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MEASURING, MAPPING, AND MANAGING OUTDOOR RECREATION ON

PUBLIC LANDS IN UTAH WITH SOCIAL MEDIA DATA

by

Hongchao Zhang

A dissertation submitted in partial fulfillment
of the requirements for the degree

of

DOCTOR OF PHILOSOPHY

in

Environment and Society

Approved:

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UTAH STATE UNIVERSITY
Logan, Utah

2021

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ABSTRACT

Measuring, Mapping, and Managing Outdoor Recreation on

Public Lands in Utah with Social Media Data

by

Hongchao Zhang, Doctor of Philosophy

Utah State University, 2021

Major Professor: Dr. Jordan W. Smith
Department: Environment and Society

Outdoor recreation plays a significant role in state economies while also contributing to the well-being of residents and tourists. In nearly all states however, public outdoor recreation resources are managed by a variety of different agencies and organizations. Each of these agencies and organizations implement, to different extents, distinct visitor use monitoring systems to measure and understand visitation. These disparate visitor use monitoring systems each have different strengths and weaknesses. In this dissertation, I explore the utility of a common type of data – social media – to inform the measurement, mapping, and management of outdoor recreation on public lands. The three investigations described here are focused on Utah, USA, where the vast majority of the state's public lands accommodate public recreation. In the first study, I investigate the ability of social media to yield valid measures of visitation to national parks, national forests, and state parks within Utah. I also use exploratory spatial analyses to investigate the spatial patterns of visitation to public lands at three different spatial scales. The analysis demonstrates how social media can be used to inform proactive outdoor recreation and tourism planning efforts and supplement traditional methods for measuring visitation. In the second study, I use the Recreation Opportunity Spectrum (ROS) as a theoretical framework to develop a data-driven and generalizable model for classifying recreation opportunities at multiple spatial scales. I propose a hypothetical and prescriptive ROS classification system that is well suited to overcome the limitations of the existing ROS framework. Through the use of publicly available data and the generalizable model, I define and illustrate ROS classification at different spatial scales. The flexible and generalizable model yields meaningful information for distinct audiences who operate at each of those scales (e.g., state legislatures, public land managers, regional collaborative initiatives). In the final study, I reach out to a diverse group of stakeholders in recreation and tourism planning (e.g., public land managers, county and city government officials, local business owners) and identify challenges and opportunities for tourism development through participatory workshops that present big data in a distilled and actionable manner. The purpose of this final study is to illustrate how a two-way communication process can be coupled with big data to co-create knowledge and a mutual understanding of the challenges and opportunities associated with increased participation in outdoor recreation. Collectively, the three investigations illustrate the variety of ways social media can be used to inform the measurement, mapping, and management of outdoor recreation on public lands.

(166 pages)

PUBLIC ABSTRACT

Measuring, Mapping, and Managing Outdoor Recreation on Public Lands in Utah with Social Media Data

Hongchao Zhang

Social media platforms allow people to post photos, text, and video clips that include embedded information about the geographic location, time, and date that of the posts. Recently, researchers have utilized these data to study outdoor recreation management. In particular, geotagged social media posts can be used to understand outdoor recreation behavior and visitation patterns on public lands. Consequently, it can be used to inform the decisions of agencies and organizations that manage recreational uses of public land. I conducted three studies to explore the ways social media information can help provide recreation managers with a better understanding of visitor use. First, I tracked the locations of recreation users' social media posts to describe how their visits are distributed across the public lands in the state of Utah (USA). Next, I combined social media data with a tool that recreation managers often use called the Recreation Opportunity Spectrum (ROS), proposing a way to improve the ROS so it can be used to proactively guide management actions at different spatial scales. Finally, I convened workshops with recreation managers, business owners, and government leaders to if and how social media can be used to inform decisions about recreation management within Utah. In sum this dissertation presents the variety of ways social media can be used to measure, map, and manage outdoor recreation on public lands.

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I am sincerely thankful to my parents (Juanjuan Lu and Yuesheng Zhang) who always support my decisions and provide generous supports since I decided to pursue my education and career in the United States. Additionally, ten years (2011-2021) of study abroad could not be successful without the love and understanding from my grandparents (Anqing Zhang, Zhenfang Liu, Jiting Lu, and Zhengyuan Yang) and my girlfriend (Shuaini Tan). I would also like to thank the faculty at the University of Maine, who helped me established academic interest in outdoor recreation management. I am grateful for Dr. Sonja Wilhelm Stanis, who introduced me to the field of outdoor recreation and climate change while I was a Master's student at the University of Missouri. Without the academic training provided by Dr. Sonja Wilhelm Stanis, I could not be accepted to Utah State University and continue my academic dream. Lastly, I would like to appreciate the great USU QCNR grad community, especially the graduate students in the IORT including Emily Wilkins, Chase Lamborn, Noah Creany, and Stan Rhodes.

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CHAPTER I

INTRODUCTION

The multiple uses of public land contribute significantly to the economy in the United States. In particular, the recreational use of public land in the Intermountain West contributes between 2.2 and 4.7% of the states' GDP (Pattni, Saladino, & Brown, 2020). In the state of Utah, tens of millions of people visit public lands each year (Smith & Miller, 2020). These public lands are managed by disparate agencies such as the USDA Forest Service, the National Park Service, the Bureau of Land Management, and the Utah Department of Natural Resources. The high volume of visitation to Utah's public lands not only generates tax revenue for the state's government, but it also supports local economies that cater to outdoor recreationists and tourists. However, the adverse impacts from increased outdoor recreation and tourism cannot be ignored. For example, increases in outdoor recreation participation when not adequately managed for can negatively impact wildlife habitat and degrade other natural resources (D'Antonio & Monz, 2016; Geffroy, Samia, Bessa, & Blumstein, 2015; Marion, Leung, Eagleston, & Burroughs, 2016).

The increase in outdoor recreation participation is likely as the state's population and economy continue to grow rapidly (Smith & Miller, 2020). Therefore, it is crucial for public land management agencies to properly measure, map, and manage visitation to Utah's public lands in ways that mitigate potential negative impacts. In this research, I use social media to measure and map outdoor recreational visits to Utah's public lands at different spatial scales, build a data-driven model to classification recreation opportunities across the entire state, and conduct an exploratory investigation into the efficacy of using social media to catalyze the co-creation of knowledge about the benefits and tradeoffs associated with increased outdoor recreation and tourism.

1. Background

1.1 Public lands and Visitation Monitoring in Utah

In the state of Utah, federal and state government agencies manage over 30 million acres of land, approximately 60% of the state's total land area. Utah contains five national parks (Arches, Bryce Canyon, Capitol Reef, Canyonlands, and Zion) as well as seven other national park units (a total of 8,479 km^2). The state also contains five national forests (Ashley, Dixie, Fishlake, Manti-LaSal, and Uinta-Wasatch-Cache[1]; a total of 33,102 km^2) and 46 state parks (a total of 489 km^2). These public lands support a vast array of outdoor recreation opportunities ranging from alpine skiing to sailing.

The governing bodies for all federally and state-managed public lands noted above report the number of visitors accessing their sites. Common or traditional monitoring methods include traffic or trail counters, visitor surveys, on-site observations, and administrative data (e.g., fees, permits, registration). At the National Park Service, the agency's Social Science Program is responsible for establishing counting protocols for how each park unit records a recreation visit (Ziesler & Pettebone, 2018). These protocols vary by park unit. Regardless of the protocols used, park visitation is aggregated and reported at the monthly time scale. The USDA Forest Service, by comparison, estimates visitation for each national forest at five-year intervals using data

[1] The state also contains marginal amounts of the Sawtooth, Caribou-Targhee, and Humboldt-Toyabee National Forests.

collected through on-site interviews conducted at systematically sampled recreation settings within each forest. These data are annual but are only reported for years in which a forest is monitored (i.e., every 5-years). The program is referred to as the National Visitor Use Monitoring Program. Finally, the Utah Division of Parks and Recreation reports annual visitation to each state park unit based upon internal protocols established by each park unit. It is clear just by comparing the variation in monitoring and reporting protocols used across just these three types of public lands, that little exists in the way of common, let alone universal, measures of a recreation visit. The rise of the internet, social media, and the public's desire to share their outdoor recreation experiences have begun to change that however.

1.2 Social Media Data and Outdoor Recreation Management

Social media platforms provide a service to allow individuals or organizations to post and exchange content on the Internet (Kaplan & Haenlein, 2010). The user-generated social media data can be acquired manually by a platform's search functions or by its Application Programming Interface (if one exists). Information stored in social media data contain images, text, and video; users' comments are also included as well. When a social media post is uploaded via a GPS-enabled device, such as smartphone or smartwatch, the geographical coordinates of the social media post are stored in the metadata of the social media platform. Alternatively, social media posts taken on a non-GPS-enabled device (e.g., DSLR camera, GoPro, drone) can be manually geolocated within some platforms such as *Flickr*.

Recent research has documented the growing body of research comparing visitation data collected through traditional methods with social media data (Wilkins, Wood, & Smith, 2020). The general conclusion is that geotagged social media posts can generate accurate visitation estimates when compared to measures generated from traditional methods (van Zanten et al., 2016; Wood, Guerry, Silver, & Lacayo, 2013). Social media may be a new data source that can be part of the standard monitoring protocols of public land management agencies.

In addition to the potential they hold for use in visitor use monitoring, social media also holds the promise of providing insights on visitor preferences for recreational ecosystem services (Clemente et al., 2019; Muñoz, Daigle, Hausner, Runge, & Brown, 2020; Sinclair, Ghermandi, & Sheela, 2018; Van Berkel et al., 2018). Recent research has even applied social media to quantify the value of public lands (Sinclair et al., 2018), measure visitor preferences for visual elements across the landscape (Clemente et al., 2019; Gosal, Geijzendorffer, Václavík, Poulin, & Ziv, 2019; Vaz et al., 2019), and quantify inequitable access to ecosystem services (Martinez-Harms et al., 2018).

2. Research Objectives

As the literature above suggest, the uses of social media is growing in both volume and in topical focus. The vast majority of research using social media to inform outdoor recreation management has done so using a singular spatial scale (Wilkins, Wood, & Smith, 2020). In this dissertation, I attempt to make inroads into the literature by exploring the ability of social media to inform outdoor recreation management at a variety of spatial scales. Can social media be used to inform resource management at a site-specific level? A regional level? And at a state-wide level? What are the benefits and drawbacks of using these data at different scales and how can benefits be capitalized on and limitations be mitigated?

Most research to date has also focused more on the methodological novelty of using social media. Can it be used? How accurate is it? With the foundational literature using these data now well established, researchers can begin to focus more acutely on practical needs. The majority of recent research focused on the validity and reliability of social media. The literature is only now beginning to fully examine how social media can inform outdoor recreation management. I would argue that social media *for* outdoor recreation management has been neglected in favor of social media *for* visitor use monitoring. There is an important distinction between the two and the work in this dissertation is fully focused on the former approach.

The purpose of this dissertation is to see how social media can be used to measure, map and manage outdoor recreation use of public lands across a variety of spatial scales. Specifically, this dissertation has three main objectives: (1) Determine the scientific validity of social media to measure and map outdoor recreation at various spatial scales; (2) Couple social media with open data to develop a 21st century outdoor recreation management framework; and (3) Develop a collaborative stakeholder engagement process that examines the ability of social media to focus and catalyze the co-production of knowledge between scientists and outdoor recreation and tourism professionals.

3. Overview of the Dissertation

The dissertation consists of three independent manuscripts that have, or will be, submitted to scientific journals (second, third, and fourth chapters). Each chapter addresses one of the research objectives listed above. The final chapter of the dissertation summarize the overall findings and implications of each chapter. Research contributions, limitations, and future directions are included in the final chapter as well.

The first manuscript uses nine years of geotagged social media posts to investigate the ability of social media to measure and map spatial patterns in visitation to public lands in Utah. I correlate reported visitation data with social media and observe the differences in the amount of variance in reported visitation explained by geotagged social media posts across different types of public lands. I use exploratory spatial analyses to investigate spatial patterns of visitation. This manuscript was prepared primarily for scholars and public land managers interested in using social media analytics in outdoor recreation management research; it has been submitted and accepted to *Applied Geography*.

The second manuscript develops a data-driven and generalizable model for classifying outdoor recreation opportunities at different spatial scales. I used the Recreation Opportunity Spectrum (ROS) as a theoretical guide to build the data-driven model. Specifically, I use an array of data sources (biophysical, managerial, and social) collected from two social media platforms (*Flickr* and *Panaramio*), OpenStreetMap, and other publicly available databases and then determine what types of outdoor recreation opportunities are provided at three spatial scales (state, regional, and site-specific). The result is an ROS classification system that can be implemented worldwide, without the need for subjective input from planners and managers, at a variety of spatial scales. The system also includes managerial implications tied to each ROS classification so that the framework can be used in a more proactive, as opposed to reactive way. I believe the scale-specific ROS classifications demonstrated through my application of the system are useful to distinct types of audiences that operate at distinct scales (e.g., state legislatures, regional collaborative initiatives, and land management agencies). I submitted this manuscript to *Landscape and Urban Planning*.

The third manuscript focuses on the collaborative development of scientific and practical knowledge. I illustrate how a two-way communication process can be coupled with big data to facilitate the co-creation of knowledge. Specifically, I document how a diverse group of stakeholders including public land managers, county and city government officials, and local business owners engaged in participatory workshops intended to develop a shared understanding of the challenges and opportunities associated with increased participation in outdoor recreation in Utah. This manuscript is being prepared for an applied communication journal.

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CHAPTER II

USING SOCIAL MEDIA TO MEASURE AND MAP VISITATION TO PUBLIC LANDS IN UTAH[2]

Abstract

We used nine years of geotagged social media posts uploaded to *Flickr* and *Panoramio* to investigate the ability of social media to measure and map spatial patterns in visitation to national parks, national forests, and state parks in Utah, USA. Our analysis shows support for the use of geotagged social media to supplement data collected through traditional means (e.g., on-site counts of visitors) as part of visitor use monitoring protocols. However, we did observe notable differences in the amount of variance in reported visitation explained by geotagged social media. Social media posts made within national parks and national forests captured substantially more of the variation in reported visitation relative to posts made within state parks. We attribute this to a variety of factors including the unique types of sites managed within the state park system, lower levels of visitation relative to national parks and forests within the state, and the method by which the state estimates visitation. We use exploratory spatial analyses to investigate spatial patterns of visitation across public lands. The analysis, performed at three different spatial scales (statewide, region, and county) illustrate the diversity of ways in which geotagged social media can inform outdoor recreation and tourism planning efforts and supplement traditional methods of measuring visitation. Our investigation demonstrates

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[2] This chapter is published in Applied Geography and can be accessed at https://doi.org/10.1016/j.apgeog.2021.102389.

how social media can serve as a useful tool to inform proactive planning and management efforts.

1. Introduction

The recreational uses of public lands in the U.S. are often measured by land management agencies through a variety of methods including fee slips, on-site interviews, online reservations, as well as trail and vehicle counters. While there has been a long tradition of determining visitation to parks and protected areas using traditional methods, emerging technologies including smartphones, GPS, and social media present new opportunities for understanding the where and why of outdoor recreation (Leggett et al., 2017). Social media in particular, provides publicly available user-generated data that can be used to estimate the volume of use, the spatial distribution of that use, and the experiences of visitors (Wilkins et al., 2020). Previous research has identified numerous advantages of using social media in outdoor recreation and tourism research. The most notable advantages include reductions in the time, labor, and financial cost of collecting visitation data (Wood et al., 2013). Additionally, social media can cover large spatial scales that cross administrative boundaries and longer temporal scales than are permitted by cross-sectional or site-specific data collection efforts. Consequently, social media may serve as a useful compliment to existing visitor use monitoring methods being used by outdoor recreation managers and tourism planners (Leggett et al., 2017; Teles da Mota & Pickering, 2020; Wilkins et al., 2020).

While there are several notable advantages to using social media to complement existing visitor use monitoring methods, it is unclear whether the data accurately represent visitation to outdoor recreation destinations across all types of public lands.

Nearly all previous research to date has focused on one particular park or forest or a set of parks or forests managed by a common agency (e.g., the National Park Service) (Wilkins et al., 2020). Only very recently, have researchers attempted to use social media to measure visitation across multiple types of public lands (Wood et al., 2020). There are several reasons why the type of public land to which social media are being applied may influence the extent to which the data can be used to measure visitation. First, different types of public lands use different methods to measure and record outdoor recreation and tourism visitation. The quality of the visitor use monitoring protocols used by an agency affects the validity of their reported visitation measures. This, in turn, will affect any analyses attempting to approximate those visitation measures with social media. Second, outdoor recreation opportunities and tourism experiences provided on public lands vary considerably by the mission and orientation of the agency responsible for management. Some outdoor recreation settings and tourism destinations tend to be heavily photographed and shared, while others do not. This variability may influence the ability of social media to accurately represent visitation. Finally, the spatial scales at which visitation measures are collected are unique to each park and/or tourism destination. The variable size of outdoor recreation settings almost certainly influences social media's ability to measure visitation.

Our research expands the scope of social media research to inform visitor use monitoring and management by examining the ability of social media to proxy visitation on public lands managed by different agencies. The primary purpose of our work is to determine the ability of social media to reliably estimate visitation data collected through traditional means for a large geographic area (>220,000 km^2) with parks and protected areas managed by multiple agencies for differing purposes. Specifically, our work focuses on all public land in Utah for which outdoor recreation is a primary use; this includes national park units, national forests, and state park units. The secondary purpose of our work is to examine the utility of social media to identify spatial patterns in outdoor recreation use on public lands at various spatial scales (at the state, regional, and county level) and determine if there are differences in the characteristics of public lands with distinct spatial patterns of visitation.

2. Literature Review

2.1 Social Media in Outdoor Recreation and Tourism Research

Social media platforms provide a service to allow individuals or organizations to post and exchange content on the Internet (Kaplan & Haenlein, 2010). Users can share posts that contain images, text, and video; and users can like, share, and comment on others' posts. Users are often unaware that in addition to their content (i.e., text, photographs, likes, etc.), social media platforms collect a host of other data including geotags. When a photograph is taken with a GPS-enabled device, such as a smartphone, the coordinates of the phone are included in the phone as metadata; these metadata are included within the photograph when it is shared on social media platforms like *Flickr* and *Panaramio.* Alternatively, users of these platforms can manually geolocate their photographs within the platform, if those photos were taken on a non-GPS-enabled device (e.g., a DSLR camera).

User-generated social media and their associated metadata can be acquired by either manually searching individual social media platforms via their search functions (e.g., McCreary et al., 2020; Wood et al., 2020) or through an individual platform's Application Programming Interface (API) (Batrinca & Treleaven, 2015; Lomborg & Bechmann, 2014). APIs provide a set of protocols to collect data from social media platforms in a programmatic way (Toivonen et al., 2019). The vast majority of research using social media to either estimate visitation on public lands or to understand visitor experiences has used APIs (Teles da Mota & Pickering, 2020; Wilkins et al., 2020). Table 2.1. lists the major social media platforms that provide publicly available data, accessible through APIs.

Table 2.1. Social media platforms most frequently used in outdoor recreation and tourism management research

Platform	Description	API link	Accessibility
Flickr	Image sharing platform popular with landscape photographers	Flickr API: https://www.flickr.com/services/api/	API is accessible for noncommercial use. Users may have a creative commons license attached to their photos.
Facebook	Social networking site which allows content to be shared on personal profiles, groups, and official pages	Facebook Graph API: https://developers.facebook.com/docs/graph-api/	Closed in April 2018 due to privacy issues.
Twitter	Micro-blogging service for posting short content (240 characters)	Different APIs available, mainly Twitter Search API and Twitter Streaming API: https://developer.twitter.com/en/docs	The standard Search API supports sampling posts within the past 7 days and online streaming.
Instagram	Photo and video sharing platform	Instagram Platform API: https://www.instagram.com/developer/	APIs were implemented in 2016 and 2018 and was deprecated in 2020.
Panoramio	Image sharing platform linked to Google Earth/Maps.	No longer available since 2016.	This platform was deprecated in 2016.
Weibo	Popular Chinese micro-blog platform	http://open.weibo.com/wiki/API%E6%96%87%E6%A1%A3/en	Requires knowledge of Chinese and official documentation has not been updated.

* Categories of social media platforms were adapted from Toivonen et al. (2019)

Despite the benefits of using social media to supplement existing visitor use monitoring methods, acquiring and working with social media comes with several notable limitations. First, obtaining social media requires advanced data- and/or text-mining skills that are often absent in the field of park and protected area management and tourism planning and development (Rashidi et al., 2017; Stock, 2018). Second, most often social media do not contain information on visitors' sociodemographic characteristics (Donahue et al., 2018; Wood et al., 2013). However, social media users' home locations can be accurately predicted by analyzing the spatial patterns of their posting behavior (Sinclair et al., 2020; Toivonen et al., 2019). Third, social media do not provide *direct* information on visitor preferences. Inferring visitor preferences from social media posts requires either content analysis of text or images (e.g., Clemente et al., 2019; Retka et al., 2019; Rossi et al., 2020) or other geospatial data that can be used to generate predictive models of why people are visiting certain locations (e.g., Walden-Schreiner, Leung, et al., 2018; Walden-Schreiner, Rossi, et al., 2018). Understanding visitor preferences is essential for public land managers to prioritize management actions and critical for tourism planners to shape tourism marketing plans. Acquiring detailed information on visitor preferences may require the use of visitor surveys to supplement any analysis using social media (and the need for, or use of, a survey obviously curtails some benefits of using social media in the first place). A recent study found visitor preferences inferred from social media are consistent with the preferences identified by visitor surveys (Komossa et al., 2020). Finally, several major social media platforms, most notably *Facebook* and *Instagram*, have restricted access to their databases by limiting the functionality of their APIs (Toivonen et al., 2019). The lack of available social media from multiple platforms may diminish the ability of social scientists, public land managers, and tourism planners to understand visitation patterns across different types of visitors with different platform-preferences (Wilkins et al., 2020).

2.2 Social Media and Traditional Methods of Quantifying Visitor Use

A growing body of research has compared visitation data collected through traditional means with social media (Wilkins et al., 2020). The first, and most commonly cited, investigation to do this correlated 197 million geotagged photos posted to the photo-sharing site *Flickr* with reported visitation at 836 recreation destinations around the world (Wood et al., 2013). Wood and colleagues found a strong (0.62) correlation between social media and reported visitation, concluding that crowd-sourced information can provide reliable visitation estimates when compared to measures generated through traditional methods. Subsequent work focused on park and protected area management has found similarly strong measures of association, with correlations averaging 0.69 (Wilkins et al., 2020).

Research focused on quantifying visitor use with social media are often limited to one particular site, type of outdoor recreation setting, or tourism destination (Teles da Mota & Pickering, 2020; Wilkins et al., 2020). There is a notable lack of research examining the extent to which social media represents reported visitation at various spatial scales across multiple types of public land management agencies which provide outdoor recreation opportunities. Given many outdoor recreation resources and tourism destinations cross the administrative boundaries of different land management agencies, more cross-boundary investigations are needed (Wood et al., 2020). Moreover, exploratory spatial analyses of social media at varying scales may provide some insights into *where* visitors are going within parks and protected areas.

2.3 Using Social Media to Quantify Spatial Patterns of Visitation

Visitation data collected through traditional methods are often used to decipher spatial patterns of visitor use (Leung et al., 2015). However, biases can occur in these data if visitors are reluctant to participate in visitor surveys, unwilling to providing details about their travel, if there are technical difficulties or errors in onsite monitoring equipment, or if visitors alter their use patterns and behaviors because their movements are monitored (Newsome et al., 2012). Further, these traditional methods for monitoring visitor use are often limited to relatively small study sites (most often closed-loop trail systems) and short temporal spans (often ranging from several weeks to months). Scientists have begun to use social media to study the spatial distribution of visitation within parks and protected areas. Some of this research has used route data (i.e., polyline geometry) to examine the volume of trail use (Campelo & Nogueira Mendes, 2016; Norman et al., 2019, 2019; Norman & Pickering, 2017; Rice et al., 2019). The majority of this work, however, has used point data to map the spatial distribution of visitation. Sonter and colleagues (2016) mapped visitation across parks and protected areas in Vermont using *Flickr* data, finding the type of ownership (e.g., private, state, etc.) of protected area was a significant predictor of the number of photo-user-days within an area. More recent work has used social media to examine the spatial distribution of visitation across specific parks within a country (e.g., national or heritage parks; Kim et al., 2019; Sinclair et al., 2020), metropolitan area (e.g., Donahue et al., 2018; Hamstead et al., 2018; Heikinheimo et al., 2020; Li et al., 2020; Song et al., 2020; Ullah et al., 2020; Zhang & Zhou, 2018), or across distinct sub-regions within individual parks (e.g., subregions of a national park; Heikinheimo et al., 2017). At the finest resolution of analyses, social media have been used to measure and map visitation hot spots within individual parks. For example, Walden-Schriener and colleagues (2018) use *Flickr* to map hotspots of visitation to protected areas in Argentina, Australia, and the United States. Recent work has focused less on the use of social media to quantify visitation within a particular park, focusing instead on using these data to identify distinct types of users (Gosal et al., 2019), parameterize models of visitor flows (Orsi & Geneletti, 2013), and quantify the value of parks and protected areas (Sinclair et al., 2018). Recent work has also used social media to measure preferences for (e.g., Clemente et al., 2019; Gosal et al., 2019; Hausmann et al., 2017; Johnson et al., 2019; Muñoz et al., 2020; Retka et al., 2019; Vaz et al., 2019; Vieira et al., 2018; Yoshimura & Hiura, 2017), or inequitable access to (Martinez-Harms et al., 2018, p.), ecosystem services.

3. Methods

3.1 Study Area

Our study region consists of all public land within each of Utah's 29 counties. We define public land as areas managed by federal agencies such as the National Park Service, the USDA Forest Service, and the state of Utah's primary park management agency, the Utah Division of Parks and Recreation that under the Utah Department of Natural Resources (DNR). Utah contains five national parks (Arches, Bryce Canyon, Capitol Reef, Canyonlands, and Zion) as well as seven other national park units (a total of 8,479 km^2). The state also contains five national forests (Ashley, Dixie, Fishlake, Manti-La Sal, and Uinta-Wasatch-Cache; a total of 33,102 km^2) and 45 state parks (a total of 489 km^2). Collectively, these areas support a vast array of outdoor recreation opportunities ranging from alpine skiing to sailing. The governing bodies for all federally and state-managed outdoor recreation destinations noted above report the number of visitors accessing their sites. At the National Park Service, the agency's Social Science Program is responsible for establishing counting protocols for how each park unit records a recreation visit (Ziesler & Pettebone, 2018). These protocols vary by park unit. Across all units, park visitation is aggregated to a monthly time scale. The USDA Forest Service estimates visitation for each national forest at five-year intervals using data collected through on-site interviews conducted at systematically sampled recreation settings within each forest. The program is referred to as the National Visitor Use Monitoring Program. Finally, the Utah Division of Parks and Recreation reports annual visitation to each state park unit based upon internal protocols established by each park unit. In this study, we use annual unit-specific visitation estimates reported by the National Park Service, the USDA Forest Service, and Utah State Parks to develop a validation model which assesses the ability of social media to proxy reported visitation to public lands within Utah. Lands managed by the Bureau of Land Management were excluded from our validation model because they lack a visitor use monitoring programs designed to generate total visitation estimates.

3.2 Data Collection

Reported annual visitation data were collected from the National Park Service, the USDA Forest Service, and Utah State Parks for the period of time between 2006 and 2014. Annual visitation data for National Park Service units were collected from the agency's Integrated Resource Management Applications portal (https://irma.nps.gov/Portal/). Data on annual recreation visits to national forests were collected from the USDA Forest Service's Natural Resource Manager web portal (https://www.fs.fed.us/recreation/programs/nvum/). Visitation data for all Utah State Parks were collected from the Division of Parks and Recreation's website (https://stateparks.utah.gov/resources/park-visitation-data/).

Social Media. We compiled two social media datasets, one containing all posts uploaded to the *Panoramio* platform and the other containing posts to the *Flickr* platform. *Panoramio* was a social media platform, active between 2005 and 2016, which allowed its users to upload geotagged photos to a central database. At the time the *Panoramio* platform was discontinued in 2016, the database consisted of 120 million photos (Toivonen et al., 2019). *Flickr* is a photo-sharing platform that has been in continuous operation since 2004. By the end of 2017, the platform had received 6.5 billion uploads from users. *Panoramio* and *Flickr* are the most frequently used platforms in the scientific literature for estimating or monitoring visitation to parks and protected areas (Teles da Mota & Pickering, 2020; Wilkins et al., 2020).

Posts made to both the *Panoramio* and *Flickr* platforms are accessible through each platform's API, which allow anyone to download both post content (i.e., the image uploaded, comments, etc.) and metadata (e.g., post coordinates, user identification, upload date, etc.) (Di Minin et al., 2015). We collected data from both platforms through their respective APIs, filtering data by the geographic boundaries of National Park Service units, national forests, and state park units. The *Panoramio* and *Flickr* data covers the same period of time (2006 to 2014) as the reported visitation from each land management agency. We limited the time period for our investigation to the years between 2006 to 2014 because the *Panoramio* API only provides data between 2006 to

2014. In order to compare the validity of the two platforms, *Flickr* data were also only collected between 2006 and 2014.

3.3 Data Analysis

3.3.1 Social Media Management and Validation

Photo-User Days. The full methodological workflow is shown in the supplemental material. All social media was processed and filtered in *R*. Specifically, we filtered posts by users' unique id, the date of post, and the park unit or forest in which the photograph was taken; this results in a dataset comprised of photo-user-days (PUDs), as opposed to all uploaded photos. The filtering process is necessary because multiple uploads per day should be attributed to the same recreation visit, as opposed to multiple visits.

The Validation Model. To validate the ability of social media to proxy reported visitation, we first calculated Pearson correlation coefficients between the social media and reported visitation data. We then use linear regression models to ascertain the proportion of variance in reported visitation explained solely through the social media. The regression models examine the statistical relationship between the total annual outdoor recreation visits to an area in a specific year (y_{it}) with total number of PUDs within that same area for the same year (x_{it}). The model can be specified as:

$$y_{it} = x_{it} + \epsilon_{it}$$

where the subscripts *i* and *t* refer to each park unit or forest and each year respectively. The error term is denoted as ϵ_{it}. Social media and reported visitation are log transformed prior to estimation to reduce or remove the skewness that is common in spatial counts of social media.

3.3.2 Spatial Analysis and Visualization

To identify spatial patterns of visitation on Utah public lands, we created a second PUD measure, one that filtered photos by user id, date, and a 5 km hexagonal grid (as opposed to individual park units and forests). The revised PUD measure is more appropriate for mapping spatial patterns of visitation within individual park units and forests because: 1) it is more capable of capturing visits to multiple settings within the same park or forest on the same day (i.e., is a better measure of within-unit use); and 2) it reduces the probability of sampling error (i.e., more data are retained). We chose a hexagonal grid because it can reduce edge effects. Additionally, the 5 km hexagonal grid was chosen over smaller and larger scales as it clearly identifies managerially relevant outdoor recreation and tourism destinations (e.g., ski resorts, visitor centers and their surrounding areas, park entrances, etc.) and does not result in an excessive number of cells with zero PUDs[3] which would prohibit the ability to examine spatial relationships. All aggregated PUDs in Utah were clipped by the combined public land boundaries, which include all National Park Service units, national forests, state park units, Bureau of Land Management lands, and other types of public lands that provide outdoor recreation opportunities. In order to identify spatial patterns of visitation on Utah public lands, we first checked for the presence of spatial clustering in PUDs. Using the queen weights matrix, we computed the Global Moran's *I* statistic to identify the extent of spatial autocorrelation existing in the PUDs on Utah's public lands.

[3] The proportion of cells with zero PUDs to all cells are: 93.71% at a 1 km resolution; 74.70% at a 3 km resolution; 56.82% at a 5 km resolution; and 30.58% at a 10 km resolution. The relatively high proportion of cells with zero PUDs to all cells was due to the low number of PUDs on BLM lands.

We also examined the Local Indicators of Spatial Association (LISA) (Anselin, 1995) to identify statistically significant categories of PUDs on public lands in Utah. LISA analysis compares the local sum for a grid cell and its adjacent cells to the sum of all grid cells in the study sample. Visitation patterns are identified if the local sum is significantly larger than the expected local sum and too large to be attributed to random chance. The LISA analysis yields a z-score of local spatial association; these statistics are converted from a continuous to a categorical variable and then summarized across four categories (high-high, high-low, low-high, low-low). These categories can be interpreted as follows:

- "high-high", a relatively high concentration of social media posts surrounded by other cells with a high concentration of posts;
- "low-low", a relatively low concentration of social media posts surrounded by other cells with a low concentration of social media posts;
- "high-low", a relatively high concentration of social media posts surrounded by cells with a relatively low concentration of social media posts; and
- "low-high", a relatively low concentration of social media posts surrounded by cells with a relatively high concentration of social media posts.

3.3.3 Exploring Differences Across Public Lands with Distinct Spatial Patterns of Visitation

To explore how the characteristics of public lands with distinct spatial patterns of visitation differed, we merged all grid cells within each of the four LISA classifications. We subsequently calculated the proportion of the land managed by each agency within each of the four LISA classifications. Wald chi-square statistics were used to determine significant differences across the four classifications.

4. Results

4.1 Reported Visitation and Photo-user Days

Summary statistics for both reported visitation and PUDs are presented in Table 2.2. In national parks and state parks, which report visitation for each unit annually, visitation gradually increased between 2006 and 2014. The same trend is not observable with the USDA Forest Service data, given they only report data for each forest (which vary considerably in use levels), every five years. None of the national forests in Utah were surveyed in 2010. For the National Park Service, PUDs also increased each year between 2006 and 2014. Over this time, PUDs ranged from 2 for Timpanogos Cave National Monument in 2011 to 913 for Arches National Park in 2013. There are no obvious trends in the number of PUDs for either national forests or state park units. Variation in photo-user days for national forests ranged from 2 for the Fishlake National Forest in 2006 to 969 for Uinta-Wasatch-Cache National Forest in 2013. The range of PUDs for state park units spanned 0 for Anasazi State Park in 2006 to 285 for Great Salt Lake State Park in 2011.

Table 2.2. Reported annual visitation and photo-user days to national park units, national forests, and state park units in Utah (2006-2014)

Unit Types	Annual Visitation								
	2006	2007	2008	2009	2010	2011	2012	2013	2014
Reported Visitation									
National park units	8,182,501	8,472,139	8,742,098	9,047,488	9,276,527	9,606,786	9,877,368	9,329,851	10,910,966
National forests	672,000	7,330,000	531,000	561,000	*	352,000	7,924,000	337,000	787,000
State parks units	4,465,294	4,751,582	4,540,957	4,822,777	4,842,918	4,803,770	5,081,558	4,044,215	3,720,873
Photo-User-Days *(one photograph, per unique user, per day, per park or forest)*									
National park units	301	1,829	2,107	2,261	2,493	3,351	3,260	3,483	2,679
National forests	122	929	1,200	1,209	1,258	1,328	1,437	1469	1,085
State parks units	83	459	594	628	554	855	818	1,016	715

* None of the national forests in Utah were surveyed in 2010.

Table 2.3. Ratio of annual photo-user days to reported visitation (10,000) for national park units, national forests, and state park units in Utah (2006-2014)

Unit Types	Ratio of Annual Photo-users-day to Reported Visitation								
	2006	2007	2008	2009	2010	2011	2012	2013	2014
National park units	0.37	2.16	2.41	2.50	2.69	3.49	3.30	3.73	2.46
National forests	1.82	1.27	22.60	21.55	*	37.73	1.81	43.59	13.79
State parks units	0.19	0.97	1.31	1.30	1.14	1.78	1.61	2.51	1.92
Average Ratio	0.79	1.46	8.77	8.45	1.92	14.33	2.24	16.61	6.05

Note. PUD = one photograph, per unique user, per day, per park or forest.

* = None of the national forests in Utah were surveyed in 2020.

As shown in Table 2.3., there is an observable increase between 2006 and 2014 in the average ratio of annual PUDs to thousands of reported visits for each type of public land. For national park units, the ratio ranged from 0.37 in 2006 to 3.73 in 2013. This ratio ranged from 1.27 in 2007 to 37.73 in 2011 for national forests (more variation exists for national forests because visitation data are only collected every five years). State park units received the lowest ratio of annual PUDs to thousands of reported visits, with values between 0.19 in 2006 and 2.51 in 2013.

4.2 Model Validity

Pearson correlation coefficients for each land management agency as well as each social media platform independently (as well as for both platforms combined) are provided in Table 2.4. The correlations for national park units and national forests are within the range of those reported in previous research, while the correlations for state park units are notably low (see Wilkins et al. (2020) for correlations reported in previous studies). Collectively, the models explained about half of the variance in visitation to national park units, national forests, and state parks in Utah ($R^2 = 0.53$). Both the *Panoramio* and *Flickr* data explained comparable proportions of the variance in reported visitation. Given this, and previous research documenting relatively little differences in the spatial variation in posts across platforms (van Zanten et al., 2016), subsequent analyses utilizes the combined social media datasets.

Table 2.4. Pearson correlation coefficients for annual photo-user days and annual reported visitation to national park units, national forests, and state park units in Utah (2006-2014)

	Site Type			
Social Media Platform	National Park Service Units	National Forests	Utah State Parks Units	Overall
Panoramio	0.73	0.73	0.27	0.71
Flickr	0.75	0.78	0.32	0.68
Combined	0.78	0.74	0.26	0.70

Note. PUD = One photograph, per unique user, per day, per park or forest.

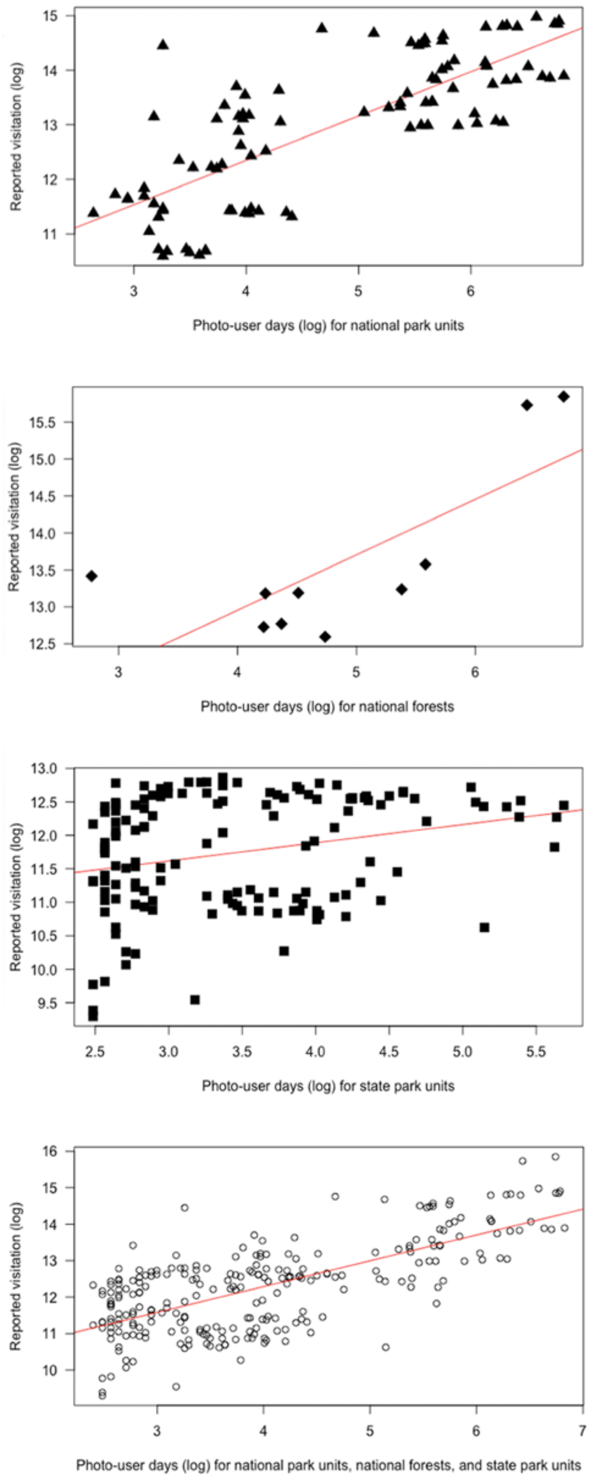

Figure 2.1. Association between reported visitation and photo-user-days for National Park Service units (a), national forests (b), state park units (c), and all three land management agencies combined (d).

Table 2.5. Results of the validation model examining the relationship between annual photo-user days and annual reported visitation for national park units, national forests, and state park units in Utah (2006-2014)

	Coef.	S.E.	T-value
Overall photo-user days			**(adjusted R^2 = 0.53)**
Intercept	194.86	47.46	4.11***
Year	-0.09	0.02	-3.91***
PUD	0.67	0.05	12.53***
Unit types	0.16	0.08	2.41*
Photo-user days within national park units			**(adjusted R^2 = 0.63)**
Intercept	207.44	67.09	3.09**
Year	-0.10	0.03	-2.96**
PUD	0.87	0.07	12.91***
Photo-user days within national forests			**(adjusted R^2 = 0.71)**
Intercept	356.24	179.23	1.99*
Year	-0.17	0.09	-1.93*
PUD	0.88	0.22	4.06***
Photo-user days within state park units			**(adjusted R^2 = 0.09)**
Intercept	152.06	64.80	2.35**
Year	-0.07	0.03	-2.18**
PUD	0.32	0.09	3.65***

Note. PUD = One photograph, per unique user, per day, per park or forest.
* p-value < 0.1
** p-value < 0.05
*** p-value < 0.01

The regression models revealed substantial differences in the ability of PUDs to proxy reported visitation across the three types of public lands (Figure 2.1.; Table 2.5.). Specifically, PUDs were a substantially better predictor of visitation to national forests (r = 0.74; R^2 = 0.71) and national parks (r = 0.78; R^2 = 0.63) relative to state park units (r = 0.26; R^2 = 0.09). However, our validation models do suggest combined PUDs were significantly and positively related to reported visitation to National Park Service units, national forests, and state park units (Coef. ≥ 0.32; $p \leq 0.01$). Similar to the R^2 statistics, our validation model shows that PUDs were a better predictor of reported visitation to national forests (Coef. = 0.88; $p \leq 0.01$) and national parks (Coef. = 0.87; $p \leq 0.01$) than state parks (Coef. = 0.32; $p \leq 0.01$). The differences between national parks, national forests, and state parks can be explained by the ratio of PUDs to reported visitation (Table 3). The ratio of PUDs to thousands of reported visits at state parks was only about one-fifth the mean ratio for all three types of public lands combined. The model using data for all three land management agencies included agency type as a fixed effect. This variable was significantly related to reported visitation (Coef. = 0.16; $p \leq 0.1$), consistent with previous research (Sonter et al., 2016).

4.3 Spatial Patterns of Visitation to Utah's Public Lands

Descriptive statistics of PUDs by the 5 km grid are provided in Table 2.6. The total number of PUDs on Utah's public lands was 102,098, with a range from 0 to 2,450 across the 12,169 hexagonal grids. The densities of PUDs across Utah's public lands are shown in Figure 2.2, Panel B. For all aggregated PUDs on public lands in Utah, the global Moran's I statistic indicates the aggregated PUDs in Utah were not randomly distributed (Moran's $I = 0.427$; $p < 0.01$).

Table 2.6. Descriptive statistics for aggregated photo-user days on public lands in Utah (2006-2014) using a 5 km hexagonal grid.

Statistic	Photo-User Days
Minimum	0
Maximum	2,450
Total	102,098
Mean	8.39
Standard deviation	56.45

Note. PUD = One photograph, per unique user, per day, per 5 km grid.

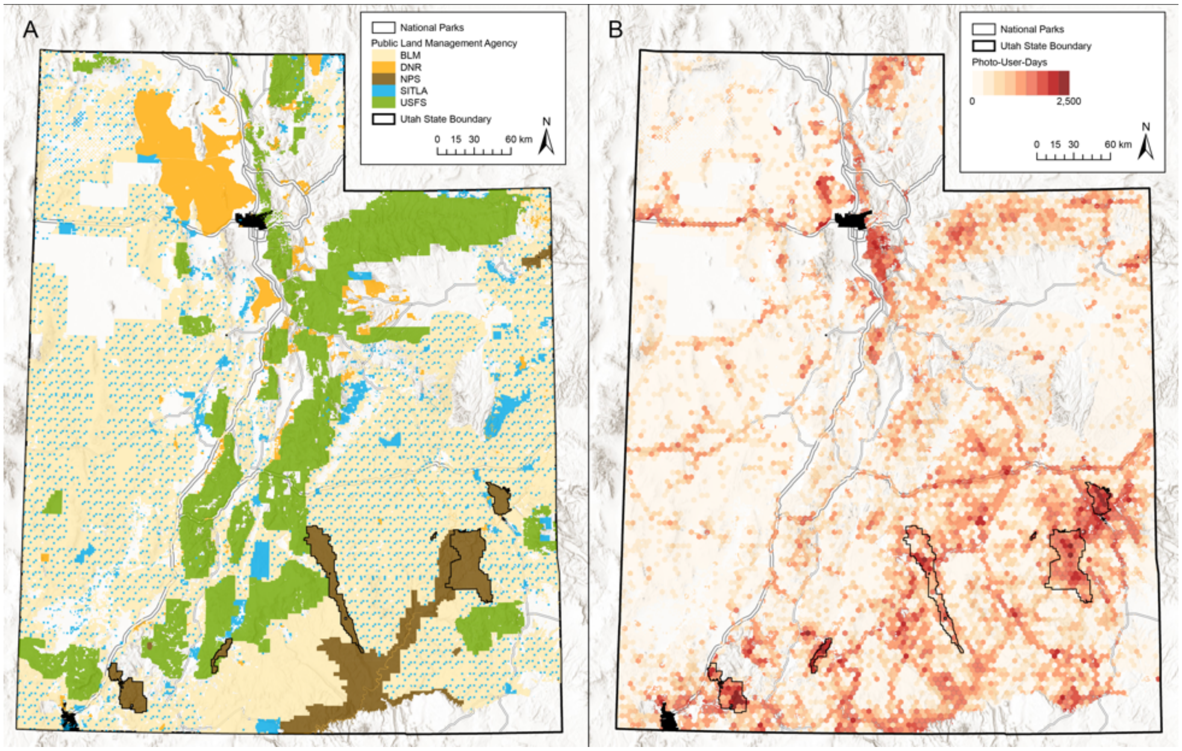

Figure 2.2. Public lands accessible for outdoor recreation in Utah by management agency (a) and photo-user-days aggregated by a 5-km grid across these lands (b)

We created visualizations of the most photographed places (i.e., 5 km grid cells) across 5 geographic regions within the state; an example of these maps from the southeastern region of the state is provided in Figure 2.3. Additionally, we also visualized unaggregated (i.e., raw) PUDs for each of the 29 counties within the state; an example from Grand County is shown in Figure 4. All maps have been made publicly available at [https://doi.org/10.3886/E131163V1].

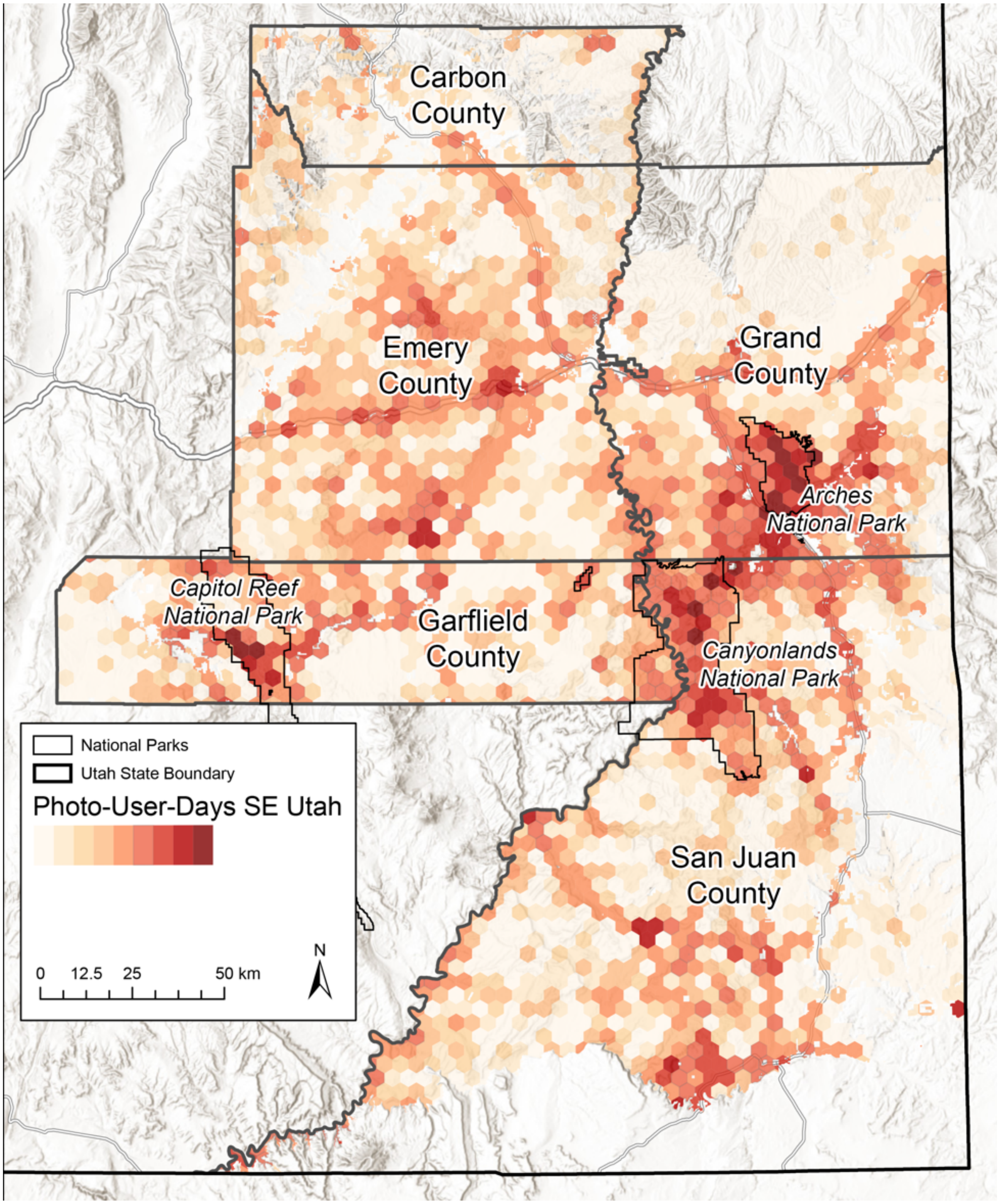

Figure 2.3. Photo-user-days aggregated by a 5-km grid across public lands within the southeastern region of Utah.

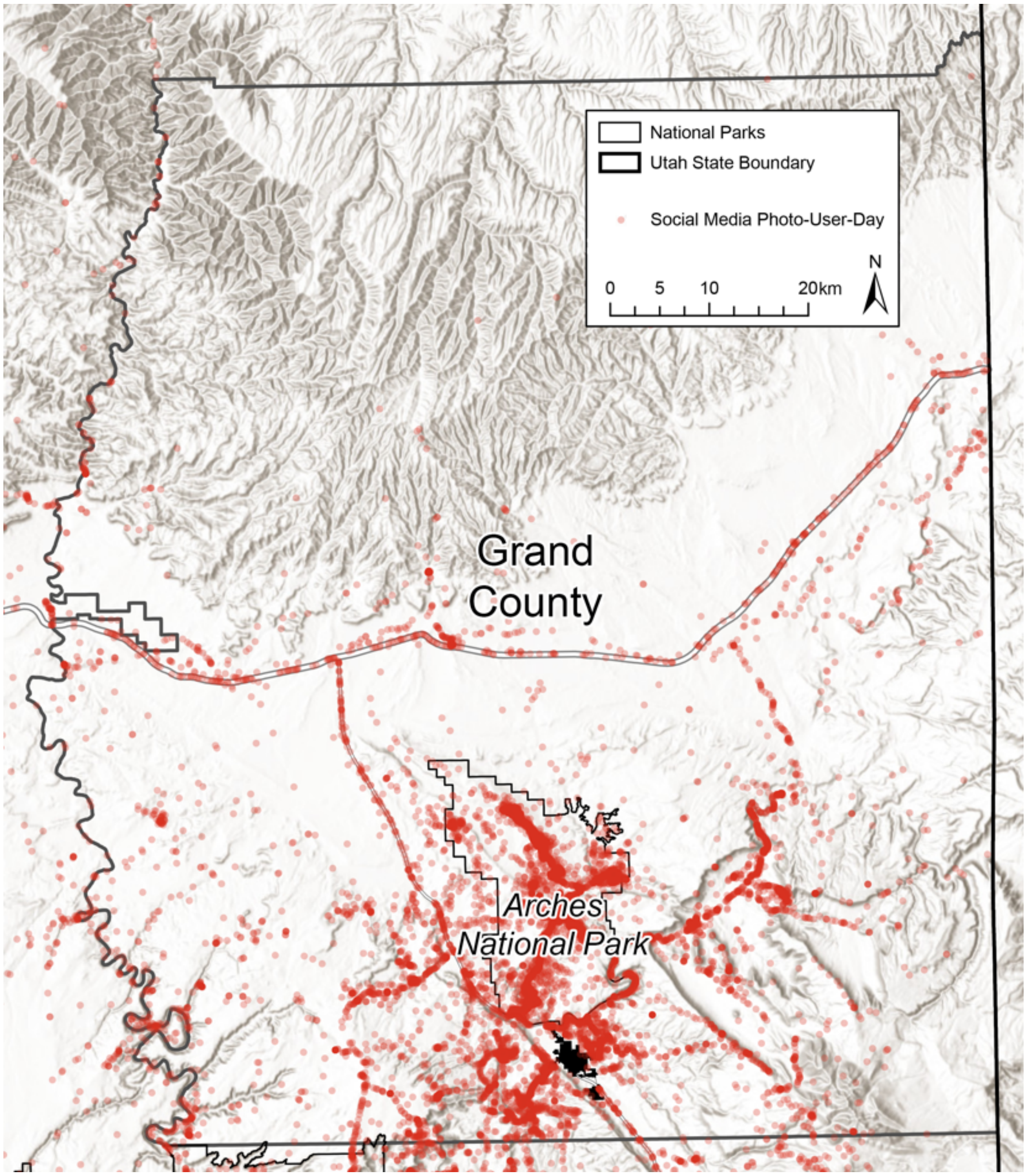

Figure 2.4. Photo-user-days on public lands within Grand County, Utah.

Local indicators of spatial association are shown in Figure 2.5. The map illustrates high-high areas (cells with high PUD counts surrounded by other cells with high PUD counts) are clustered around two areas, the Arches/Canyonlands/Moab area in the southeastern region of the state and Zion National Park in the extreme southwestern portion of the state. Pink areas (high-low) illustrate cells with high PUD counts surrounded by other areas with relatively low PUD counts. These areas cover some portions of national parks, national forests, and suburban areas with natural amenities (e.g., the canyons above Salt Lake City). Light blue areas on the map indicate cells with relatively low PUD counts surrounded by cells with relatively high PUD counts. These light blue areas are public lands with relatively low and scattered visitation surrounded by areas that see significantly higher use. Dark blue, or low-low areas are public lands with relatively low or dispersed use surrounded by similar areas.

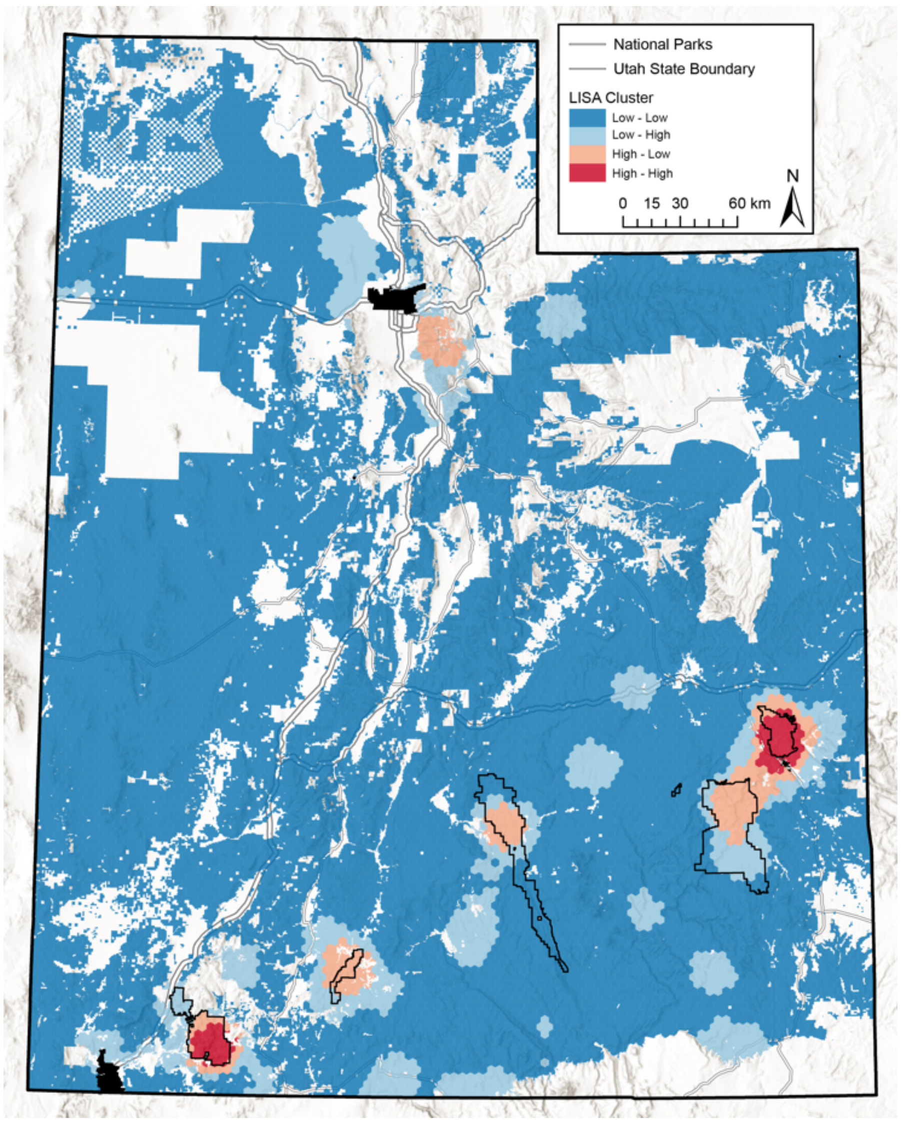

Figure 2.5. Local Indicators of Spatial Association (LISA) categories of photo-user-days across public lands within Utah.

The percentage of land managed by each agency within the four LISA categories is shown in Table 2.7. Over 90% of Bureau of Land Management and USDA Forest Service lands are within the low-low category; while about half of the National Park Service lands (58.5%) and Utah Division of Parks and Recreation lands (47.3%) are within this category. Only 6.7 % of Bureau of Land Management and 7.5% of USDA Forest Service lands are within the low-high category; the National Park Service and Utah Division of Parks and Recreation have larger proportion of their lands within this category (21.8% and 42.1% respectively). As might be expected, the National Park Service had the greatest concentration of land in the high-high LISA category (6.6%); the agency also had the greatest concentration of land in the high-low LISA category as well (13.0%).

The differences across all categories and agencies are significant ($\chi^2 \geq 22,656.47$; $p \leq 0.01$). Each LISA category is not distributed similarly across the different types of public lands in Utah (Table 2.7.).

Table 2.7. Area and proportion of each Local Indicators of Spatial Association category by land management agency

LISA Category	National Park Service	USDA Forest Service	Utah Division of Parks and Recreation	Bureau of Land Management
Low-Low (km^2)	7,030.2	34,756.8	759.7	103,214.4
Low-Low (%)	58.5%	90.2%	47.3%	91.3%
Low-High (km^2)	2,616.9	2,892.1	676.0	7,610.2
Low-High (%)	21.8%	7.5%	42.1%	6.7%
High-Low (km^2)	1,564.7	882.3	170.8	1,686.6
High-Low (%)	13.0%	2.3%	10.6%	1.5%
High-High (km^2)	798.0	0.0	0.0	579.4
High-High (%)	6.6%	0.0%	0.0%	0.5%

$\chi^2 \geq 22,656.47$; p-value ≤ 0.001

5. Discussion

5.1 Effectiveness of Social media to Proxy Visitation Data

Our results suggest social media can provide a relatively good proxy for visitation data collected through traditional means, at least for all public lands within Utah where reported visitation data are available. These findings align with previous research which has found social media collected from *Panoramio* and *Flickr* can accurately reflect visitation to outdoor recreation and tourism destinations. As noted above, there is a lack of research testing the effectiveness of using social media to approximate visitation data across different land management agencies. For example, the work of Fisher et al. (2018) focused on visitation to a national forest, while the work of Walden-Schreiner and colleagues (2018) focused on a U.S. National Park. By broadening the scope of analysis to include state parks, as well as national parks and national forests, our analysis illustrates there are significant differences in the ability of social media to accurately measure visitation to public lands managed by different agencies, at least within Utah. Results from our validation model show a significant and positive relationship between social media and reported visitation at National Park Service units and national forests while there is a relatively weak relationship for state parks. There are two likely explanations for this finding.

First, The National Park Service and the USDA Forest Service have robust visitor use monitoring systems. The National Park Service measures visitation to all units on a daily basis and while measurement protocols are not identical across all park units, they are internally consistent (Ziesler & Pettebone, 2018). The USDA Forest Service replicates a visitation measurement protocol within each forest; individual forests are surveyed once every five years (English et al., 2020). The internal consistency of this method yields scientifically valid visitation estimates. By comparison, the Utah Division of Parks and Recreation estimates visitation as a function of the annual revenues generated within each park (Rasmussen, personal communication). This method may lead to inaccurate estimates of park visitation as there are a variety of exogenous factors (e.g., the health of a state's economy) that influence the revenue a park system generates through entrance fees and license sales (Siderelis & Smith, 2013). Consequently, there is more likely to be noise in the visitation data for state parks relative to federally managed parks and protected areas.

Second, the attributes and characteristics that attract visitors to state parks differ significantly from the attributes and characteristics that attract visitors to national parks units and national forests (Sotomayor et al., 2014). Several Utah State Park units are comprised solely of historic structures (e.g., local cultural or historical sites, courthouses and state homes) which are much less likely to be photographed and shared on social media platforms that are preferred by outdoor recreationists (Figueroa-Alfaro & Tang, 2017). By contrast, national parks and national forests provide scenic vistas and iconic landscapes that tend to be photographed more than historic structures (van Zanten et al., 2016). Consequently, this results in the average ratio of annual PUDs to be lower for state parks relative to national parks and national forests.

5.2 Spatial Patterns of Visitation to Utah's Public Lands

Previous research has used social media to examine spatial patterns of visitation for a single national forest (e.g., Fisher et al., 2018) or national park (e.g., Walden-Schreiner et al., 2018a; Walden-Schreiner et al., 2018b). This study shows it can be accomplished at multiple spatial scales and that each of those spatial scales can be used to inform different types of decisions.

At the largest spatial scale that we examined (the state), our results show that the Wasatch Front's prominent ski resorts and five national parks were shared the most on *Panoramio* and *Flickr*. This finding is not surprising for residents of the state or anyone familiar with Utah's outdoor recreation opportunities. These locations are some of the most difficult to manage destinations within the state because of the exceptionally high demand placed on them. Recently, the Utah Office of Tourism and Film developed a 'Road to Mighty' campaign intended to divert visitors away from the state's national parks toward state parks and less well-used outdoor recreation destinations (Drugova et al., 2020). Our maps of the spatial distribution of visitation across the state can help campaigns like this identify less-used outdoor recreation destinations proximate to more heavily visited ones.

At a regional spatial scale, the results of our LISA analysis demonstrated low-use Bureau of Land Management lands surrounding high-use lands managed by the National Park Service (Figure 3). Additionally, our LISA analysis showed that many Bureau of Land Management lands adjacent to National Parks are already included in the highest density category that we identified (i.e., the High-High category). These findings suggest there is a substantial amount of 'spatial spillover' in visitation from national parks to nearby Bureau of Land Management lands. The high concentrations of visitation to Bureau of Land Management lands adjacent to national parks will require the Bureau of Land Management to concentrate its efforts to control and manage visitor use of these areas. Our findings also show there are low-use Bureau of Land Management lands that have yet to experience the spatial spread associated with increased visitation. The Bureau of Land Management lands around Moab and Arches and Canyonlands National Parks provide an example of this phenomenon (Figure 6). Impacts on Bureau of Land Management lands caused by increased visitation may not be manageable since the Bureau of Land Management does not have a well-established visitor use monitoring or management program similar to the National Park Service. It may be appropriate for the Bureau of Land Management and National Park Service to establish a cross-jurisdictional visitor use monitoring and management programs to help the agencies oversee visitation flow and manage impacts associated with increased visitation.

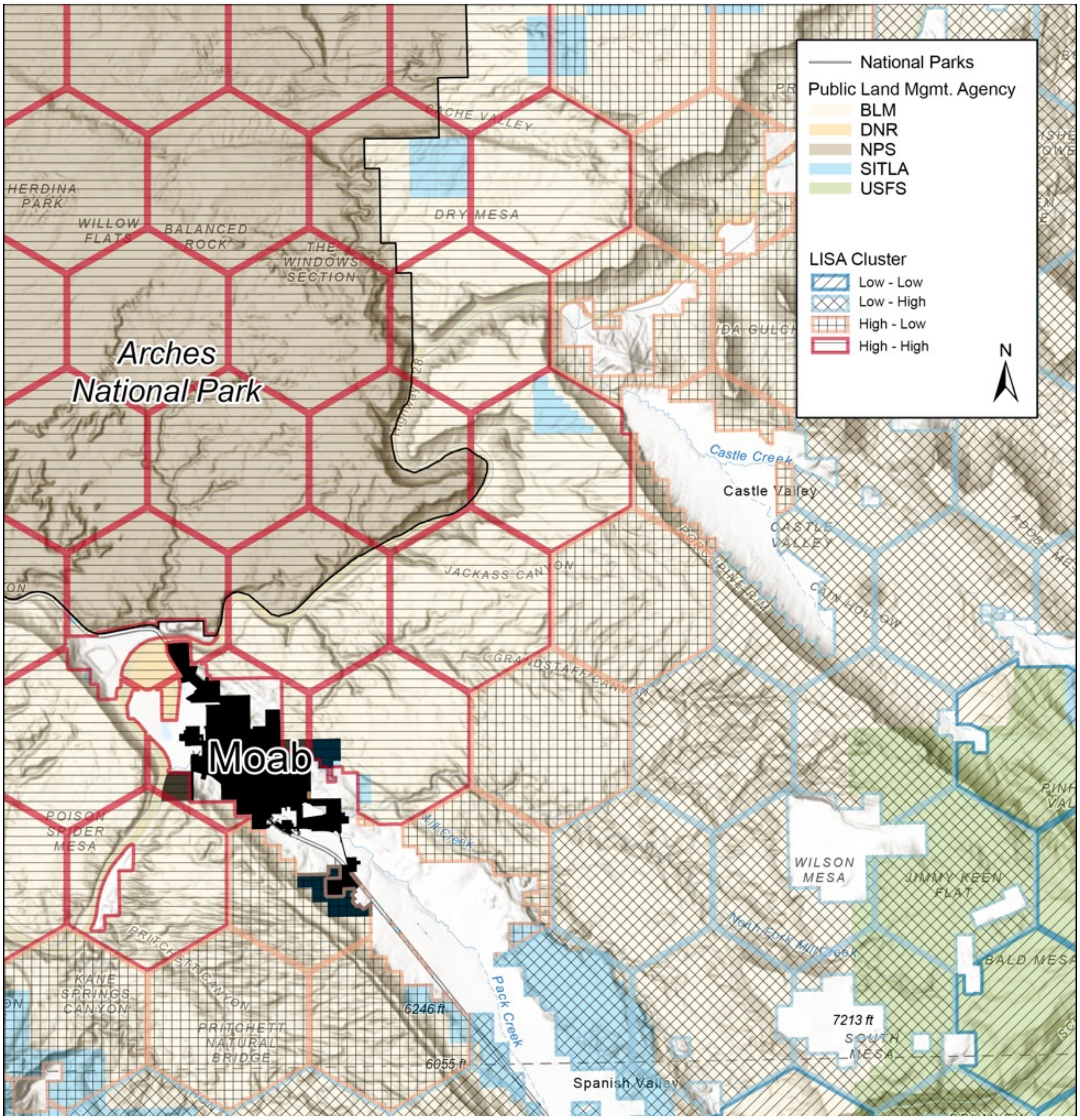

Figure 2.6. Local Indicators of Spatial Association (LISA) categories of photo-user-days across public lands around Moab, Utah.

At the smallest spatial scale investigated (the county), our analysis highlights locally relevant patterns of visitation (Figure 4). This information can inform the work of local economic development and tourism offices who often lack information about which of their natural amenities are most visited (and consequently may not need additional promotion), and which amenities are not as visited as they would like (warranting more active marketing efforts).

While the four types of public lands included in this study are managed using different frameworks, missions, and philosophies, our findings can be used to help guide collaborative, interagency, efforts. Specifically, our analysis identifies geographic boundaries where agencies can work together to either concentrate or disperse outdoor recreation use. Low-high cells are areas where visitation is currently low, but where demand is likely to grow as visitation to high-use areas (i.e., high-high cells) continues to grow (Smith & Miller, 2020). The areas around Arches and Canyonlands National Parks (described above) are a primary example. Managers should work to identify visitor use management strategies that limit the continued spatial expansion of outdoor recreation and the negative environmental impacts that come from unmanaged and rapidly-increasing use (Hammitt et al., 2015).

5.3 Limitations and Future Research

There are limitations that should be considered when interpreting our findings. First, one of the social media platforms we used for our analysis (*Panoramio*) is no longer available. Scholars who are interested in using social media to inform outdoor recreation management decisions should seek alternative platforms which still provide publicly available data or establish direct collaborations with social media platforms (Toivonen et al., 2019). Second, the Flickr database may change over time as the platform changes its data storage practices. In 2019 for example, the platform implemented new limitations on the number of photographs individuals can share on the site. This limits the ability of replication of methods using these data. Third, social media users may not be representative of all public land visitors (Teles da Mota & Pickering, 2020; Wilkins et al., 2020). This is a well-documented limitation within this line of research (Wilkins et al., 2020). Future research can mitigate this limitation by combining data from multiple social media platforms and combining social media with other volunteered geographic information (e.g., public participation geographic information systems) (e.g., Muñoz et al., 2020) and finding cooperative solutions with social media companies to improve researchers' access to data. Fourth, the absence of annual visitation data prohibited us from validating the use of social media as an accurate representation of visitation across Bureau of Land Management lands. Nonetheless, we recognize the outdoor recreation opportunities offered on Bureau of Land Management lands, and the characteristics of those lands themselves, are comparable to other federally managed lands, particularly national forests, that we included in our identification of spatial patterns of visitation across the state. Future research explicitly testing this assumption might be warranted. Fifth, we recognize this study does not describe specifically which attributes draw visitors to the areas with the highest concentrations of visitation. Our work is exploratory, not explanatory, and explanatory research investigating the reasons for the spatial variation in visitation across public lands in Utah is needed. Sixth, since we focused primarily on the spatial patterns of visitation to Utah's public lands, the temporal dynamics of visitation has been neglected. Again, future research might provide additional managerial guidance by examining visitation patterns that reflect both spatial and temporal dynamics of visitation. Lastly, our use of social media does not measure or quantify the meanings or values ascribed to parks and public lands. Manual content analysis and machine learning can be used to elucidate some of these meanings and values (see e.g., Callau et al., 2019; Wartmann et al., 2019; McCreary et al., 2020). These methods should be integrated into future research to take full advantage of all the information embedded within social media.

6. Conclusion

In an era where large geospatial datasets are freely available, public lands managers, outdoor recreation planners, and tourism professionals need a scientifically grounded understanding of how these data can be used to inform their decisions. In this research, we have expanded that understanding by examining the ability of social media to reliably measure the amount of visitation to public lands. For some land management agencies that are home to iconic destinations and scenic landscapes that are shared on photo-sharing platforms like *Panoramio* and *Flickr,* social media can provide a reliable proxy for reported visitation. However, for other agencies who manage destinations that are less likely to be shared on social media, using these data as a measure of visitation will be more tenuous. The use of social media should be approached with caution, with an appreciation that while it may have many benefits relative to traditional visitor use monitoring methods it may not be appropriate in all contexts and for all questions. Our analysis suggests the questions with which social media are well suited to answer depends on both managerial context (i.e., what types of destinations are being managed) and spatial scale (i.e., what is the scope at which tourism management decisions are being made).

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CHAPTER III

A DATA-DRIVEN AND GENERALIZABLE MODEL FOR CLASSIFYING RECREATION OPPORTUNITIES AT MULTIPLE SPATIAL SCALES

Abstract

The Recreation Opportunity Spectrum (ROS) is an integral component of numerous outdoor recreation and tourism planning efforts worldwide. However, the effectiveness of the ROS as a management tool has been limited for a variety of reasons. Principally among these is its dependence on anecdotal perceptions of managers as opposed to objective and reliable metrics. Additionally, the framework's value has been limited because it is used in a descriptive as opposed to prescriptive way (i.e., to describe what types of recreation opportunities are provided as opposed to what opportunities will be needed in the future). In this study, we present a data-driven and generalizable model to define and quantify ROS classifications at multiple spatial scales. The model is structured around the three setting characteristics (biophysical, managerial, and social) believed to influence the types of outdoor recreation opportunities provided in a particular place. Each characteristic is quantified using free and publicly available data. The model's analytical workflow yields discrete ROS classifications unique to the spatial extent to which it is being applied (e.g., statewide, across an entire national forest, across just a ranger district, etc.). We demonstrate the flexibility and utility of the model by applying it to three spatial extents (statewide, regional, and site-specific). Each application yields meaningful characterizations of the outdoor recreation opportunities provided across the landscape. These scale-specific ROS characterizations are useful to

distinct types of audiences that operate at distinct scales (e.g., state legislatures, regional collaborative initiatives, and land management agency line officers).

1. Introduction

Public lands in the U.S. are managed for a variety of uses including energy development, livestock grazing, habitat conservation, timber harvesting, and outdoor recreation (Brice et al., 2020). These uses generate substantial economic activity and also provide humans with a wide variety of ecosystem services (Karimi et al., 2020; Rodríguez et al., 2006). As the U.S. population continues to grow, so too has the demand for outdoor recreation and tourism on public lands (Cerveny et al., 2020; Miller et al., 2020; Sanchez et al., 2020). Consequently, many public land management agencies now consider outdoor recreation a primary use of the lands they manage (Thomas & Reed, 2019).

If the demand for outdoor recreation on federally managed public lands continues to grow, it is unclear whether many of the same outdoor recreation opportunities that are provided today will be able to be available to future generations. Outdoor recreation planners and managers, as well as state and local officials who have an interest in outdoor recreation, could benefit from a scientifically grounded approach to identifying where specific types of outdoor recreation opportunities are provided. Moreover, these planners, managers, and public officials could benefit from an approach that allows for the comparison of outdoor recreation opportunities at different spatial scales.

The purposes of this study are three-fold: (1) define a generalizable model and data sources that can be applied at different spatial scales to quantify outdoor recreation opportunities; (2) determine how different biophysical, managerial, and social characteristics contribute to the recreation opportunities offered at different locations; and (3) explore how the generalizable model can be applied at different spatial extents to identify context-dependent recreation opportunities. Our generalizable model is grounded in the Recreation Opportunity Spectrum (ROS) (Clark & Stankey, 1979), a well-established management framework codified into the planning and management actions of several public land management agencies. We apply our generalizable model to the state of Utah, where over 75% of the state is managed by federal and state public land management agencies. The state's public lands provide numerous opportunities for outdoor recreation activities for both in-state and out-of-state visitors. Utah's diverse public lands, which include the forests of the Wasatch mountains, the high deserts of the Colorado Plateau and the Great Basin, and portions of the Mojave Desert, support an outstanding diversity of outdoor recreation opportunities.

1.1 Quantifying Recreation Opportunities

The ROS framework emerged from the need to provide managerial guidance for a diversity of outdoor recreation settings (Joyce & Sutton, 2009; Perez-Verdin et al., 2008; Shafer & Mietz, 1969), and provide a diversity of opportunities both within and between outdoor recreation activities (Kliskey, 1998). The framework operates by spatially delineating a landscape into discrete classes based on its biophysical, managerial, and social characteristics. While ROS "classes" have been defined differently across the world, they commonly include *urban*, *rural*, *roaded natural*, *semi-primitive motorized*, *semi-primitive nonmotorized*, and *primitive* distinctions (Perez-Verdin et al., 2008). The assumption of the ROS framework is that each of these discrete classes facilitates the provisioning of specific types of outdoor recreation opportunities. For example, opportunities to experience solitude are more likely to occur within an area classified as primitive while opportunities to spend time with close friends and family members may be more prevalent in areas closer to the urban end of the ROS spectrum.

The ROS framework is used by federal land management agencies to: (1) establish managerial goals and objectives for specific types of outdoor recreation settings; (2) analyze impacts to recreation opportunities (i.e., the particular class of an ROS setting might be changed as a result of proposed management actions); (3) monitor established standards and conditions for recreation opportunities; and (4) provide specific objectives and standards for management plans (Clark & Stankey, 1979; Joyce & Sutton, 2009). Unique regulations and restriction are applied to the recreation settings within each ROS class in order to decrease the potential for conflict among different types of outdoor recreation activities that are presumed to have distinct and conflicting experiences. Outdoor recreation dependent upon motorized vehicles, for example, is not permitted in areas classified as semi-primitive nonmotorized and primitive.

The biophysical characteristics of the ROS framework generally refers to a site's physical geography, its land cover, and the presence and abundance of natural features (Byczek et al., 2018; Cortinovis et al., 2018; Dhami & Deng, 2018; Merry et al., 2018; Shilling et al., 2012). Recent research has used specific indicators such as the degree of naturalness and the presence of water bodies and viewsheds to define the biophysical characteristics of outdoor recreation settings (Maes et al., 2012; Paracchini et al., 2014; Peña et al., 2015). Following the ROS framework, Byczek et al. (2018) used land cover to determine the potential for different areas across a landscape to offer unique outdoor recreation opportunities. Byczek and colleagues (2018) as well as other investigators (Cortinovis et al., 2018; Dhami & Deng, 2018) have also used the remoteness and size of public lands/protected areas to determine ROS classifications.

The managerial characteristics of the ROS framework commonly refers to the presence, amount, and type of built infrastructure that supports outdoor recreation at a site; it also refers to the presence of restrictions on allowable visitor behavior (e.g., the use of motorized outdoor recreation equipment). In general, managerial characteristics of the ROS framework can be categorized into three groups: use restrictions; density of infrastructure; and accessibility. Use restrictions often include limits on where motorized vehicles are allowed. However, they may also include limits on mechanized equipment, such as mountain bikes, in designated Wilderness areas. Use restrictions can also include specific limits on the size of groups allowed to use an area or acceptable speeds for motorized travel (e.g., no wake zones in water-based recreation settings). Density of infrastructure refers to the types and amount of outdoor recreation infrastructure in place on the landscape. The most often quantified types of recreation infrastructure include campsites, restroom facilities, and visitor centers. Accessibility refers to how easily outdoor recreationists can access a site. Common distinctions include delineating between sites that are accessible via paved roads (e.g., roadside turnouts), dirt roads (e.g., many campgrounds), or by trail only (e.g., backcountry campsites).

Finally, the social characteristics of the ROS framework generally refers to the amount of use that recreation settings within a particular ROS class are likely to experience. ROS classes closer to the urban end of the spectrum typically receive higher levels of use relative to those closer to the primitive end of the spectrum.

1.2 A Generalized Model

Although the ROS framework has been used by federal land management agencies since 1970s, its effectiveness as a management tool has been limited for several specific reasons. First, the ROS is almost universally applied at a single spatial scale, most commonly an entire national forest or field office[4]. Implementing the tool in this way results in a lost ability to quantify and characterize outdoor recreation settings in a way that is meaningful to how the vast majority of individuals participate in outdoor recreation – evaluating potential destinations that can be visited given time and financial constraints (Joyce & Sutton, 2009). The larger the spatial scale at which recreation opportunities are classified, the harder it becomes to characterize meaningful differences in the ways outdoor recreation settings are perceived and used. It does managers little good to know that large portions of the land they manage are classified as 'semi-primitive non-motorized' for example, if they know that resource provides multiple (potentially conflicting) types of outdoor recreation experiences. For the ROS to be more effective as a management tool, it needs to have the capacity to quantify and characterize outdoor recreation opportunities at a variety of managerially relevant scales. By developing a generalizable model and data sources that can be used at various spatial scales, our approach allows the ROS to be used more broadly across an agency, and not solely by the highest levels of planning and management.

[4] The ROS is used as a managerial tool by the USDA Forest Service and the Bureau of Land Management. Lands managed as part of the USDA Forest System are managed through a hierarchical system which aggregates relatively small ranger districts to larger national forests. The Bureau of Land Management similarly manages land through a hierarchical system in which discrete portions of land are managed by field offices. The policy and managerial actions of individual field offices are coordinated at the state level.

Second, the ROS has been inconsistently applied over the years and across different management agencies. Managers and planners have used different measures to define the biophysical, managerial, and social characteristics of the lands they manage. Often, data quality and availability vary across a landscape, requiring managers and planners to make subjective decisions about how specific settings should be classified. Subjective judgements[5] on selecting recreation opportunity classifications can substantially influence the accuracy and function of the ROS. In our generalizable model, we incorporate free and publicly available data to define outdoor recreation opportunities. The data-driven approach increases transparency, which may lead to the tool being more publicly acceptable (Powers & Hampton, 2019).

The final reason why the effectiveness of the ROS as a management tool has been limited is a result of it being used in a descriptive as opposed to prescriptive way. The ROS is almost universally used in a descriptive manner to characterize the types of outdoor recreation opportunities that are currently offered across the landscape[6]. ROS classifications are not used in a prescriptive way to shape the types of opportunities that managers would like to provide for their constituents. The retrospective nature in which the ROS framework is applied leads to its infrequent use. For example, the USDA Forest Service is required to update their ROS classification maps every time they create a new forest plan (approximately every 10 years). The classification maps are the product of existing transportation and outdoor recreation infrastructure as well as managers' assessment of site-specific use levels; they are only infrequently used to determine if

[5] ROS classifications are typically created through planning processes that incorporate other uses besides outdoor recreation.

[6] Federal land management documents do describe desired conditions and management objectives, however they are very rarely connected to the ROS.

proposed management actions would affect existing outdoor recreation opportunities (e.g., via an environmental impact assessment) (Harshaw & Sheppard, 2013; Manning et al., 2011). For the ROS to be more frequently and effectively used, we argue that it needs to be applied in a prescriptive manner with outdoor recreation planners, managers, and their constituents collaboratively defining the types of outdoor recreation opportunities that *should* be provided across a landscape. In other words, the ROS classifications should be used as a management tool to solve complex challenges associated with providing recreation opportunities on public lands. Doing so would allow outdoor recreation planners and managers to more explicitly incorporate knowledge about the demand for outdoor recreation opportunities in the future into their planning and management actions. We return to this point more substantively in our discussion, but point out here that by leveraging free and publicly available data sources, our generalizable model has the capacity to be implemented as a prescriptive management tool.

Our data-driven and generalizable model is illustrated in Figure 3.1. Free and publicly- available data are used as indicators of the three characteristics which define outdoor recreation opportunities. Instead of classifying outdoor recreation opportunities along a linear continuum as has been done in the past, we provide equal conceptual weight to the biophysical, managerial, and social characteristics that can define a setting. The result is a hypothetical three-dimensional matrix (Figure 3.2) within which any outdoor recreation opportunity can be placed. A remote natural setting with relatively low management presence and little use will be defined as “biophysical (high) – managerial (low) – social (low)”. Allowing each of the three dimensions of an outdoor recreation setting to have two levels (high and low), allows the three-dimensional conceptualization to distinguish between eight classifications of outdoor recreation opportunities. These eight hypothetical classifications are described in detail in Table 3.1. As an example, frequently visited sites ("high" on social characteristics) with numerous facilities and other infrastructure ("high" on managerial characteristics) that are easily accessible via roadways ("low" on biophysical characteristics) will be categorized into an H_6 ROS classification. We argue that providing equal conceptual weight to the biophysical, managerial, and social characteristics that define a setting allows us to more accurately capture the diversity and variability in outdoor recreation settings and the opportunities they provide. This approach also allows the model to define ROS classifications that are scale-dependent, providing land managers with a more flexible tool to guide the wide-range of decisions they make; these decisions can range from site-specific (e.g., "should we install shower facilities in this particular campground?") to landscape-scale (e.g., "where would large pavilions be needed the most across the forest?").

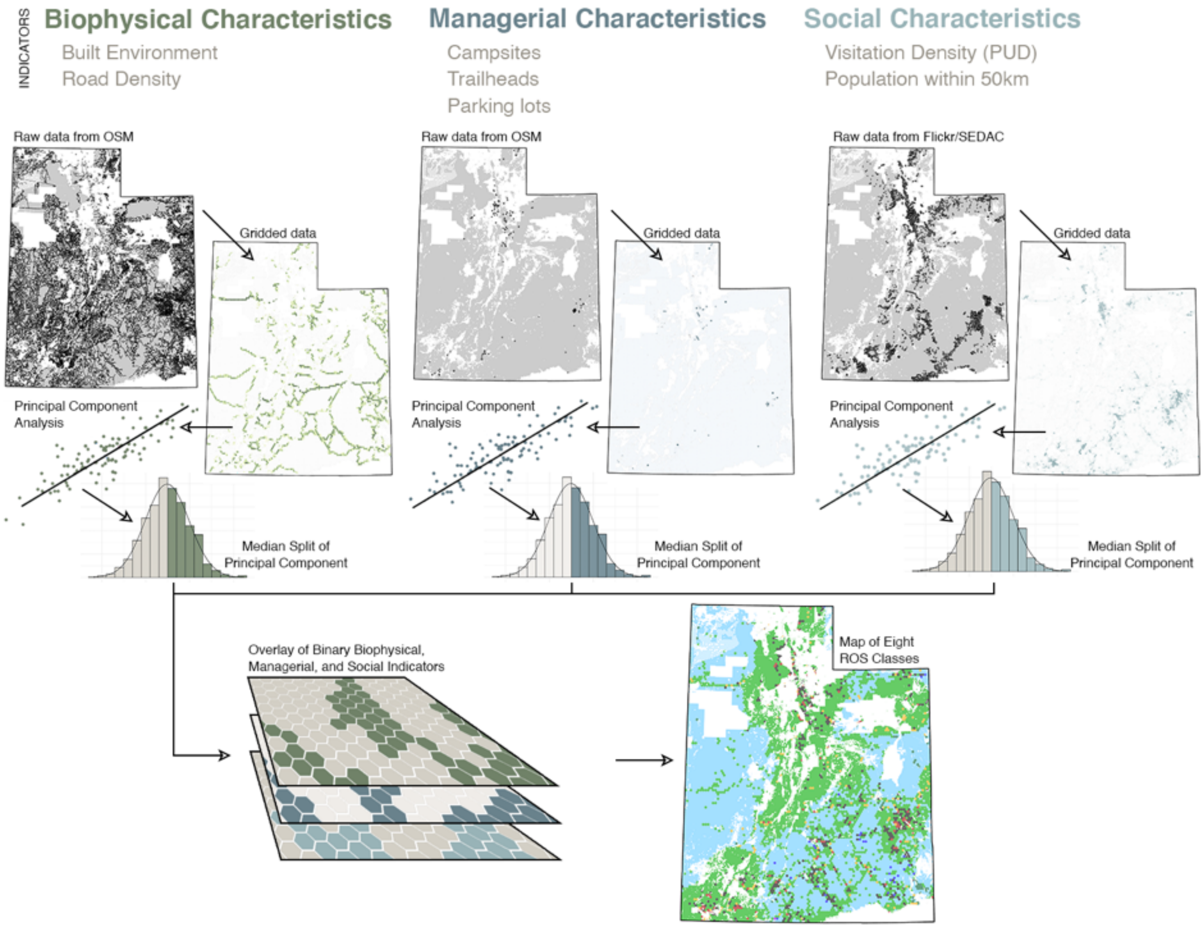

Figure 3.1. A data-driven and generalizable methodological workflow for quantifying outdoor recreation opportunities.

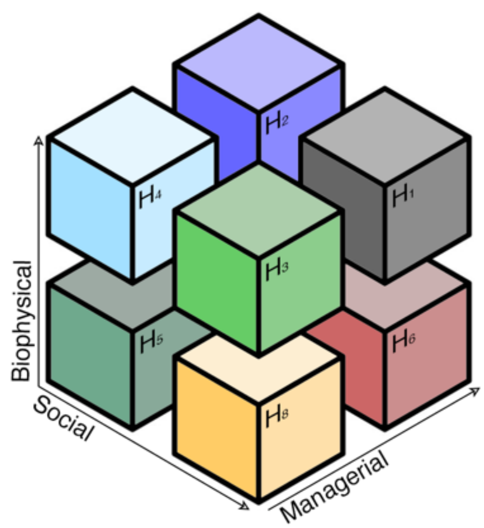

Figure 3.2. Eight discrete classes of recreation opportunities based on high/low classifications of the biophysical, managerial, and social characteristics of a recreation setting.

Table 3.1. The eight discrete classes of recreation opportunities based on high/low classifications of the biophysical, managerial, and social characteristics of a recreation setting.

Setting Characteristic	Hypothetical opportunity classifications							
	H_1	H_2	H_3	H_4	H_5	H_6	H_7	H_8
Biophysical	high	high	high	high	low	low	low	low
Managerial	high	high	low	low	low	high	high	low
Social	high	low	high	low	low	high	low	high
	Descriptions of each classification							
	More natural settings with more managerial presence and heavy use	More natural settings with more managerial presence and little use	More natural settings with less managerial presence and heavy use	More natural settings with less managerial presence and little use	Less-natural setting with less management presence and little use	Less-natural setting with more managerial presence and heavy use	Less-natural setting with more managerial presence with little use	Less-natural setting with less managerial presence and heavy use
	Management implications for each classification							
	Assure existing infrastructure minimizes ecological degradation from visitor use; continue to invest in maintenance and infrastructure; Assure existing infrastructure supports large and diverse groups.	Ensure investments in maintenance and infrastructure preserve activities with low visitor use densities.	Invest in infrastructure to minimize ecological degradation from visitor use.	Preserve opportunities for activities with low visitor use densities.	Monitor use for possible increases in demand and associated environmental impacts.	Continue to invest in maintenance and infrastructure; Assure existing infrastructure supports large and diverse groups.	Reallocate management resources to areas with more demand.	Invest in infrastructure to meet demand.

2. Methods

2.1 Study Area

Our study area covers all public lands in Utah; this is inclusive of lands managed by the National Park Service, the USDA Forest Service, Bureau of Land Management, the Utah Division of Parks and Recreation, and other public lands managed by either federal or state agencies. Utah contains five popular U.S. national parks (Arches, Bryce Canyon, Canyonlands, Capitol Reef, and Zion) as well as several other national park units, and large proportions of five national forests (Ashley, Dixie, Fishlake, Manti-LaSal, and Uinta-Wasatch-Cache). The public lands managed by the Bureau of Land Management are located throughout the entire state. Public lands in Utah contain diverse landscapes which support a wide range of outdoor recreation opportunities.

2.2 Data Collection and Processing

Specific indicators for the biophysical, managerial, and social characteristics of public lands are drawn from previous research mapping recreation opportunities (Table 3.2.). Indicators, along with their data sources are noted in Table 3.3. All data are aggregated to a 5-km hexagonal grid using *R*[7]. Biophysical setting characteristics are measured as either a proportion of each setting (cell) (e.g., the proportion of a setting that is developed) or the length of paved road within the setting (cell). Managerial setting characteristics are calculated based on the number of units (e.g., campsites) within each setting (cell). The social characteristics of outdoor recreation settings on public lands is quantified using publicly available social media as well as the population living within

[7] A 5-km (long diagonal length) spatial grid was chosen over smaller or larger grids because it can identify, and differentiate between, nearly all types of non-linear recreation settings (e.g., campsites, marinas, trailheads, etc.). Doing so allows recreation settings to be classified in more managerially meaningful ways (e.g., ski areas are not aggregated in with nearby natural lakes, roadside turnouts, and natural lakes).

50-km of each setting (cell). Data from two social media platforms are, *Flickr* and *Panoramio*, are used; these data are acquired through their respective APIs. Geotagged posts are transformed to 'photo-user-days' following best practices in the field (Wilkins et al., 2021; Wood et al., 2013) and aggregated to the 5-km hexagonal grid. Previous analyses of these data has shown they capture approximately 70% of the variation in visitation data reported by public land management agencies (Zhang et al., 2021). Population data were acquired from the Socioeconomic Data and Applications Center administered by the National Aeronautics and Space Administration of the United States.

Table 3.2. The common characteristics related to Recreation Opportunity Spectrum Planning Framework.

Setting Characteristic	Variables	References
Biophysical	Naturalness/remoteness: distance(areas) to major urban areas	Byczek et al., 2018; Cortinovis et al., 2018; Dhami & Deng, 2018; Merry et al., 2018; Shilling et al., 2012
	Water bodies	Byczek et al., 2018; Cortinovis et al., 2018; Maes et al., 2012; Merry et al., 2018; Paracchini et al., 2014; Peña et al., 2015; Rahman et al., 2020; Sæþórsdóttir & Ólafsson, 2010; Tarrant & Smith, 2002
	Accessibility (density of road)	Dhami & Deng, 2018; Gundersen et al., 2015; Oishi, 2013; Sæþórsdóttir & Ólafsson, 2010; Tarrant & Smith, 2002
Managerial	Area under restrictive management (e.g., wilderness, the NPS lands)	Byczek et al., 2018; Cortinovis et al., 2018; Dhami & Deng, 2018
	Density of infrastructure (e.g., visitor centers, showers, dump stations, internet access, trailheads, parking lots, etc.)	Cortinovis et al., 2018; Kil et al., 2014; Oishi, 2013; Sæþórsdóttir & Ólafsson, 2010; Tarrant & Smith, 2002
Social	Visitation density (or social encounter), population density.	Cole & Hall, 2009; Oishi, 2013; Sæþórsdóttir & Ólafsson, 2010; Tarrant & Smith, 2002

Table 3.3. Data and measurements related to the ROS framework.

Setting Characteristic	Variables	Data Sources	Descriptions	Measurements
Biophysical	Naturalness	*OpenStreetMap (OSM)*	A spatial layer of built environment	Proportion of built environment in each grid cell.
	Remoteness	*OpenStreetMap (OSM)*	A spatial layer of paved road	Total length of paved road in each grid cell.
Managerial	Campsites	*OpenStreetMap (OSM)*	A spatial layer shows campsites (fee required).	Number of campsites (fee required) in each grid cell.
	Dump/sanitary stations	*OpenStreetMap (OSM)*	A spatial layer shows all dump/sanitary stations on Utah's public lands.	Amount of dump/sanitary stations in each grid cell.
	Showers	*OpenStreetMap (OSM)*	A spatial layer shows all showers on Utah's public lands.	Number of showers in each grid cell.
	Toilets	*OpenStreetMap (OSM)*	A spatial layer shows all toilets on Utah's public lands.	Number of toilets in each grid cell.
	Drinking water	*OpenStreetMap (OSM)*	A spatial layer shows availability of drinking on Utah's public lands.	Availability of drinking water in each grid cell.
	Trailheads	*OpenStreetMap (OSM)*	A spatial layer shows all the accessible trail heads on Utah's public lands.	Number of trailheads in each grid cell.
	Parking lots	*OpenStreetMap (OSM)*	A spatial layer shows all parking lots on Utah's public lands.	Amount of parking lots in each grid cell.
	Visitation density (PUDs)	*Flickr and Panoramio*	A rasterized layer shows visitation level to Utah's public lands.	Amount of visit in each grid cell.
Social	Population density	*Socioeconomic Data and Applications Center (SEDAC)*	A rasterized layer shows population density in a 50-km range near public lands.	Amount of population in a 50-km proximity of each grid cell.

2.3 Principal Component Analysis for Spatial Data at Three Spatial Extents

We used Pearson's correlation coefficients to identify high correlations ($r > 0.50$) and generate a parsimonious set of variables representing the three ROS characteristics (the full correlation matrix is shown in Supplemental Figure A). At least two measures are retained for each characteristic. Principal Component Analysis (PCA) is then used on the variables within each ROS classification to identify the most common 'principal component' within that set of variables. Prior to conducting the PCAs, all numeric variables are standardized and joined to a compiled data frame by the identification number of the 5-km hexagonal grid. For each ROS characteristic, the principal component explaining the highest proportion of variance is selected to represent that particular characteristic. The standardization and PCA analysis can be repeated at any spatial extent desired. Here, we repeat the analysis at three spatial extents to demonstrate the flexibility and utility of the model. The first spatial extent we analyzed was the entire state, a scale at which identifying distinct ROS classifications is meaningful for offices with state-wide mandates (e.g., the Utah Office of Tourism and Film and the Utah Office of Outdoor Recreation). The second spatial extent we analyzed was the four-county region (Garfield, Iron, Kane, and Washington) in the southwestern portion of the state. This region includes a diverse set of public lands that consist of different landscapes (desert, forested land, and canyons, etc.) and different managing agencies. The region includes Bryce Canyon and Zion National Parks, the Dixie National Forest, as well as numerous state parks. The region is experiencing rapid growth in the demand for outdoor recreation opportunities driven, in-part, by urban growth near the city of St. George (Smith & Miller, 2020). The final spatial extent that we analyzed was the Salt Lake Ranger District of the Uinta-Wasatch-Cache National Forest. Like the southwestern region of the state, the Salt Lake Ranger District is experiencing rapid growth in the demand for outdoor recreation opportunities driven by the urbanization of the Salt Lake Valley (Smith & Miller, 2020).

Distinct ROS classifications are identified by transforming derived principal components into dichotomous “high-low” variables based on median values. These dichotomous classifications are then combined to generate unique combinations of the three measures that represent the biophysical, managerial, and social characteristic of each settings; these unique combinations map to the eight discrete hypothetical ROS classifications proposed above (Table 3.1.). For example, if a grid cell was “low” on the biophysical characteristic, “high” on the managerial characteristic, and “high” in social characteristic, it will be categorized in the H_6, which refers to intensely managed urban-proximate setting with heavy use.

3. Results

3.1 Descriptive Statistics of Recreation Setting Characteristics

Descriptive statistics for each variable representing biophysical, managerial, and social characteristics, across the three spatial extents we performed the analysis at, are presented in Table 3.4.

3.2 Variable Selection

The correlation matrix of all variables initially under consideration is shown in Supplemental Figure A. Overall, variables representing biophysical and social characteristics were not highly and significantly correlated to each other. The biophysical characteristics of outdoor recreation settings are represented by the amount of an area with a land cover classification of ‘built environment’[8] and the length (km) of roads

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[8] Built environment is a combined spatial layer that includes commercial, residential, and industrial development as defined in the *Open Street Map* (OSM) Land use and Landcover database (landuse = commercial + industrial + residential).

within that area. However, for the variables representing managerial characteristics, we found the number of showers, toilets, and the presence of drinking water were highly and positively correlated with the number of trailheads ($r > 0.5$). We subsequently dropped these variables, retaining only the number of trailheads. The final set of variables representing the managerial characteristics of outdoor recreation settings were: (1) the number of campsites; (2) the number of trailheads; and (3) the number of parking lots.

Table 3.4. Descriptive statistics for each of the three spatial extents examined (data are aggregated or calculated across 5-km hexagonal grid cells, n = 12,169).

	Statewide			Southwestern Utah[1]			Salt Lake Ranger District of the Uinta-Wasatch-Cache National Forest		
	Total	**Mean (range)**	**Std. Dev.**	**Total**	**Mean (range)**	**Std. Dev.**	**Total**	**Mean (range)**	**Std. Dev.**
Biophysical									
Built Environment (km^2)	6.67	0.03 (0-0.46)	0.07	1.5	0.00 (0-0.43)	0.01	0.24	0.00 (0.14-0.24)	0.01
Proportion of built environment in each cell (%)		0.04 (0-100.00)	1.37		0.01 (0-7.16)	0.2		1.36 (0-100.00)	10.54
Road density (km)	6,457.86	0.01 (0-5.24)	0.15	1313.40	0.02 (0-5.23)	0.19	53.68	0.03 (0-2.56)	0.26
Managerial									
Campsites	1,062	0.09 (0-117)	1.72	177	0.07 (0-51)	1.57	112	1.02 (0-24)	3.91
Dump/sanitary stations	121	0.01 (0-34)	0.48	31	0.01 (0-31)	0.63	3	0.03 (0-3)	0.29
Showers	154	0.01 (0-42)	0.56	20	0.01 (0-19)	0.39	3	0.03 (0-3)	0.29
Toilets	473	0.04 (0-42)	0.86	57	0.02 (0-20)	0.6	48	0.44 (0-21)	2.40
Drinking water	325	0.03 (0-28)	0.66	41	0.02 (0-20)	0.56	63	0.57 (0-24)	3.24
Trailheads	65	0.01 (0-3)	0.09	17	0.01 (0-2)	0.09	n/a	n/a	n/a
Parking lots	6,961	0.57 (0-166)	4.69	1,727	0.71 (0-166)	5.53	559	5.08 (0-88)	13.60
Social									
Visitation density (PUDs)	102,098	8.39 (0-2,450)	56.45	35,015	14.30 (0-2,450)	87.14	4,759	43.26 (0-749)	96.18
Population density (50km)	5,026,028	6,083 (0-1,002,401)	18,710.93	837,671	85,585.57 (0-304,105)	73,067.89	2,812,516	565,644.80 (70,504-1,002,401)	329,304.00

[1] Defined as the four-county region comprised of Garfield, Kane, Iron, and Garfield Counties.

3.3 Principal Component Analysis for Spatial Data at Three Spatial Extents

The results of the PCA for each ROS setting, by the spatial extent of analysis, is shown in Table 3.5. There was little difference in terms of factor loadings across the three scales of analysis, suggesting the indicator variables are robust across different applications. The visualizations and spatial distribution of the aggregated ROS classification are presented in Figures 3.3, 3.4, and 3.5. Percentages of ROS classification at three spatial scales are provided in Table 3.6.

Table 3.5. Results of the principal components analysis for setting classification for each of the three spatial extents examined.

