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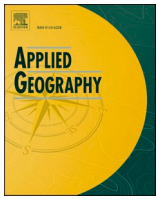

Using social media to measure and map visitation to public lands in Utah

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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 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, Horsch, Smith, & Unsworth, 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, Wood, & Smith, 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, Guerry, Silver, & Lacayo, 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, Wood, & Smith, 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, Wood, & Smith, 2020). Only very recently, have researchers attempted to use social media to measure visitation across multiple

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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, Seekamp, Davenport, & Smith, 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, Wood, & Smith, 2020). Table 1 lists the major social media platforms that provide publicly available data, accessible through APIs.

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, Abbasi, Maghrebi, Hasan, & Waller, 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, Mayer, Woltering, & Ghermandi, 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, Barros, Walden-Schreiner, & Pickering, 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, & Tateosian, 2018; Walden-Schreiner, Rossi, Barros, Pickering, & Leung, 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, Wartmann, Kienast, & Verburg, 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, Smith, & Keane, 2020).

Table 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 will be 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).

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, Wood, & Smith, 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, Wood, & Smith, 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, Wood, & Smith, 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, Moore, & Dowling, 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; Norman & Pickering, 2017; Rice, Mueller, