 3 if conditions met for Tmax, Tmin, P, or W

Figure 1. Climate region and seasonal CCI score (1984 – 2019 average).

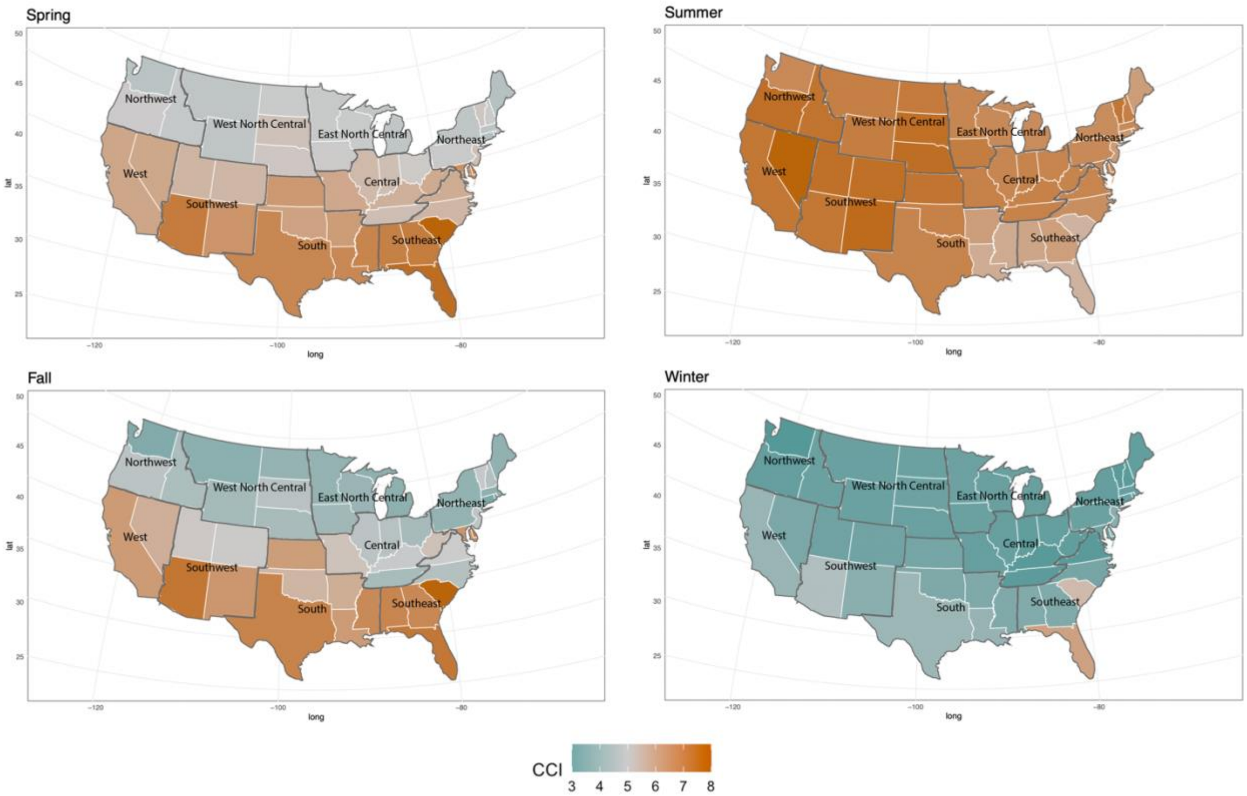

Figure 2. Climate region and seasonal change in CCI ideal days from 1984 to 2019.

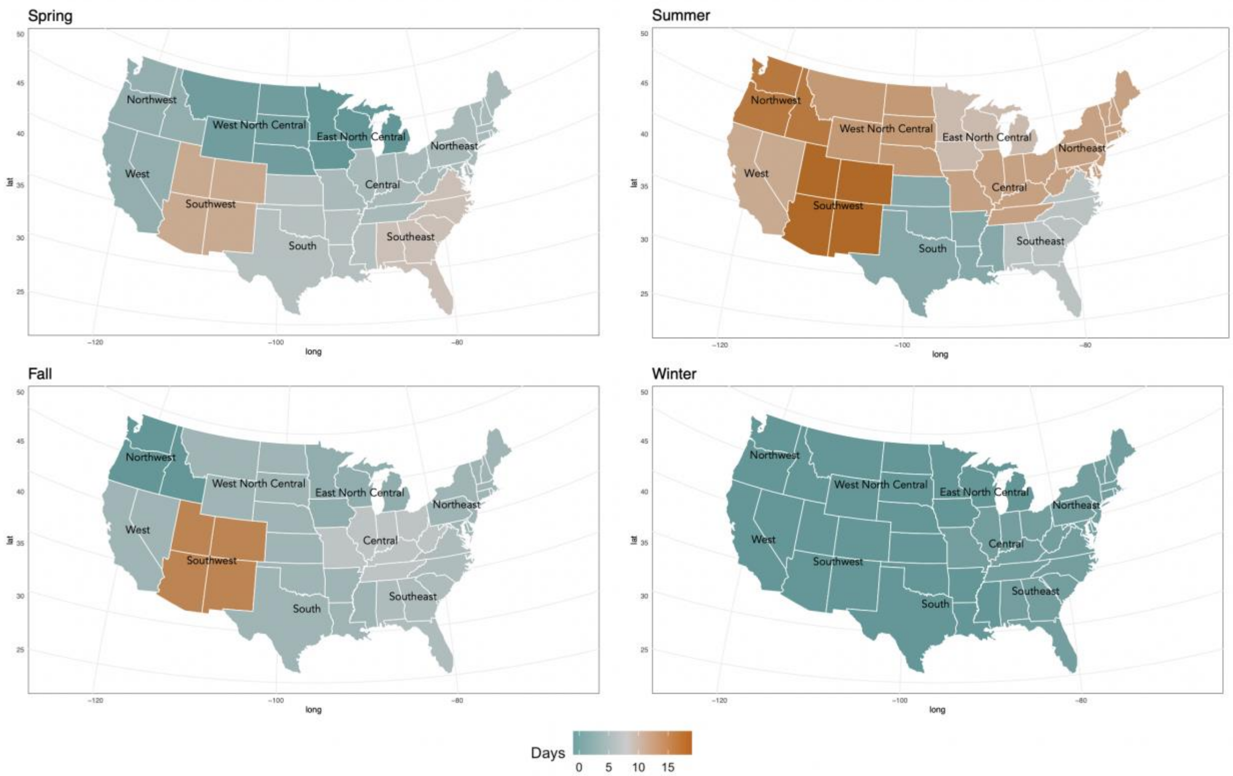

Table 2. US states and state-level average CCI score (1984 – 2019 average).

States	Abb.	Climate region	Spring	Summer	Fall	Winter
Connecticut	CT	NE	4.5	6.3	4.2	3.0
Delaware	DE	NE	6.5	6.7	5.9	4.0
Maine	ME	NE	4.5	6.1	4.4	3.1
Maryland	MD	NE	6.3	6.7	5.6	3.6
Massachusetts	MA	NE	4.7	6.6	4.4	3.0
New Hampshire	NH	NE	4.9	6.9	4.8	3.1
New Jersey	NJ	NE	5.3	6.2	4.9	3.5
New York	NY	NE	4.7	6.5	4.4	3.0
Pennsylvania	PA	NE	4.9	6.6	4.4	3.2
Rhode Island	RI	NE	4.6	6.5	4.3	3.0
Vermont	VT	NE	5.1	7.1	4.9	3.1
Iowa	IA	ENC	5.0	6.9	4.5	3.0
Michigan	MI	ENC	4.8	6.5	4.4	3.0
Minnesota	MN	ENC	4.9	6.7	4.4	3.1
Wisconsin	WI	ENC	4.9	6.6	4.5	3.1
Montana	MT	WNC	4.7	6.9	4.3	3.0
Nebraska	NE	WNC	5.1	7.3	4.6	3.2
North Dakota	ND	WNC	4.9	7.0	4.4	3.0
South Dakota	SD	WNC	5.2	7.3	4.8	3.1
Wyoming	WY	WNC	4.7	6.9	4.6	3.0
Idaho	ID	NW	4.9	7.2	4.7	3.1
Oregon	OR	NW	5.0	7.3	4.8	3.2
Washington	WA	NW	4.6	6.6	4.2	3.1
Illinois	IL	C	5.4	6.7	4.8	3.1
Indiana	IN	C	5.3	6.8	4.8	3.2
Kentucky	KY	C	5.6	6.8	4.9	3.1
Missouri	MO	C	5.8	6.8	5.1	3.3
Ohio	OH	C	5.1	6.7	4.6	3.1
Tennessee	TN	C	5.3	6.8	4.6	3.0
West Virginia	WV	C	5.7	6.8	5.1	3.2
Alabama	AL	SE	6.7	5.9	5.8	3.8
Florida	FL	SE	7.2	5.6	6.0	5.5
Georgia	GA	SE	6.8	6.1	5.8	3.9
North Carolina	NC	SE	5.5	6.5	4.8	3.3
South Carolina	SC	SE	7.4	5.6	6.2	5.1