	Statewide	**Southwestern Utah[1]**	**Salt Lake Ranger District of the Uinta-Wasatch-Cache National Forest**
Biophysical			
Built Environment	0.71	0.71	0.71
Road density (km)	0.71	0.71	0.71
Proportion of variance (%)	52.07	51.66	51.01
Managerial			
Campsites	0.61	0.70	0.71
Trailheads	0.38	0.07	n/a
Parking lots	0.70	0.71	0.71
Proportion of variance (%)	44.79	55.67	64.89
Social			
Visitation density (PUDs)	0.71	0.71	0.71
Population density	0.71	0.71	0.71
Proportion of variance (%)	53.11	50.65	67.84

[1] Defined as the four-county region comprised of Garfield, Kane, Iron, and Garfield Counties.

Table 3.6. Percentages of setting classifications for each of the three spatial extents examined.

Setting Classification	Description	Statewide	Southwestern Utah[1]	Salt Lake Ranger District of the Uinta-Wasatch-Cache National Forest
H_1	More natural settings with more managerial presence and heavy use	3.92	3.80	20.00
H_2	More natural settings with more managerial presence and little use	0.25	1.96	10.00
H_3	More natural settings with less managerial presence and heavy use	43.41	43.28	28.18
H_4	More natural settings with less managerial presence and little use	49.33	47.33	36.36
H_5	Less-natural setting with less management presence and little use	0.43	0.53	1.82
H_6	Less-natural setting with more managerial presence and heavy use	0.95	1.39	0.00
H_7	Less-natural setting with more managerial presence with little use	0.01	0.20	1.82
H_8	Less-natural setting with less managerial presence and heavy use	1.69	1.51	1.82

[1] Defined as the four-county region comprised of Garfield, Kane, Iron, and Garfield Counties.

As presented in Figure 3.3, outdoor recreation opportunities provided across all public lands in Utah are predominantly (49.33%) classified as H_4 (more natural settings with less managerial presence and little use). The vast majority of these lands are managed by the Bureau of Land Management, which manages the greatest proportion (43.54%) of public lands within the state (Smith & Miller, 2020). More natural settings with less managerial presence and heavy use (H_3) are also relatively common across the state, occurring on 43.41% of the state's public lands. These opportunities occur on more accessible and urban-proximate lands managed by both the Bureau of Land Management and the USDA Forest Service. This pattern can be seen around the rapidly growing southwestern region, and along Interstate 15 which stretches up the center of the state (Figure 3). Intensely managed, more natural settings with heavy use (H_1) tend to be concentrated in outdoor recreation and tourism 'hotspots' throughout the state (Zhang et al., 2021). This pattern can be seen in the concentration of H_1 classified public lands in the state's five national parks and in the heavily visited and intensely managed ski resorts located in the Wasatch Mountains east of Salt Lake City (Figure 3). Less-natural settings with little to no management presence only occur rarely, on 1.69% of public lands throughout the state. These areas are dispersed but tend to be located at scenic viewpoints located on major transportation routes and along scenic byways (Figure 3). Intensely managed, less-natural settings with heavy use (H_6) are also relatively rare (occurring on only 0.95% of the state's public lands). These areas, like those classified as H_1 are within the high-volume traffic areas of national parks (e.g., Zion Canyon) as well as in high-volume traffic areas near outdoor recreation hotspots (e.g., Bureau of Land Management lands surrounding Moab); they are also concentrated in heavily visited and developed settings within national forests (e.g., ski resorts).

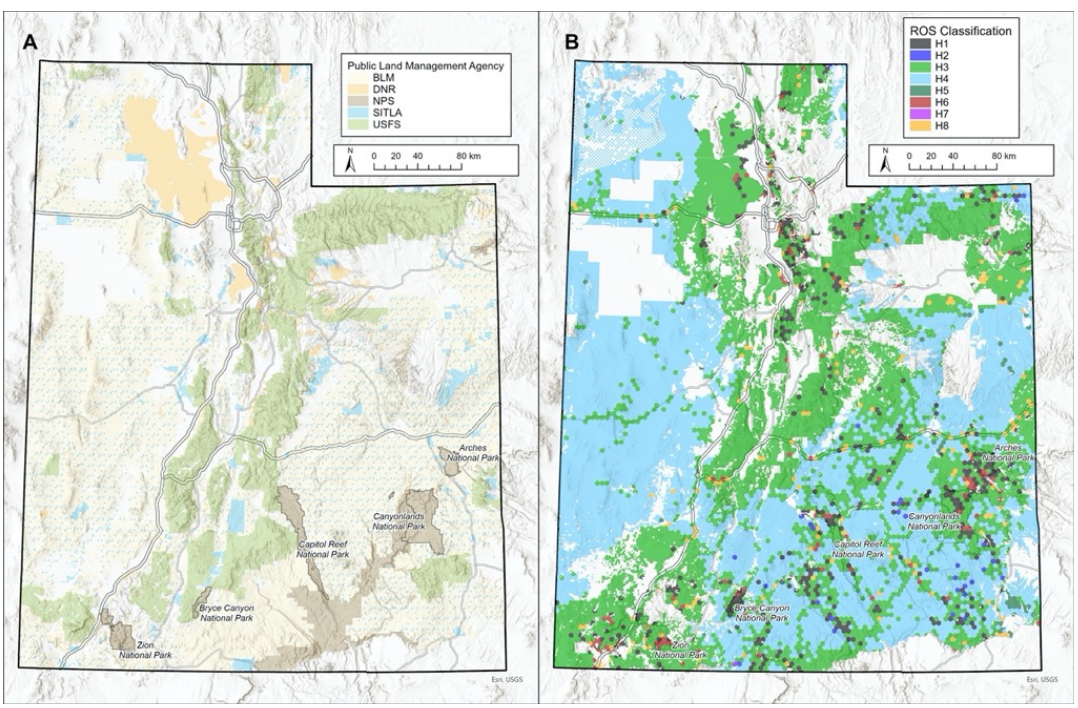

Figure 3.3. Recreation Opportunity Spectrum (ROS) classifications for all public lands in Utah.

At the regional scale, Figure 3.4 shows the ROS classification for the southwestern region of the state. The spatial distribution of classifications is similar, by and large, to the patterns seen across the state as a whole. Nearly a majority of the region's public lands (47.33%) are classified as more natural with little to no management presence and low use (H_4). The majority of these areas occur in the eastern half of the state and are predominantly managed by the Bureau of Land Management and the USDA Forest Service. Nearly as much of the region's public lands (43.28%) are classified as H_3, more natural with little management presence and high levels of use. These areas occur closer to cities, towns, and transportation corridors relative to those classified as H_4, suggesting urban proximity is associated with higher use levels which would be expected. Nearly 4% of the region's public lands are classified as more natural, with more of a managerial presence and high levels of use (H_1). These areas occur primarily within Bryce Canyon National Park and Cedar Breaks National Monument (Figure 3.4). The other ROS classifications were less common (< 2% of the region's public lands). There is a concentration of H_2 settings along the Hole in the Rock Road located in eastern Kane County. These areas are characterized as more natural, with more managerial presence, and relatively little use. The Zion Canyon corridor within Zion National Park is classified as less natural, with more of a managerial presence, and heavy use (H_6). This classification of public land also occurs in locations adjacent to cities and towns throughout the region (e.g., around St. George).

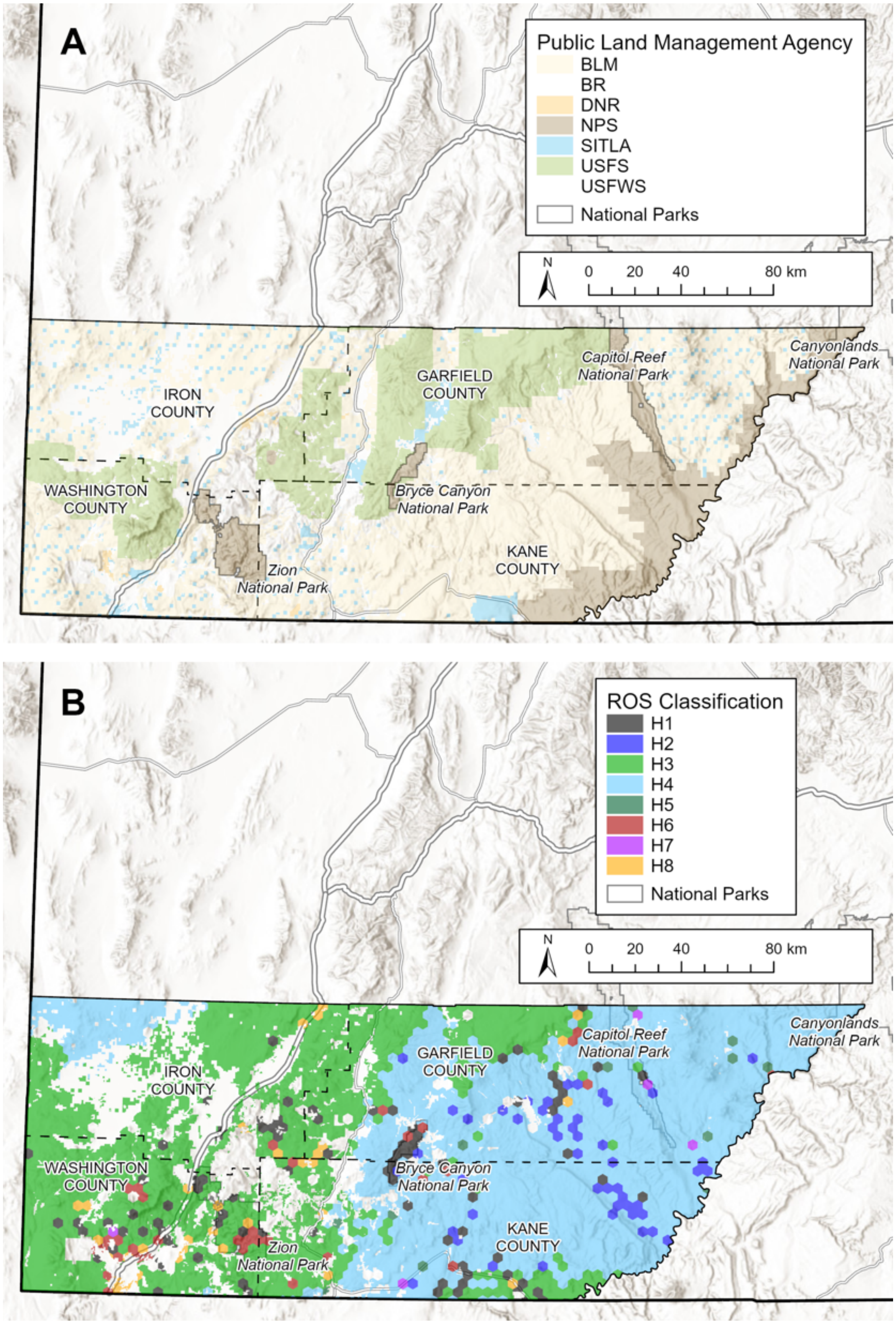

Figure 3.4. Recreation Opportunity Spectrum (ROS) classifications for southwestern Utah (defined as the four-county region comprised of Garfield, Kane, Iron, and Garfield Counties).

The ROS classification of the Salt Lake Ranger District shows a distinct pattern (Figure 3.5). More natural settings with little use (H_4) are concentrated in areas further away from metropolitan areas with the central Wasatch mountains above Salt Lake City being classified as either more natural settings with heavy use (H_1) or more natural settings with less managerial presence and heavy use (H_3).

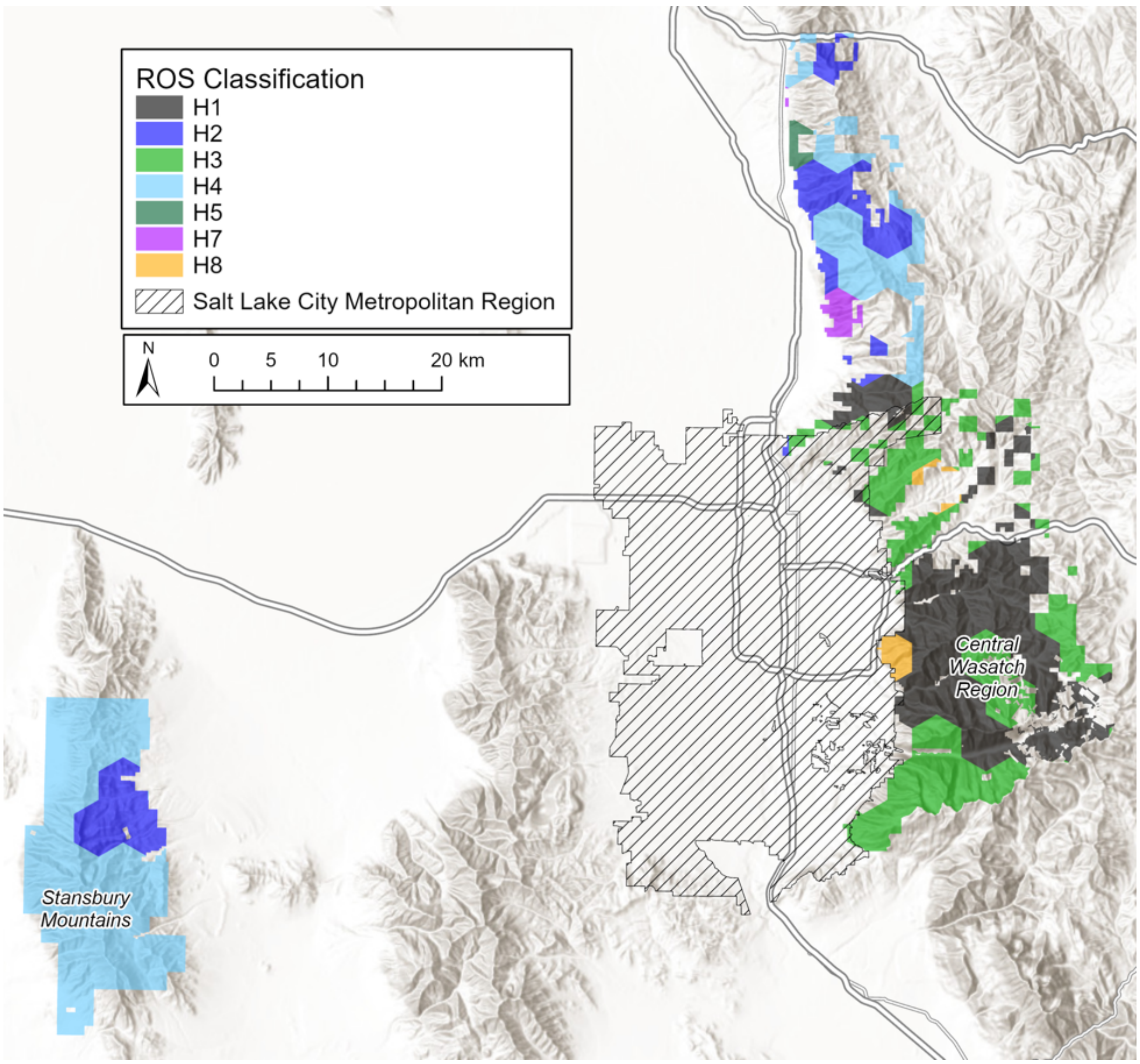

Figure 3.5. Recreation Opportunity Spectrum (ROS) classifications for the Salt Lake Ranger District.

4. Discussion

4.1 Leveraging Big and Open Source Data

Big data are not only characterized by their volume, but also by their ability to be manipulated and transformed (Kitchin, 2014). These characteristics have allowed researchers to ask a wide variety of research questions that previously could not be addressed and ask long-standing research questions in new ways that shed light on our understanding (Rashidi et al., 2017). The increasingly common use of big data in social science has led to a shift away from more conventional theory-driven research to data-driven, computational research (Frické, 2015).

Our scientific understanding of how to best provide and manage outdoor recreation settings has begun to follow the trend across the broader social sciences, using new, large, and often spatial datasets to address standing challenges within the field. For example, social media have been used to gauge the use and spatial distribution of visitation to public lands (e.g., Toivonen et al., 2019; Van Berkel et al., 2018; van Zanten et al., 2016; Wilkins et al., 2021; Wood et al., 2013). Our data-driven and generalizable model capitalizes on the seemingly ubiquitous availability of data, and leverage it to reconsider one of the most foundational resource management frameworks used by park and protected area managers around the world.

The model was purposefully constructed to ensure it could be reproduced across geographic locations and landscapes similar to Utah. All data come from free and open-source datasets. Assembling the model in this way obfuscates previous limitations of the ROS framework, namely that it was informed primarily by the beliefs and perceptions of recreation planners and other managers. The use of free and open-source datasets can also help ensure management plans are developed through a transparent and replicable process. Addressing the "replication crisis" and supporting the "credibility revolution" are cornerstones of the movement towards open, accessible, and replicable science (Engzell & Rohrer, 2020). Our generalizable model can ameliorate the variability in how ROS classifications are developed, leading to more consistent classifications across land management units and agencies. As the data used in the model are available worldwide, our model can also open up the possibility of developing a global standard for ROS classification.

4.2 The Generalized Model for Defining and Mapping ROS

As noted above, the ROS has almost exclusively been used to establish classifications at a single spatial scale (e.g., a field office or ranger district). Our model allows for the rapid development and evolution of ROS classifications at a variety of spatial scales. At least in the US context, the scale-dependent model is needed as a prescriptive planning tool by a variety of different agencies, offices, and interests involved in planning for, developing, or managing outdoor recreation settings.

At the state-level, state offices of outdoor recreation are becoming increasingly involved in the disbursement of state funds to develop outdoor recreation infrastructure (Sausser et al., 2019). State offices of tourism also play an active role in shaping where outdoor recreation happens within a state through their influential marketing campaigns (Drugova et al., 2020). Having statewide ROS classifications can enable organizations like these to think more strategically about where investments in outdoor recreation infrastructure are needed. Specifically, the ROS classification can be used to target investments in infrastructure to areas with heavy use and very little, if any, management presence (H_3 and H_8). Our application to the state of Utah shows these areas occur proximate rapidly urbanizing regions (namely the St. George area and the southern Wasatch Front) (Figure 3.3). These areas also occur on the periphery of well-known outdoor recreation and tourism ‘hot spots’ (namely the greater Moab area). Focused investments in infrastructure would be warranted here to meet the existing demand for outdoor recreation and also to minimize environmental impacts that could happen without the appropriate infrastructure (Hammitt et al., 2015).

At the regional level, ROS classifications can help land managers develop shared priorities that cross administrative boundaries. In our example from southwestern Utah, it is clear that ROS classifications are not randomly distributed. More natural settings with less of a management presence are concentrated in the eastern half of the region in areas managed by the Bureau of Land Management. Areas with more management presence and visitor use are concentrated in the western half of the county, particularly in and around Bryce Canyon and Zion National Parks. Visualizing ROS classifications across administrative boundaries like this can help outdoor recreation planners and managers see if outdoor recreation planning and management decisions within their particular administrative unit are needed given the regional scope of outdoor recreation opportunities that are provided. The managers of the Dixie National Forest, for example, may be more inclined to monitor use for possible increases in demand and associated environmental impacts knowing that Bureau of Land Management lands between the forest and sprawling municipalities have relatively high use levels (i.e., H_1, H_3, H_6, or H_8) (Figure 3.4, Panel B).

We applied the data-driven and generalizable ROS model to the Salt Lake Ranger District of the Uinta-Wasatch-Cache National Forest to illustrate its utility at the district or field office level (Figure 3.5). The analysis illustrated a clear differentiation between the heavily used and heavily managed Central Wasatch (H_1 and H_3) and the lesser used and lesser managed Stansbury Mountain Range (H_2 and H_4). Knowing this, the ranger district's outdoor recreation planners and managers would be well served to ensure any investments in infrastructure within areas classified as H_1 or H_3 preserve opportunities for activities with low visitor use densities (e.g., backcountry hiking and camping). These areas may experience an increase in use if outdoor recreationists who typically use the Central Wasatch become displaced due to crowding.

The management implications noted here are just a few of the ways that ROS classifications can be used in a proactive manner to guide the decisions of outdoor recreation planners and managers. We have provided guidance for each of our potential ROS classifications in Table 3.1. These management implications are intended to provide initial guidance for planners and managers using the model to differentiate between outdoor recreation settings that provide different types of outdoor recreation opportunities. When the model is applied across administrative boundaries, this initial guidance can help align management objectives; this can lead to a system of public lands that provide complimentary outdoor recreation opportunities and reduce the burden of managers and planners thinking they have to provide all types of outdoor recreation opportunities on the lands they manage.

4.3 Limitations and Future Research

Although our data-driven and generalized model provides a consistent method that can be used by different agencies to define and quantify ROS classifications at different scales, we are aware of several limitations associated with the use of free and publicly available data worth noting. First, implementing our model requires skilled personnel with the capacity to understand statistical programming software (e.g., *R*). Training and hiring personnel with these skills can be costly to state legislatures, federal agencies, regional planning initiatives, and other public land management agencies. To mitigate this concern, and to make the model more accessible and ease adoption, we have made all data and code used to conduct the analysis demonstrated here publicly available at a persistent DOI (removed for peer review). Second, the use of social media data to estimate outdoor recreation and tourism use has been met with skepticism by some (see Wilkins et al. (2021) for a detailed review). Primarily among these concerns is the ability of social media to represent the many types of visitors to public lands. While this is concern is valid, previous work has demonstrated that social media provide a relatively good indicator of the overall number of recreation visits occurring on public lands (again see Wilkins et al. (2021) for an exhaustive review). Specific to our application, Zhang et al. (2021) found social media captured approximately 70% of the variation in recreational visits to national parks, national forests, and state parks within Utah. The third limitation of this study is the quality (i.e., positional accuracy, completeness, logical consistency, thematic and temporal accuracy, etc.) of free and publicly available data. OpenStreetMap is a crowdsourced data curation project where registered contributors can create and edit the project's geospatial data (openstreetmap.org). Because OpenStreetMap data are user generated, their quality varies as well. Existing literature suggests the quality of OpenStreetMap data is heterogeneous across space (Minghini & Frassinelli, 2019). Given this, we encourage those applying our model to their own regions, forests, or field offices, to verify the quality of OpenStreetMap data with authoritative data if they exist. Finally, we suggest future research which applies our model could involve scale-dependent ground truthing experiments at randomly selected locations. We believe this step will allow us to confirm the accuracy and reproducibility of the data-driven model.

5. Conclusion

The data-driven and generalizable model presented here pushes outdoor recreation research towards the broader trend experienced across the social sciences where new, large, and often spatial datasets are leveraged to ask long-standing research questions. Specifically, we have developed a model that can define and quantify ROS classifications at multiple spatial scales. The model is structured around the same three setting-characteristics (biophysical, managerial, and social) that have proven themselves as an integral component of numerous outdoor recreation and tourism planning efforts worldwide. Our model's analytical workflow yields discrete ROS classifications unique to the spatial extent to which it is being applied (e.g., statewide, across an entire national forest, across just a ranger district, etc.). The model is also flexible across different applications, as demonstrated by our applications to three distinct spatial extents (statewide, regional, and site-specific). For each application, we showed how the model can yield meaningful characterizations of the outdoor recreation opportunities provided across the landscape. These scale-specific ROS characterizations are useful to distinct types of audiences (e.g., state legislatures, regional collaborative initiatives, and land management agency line officers). Importantly, we have also demonstrated how these classifications can be used in a prescriptive, as opposed to descriptive, way. The model presented here can serve as a catalyst capable of unifying disparate visitor use management frameworks around common data, and a common model, for classifying distinct types of wildland recreation settings upon which outdoor recreation opportunities depend.

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CHAPTER IV

IDENTIFYING CHALLENGES AND OPPORTUNITIES FOR TOURISM DEVELOPMENT THROUGH PARTICIPATORY WORKSHOPS AND BIG DATA

Abstract

The collaborative development of scientific and practical knowledge is fostered through processes which allow scientists and stakeholders to work together towards common interests and goals. The purpose of this study is to illustrate how a two-way communication process can be coupled with big data to facilitate the co-creation of knowledge. We document how we engaged a diverse group of stakeholders including public land managers, county and city government officials, and local business owners, in a participatory workshop intended to develop a shared understanding of the challenges and opportunities associated with increased participation in outdoor recreation in Utah, USA. Our work provides an example of how big data can be integrated into two-way science communication efforts. The process we employed used a singular participatory workshop, which may have hindered stakeholders' ability to develop shared interpretations and implications from the data presented. This finding highlights the need for on-going collaborative science communication efforts to more effectively enable the co-production of knowledge.

1. Introduction

Outdoor recreation and tourism are significant parts of the economy across the United States; this is especially true within the Intermountain West region where outdoor recreation and tourism contribute between 2.2 and 4.7% of the states' GDP (Pattni et al., 2020). Most state governments throughout the Intermountain West have realized the value outdoor recreation and tourism can add to their economies. Utah established the first state 'office' of outdoor recreation in 2013, with Colorado, Montana, New Mexico, and Wyoming following suit in subsequent years (Sausser et al., 2019). Often, these state offices advocate for more outdoor recreation, working with state tourism offices and organizations to increase visitation and visitor spending. These efforts can be very effective at expanding the tourism markets and increasing demand (Carl Bonham & Mak, 1996). In the case of Utah, USA, state-led marketing efforts have been so effective that the state has actively tried to demarket destinations which have experienced exceptionally high levels of demand (Drugova et al., 2020). The success of state, or even regional and local, marketing efforts can compound the already difficult challenges faced by outdoor recreation planners and managers struggling to operate their facilities under current use levels (Hall & Wood, 2021). Often, outdoor recreation planners and tourism professionals struggle to balance the need to provide high-quality outdoor recreation opportunities and tourism experiences in the face of rapidly growing demand fueled by natural growth and increased marketing and advertising efforts (Thomas & Reed, 2019).

A large body of scientific evidence from the outdoor recreation and tourism management literature has demonstrated how increased participation in outdoor recreation, if left unchecked, can lead to negative ecological impacts as well as a degradation of visitor experiences (Hammitt et al., 2015). For example, increases in outdoor recreation can have adverse impacts on the abundance, diversity, and behaviors of wildlife as well as negative impacts to wildlife habitat (Geffroy et al., 2015; Kangas et al., 2010; Reed & Merenlender, 2008). Other natural resources, such as soil, vegetation, and water can also be degraded as a result of more outdoor recreation and tourism (Ballantyne & Pickering, 2015; D'Antonio & Monz, 2016; Marion et al., 2016; Monz et al., 2013). Increased outdoor recreation participation, if not preemptively managed for, can substantially and negatively affect visitors' experiences and alter visitor behaviors; it can also lead to negative impacts (e.g., lack of affordable workforce housing, severe congestion) in communities adjacent to those tourism hotspots.

Considering the potential opportunities and significant challenges associated with the increased demand for outdoor recreation and tourism, processes that enable inter-organizational dialogue on the ways that opportunities can be maximized, and challenges can be mitigated or minimized are warranted. These processes hold the potential to develop a shared understanding of the common opportunities and challenges faced by local business owners, city and county governments, and public land managers. Often however, these disparate organizations use their own methods to monitor trends in outdoor recreation and tourism behavior, they have discrete jurisdictional boundaries which they are responsible for, and they operate under different mandates and priorities. Volunteered geographic information on visitor use that spans administrative boundaries may provide a common focal point to initiate discussions of the shared opportunities and challenges faced by outdoor recreation planners and managers.

The purpose of this research is to document a process by which big data characterizing the volume and spatial distribution of outdoor recreation and tourism behavior can be used to initiate collaborative discussions amongst outdoor recreation planners and managers as well as tourism officials. Specifically, we present a process in which spatially explicit social media is used to engage stakeholders in a collaborative dialogue focused on the opportunities and challenges associated with increased outdoor recreation and tourism. Our specific objectives in this research are to:

(1) demonstrate a process by which big data characterizing outdoor recreation and tourism behavior can be used to initiate dialog amongst disparate types of outdoor recreation planners, managers, and tourism professionals, about regional outdoor recreation and tourism 'hot spots';
(2) assess the effectiveness of sharing big data through participatory workshops; and
(3) shape the collaborative development of practical knowledge regarding the opportunities and challenges outdoor recreation planners, managers, and tourism professionals face as a result of increased outdoor recreation and tourism.

Our research framework and processes are built around concepts from co-production of knowledge and science communication.

2. Literature Review

2.1. The Information Deficit Model in Science Communication

Science communication can be an essential component of translating scientific findings into practical needs (Ehret et al., 2017). However, scientific findings are most commonly shared with the public following a mode of one-way communication, the information deficit model. The information deficit model is described as a linear or one-way communication method in which scientific information comes *from* scientists *to* the public without the opportunity for interaction and engagement (Simis et al., 2016). The simplistic nature of the information deficit model has been criticized by many science communication scholars because it does not account for the heterogeneous nature of recipients' learning styles. Culture, sociodemographic characteristics, and individual experiences and worldviews all shape how people engage with, and retain, scientific information (Simis et al., 2016). Suldovsky (2017) also suggests the information deficit model is limited in its utility because complex and nuanced science must be boiled down to oversimplified messages or summaries that fail to align with the audience's existing attitudes, knowledge, and behaviors.

Seeking better ways to communicate scientific information, scientists have begun to share scientific findings using experience-dependent, personal, and local evidence (Howe & Leiserowitz, 2013; Kim, 2017). This approach, commonly referred to as the contextual model (a mode of the one-way communication), utilizes audience segmentation as a tool to convey scientific information in the most relatable and understandable way. For example, Howe and Leiserowitz (2013) suggest the presence of localized impacts and occurrences of climate change can be used to communicate climate change in a more tangible and personally meaningful way. These authors' work shows the public's beliefs about climate change do not only rely on contextualized climate information but also upon individuals' personal beliefs and experiences (Howe & Leiserowitz, 2013). While the contextual model's use of localized, personally relevant, and evidentiary information, is an improvement over the information deficit model, it has been criticized for merely providing scientific information in a more 'eye-catching' manner (Suldovsky, 2017). This model of communication may be insufficient to deal with scientific information in a way that allows audiences to *engage* with the scientific process or scientific findings in a *meaningful* way. In other words, the contextual model has been criticized for enhancing the information deficit model while not providing the opportunity to interact or engage.

2.2. The Public Engagement Model in Science Communication

The public engagement model addresses some of the limitations of the information deficit and contextual models. Introduced by Biggs (1989), the public engagement model is characterized by two-way communication processes focused on developing co-produced knowledge (Corner & Randall, 2011; Meadow et al., 2015; Popovici et al., 2020). The public engagement model emphasizes the need for, and value of, substantively engaging the public in meaningful dialog. There is no prescriptive method (e.g., town hall style question and answer sessions, virtual forums and public webinars, etc.) through which this dialog can happen. However, advocates for the public engagement model suggest the co-production of knowledge is facilitated by communication that is structured (e.g., professionally facilitated) and transparent (e.g., notes and/or transcriptions of the engagement are made publicly available). In addition, the co-production of knowledge can be fostered when a diversity of interests are involved in the communication (Garcia & Brown, 2009; Meadow et al., 2015; Popovici et al., 2020; Wall et al., 2005). In the context of outdoor recreation and tourism management, this can involve user groups (i.e., outdoor recreationists and tourists), local and regional elected officials, municipal, state, and federal outdoor recreation planners and tourism development specialists, and relevant non-profit groups.

The co-production process is the unique and arguably essential component of science communication efforts using a public engagement model (Beier et al., 2017; Pohl et al., 2010; Popovici et al., 2020; Vincent et al., 2018). The need for, and value of, co-production processes in sharing scientific findings stems from the failures of communication efforts that utilize top-down communication efforts (Beier et al., 2017; Bovaird, 2007). The participatory and collaborative nature of the co-production process involves acknowledging, responding to, and integrating the attitudes, beliefs, and values of multiple stakeholders into the scientific process so that management decisions, findings, and recommendations, are more likely to be accepted, understood, and acted upon (Figure 4.1.) (Meadow et al., 2015; Popovici et al., 2020; Vincent et al., 2018).

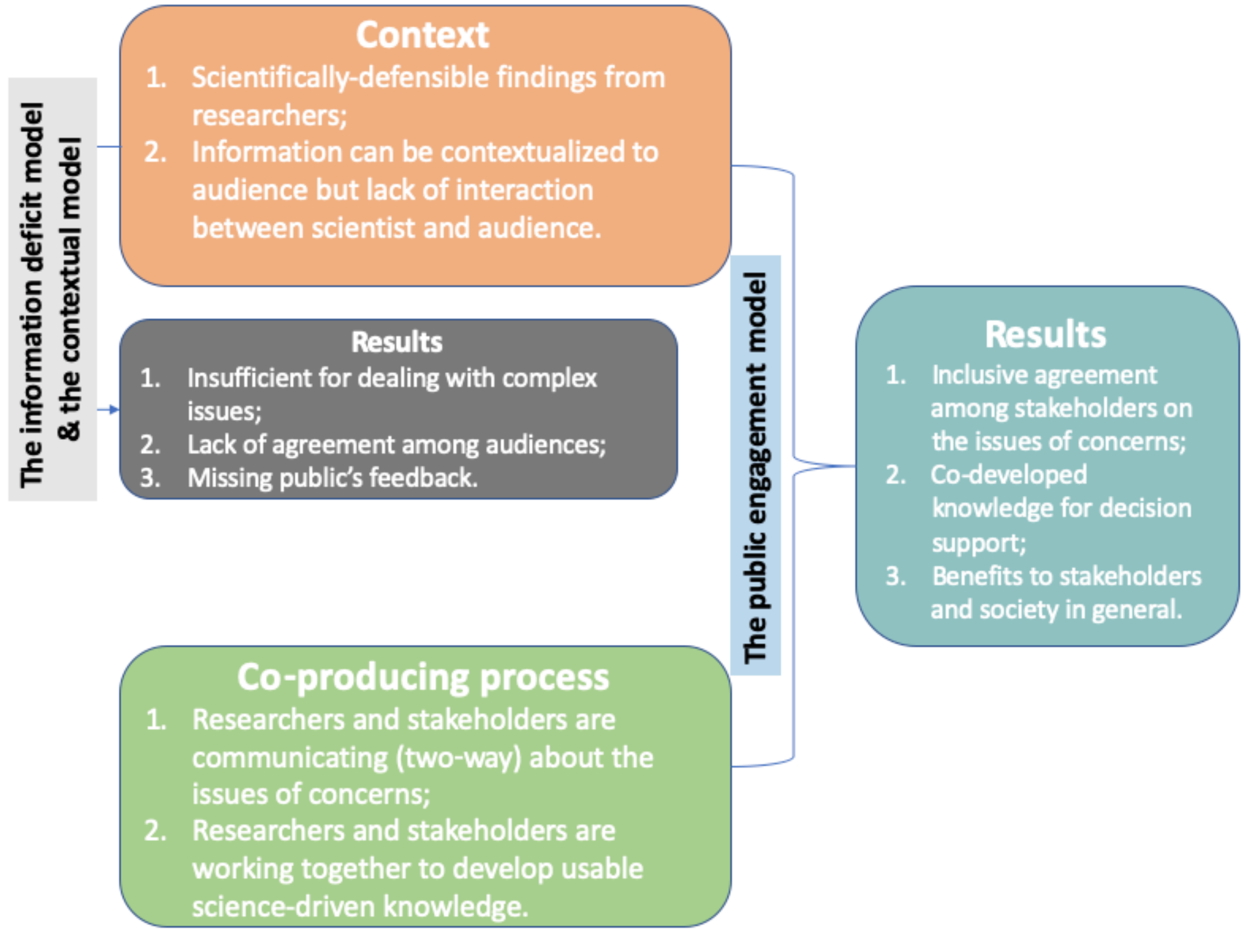

Figure 4.1. A conceptual diagram showing the difference between the Information deficit model and the public engagement model.

2.3. Modes of Public Engagement

There are four overarching types of engagement between scientists and stakeholders – contractual, consultative, collaborative, and collegial (Meadow et al., 2015; Table 4.1).

Table 4.1. Types of public engagement, adapted from Meadow et al. 2015.

Type	**Objective**	**Origin of research question**	**Type of relationship**	**Stakeholder involvement**
Contractual	Test applicability of new technology or knowledge	Researchers	Unidirectional flow of information from researchers to stakeholders	Primarily as passive recipient of new knowledge or technology
Consultative	Use research to solve real-world problems	Stakeholders or researchers	Researchers consult with stakeholders, diagnose the problem, and try to find a solution	At specific stages of research such as problem definition, research design, diffusion of findings
Collaborative	Learn from stakeholders to guide applied research	Stakeholders	Stakeholders and researchers are partners	Continuous with emphasis on specific activities, depending on joint diagnosis of the problem
Collegial	Understand and strengthen local research and development capacity	Stakeholders	Researchers actively encourage local research and development capacity	Variable, but ongoing

Contractual engagements refer to contracts between scientists and end users to test new scientific findings for practical needs (Biggs, 1989). The relationship between scientists and stakeholders is unilateral and stakeholders are involved merely as passive recipients of new information or knowledge. The contractual mode lacks a participatory and collaborative way to gather feedback from its audiences; this is similar to the information deficit and contextual models described above.

Consultative engagements involve stakeholder engagement through diagnosing, designing, and testing the usability of research findings (Meadow et al., 2015). This type of engagement allows for research questions to be proposed by stakeholders or researchers; it allows them to work together to develop solutions.

In collaborative engagements, scientists and stakeholders work together on issues that require stakeholders' knowledge and experience. Stakeholders are not only passive audiences of new knowledge but also experts that can jointly discuss and diagnose complex issues (Meadow et al., 2015). The collaborative type of public engagement is particularly successful in situations where a specific decision needs to be made and when there is a clear and time-managed process through which collaboration occurs (Vincent et al, 2018).

Finally, the collegial type of public engagement focuses on understanding and strengthening local research and development capacity (Meadow et al., 2015). This type of public engagement aims to enhance local stakeholders' ability to design and conduct research through training in data collection or analysis. Many citizen science efforts can be categorized as this type of public engagement. Here, the public's engagement in the scientific *process* can be somewhat ambiguous, especially to the public. This is not always the case however, as many science communication efforts place a great deal of emphasis on letting the public know how they are shaping both the process and outcomes of the research.

2.4. Big Data Analytics and Science Communication

Big data are defined by their volume, their ability to address questions at multiple scales (both spatial and otherwise), and their ability to be flexibly integrated with other data. These characteristics have allowed social scientists to investigate social phenomenon in ways that are not possible with traditional research (Kitchin, 2014). As a consequence, big data has the potential to shift social science away from theory-driven methods and towards data-driven investigations (Frické, 2015). Although the rising interest in using big data in science communication research has led to a growth of discussion on how big data can be used to improve science communication concepts and methods (Choi, 2020; Lember, 2020; Wiesenberg et al., 2017), very few studies have actually applied big data analytics in science communication research (Parks, 2014). For example, Wiesenberg and colleagues (2017) examined the effectiveness of big data in science communication, finding the use of big data alone can make stakeholders more interested and willing to engage with the science using those data. Importantly, the major downsides of using big data in communication and media research have also been noted (Wiesenberg et al., 2017). For example, data mining and big data analytics can be costly, and require analytical and technical skills to distill information down to useful summaries or visualizations. Additionally, limitations on data availability and anonymity pose additional challenges to the use of big data in communication research.

While there is a burgeoning body of work focused on the interface of big data and science communication, there is a limited understanding of how big data analytics can be integrated into public engagement processes (Lember, 2020). Can big data be used effectively in a public engagement process? How do diverse types of stakeholders perceive and respond to the use of big data? And can big data analytics be used to catalyze collaborative discussions and the co-production of knowledge? In this investigation, we make important inroads by addressing these questions.

3. Methods

We engaged a diverse group of stakeholders in a science communication effort designed to develop a shared understanding of the challenges and opportunities associated with increased participation in outdoor recreation in Utah, USA. Our process involved a participatory workshop as well as a pre- and post-workshop survey in three regions of the state. These regions included a five-county region of Southeastern Utah, an eleven-county region of Southwestern Utah, and a six-county region of Northern-Wasatch (Figure 4.2.).

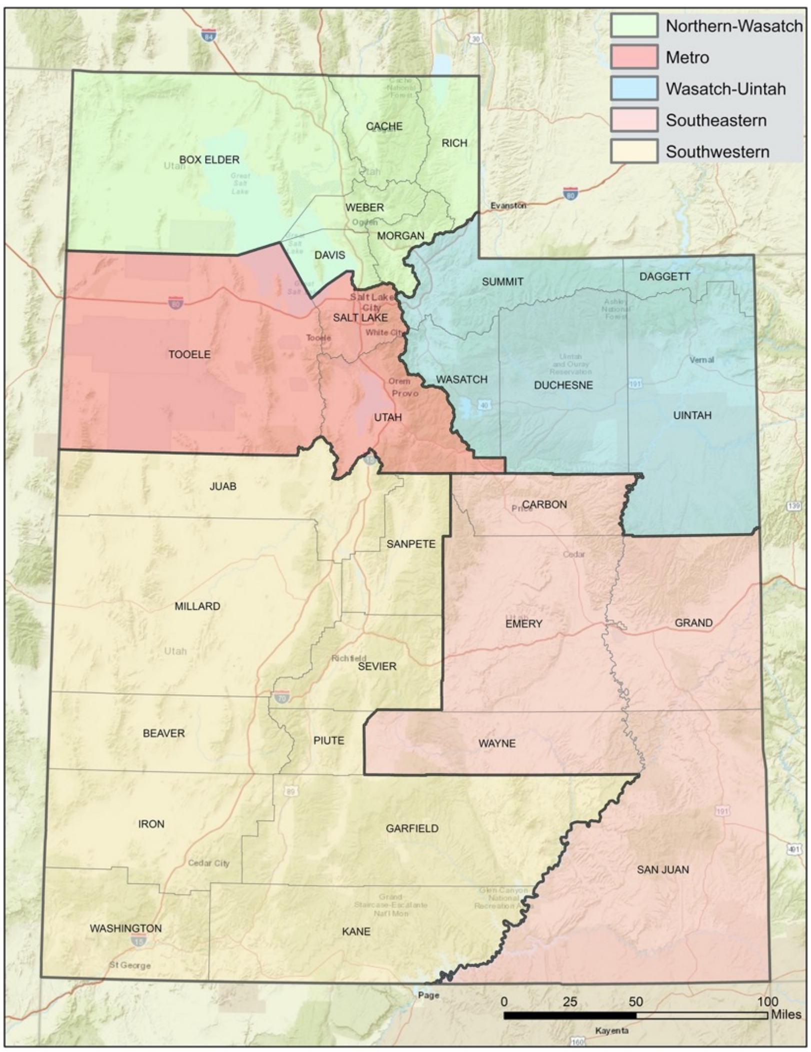

Figure 4.2. Administrative regions in Utah.

Workshop participants consisted of federal and state agency staff, county and municipal officials and planning staff, as well as local business owners in the outdoor recreation and tourism industry. Table 4.2. provides generic titles that were used to help guide stakeholder selection. All invited participants lived or worked in the regions where their workshop took place. All potential participants were emailed an invitation to participate in the workshop[9]. Initial invitations were followed by two subsequent invitations sent 1-week apart if an invitee had not responded. In total, 372 individuals were invited to participate in the regional workshops and 40 agreed to participate (Table 4.3.)[10].

Table 4.2. Generic titles and types of stakeholders invited to participate in the workshops.

Type of Stakeholder	Examples of positions/titles
Federal land manager	• National Park Superintendent • NPS Chief of Visitor Services • NPS Chief of Interpretation • NPS Chief of Resource Stewardship and Science • National Forest Supervisor • National Forest District Ranger • National Forest Recreation Planner • National Forest Landscape Architect • BLM Field Office Supervisor • BLM Recreation Planner • BLM Landscape Architect
State land manager	• State Park Manager • State Sovereign Lands Coordinator
County interests	• County Park Systems Managers • County Convention and Visitor Bureau Director • County Economic Development Director
Municipal interests	• Mayor • City Council Member

[9] The invitation also included an informed consent form detailing the purpose of the study, the use of data collected from the project, and all reasonable risks associated with participation. The informed consent form was approved by Utah State University's Institutional Review Board (USU IRB protocol #10517).

[10] This seemingly low engagement rate is most likely attributable to the fact we were as inclusive as possible in extending invites. For example, we reached out to *all* business owners who owned a business in the leisure and hospitality industry (e.g., outdoor recreation equipment sale/rental shops, outfitters and guides, lodging business owners, restaurant and bar owners, etc.).

• City Park System Manager • City Tourism Development Office Director

Table 4.3. Affiliations of study participants.

Affiliation	Number of Participants
Federal or state natural resource management agency	16
City or county government	13
Local Business owner/operator	8
Other	3

3.1 Pre-workshop Survey

We assessed the ability of the workshops to foster the co-production of knowledge through pre- and post-workshop surveys asking participants to identify the opportunities and challenges associated with increased outdoor recreation and tourism throughout their region. The surveys were administered via email 1-week before and 1-week after the in-person workshop took places.

Participants were asked to identify their affiliation and the specific counties in which their agency, business, or organization manages land or provides services related to outdoor recreation and tourism. This question was asked to provide the research team with a check on the geographic representation of participants.

Participants were also asked to identify what they believed were the five most visited outdoor recreation and tourism destinations within the region; response were open ended. This question was asked to help familiarize participants with the scope and purpose of the workshops.

Participants were asked about what they believed were the main drivers (e.g., access to major highways, number of designated trails, amount of water, the presence of cultural/historical sites, location within a national park, etc.) influencing outdoor recreation and tourism participation throughout the region. Perceived level of influence was gauged through a 7-point Likert-type scale ranging from *major negative influence* to *major positive influence*.

Next, participants were asked to indicate their level of concern for a variety of possible consequences (e.g., lower visitor satisfaction due to crowding, worse traffic during peak seasons, disturbance to wildlife and vegetation, etc.) associated with increased outdoor recreation and tourism throughout their region. Level of concern was measured on a 5-point Likert-type scale that ranged from *not concerned at all* to *extremely concerned*.

Finally, participants were asked about how, and to what extent, they believed increased outdoor recreation and tourism throughout their region benefitted the region. Possible benefits asked about included increased sales revenue to support public infrastructure, increased property values, etc. Level of perceived benefit was assessed using a 5-point Likert-type scale ranging from *no benefit at all* to *substantial benefits*.

Participants were also given the ability to describe specific opportunities and challenges associated with increased outdoor recreation and tourism throughout the region via an open-ended dialog box.

3.2 Participatory Workshops

Spatial patterns of outdoor recreation and tourism were measured through the use of social media and validated through comparisons to reported visitation levels where those data are available. The spatial mapping and validation process are detailed in Zhang et al. (2021) and publicly available on the openICPSR repository (https://doi.org/10.3886/E131163V1). The mapping process generated statewide, regional, and county-specific maps of outdoor recreation and tourism participation on public lands. We also distilled the statewide and regional maps into ‘top-10’ lists of the most visited tourism destinations. Examples of each type of map and the lists are shown in Figure 4.3. These maps were presented to workshop participants via large (0.9 x 1.2 m) foam core poster boards set up on easels around a large meeting room.

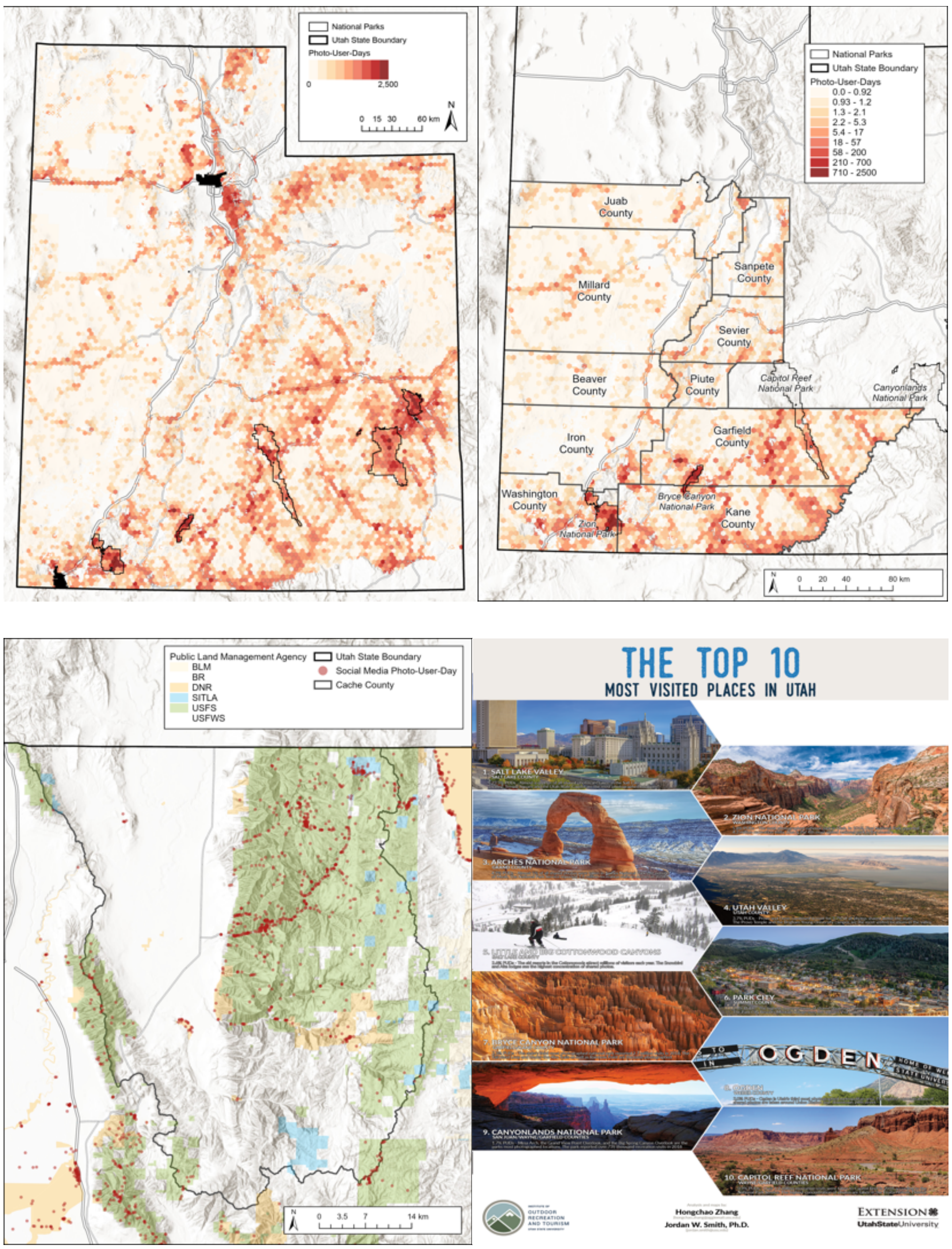

Figure 4.3. Examples of each type of map and the list.

During the workshops, we first gave a short (10-15 min) presentation about how social media is being used in outdoor recreation and tourism research, management, and planning. The process of acquiring and analyzing data were briefly mentioned as well.