Table 2. US states and state-level average CCI score (1984 – 2019 average). (Cont.)

Virginia	VA	SE	5.7	6.7	5.0	3.1
Arkansas	AR	S	6.1	6.1	5.3	3.6
Kansas	KS	S	6.1	7.1	5.5	3.3
Louisiana	LA	S	6.5	5.8	5.5	4.0
Mississippi	MS	S	6.6	5.8	5.7	3.8
Oklahoma	OK	S	5.9	6.8	5.3	3.5
Texas	TX	S	6.6	6.8	5.8	4.2
Arizona	AZ	SW	6.8	7.1	6.0	4.3
Colorado	CO	SW	5.5	7.3	5.0	3.1
New Mexico	NM	SW	6.2	7.4	5.6	3.7
Utah	UT	SW	5.5	7.3	5.0	3.2
California	CA	W	5.8	7.1	5.5	4.1
Nevada	NV	W	5.8	7.6	5.3	3.5

Table 3. Climate region and change in CCI ideal days from 1984 to 2019.

Name	*Annual Change*	*Sig.*
Central	+21 days	$p < .001$
East North Central	+10 days	$p < .05$
Northeast	+17 days	$p < .001$
Northwest	+18 days	$p < .0001$
Southeast	+6 days	$p >.1$
South	+7 days	$p > .1$
Southwest	+40 days	$p < .0001$
West	+16 days	$p < .01$
West North Central	+15 days	$p < .01$

*Note. Change indicates annual day improvement at the end of the 36-year study period, not day/year improvement.

Chapter 5. Discussion and conclusion

This dissertation focuses on the fast-growing and climate-sensitive nature-based tourism sector on the issue of managing the impacts of climate change and weather extremes in the United States. Chapters 2 – 4 collectively provide novel insights into the development and application of climate indices to better understand the ever-growing climate challenges to the nature-based tourism industry in the United States. This discussion and conclusion chapter begins with a summary of the significant findings of each chapter through a discussion of the contribution to the for-profit camping sector, non-profit camping sector, and the nature-based tourism organizations in the United States. The future research will be discussed followed by concluding remarks.

5.1 Study Synopsis

Researchers have long recognized the significance of climate and climate change in sustainable tourism (Scott, 2021; Guo et al., 2019; Moyle et al., 2018). Studies have explored the vulnerability of nature-based tourism to climate variability and weather extremes in different segments of the tourism industry worldwide (Dogru et al., 2019; Nkemelang et al., 2018; Lane, 2018). As the climate plays a decisive role in tourism destination choice and duration of stay (Hamilton et al., 2015; Gossling et al., 2012), the assessment of the overall climate wellbeing of nature-based tourism experience under the changing climate is critical.

Due to the multifaceted nature of weather and the complex ways that the weather variables interact with tourists, the integrated climate index approach has been proved practical and has been widely used for the measurement and evaluation of the tourism climate resource (Ma et al., 2020; Olya & Alipour, 2015; Scott & McBoyle, 2001). The indexing method considers three aspects of leisure participants' perception of weather conditions: heat, physics, and aesthetics. The thermal aspect is how participants perceive heat and comfort according to the atmospheric environment (including temperature, relative humidity, and wind speed). The physical aspect involves the presence of specific meteorological elements, such as rain, snow and strong winds, which directly affect or restrict the activities of the participants. The aesthetic aspect is based on the visibility, the comfort of the scenery on sunny and cloudy days and the main weather conditions.