Following this short presentation, participants were given the opportunity to walk around the boards and discuss the spatial patterns of visitation informally amongst themselves. After viewing the maps, we led participants through an interactive and collaborative discussion that solicited participants' observations of the spatial patterns of outdoor recreation and tourism on public lands. Following this initial period where they could express their initial reactions, workshop participants were teamed up into groups of 4 to 5 to discuss, and come to agreement on, the opportunities and challenges associated with increased outdoor recreation and tourism within their region. The groups of 4 to 5 were purposefully constructed to ensure each group had representation from a federal land manager, a state land manager, and a municipal interest. Groups were given ample time to discuss potential opportunities and challenges amongst themselves and also to ask any clarifying questions of the research team. Each group was given a large (0.9 x 1.2 m) poster board to list the challenges and opportunities they discussed. After each group had reached consensus, they were invited to share with the larger group while the research team recorded common challenges and opportunities identified across the groups. These common challenges and opportunities were used to generate open discussions of how the region could: 1) mitigate the negative consequences associated with increased visitation; and 2) capitalize on identified opportunities. The workshops concluded by thanking participants and providing them with information about where they could access the maps and study findings on the internet (a project-specific website hosted all maps and made them publicly available). The regional workshops last between two to two and a half hours.

The full workshop script is included in the supplemental material.

3.3 Post-workshop Survey

An online post-workshop survey was sent out to all participants one day after the regional workshops took place. All workshop participants were given one week to complete the survey after they were initially invited. Following the structure of the pre-workshop survey and regional workshops, the post-workshop survey was mainly focused on: 1) the main drivers of increased outdoor recreation participation to the region; and 2) the challenges and opportunities associated with increased participation. The post-workshop survey used the same questions and measurement scales as the pre-workshop survey. Asking the same questions provided us with a gauge on the extent to which the interactive and participatory workshop changed participants' perceptions and beliefs.

3.4 Data Analysis

All survey responses were collected via the Qualtrics survey application and uploaded into SPSS v.27 for data cleaning and analysis. Data cleaning included checking for participants who either stopped providing responses at a certain question or answered every item with the same response option. Descriptive statistics were used to analyze the majority of the pre- and post-workshop survey data. The common challenges and opportunities identified during the workshops were transcribed and later archived and shared with workshop participants.

4. Results

4.1 Pre-workshop Survey

A total of 40 study participants completed the pre-workshop survey. The majority of participants were primarily from federal or state natural resource management agencies (*n* = 16, 40%), with slightly less from city or county governments (*n* = 13, 33%). Local business owners and operators represented 20% of all participants (*n* = 8) and there were three participants with some other type of affiliation.

When asked about the most influential factors driving where outdoor recreation and tourism happens within the region, location within a national park topped the list in the pre-workshop survey[11] (*M* = 6.47; *SD* = 1.02). Other factors that participants rated highly included: location within a state park (*M* = 5.88; *SD* = 0.94); the number of designated trails (*M* = 5.83; *SD* = 1.26); and access to major highways (*M* = 5.80; *SD* = 1.34). Nearly all of the factors that we asked about were believed to have at least a marginal positive influence on where outdoor recreation and tourism happens within the region[12] (Table 4.4). In addition to the items we asked about, two respondents commented that locations being shared via social media had a major and positive influence on the amount of outdoor recreation and tourism happening within an area.

Table 4.5 shows perceived challenges associated with increased outdoor recreation and tourism visitation to each of the three regions. Damage to cultural/historical resources (*M* = 4.08, *SD* = 1.10) was the most prominent concern

[11] The Southeastern region contains Arches, Canyonlands, and Capitol Reef National Parks while the Southwestern region includes both Bryce and Zion National Parks. There is no National Park in the Northern Wasatch region.

[12] The presence of agricultural land was believed to have a slight negative influence on the amount of outdoor recreation and tourism happening in both the Northern Wasatch region (*M* = 3.88, *SD* = 1.46) and the Southeastern region (*M* = 3.86, *SD* = 1.06).

amongst participants. Additionally, higher cost to maintain public infrastructure was a concern amongst participants in all three regions (*M* = 3.85; *SD* = 1.17), as was higher costs to maintain outdoor recreation infrastructure (*M* = 3.85; *SD* = 1.08). Disturbance to vegetation, worse traffic during peak seasons, and lower visitor satisfaction due to crowding were all of at least somewhat concerning to participants in all three regions (Table 4.5).

Table 4.4. Influential drivers shaping where outdoor recreation and tourism happens.

	Pre-workshop Survey (*n* = 32-40)		**Post-workshop Survey (*n* = 11-14)**		**Mean Difference**
	Mean[1]	**SD**	**Mean**	**SD**	
Location within a national park[2]	6.47	1.02	6.64	0.92	0.17
Location within a state park	5.88	0.94	6.00	0.88	0.12
Amount of designated trails	5.83	1.26	6.29	0.73	0.46
Access to major highways	5.80	1.34	6.43	0.65	0.63
Location within a national forest	5.35	0.98	5.57	0.85	0.22
The presence of cultural/historical sites	5.31	0.73	5.71	0.83	0.40
The presence of forested land	5.23	1.11	5.23	0.73	0.00
Amount of water (i.e., lakes, rivers, streams, etc.)	5.15	1.10	5.07	1.07	-0.08
The presence of residential and urban development	4.05	1.30	5.07	1.33	1.02
The presence of agricultural land	4.02	1.12	3.86	1.10	-0.16

[1] 1 = *Major negative influence*, 7 = *Major positive influence*
[2] The Southeastern region contains Arches, Canyonlands, and Capitol Reef National Parks while the Southwestern region includes both Bryce and Zion National Parks. There is no National Park in the Northern Wasatch region.

Table 4.5. Challenges associated with increased outdoor recreation and tourism

	Pre-workshop Survey (*n* = 40)		**Post-workshop Survey (n = 14)**		**Mean Difference**
	Mean[1]	**SD**	**Mean**	**SD**	
Damage to cultural/historical resources	4.08	1.10	4.21	0.80	0.13
Higher costs to maintain public infrastructure (e.g., roads, etc.)	3.85	1.17	4.07	0.73	0.22
Higher costs to maintain outdoor recreation infrastructure (e.g., visitor centers, restrooms, facilities, trails, etc.)	3.85	1.08	4.29	0.73	0.44
Disturbance to vegetation	3.73	1.09	4.14	1.03	0.41
Worse traffic during peak seasons	3.63	1.17	3.64	1.01	0.01
Disturbance to wildlife	3.58	1.22	4.00	1.11	0.42
Lower visitor satisfaction due to crowding	3.30	1.27	4.00	0.78	0.70
An inability to serve more diverse types of visitors (e.g., from different cultural backgrounds)	2.70	1.20	2.79	1.25	0.09

Insufficient dining and lodging options to accommodate visitors	2.63	1.33	2.57	1.16	-0.06

[1] 1 = *Not concerned at all*, 5 = *Extremely concerned*

When asked about perceived opportunities associated with increased outdoor recreation and tourism (Table 4.6), increased sales revenue to support public infrastructure was seen as the largest possible benefit (*M* = 3.63; *SD* = 0.98). An increase in the number of businesses to serve outdoor recreationists as well as an increase in property values were also consistently seen as possible benefits across the three regions (Table 4.6).

Table 4.6. Opportunities associated with increased outdoor recreation and tourism

	Pre-workshop Survey (*n* = 40)		**Post-workshop Survey (n = 21)**		**Mean Difference**
	Mean[1]	**SD**	**Mean**	**SD**	
Increased sales revenue to support public infrastructure	3.63	0.98	4.07	0.83	0.44
Increased number of business to serve outdoor recreationists and tourists	3.50	0.91	4.14	0.86	0.64
Increased property values	3.13	1.04	3.57	0.85	0.44

[1] 1 = *no benefit at all*, 5 = *Substantial benefits*

4.2 Participatory Workshops

The participatory workshops in which participants could explore and discuss spatial patterns of visitation worked well in effectuating conversation and dialogue. We found participants were eager to explore the maps and discuss the spatial patterns that did, and did not, align with their expectations. Participants were first provided with a basic understanding of how we used the social media to measure and map visitation in their region and across the state as a whole, through an interactive presentation. The presentations included questions from participants about where the data were coming from, whether or not it was anonymous, and how representative it was of all outdoor recreationists and tourists within the region. These are common concerns within the academic community (Wilkins et al., 2020), and our workshops suggest they are common concerns amongst interested stakeholders as well.

The presentations were followed by an opportunity for participants to explore the maps on the poster boards placed around the workshop room. We found it was difficult to reconvene participants to have a more structured discussion about the patterns presented on the maps once they were up, exploring, and talking amongst themselves.

Once we were able to reconvene participants, the structured discussions focused on the challenges and opportunities associated with increased outdoor recreation and tourism within the region. These discussions produced a litany of potential challenges and opportunities voiced by participants (Table 4.7). Many of the challenges and opportunities were similar, if not identical, to the ones we had asked about in the pre-workshop survey. Common challenges across the three regions that were reflective of the challenges asked about in the pre-survey included: insufficient dining and lodging options; damage to natural resources (e.g., vegetation and wildlife); crowding issues; and higher costs to maintain infrastructure. There were also numerous challenges listed that were beyond the scope of our initial thinking. For example, workshop participants noted the lack of funding to support increased use, disturbance to the local sense of community, affordable housing for employees, lack of employees, and government pressure due to increased population.

Table 4.7. The challenges and opportunities identified during the participatory workshops

Challenges	Opportunities
• Higher costs to maintain infrastructure • Insufficient services (e.g., dinning and lodging) • Lack of employees • Negative impacts on visitor experience (e.g., crowding) • Disturbance to local community • Overcrowding issues at tourist hot spots • Insufficient facilities and infrastructure • Affordable housing for employee • Lack of funding support • Representativeness of social media data • Changes in visitation patterns • Damage to natural resources (watershed/wildlife habitat) • Carrying capacity of recreational resources • Local government's pressure due to increased population	• Increasing sale tax and tourism tax • Self-marketing • Expand access for visitor use • Identity/branding • Partnerships across government and private sectors • Increasing local services and businesses • Data use for making managerial decisions • Disperse people from hotspots

The structured participatory workshop discussions confirmed participants' perceptions about opportunities associated with increased outdoor recreation and tourism, as elicited through the pre-workshop survey. Opportunities for increasing sales revenue to support public infrastructure and local economic expansion were identified in both the pre-workshop survey and in the structured discussions. Participants also elucidated new potential opportunities based on their interests and expertise. For example, participants across all three workshops noted how increased outdoor recreation and tourism might force their hand into managing recreation resources in a more collaborative way through partnerships (Table 4.7). Participants in all three regions also noted how increased outdoor recreation and tourism provided the opportunity/necessity to be more conscious about how they present their region's 'brand' to non-locals.

When asked specifically about whether or not participants believed social media could be a useful tool for stakeholders like themselves, participants were optimistic about its utility. For example, some participants noted how seeing the spatial patterns of visitation could be useful for their efforts to try to disperse visitation away from those locations where crowding and traffic have become persistent problems during the busy season. Others noted how the data could be used to prioritize the management actions of land managers. Some even noted how the data could be used to inform the marketing and branding strategies of municipalities and counties. The use of social media was not without pause however, as several participants expressed concerns about the representativeness of the data. Numerous participants were skeptical the data were accurate given so few of them used social media to share their outdoor recreation experiences.

4.3 Post-workshop Survey

A total of 14 workshop participants completed the post-workshop survey. The results of questions about the influential factors shaping where outdoor recreation and tourism happens within the region as well as questions about the challenges and opportunities associated with increased outdoor recreation and tourism are provided in Tables 4.4-4.6. On average, the mean scores of each item in each question of the post-workshop survey were higher than the mean scores in the pre-workshop survey. However, the rankings of response options were very similar.

Location within a national park was still viewed as the most influential factor driving where outdoor recreation was happening within the region (*M*=6.64, SD=0.92). This was followed by access to major highways (*M*=6.43, SD=0.65), number of designated trails (*M*=6.29, SD=0.73), and location within a state park (*M*=6.00, SD=0.88). The presence of agricultural land (*M*=3.86, SD=1.10) was again identified as the least influential driver of where outdoor recreation was happening within the region. Notably, the perceived influence of nearly every factor we asked about was stronger (i.e., having more influence) in the post-workshop survey. This finding suggests that seeing the spatial patterns of visitation during workshop may have bolstered individuals' beliefs about how important each of the factors were.

Data from the post-workshop survey also revealed higher costs to maintain outdoor recreation infrastructure (*M*=4.29, SD=0.73), damage to cultural/historical resources (*M*=4.21, SD=0.80), disturbance to vegetation (*M*=4.14, SD=1.03), and higher costs to maintain public infrastructure (*M*=4.07, SD=0.73) were still the biggest challenges associated with increased outdoor recreation and tourism, when compared to data from the pre-workshop survey. Again, these perceptions were all strong in the post-workshop survey relative to the pre-workshop survey.

The post-workshop survey also revealed that an increased number of businesses to serve outdoor recreationists and tourists (*M*=4.14, SD=0.86), increased sales revenue to support public infrastructure (*M*=4.07, SD=0.83), and increased property values (*M*=3.57, SD=0.85) were all thought to be of at least some benefit to the region. These perceptions were, again, stronger in the post-workshop survey relative to the pre-workshop survey, suggesting the workshop may have bolstered individuals' beliefs about how much an opportunity there is.

5. Discussion

5.1 Effectiveness of Sharing Big Data Through a Participatory Workshop

Through this work, we have demonstrated a process of sharing big data characterizing the volume and spatial distribution of outdoor recreation and tourism with interested stakeholders. More importantly, we have shown how this process can be used to catalyze discussion and the co-creation of new knowledge on how to capitalize on the opportunities, and mitigate the challenges, associated with increased outdoor recreation and tourism.

We found that social media, as one type of big data, can provide a focal point through which stakeholders from a diverse set of backgrounds can engage in dialogue and collaborative discussions. In contrast to the traditional visitation monitoring methods, social media provides a universal measure of outdoor recreation activity. Traditional visitor use monitoring programs are established by individual federal, state, and local agencies/organizations (e.g., the USDA Forest Service, the National Park Service, and state agencies). Each of these agencies has unique mandates and priorities, contributing to a large amount of variation in how visitors are counted. Different data sources and different counties methodologies has hindered the ability of agencies to work collaboratively, across their jurisdictional boundaries, to address (or even develop a common understanding of) the challenges associated with increased outdoor recreation and tourism.

The collaborative process we have demonstrated here can be an effective way to develop a shared understanding of outdoor recreation participation amongst different types of outdoor recreation planners, managers, and tourism professionals. Prior to the exhibition of data in the participatory workshops, study participants ranked location within national parks, location within state parks, number of designated trails, and access to major highways as the four most influential drivers of outdoor recreation within their region. These pre-workshop assessments were informed solely by stakeholders' personal observations and beliefs. After seeing the volume and spatial distribution of visitation during the participatory workshop, stakeholders' perceptions changed. As evidenced by the post-workshop survey, stakeholders ranked access to major highways and designated trails as more influential relative to the pre-survey. We found similar shifts in respondents' perceptions of the most salient challenges and benefits associated with increased outdoor recreation and tourism. This finding suggests the presentation of, and discussion focused on, visitation patterns altered stakeholders' perceptions, arguably toward a more accurate representation of the truth.

The true value of the participatory workshops was not seen in the pre- and post-workshop survey data, but rather in the rich and constructive dialog that was generated during the workshops. Participants were able to identify a common set of challenges and opportunities associated with increased outdoor recreation and tourism using the social media to guide their discussions and the refinement of these lists. While the challenges and opportunities are not meant to be exhaustive or prioritized, the ease in which they were generated by workshop participants (over one 1-hour workshop) hint at the utility of using big data to catalyze productive discussion and avoid getting bogged down into the minutia of how the type and extent of data from one agency/organization compares to the type and extent of data from another agency. The relative immediacy with which we were able to develop a collaborative and focused discussion amongst participants speaks to the promise of social media, and possibly other types of big data, as a common focal point around which discussion, collaboration, and possibly even proactive management, can be grounded.

With that said, the process we employed used a single participatory workshop which may have hindered stakeholders' ability to develop shared interpretations and a shared understanding of specific ways that they can work together to achieve mutual gains. Our future work (and we suggest the future work of others) can learn from this by integrating big data into more structured and decision-oriented models of public engagement. Previous research also suggests that collaborative public engagement can be more effective or successful when it is oriented towards a specific decision that will be made through the process (Vincent et al., 2018).

5.2 Collaborative Development of Scientific and Practical knowledge

A relatively large body of literature has suggested two-way communication and collaborative public engagement can be used to shape solutions for complex issues; this is especially true when stakeholders with multiple mandates and priorities are involved (Beier et al., 2017; Meadow et al., 2015; Popovici et al., 2020; Vincent et al., 2018). However, previous research has not explored whether big data can be used to initiate the co-production of knowledge process. Rather, this work has occurred wholly within the realm of theory-guided social science research. Here, we coupled a focused analysis of big data with the initial stage in the co-production process, which could be used to launch a full co-production process capable of allowing outdoor recreation managers, planners, and business owners to further explore questions of interest using results from big data analytics. Our exploratory analysis suggests big data can be helpful in shaping the collaborative development of scientific and practical knowledge about the challenges and opportunities associated with increased recreation and tourism visitation.

The ease at which participants were able to engage in collaborative dialogue within one another, using big data visualizations as an anchor, warrant future investigations into how, and why, particular types of data are effective at catalyzing a productive dialogue between researchers and participants. We found workshop participants had very few problems with understanding where geotagged social media, as a particular type of big data, come from and how they can be used to map the spatial patterns of outdoor recreation use across a landscape. Social media may be a bit of an anomaly in the world of big data, given the widespread use of social media across the globe. Given many people use some type of social media platform, individuals may see the data as an intuitive, logical, and transparent way to collect information on how many and where people are participating in outdoor recreation. This is important to note, as transparency is one of the main ways that big data can add value to existing management decisions (Fosso Wamba, et al., 2015). Future work is needed to determine if other types of big data, which may be less intuitive and understandable to the general public (e.g., satellite imagery), can similarly be used to catalyze collaborative discussions and focus two-way communication processes.

5.3 Limitations and Future Research

We had planned to host five regional workshops around Utah. However, two of these regional workshops (one for the Salt Lake metropolitan region and the other for the Wasatch Back region) were canceled due to COVID-19. The admittedly small number of workshops we have reported on here are not adequate to provide definitive word as to whether big data, or even social media in particular, offer a distinct advantage over more traditional data sources as a focal point to guide collaborative discussions and two-way communication efforts. This exploratory nature of our work, along with the productive dialogs we were able to rapidly engage in, suggest future (more explanatory and experimental) work is warranted.

Additionally, the small number of workshop participants that we engaged with is insufficient for conducting inferential statistical analysis, such as differences in perceived challenges and opportunities by regions or type of stakeholder (e.g., federal versus state versus local perceptions). A larger sample, and more robust statistical analyses of pre- and post-workshop perceptions would be needed to generate more conclusive results about the true utility of using social media.

Lastly, we facilitated discussions in the participatory workshops, which might have limited the breadth of possible interactions between the study participants and our research team. We suggest future work allow for discussions started by end-users *as well as* researchers could create discussions that are broader in scope and create a more robust process of co-production.

6. Conclusions

This study provides an exploratory investigation into how a two-way communication process can be coupled with big data to facilitate the co-creation of knowledge. Being outdoor recreation managers and tourism professionals, the stakeholders who participated in this study were very familiar about the influential drivers of visitation as well as the potential challenges and opportunities associated with increased recreation visitation. However, our relatively short 1-hour workshops in which social media was used as catalyst to focus and guide collaborative discussion, altered participants' perceptions. More importantly, these workshops led to the co-creation of knowledge about the common challenges and opportunities associated with increased outdoor recreation and tourism throughout the state. Our work supports the advancement of methods and processes that integrate big data into communication science. Our use of geotagged social media photographs, and the approachable topic of outdoor recreation and tourism management (which is very salient in Utah), yielded findings that warrant future investigations and open exploration by the growing body of social and spatial scientists who are beginning to integrate big data into their methodological repertoire. While our findings are far from conclusive, they do suggest big data can be integrated into two-way communication processes to facilitate the co-creation of knowledge.

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CHAPTER V

CONCLUSIONS

1. Summary of Findings

This dissertation provides a comprehensive understanding of how social media can be used for outdoor recreation management. In the first manuscript, I examined the efficacy of social media to measure and map visitation to public lands by correlating geotagged social media posts with reported visitation data. I then applied geospatial analysis and exploratory spatial statistics to understand visitation patterns across the state of Utah. In the second manuscript, I used the Recreation Opportunity Spectrum (ROS) as a theoretical guide to incorporate publicly available data sources to classify recreation opportunity provided at different spatial scales across the state. Finally, the third manuscript documents a collaborative and participatory workshop aimed at developing co-created scientific and practical knowledge of the challenges and opportunities associated with increased outdoor recreation participation in Utah. The first manuscript presents scientific findings of how social media data can be used for visitor use monitoring; the second manuscript established a data-driven model to classify outdoor recreation opportunities for various agencies or government; and the final manuscript presents a two-way communication process that allows public engagement in collaborative knowledge development.

Manuscript 1 (Chapter II). Similar to previous research using geotagged social media to estimate visitor use of public lands (Wilkins, Wood, & Smith, 2020), this study showed that social media can provide a relatively good proxy for visitation data collected through traditional means, at least for all public lands within Utah where reported visitation data are available. However, most research using social media to measure visitation does so at a single spatial scale or only for one type of public land. I investigated the effectiveness of using social media to proxy visitor use and found the effectiveness of social media to proxy reported visitation data varied by type of public land (i.e., managing agency). Previous research has used social media to examine spatial patterns of visitation for a single national forest (e.g., Fisher et al., 2018) or national park (Walden-Schreiner, Leung, & Tateosian, 2018; Walden-Schreiner, Rossi, Barros, Pickering, & Leung, 2018). No studies have examined the use of social media to understand the spatial patterns of visitation in a cross-jurisdictional setting or at different spatial scales. My work shows that social media can be used to examine spatial patterns of visitation at multiple scales and that each of those spatial scales can be used to inform different types of decisions.

Manuscript 2 (Chapter III). Free and publicly available data are used as indicators of the biophysical, managerial, and social characteristics that can define outdoor recreation opportunities. Instead of classifying outdoor recreation opportunities along a linear continuum as has been done in the past, I developed a new model that provides equal conceptual weight to the three characteristics that define outdoor recreation opportunities. The result is a set of eight hypothetical ROS classes. For each class, I provide a brief description and "prescriptive" management implications. I show how the framework can be applied at different spatial scales, again using Utah as the case study. For each spatial extent, the spatial patterns of each ROS class are visualized and align with local experts' understanding of the opportunities provided across the state.

Manuscript 3 (Chapter IV). A diverse group of stakeholders were contacted and participated in a collaborative participatory workshop intended to develop a shared understanding of the challenges and opportunities associated with increased participation in outdoor recreation in Utah. The work provides an exploratory example of how big data can be integrated into two-way science communication efforts. The process I employed used a singular participatory workshop, which may have hindered stakeholders' ability to develop shared interpretations and implications from the data presented. This finding highlights the need for on-going collaborative science communication efforts to more effectively enable the co-production of knowledge.

2. Research Contributions

In summary, these three studies aim to advance the scientific methodology of using social media to measure and map visitor use of public lands, guide planning efforts, and provide methods for how social media can facilitate collaborative dialogue amongst a diverse audience. Chapter II expands our understanding by examining the ability of social media to reliably measure the amount of visitation to public lands. For some land management agencies that are home to iconic destinations and scenic landscapes that are shared on photo-sharing platforms like *Panoramio* and *Flickr,* social media can provide a reliable proxy for reported visitation. However, for other agencies who manage destinations that are less likely to be shared on social media, using these data as a measure of visitation will be more tenuous. The use of social media should be approached with caution, with an appreciation that while it may have many benefits relative to traditional visitor use monitoring methods it may not be appropriate in all contexts and for all questions. Our analysis suggests the questions with which social media are well suited to answer depends on both managerial context (i.e., what types of destinations are being managed) and spatial scale (i.e., what is the scope at which tourism management decisions are being made).

Chapter III is the first study I am aware of that uses social media data as a latent construct or independent variable in statistical modeling or a multi-dimensional managerial framework. The data-driven and generalizable model presented pushes outdoor recreation research towards the broader trend experienced across the social sciences where new, large, and often spatial datasets are leveraged to ask long-standing research questions. Specifically, we have developed a model that can define and quantify ROS classifications at multiple spatial scales. The model is structured around the same three setting-characteristics (biophysical, managerial, and social) that have proven themselves as an integral component of numerous outdoor recreation and tourism planning efforts worldwide. The model is also flexible across different applications, as demonstrated by my applications to three distinct spatial extents (statewide, regional, and site-specific). For each application, I showed how the model can yield meaningful characterizations of the outdoor recreation opportunities provided across the landscape. These scale-specific ROS characterizations are useful to distinct types of audiences (e.g., state legislatures, regional collaborative initiatives, and land management agency line officers). Importantly, I have also demonstrated how these classifications can be used in a prescriptive, as opposed to descriptive, way. The model presented here can serve as a catalyst capable of unifying disparate visitor use management frameworks around common data, and a common model, for classifying distinct types of wildland recreation settings upon which outdoor recreation opportunities depend.

Chapter IV is the first study I am aware of that couples big data and public engagement for science communication and co-production of scientific and practical knowledge about the challenges and opportunities associated with increased participation in outdoor recreation. Some recent studies have pointed out the importance of public engagement in science communication and co-production (Meadow et al., 2015; Popovici et al., 2020; Vincent, Daly, Scannell, & Leathes, 2018), but there is a lack of using novel, scalable, accurate data for solving complex issues in natural resource management and planning. Developing collaborative and two-way communication that aims to foster a shared understanding of challenge and opportunities of tourism development is necessary for both academic and practical needs.

3. Limitations

There are limitations that should be considered when interpreting our findings. First, one of the social media platforms we used for our analysis (*Panoramio*) is no longer available. Scholars who are interested in using social media to inform outdoor recreation management decisions should seek alternative platforms which still provide publicly available data or establish direct collaborations with social media platforms (Toivonen et al., 2019). Other types of crowdsourced data, such as mobile phone data, can potentially be used for research in outdoor recreation management. Second, the *Flickr* database may change over time as the platform changes its data storage practices. Third, social media users may not be representative of all visitors to public lands. Recent research suggests social media users tend to be younger than populations as a whole (Wilkins et al., 2020).