The ultimate goal of this dissertation is to investigate the linkage between tourists' weather preferences, climate and weather information for nature-based tourism seekers, the tourism sector economic risks associated with the impact of climate change in a quantifiable framework. The ultimate goal has been achieved through the effort in addressing the three pillar objectives: 1) develop a generalized climate index that is theoretically sound and empirically tested for the nature-based tourism; 2) measure the climate resources at the non-profit United States National Parks using the tourism climate index approach; and 3) analyze the temporal and spatial distribution and re-distribution of climate resources for nature-based tourism in the contiguous United States. The following passages summarized key findings from each of the three manuscripts.

5.1.1 Climate impact on nature-based tourism (Objective 1)

Despite the large body of literature in tourism and climate study, the understanding of the integrated effect of climate and the significant impact of weather extremes on the camping industry remains understudied. The close proximity to undisturbed natural environments and inherently dependency on favorable weather conditions make camping industry particularly vulnerable to climate. The first manuscript (Chapter 2) examined the relative significance of varied climate variables for the for-profit camping industry and proposed a novel climate index to quantify the ideal as well as unfavorable climate conditions for outdoor recreation. The most significant contribution of this manuscript is the methodological application of using a data-driven method to objectively identify the threshold values for each climate variable in the index rating system.

Multivariate regression analyses indicate that thermal comfort, sunshine hours, and institutional factors (i.e., weekends, holidays) are the three most salient parameters in the nature-based tourism decision-making processes. After controlling the institutional factors and taking account of the average performances of climate factors in the seven climate zones, thermal comfort and sunshine hours were found to have an equal contribution to the participation of outdoor recreation. Extreme/adverse weather events rarely occur, but those events have an overriding effect on outdoor activities once occur. Therefore, the extreme weather thresholds are included to account for extreme/adverse weather events. Four threshold variables considered to have overridden effects were minimum temperature, maximum temperature, wind speed, and precipitation. The critical threshold values were determined using a series of iterations correlation methods.

This study found that the geography locations also influence tourists' thermal and aesthetic perceptions. The respond of camping occupancy to thermal comfort is more sensitive in the mid to high latitude regions compared with subtropical coastal regions in the United States, indicating that the perceived comfortable temperature is a more important variable in the warm to cold climate regions. This is in part determined by the relatively small annual temperature range in the subtropical climate regions and the nature of the pursuit of sunbathe in 3S (sand, sun, and sea) tourism. Furthermore, the findings of this study have revealed that altitude is another parameter influencing tourism climate preferences, which is overlooked in the existing tourism climate indices.

The Camping Climate Index (CCI) recognized the uniqueness of camping climate preferences among other tourism segments and addressed the salient gap in the literature as the first camping-sector-specific tourism climate index. The CCI is validated by a series of robust statistically significant tests against the revealed camping behaviors among other popular climate indices. It provides a useful tool for the decision-makers to perform climate risk assessment and destination management. It also demonstrates the substantial potential for the large-scale spatial and temporal evaluation of climate resources for nature-based tourism industry.

5.1.2 Climate resources for non-profit camping sector (Objective 2)

United States National Parks are globally gravitated nature-based tourism destinations, while no research has explored the influence of weather and climate resources for this valuable nature-based tourism hot spot. Accordingly, the second manuscript addressed this knowledge gap using a case study of 11 national parks that represent four out of five climate regions in the Unites States. In this study, tourism climate index approach has been applied to establish the relationship that weather and climate resources share with United States National Park visitation, recreational vehicle (RV) camping, and tent camping. Five tourism climate indices—the Tourism Climate Index (TCI, Mieczkowski, 1985), the Holiday Climate Index (HCI-urban, Scott et al., 2016; HCI-beach, Rutty et al., 2020), an optimized index for tourism (henceforth identified as the Optimized Index; Matthews et al., 2019), and the Camping Climate Index (CCI; Ma et al., 2020a)—are utilized to quantify weather and climate resources at United States National Parks to address research objective 2. Time series and trend analyses have been carried out to measure the value and changes of climate resources at the non-profit camping sector.

The study results reveal that the CCI is a more generalized index to quantify the climate resources for nature-based tourism considering all scenarios (i.e., type of tourism and climate region). The TCI demonstrates a strong performance in the arid climate region and the HCI-beach is more suitable in the sub-tropical climate regions. Not surprisingly, the HCI-urban shows a moderate performance across all scenarios given that it was designed for urban tourism. Developed based on the beach park visitation data, the data-driven optimized index performed outstandingly well in the warm climate regions. Due to the different climate thresholds triggering mechanism among indices, some contradictories have emerged in mapping the long-term historical trends of climate resources. Overall, the study has found an increasing number of "excellent" days at locations for the mid-latitude, warm (include subtropical and temperate) climate region.

Though studies have used purpose build index the to examine the climate resources at designed locations worldwide, no research has applied them to a wider tourism segment. By pushing the market boundary and exploring the mechanisms within each index, findings in this study show that despite the superior performance of a specific index in their segment, it can also be applied to another tourism sector. From the climate index development standpoint, the intercomparison of multiple climate indices provides further insights into the strengths, weaknesses, and applicability of each climate index. The utilization of multiple climate indices facilitates a better understanding of the nuance among the nature-based tourism segments and provide a guidance towards a more general application of tourism indices around the globe as well as application of tourism indices to wider tourism segments (i.e., beach use, general sightseeing, RV, and tent camping).

5.1.3 Camping climate resources in the United States (Objective 3)

To date, progresses has been made in addressing the climate resources for the general sightseeing, beach tourism, and ski industry, while the study of camping sector remains unrepresented. Accordingly, the third manuscript quantifies seasonal camping climate resources for the 48 contiguous United States and its nine climate regions from 1984 to 2019 by using the unique camping sector-specific climate index – the Camping Climate Index. The CCI was calculated daily from 1984 to 2019 with a half degree spatial resolution that covers each state in the contiguous United States. The seasonal state-level CCI were obtained from the average of grid-cell data within the states. Based on the major nine climate regions, camping climate resources, which are represented by the CCI categorical scores, demonstrate a strong spatial distribution pattern among the four seasons in the contiguous United States. Overall, the climate resources for camping in the United States are considered “good” to “ideal” in summer; are considered “unfavorable” in winter with the exception of Florida and South Carolina; a changing pattern from “ideal” to “unfavorable” can be observed from south to north during spring and fall shoulder seasons. Furthermore, the number of ideal camping days has been increasing across the United States over the past three decades with the Southwest gained a proportionally greater ideal camping day.

These findings reveal a differentiated spatial distribution of climate suitability for camping and indicate that climate change is beneficial for nature-based tourism in the contiguous United States. The continuous increase in the number of ideal CCI days across the United States, indicating an increasing number of desirable nature-based tourism destinations as well as the prolonged nature-based tourism seasons. This finding is salient in terms of tourism planning, risk management at campgrounds, and sustainable development in the tourism industry.

5.2 Research Implications

The rationale for this study is that the climate as a resource bears value and rareness for nature-based tourism choice, and different climate scenarios have different situations of impact and that the relationship between climate and tourism needs to be further understood to inform proactive adaptation and mitigation strategies. The tourism sector contributes to anthropogenic climate change (Hall et al., 2019), and in turn, it can be impacted by climate change, either detrimental or beneficial (Becken et al., 2020; Dogru et al., 2019; Verbose et al., 2018). Despite its growing significance of popularity and steady increase to the contribution of the global economy, tourism has received far less attention from climate change impacts research community relative to other economic sectors (e.g. agriculture, forestry, fishery, livestock). The research that addressed camping is even less (exceptions see Craig & Feng, 2018; Craig, 2019; Hewer et al., 2015; Hewer et al., 2017).

This research interweaved climate science, human behaviors, and social-economic perspectives to explore how climate and outdoor tourism interact by focusing on the nature-based tourism industry. It is the first to develop a camping-specific climate index to generate spatial and temporal distribution models for a better understanding of the interaction between climate change, weather extremes, tourism organizations, and human behaviors. A number of existing pieces of literature have employed varied tourism climate indices that explored the climate resources distribution for either general tourism or sector-specified tourism (specifically beach and urban), yet none exists for the major camping industry. The focus on human-environment relationships with respect to the camping industry clarified how the climate assets for outdoor recreation have changed over time and what influence it caused to human activities.

The findings in this study immensely contribute to the bulk of research body in tourism management especially concerning climate interactions with social-economic activities. Impacts of climate change are inherently local and interconnected, and vary from regions to region, subject to the regions' adaptation and mitigation ability, change of land use, people's perception and valuation toward climate variations. By integrating the multi-facets climatic characteristics to measure their social-economic impacts, the results from this study can be readily apply to the assessment and projection of climate suitability for outdoor recreations to provide inference for a widespread audience.