Although the data-driven and generalized model developed in Chapter III provides a consistent method that can be used by different agencies to define and quantify ROS classifications at different scales, I am aware of several limitations associated with the use of free and publicly available data worth noting. First, implementing our model requires skilled personnel with the capacity to understand statistical programming software (e.g., *R*). Training and hiring personnel with these skills can be costly. Second, the use of social media data to estimate outdoor recreation and tourism use has been met with skepticism. Primarily among these concerns is the ability of social media to represent the many types of visitors to public lands. The third limitation of this study is the quality (i.e., positional accuracy, completeness, logical consistency, thematic and temporal accuracy, etc.) of free and publicly available data. OpenStreetMap is a crowdsourced data curation project where registered contributors can create and edit the project's geospatial data (openstreetmap.org).

For Chapter III, I had planned to host five regional workshops around Utah. However, two of these regional workshops (one for the Salt Lake metropolitan region and the other for the Wasatch Back region) were canceled due to COVID-19. The admittedly small number of workshops we have reported on here are not adequate to provide definitive word as to whether big data, or even social media in particular, offer a distinct advantage over more traditional data sources as a focal point to guide collaborative discussions and two-way communication efforts. This exploratory nature of our work, along with the productive dialogs we were able to rapidly engage in, suggest future (more explanatory and experimental) work is warranted. Additionally, the small number of workshop participants that we engaged with is insufficient for conducting inferential statistical analysis, such as differences in perceived challenges and opportunities by regions or type of stakeholder (e.g., federal versus state versus local perceptions). A larger sample, and more robust statistical analyses of pre- and post-workshop perceptions would be needed to generate more conclusive results about the true utility of using social media.

4. Future Research Directions

Future research could mitigate the concern about the representativeness of social media data by combining data from multiple social media platforms that cover a wider range of demographics and combing social media data with other volunteered geographic information data such as public participation geographic information systems. Future research could consider the alternative social media platforms or other types of crowdsourcing data to measure recreation visitation and its spatial patterns. The spatial analyses of visitation patterns are dependent solely on the geographic coordinate of each social media post. Considering the variation in the effectiveness of using social media data to quantify visitor use across all public lands in Utah, it is necessary to conduct explanatory research that investigates the reasons or attributes for the spatial variations in visitation across public lands in Utah. In addition to that, a content analysis or machine leaning can be used to fully use the information contained in the social media.

Chapter III builds a data-driven and generalizable ROS that provides prescriptive managerial implications for the legislatures and public land management agencies. Future

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work should seek free and publicly available data with higher accuracy and logical consistency. The data-driven model for classifying recreation opportunities developed in this dissertation was the first attempt to advance the previous ROS by equally weighting the three dimensions and confirming with novel data sources. Implementing our data-driven model for the practical needs require public land managers or researchers to verify the quality of the data sources and adjust the indicators of each ROS setting as needed. Finally, the previous ROS framework and other frameworks in outdoor recreation management has been extensively tested and applied in developed western countries (e.g., United States, New Zealand, Germany etc.). It is these countries, where the ROS has been firmly engrained into management frameworks and planning documents that my framework could further be tested, refined, and eventually implemented.

The collaborative development of co-production of knowledge about challenges and opportunities associated with increased participation in outdoor recreation was documented in Chapter IV. However, my work merely presents a process of two-way communication that coupled big data analytics with public engagement for developing scientific-practical co-recreated knowledge. My use of geotagged social media photographs, and the approachable topic of outdoor recreation and tourism management (which is very salient in Utah), yielded findings that warrant future investigations and open exploration by the growing body of social and spatial scientists who are beginning to integrate big data into their methodological repertoire. While my findings are far from conclusive, they do suggest big data can be integrated into two-way communication processes to facilitate the co-creation of knowledge.

5. **Concluding Remarks**

Using social media and other free and publicly available data sources, I was able to proxy reported visitation to public lands in Utah, and develop a data-driven and generalizable model for classifying recreation opportunities at multiple spatial extents. Further, I branched out my skill set and knowledge base by exploring the science communication literature. In conclusion, the three studies presented in this dissertation contributes to the knowledge and methods of using social media to measure, map, and manage outdoor recreation use of public lands across a variety of spatial scales. The dissertation also provides an example of how big data can be integrated into two-way science communication efforts to facilitate the co-creation of knowledge.

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APPENDICES

APPENDIX A

SUPPLEMENTARY MATERIAL ASSOCIATED WITH CHAPTER II

Detailed explanation for Global Moran's *I* and Local Indicators of Spatial Association (LISA)

The equation of Global Moran's I is:

$$I = \frac{N}{W} \frac{\sum_i \sum_j w_{ij}(x_i - \overline{x})(x_j - \overline{x})}{\sum_i (x_i - \overline{x})^2}$$

Where:

N is the number of total counts of grid cells;

i refers to each grid cell and j refers to adjacent cells;

x is aggregated photo-user days;

$\overline{x}$ is the mean of x;

w_{ij} is a matrix of queen contiguity weights (indicate whether spatial units share a boundary or not); and W is the sum of all w_{ij}.

The LISA (local Moran's *I* statistic) is given as:

$$I_i = \frac{x_i - \bar{x}}{S_i^2} \sum_{j=1, j \neq i}^{n} w_{i,j}(x_j - \bar{x})$$

Where:

x_i is the aggregated number of photo-user days x in grid cell i;

$\bar{X}$ is the mean number of photo-user days;

$w_{i,j}$ is the spatial weight between individual pairs of grid cells following a queen contiguity weights form; and

S_i^2 is given as: $\frac{\sum_{j=1,j\neq i}^{n}(x_j-\bar{x})^2}{n-1}$, where n refers to the total number of grid cells.

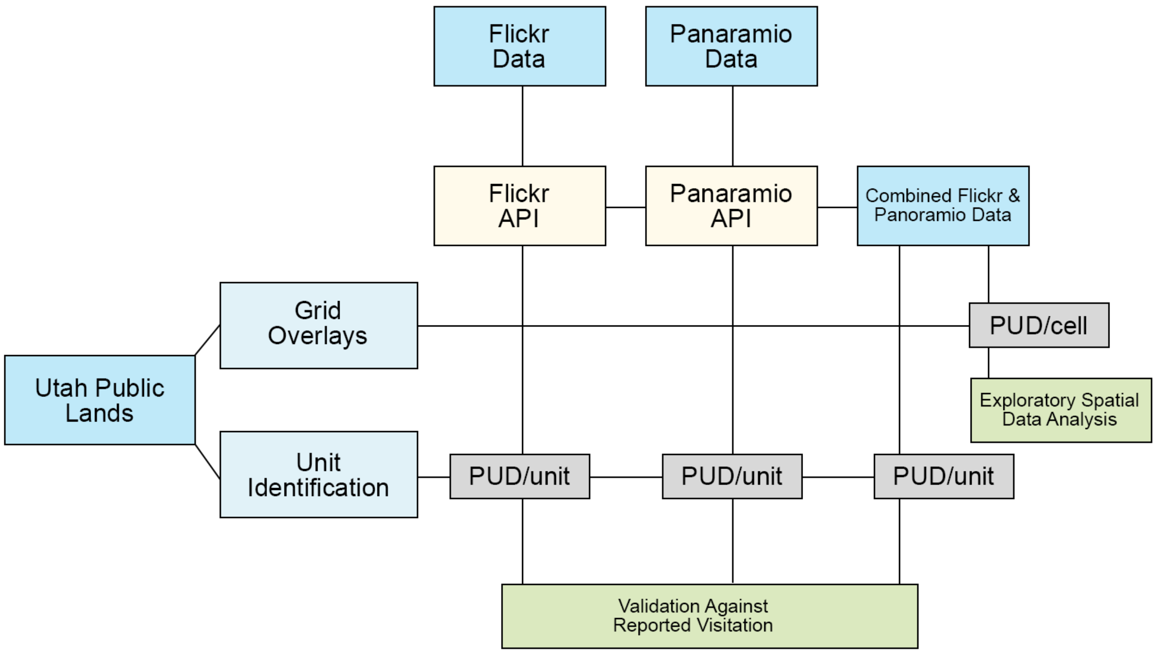

Figure A.1. *Full Methodological Workflow*
Note. Original data are shown in blue, selections within those data are shown in light blue, APIs are shown in yellow, measures are shown in grey, and statistical analyses are shown in green

APPENDIX B

SUPPLEMENTARY MATERIAL ASSOCIATED WITH CHAPTER III

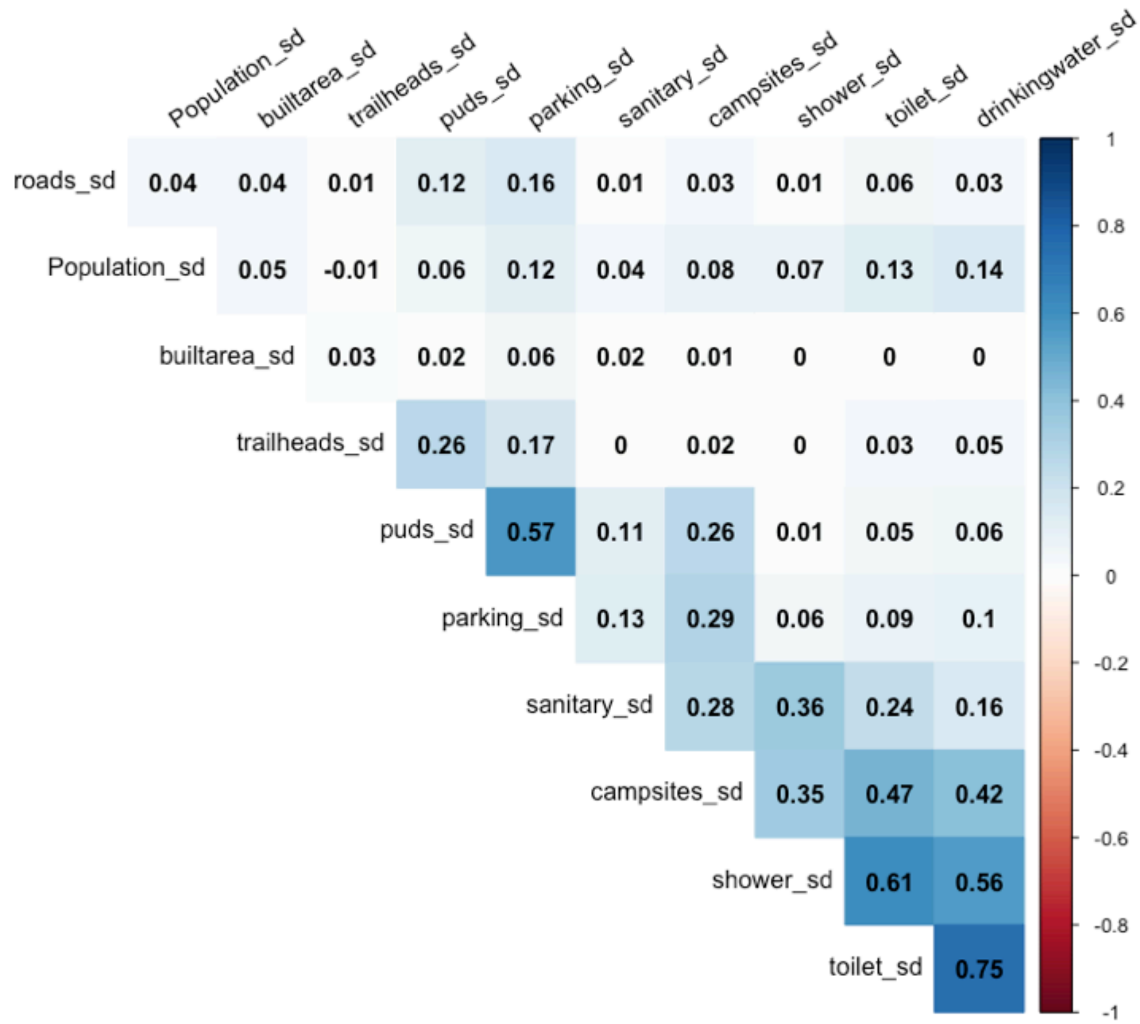

Figure B.1. Correlation matrix of all variables (standardized) related to ROS settings

APPENDIX C

SUPPLEMENTARY MATERIAL ASSOCIATED WITH CHAPTER III

Full Participatory Workshop Scripts

WELCOME – 10 minutes

Hello everyone, thanks for joining this workshop today. My name is Jordan Smith, I direct the Institute of Outdoor Recreation and Tourism at Utah State University. I'm joined by Hongchao Zhang, a PhD student also at Utah State University.

[SHORT DESCRIPTION OF THE INSTITUTE AND ITS MISSION]

We will be holding a series of 5 workshops around the state where we will be getting input from natural resource managers, city and county governments, and local business owners dependent upon outdoor recreation and tourism. The workshops are intended to start constructive conversations about how Utah can capitalize on the opportunities, and mitigate the challenges, associated with increased visitation to Utah's most visited places.

Today, we will be presenting some data and maps that allow you to see exactly where the most visited outdoor recreation and tourism destinations are in the [REGION NAME] region. Using these maps, we want to facilitate a discussion about how the region can capitalize on the opportunities, and mitigate the challenges, associated with increased visitation.

AGENDA AND ROLES – 10 minutes

First, let's walk through the agenda for today's workshop.

[AGENDA]

Your role today is to share your thoughts and opinions and listen to the thoughts and opinions from others. There are no right or wrong answers. We invite ideas that may differ from what others have said. The success of this workshop depends on your willingness to think creatively, voice your ideas, listen to other's ideas, and maintain an open mind.

Hongchao and I will play the role as information presenters and facilitators. As a facilitator, our job is to direct the flow of conversation and make sure that everyone has the opportunity to participate. We are also responsible for keeping us on task and on time, so we may need to interrupt discussions to make sure we stay on target. We know everyone's time is valuable. We hope to work together to make the most of the next two hours and will end on time.

Sign Consent Form, Background Information, and Photo Release Form

INTRODUCTIONS – 10 minutes

Although many of you may already know each other, I would like to start by having you introduce yourselves. Let's go around the room and, one at a time please tell us your name, your current affiliation and position, what you do, and what would you hope to learn from this workshop.

PROJECT OVERVIEW – 15-20 minutes

First off, I would like to begin with an overview of the project and introduce some background information about how we measure outdoor recreation and tourism visitation across large regions like [NAME OF REGION] region.

[SHORT PRESENTATION ON THE ABILITY TO USE SOCIAL MEDIA DATA TO PROXY VISITATION]

BREAK – 5 minutes

It is time to take a short break now. To help keep the day on time we kindly ask that everyone is back and ready to start in 5 minutes. As a reminder, restrooms are [LOCATION] and please help yourself to refreshments.

MAP PRESENTATION – 5 minutes

We will spend the remaining time to share our study findings and launch a discussion based on your observation on these findings.

We have set up a series of maps around the room showing the specific areas within each county across the [REGION NAME] region that get the most outdoor recreation and tourism use. Feel free to walk around and take a look at the maps. We have 30 minutes for you to review the maps and make any personal notes or comments about the things that surprised you most. Please let us know if you have any concern or questions. Afterwards, we can start the discussion about the major challenges and opportunities associated with increased visitation to those destinations.

DISCUSSION – 30-45 minutes

Okay, now that everyone has had a chance to review the maps, let's discuss them.

Q1: What observations do you have? In pre-workshop survey, we asked you to indicate three to five most visited tourism destinations in your county based on your experience and knowledge, did our study results surprise you? Do you have any comments?

Q2: This table/graph shows a list of challenges that we identified from the pre-workshop survey (one PowerPoint slide showing a list of challenges), what might be the major challenges (indicate 3-5 major challenges) associated with these most visited tourism destinations in [REGION NAME] (e.g., do you see crowding become an issue in tourism planning/management)?

Q3: This graph shows a list of how concerned you are about different consequences associated with increased visitation to outdoor recreation and tourism destinations across the region. Now that you have seen where outdoor recreation and tourism is occurring in the region, what are your concerns? Let's list them out and rank them if we can.

[LISTING AND RANKING EXERCISE]

Q4: Given your level of concern for these consequences, how can the region mitigate the consequences of increased visitation to outdoor recreation and tourism destinations across the region? Again, let's make a list.

[LISTING EXERCIES]

Q5: This graph shows a list of how you believe the region benefits from increased visitation to outdoor recreation and tourism destinations. Are there any other benefits?

[LISTING EXERCISE]

Q6: Now that you have seen where outdoor recreation and tourism is occurring in the region, what are be opportunities for you, or the region as a whole, to capitalize on increased visitation?

[LISTING EXERCISE]

CLOSING – 15 minutes

We have just a few more minutes now and one important question item before we wrap up.

Q7: Based on what you've heard and discussed today, what do you see as future priorities for regional recreation and tourism planning (what major challenges must be addressed immediately and what might be useful to accommodate increased visitation to this region)? What resources and information are needed?

[LISTING AND RANKING EXERCISE]

WORKSHOP REFLECTION – 10 minutes

Q8: Is there anything else we should know as we continue this project? Suggestions? What else would you like to know about the project?

Thank you all very much for joining us today. Your input has been extremely valuable. Based on the information we gather through regional workshops, we aimed to develop publicly available products that present Utah most visited tourism destinations through a set of statewide, regional, and county maps. Your thoughts and opinions are very important for us to shape a statewide sustainable tourism marketing plan. We will be available after. The session to answer any specific questions about the project or if you have anything else would like to share with us.

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Xu, S.,* Wilhelm Stanis, S.A., **Zhang, H.,** Groshong, L., & Morgan, M. (2020). Impacts of Travel Distance and Experience Use History on Visitors' Climate Friendly Behavior and Support for Climate Friendly Management Action. Journal of Sustainable Tourism. (SSCI Q1; Impact factor: 3.986)

Brice, E. M.,* Miller, B. A., **Zhang, H.,** Goldstein, K., Zimmer, S. N., Grosklos, G. J., ... & Brunson, M. W. (2020). Impacts of climate change on multiple use management of Bureau of Land Management land in the Intermountain West, USA. Ecosphere, 11(11), e03286. (SCI Q1; Impact factor: 2.878)

Zhang, H.,* Groshong, L., Stanis, S. W., & Morgan, M. (2020). Comparing onsite electronic survey distribution methods. Annals of Tourism Research, 102997. (SSCI Q1; Impact factor: 5.908)

Johnson, D.,* Brune, S., Dagan, D. T., Meier, E., Wilkins, E. J., & **Zhang, H.** (2020). A holistic strategy for carbon reduction programs in parks and protected areas: Leveraging three "fixes". In Parks Stewardship Forum (Vol. 36, No. 3).

Zhang, H., & Smith, J. W.* (2018). Weather and Air Quality Drive the Winter Use of Utah's Big and Little Cottonwood Canyons. *Sustainability*, *10*(10), 3582. (SSCI/SCI Q2; Impact factor: 2.075)

Under review/in active preparation:

Zhang, H.,* Smith, J. W., Howe, P., Miller, Z. D., & Van Berkel, D. B.. A Data-Driven, Generalizable Model for Classifying Recreation Opportunities at Multiple Spatial Scales.

Zhang, H.,* Groshong, L., Stanis, S. W., & Morgan, M.. Differences in Visitors' Perception of Climate Change by Demographics.

Zhang, H.,* Brunson, M., & Miller, Z. D., Van Berkel, D. B., & Smith, J. W.. Shaping Local Tourism Development Strategies through Participatory Workshops and Big Data.

OTHER PUBLICATIONS

Conference Papers

Xu, S.,* Wilhelm-Stanis, S. A., **Zhang, H.,** Groshong, L., & Morgan, M. (2020). Visitor Attitudes Toward Climate Mitigation Strategies: Influence of Travel Distance and Experience Use History. Travel and Tourism Research Association: Advancing Tourism Research Globally, 29.

Zhang, H.,* & Smith, J. W. (2020). Validating the Use of Social Media Data to Measure Visitation to Public Lands in Utah. Travel and Tourism Research Association: Advancing Tourism Research Globally, 39.

Technical Reports

Dorning, M. A., Van Berkel, D. B., Beck, S. M., Wilkins, E. J., **Zhang, H.,** & Smith, J. W.* (2019). Aesthetic Characteristics of the Front Range: An Analysis of Viewsheds Provided by Boulder OSMP Lands. Technical Report, Institute of Outdoor Recreation and Tourism, Utah State University. Logan, Utah.

Wilkins, E.J., **Zhang, H.,** Van Berkel, D. B., Dorning, M. A., Beck, S. M., & Smith, J.W.* (2018). Landscape Values and Aesthetic Preferences Across the Front Range: Visitors Perceptions of the Values Provided by Boulder OSMP Lands and their Aesthetic Preferences for Specific Landscape Features. Technical Report, Institute of Outdoor Recreation and Tourism, Utah State University. Logan, Utah.

Zhang, H.,* Wilhelm Stanis, S.A., & Morgan, M. (2016). Exploring Visitor Perceptions of Climate Change: A Study in Columbia, MO Nature Areas. Technical Report, Department of Parks, Recreation and Tourism, University of Missouri. Columbia, Missouri.

ORGANIZED CONFERENCE SESSION

Zhang, H., & Smith, J. W. (2018, June). Modeling dynamic spatial and temporal patterns in outdoor recreation behavior. Organized session for the 2018 International Symposium on Society and Resource Management, Snowbird, Utah.

PRESENTATIONS

Xu, S., Wilhelm Stanis, S., **Zhang, H.,** Groshong, L., & Morgan, M. (2020, June 16-18). Visitor attitudes toward climate mitigation strategies: Influence of travel distance and experience use history. The 51st Annual International Conference of Travel and Tourism Research Association (TTRA), Victoria, Canada. (Conference canceled).

Zhang, H.,* & Smith, J. W. (2020, June 16-18). Validating the Use of Social Media Data to Measure Visitation to Public Lands in Utah. 39. The 51st Annual International Conference of Travel and Tourism Research Association (TTRA), Victoria, Canada. (Conference canceled).

Zhang, H., & Smith, J.W. (2018, June). The Influence of Air Quality and Weather on Temporally-Dynamic Use Patterns in Big and Little Cottonwood Canyons. Presentation at the 2018 International Symposium on Society and Resource Management, Snowbird, Utah.

Zhang, H., Wilhelm Stanis, S.A., Morgan, M., Groshong, L., & Ojewola, O. (2016, June). Park Visitor Perceptions of Climate change: A Human Health Perspective. Poster presentation at the 2016 International Symposium on Society and Resource Management. Houghton, Michigan.

Ojewola, O.A., **Zhang, H.,** Morgan, M., & Wilhelm Stanis. (2016, April). Climate Change in Missouri State Parks and Historic Sites: A Managerial Perspective. Poster presentation at the 2016 Missouri Life Sciences Week. Columbia, Missouri.

Zhang, H., Wilhelm Stanis, S.A., & Morgan, M. (2016, April). Exploring Visitors' Perception of Climate Change: Differences by Income. Presentation at the 2016 Northeastern Recreation Research/National Environment and Recreation Research Symposium. Annapolis, Maryland.

Zhang, H., Wilhelm Stanis, S.A., Morgan, M., & Groshong, L. (2016, April). Comparing Onsite and Online follow-up Survey Distribution Methods: Results from a Field Study. Presentation at the 2016 Northeastern Recreation Research/National Environment and Recreation Research Symposium. Annapolis, Maryland.

Zhang, H., Wilhelm Stanis, S.A., & Morgan, M. (2016, March). Exploring Visitors' Perception of Climate Change: Differences by Income. Presentation at the MU 33rd annual Research & Creative Actives Forum. Columbia, Missouri.

Groshong, L., Wilhelm Stanis, S.A., Morgan, M., Ho, Y., Ojewola, O.A., & **Zhang, H.** (2015, April). Community Engagement in Missouri State Parks & Historic Sites: Visitors and Managers Response to Climate Change. Poster Presentation at the 2015 National Outdoor Recreation Conference/Northeastern Recreation Research Symposium. Annapolis, Maryland.

SOFTWARES AND SKILLS

- ArcGIS
- QGIS
- SPSS
- SAS
- R
- Python
- Microsoft Office

PROFESSIONAL TRAINING AND CERTIFICATE

- Data Carpentry Workshop, Utah, State University, CAS program, Fall, 2017
- Qualtrics Training, University of Missouri, Division of Information. Spring, 2016
- SPSS Training, University of Missouri, Division of Information. One-day technology training workshop. Fall, 2014
- Certified Interpretive Guide Training, Fall 2013 (Certificate Earned)
- Leave No Trace Training, Spring 2013 (Certificate Earned)

HONOR AND AWARDS

- 3rd place in the category of Social Sciences (Quantitative) at the MU 33rd annual Research & Creative Actives Forum. March 12, 2016.
- University of Missouri Graduate Professional Council Travel Scholarship. Spring 2016.
- University of Missouri Organization Resource Group Travel Award. Spring 2016.
- Missouri Park and Recreation Scholarship, Missouri Park and Recreation Scholarship Charitable Trust. Spring 2016.
- University of Missouri Organization Resource Group Travel Award. Spring 2015.

- Missouri Park and Recreation Scholarship, Missouri Park and Recreation Scholarship Charitable Trust. Spring 2015.
- Dean's list in the College of Natural Sciences, Forestry, and Agriculture, UMaine, Fall 2013.
- George L. Houston Scholarship, UMaine, Spring 2013.

SERIVCE

Journal Article Reviewed:

Leisure Sciences

Journal of Outdoor Recreation and Tourism

Global Ecology and Conservation

International Journal of Environmental Research and Public Health

Conference Planning and Hosting:

2018 International Symposium on Society and Resource Management, Snowbird, Utah

(Doctoral student co-chair of symposium planning committee)

ORGANIZATIONS

Member of International Association for Society and Natural Resources.

Member of Missouri Park and Recreation Association.

Treasurer of MU PRT Graduate Student Association. Fall 2014-Summer 2016