With the more accessible comprehensive climate information of the destinations, the travelers, particularly leisure tourists, can plan the trips wiser. The tourism business owners and practitioners will get more information about the necessary knowledge with respect to the suitability of the business operation thus performing strategic management accordingly to elude possible loss and grasp the potential economic opportunities. Moreover, the easy-to-read climate information for outdoor recreations will help to increase the general public's knowledge of the environmental impact of travel and the potential responses to policy intervention and raise the general public's interests and attention to climate change-related issues.

5.3 Future research

This dissertation addressed the potential of the index approach to transforming climate information into a useful product into climate risk assessment and decision-making process by closely examine the weather stimuli to nature-based tourism responses. Based on the comprehensive literature review, it is evident that the nature-based tourism industry has become an increasingly important economic sector and continues to draw more attention from the scientific community. Nevertheless, much work remains to be done to understand the complexity of the interrelationships among tourism participation, outdoor recreation, and climate system. Although the semi-empirical research presented in this dissertation improved our understanding of these relationships, a number of unknowns also being raised to be clarified and therefore pointed to future research areas.

To date, the evaluation of the future climate resources for the tourism sector is still very limited, which has only been studied in North America (Scott et al., 2004) and Europe (Perch-Nielsen et al., 2010). The climate resources projection for nature-based tourism can improve our understandings and predictability of climate-related social behaviors and is critical to managing the valuable climate resources for sustainable development in the tourism industry. With the evolution of the climate index in tourism services and the continuous improvement of global climate models, studies to predict the long-term effects of climate change on the tourism industry will become more feasible and be able to achieve high accuracy with minimum uncertainties. Future research could expand the scope of this dissertation to evaluate the climate assets to a broader geographic region, as well as integrate global climate model to project future distribution and re-distribution of climate resources around the globe.

The findings from the three manuscripts confirm that camping seasons in terms of climate conditions in the United States has changed in the past half a century, and under the predictable climate change, the camping season is projected to experience a similar changing pattern into the future. Specifically, in terms of favorable climate conditions, nature-based tourism is generous benefits from the changing climate in mid-to-high latitude and higher altitude regions. In the tropical, sub-tropical, and hot arid climate regions, however, global change has posed increasing risks and uncertainties to the nature-based tourism industry. Despite the discussion of climate resources redistribution for tourism, the significant factors and mechanisms that driving the change are yet to be discovered. It’s reasonable to speculate the warming trends has contribute to the spatial and temporal distribution of climate resources, but we are unaware of to what extent and has the warming alter the change. In addition, the impact of the extreme weather occurrence to the nature-based tourism remains unknow. Therefore, future research can conduct quantitative analysis that decompose the climate indices to examine the relative contribution of each climate factors in causing the long-term change.

Lastly, the relationship of climate well-being to tourist’s behavior has broadly established through a thorough research in this dissertation, which leads to a potential to advance tourism management scholars in the use of climate indices to inform future accommodation, entrance tickets, operation seasons, energy use, transportation regulation, or business expansion planning. Traditional tourism and hospitality literature has largely focused on the study of social-economic factors and organizational management realms for the tourism services, while the inclusion of climate indices in the management of tourism business has not been conducted to date. Human, communities, and businesses are facing the grand challenges under global change in the coming decades, understanding the role of climate in businesses by integrating climate factors in both individual and institutional decision-making process is an intriguing and promising future research area.

5.4 Concluding remarks

This study synthesis the literature regarding nature-based tourism and climate-relevant issues. In the course of the changing climate, it is the hope of this study to improve our knowledge to gauge the alterations. Three themes were identified in this research: 1) the weather variables and its threshold values that significant influence nature-based tourism; 2) the method of inquiry to explore the relationships among climate, weather, and the tourism organizations; and 3) the change of climate resources for nature-based tourism and its potential feedback. This interdisciplinary study exploits the potential of using flexible climate indices to improve our understanding of the intertwined social, economic, business, and environmental relationships. The capability to transform complex weather messages and perceivable social phenomenon to a quantifiable tool enables the index to continuously provide useful and practical information to decision-making processes for individual travelers and climate risk management. The connection between weather and outdoor recreation is extensive and complex. The research to investigate the connections among outdoor recreation, nature-based tourism and weather appear equally complex and the complexity is presumable to continue as well. This underscored the collaborate efforts from multiple discipline to address the pressing human-climate relationships issues in the anthropogenic climate change.

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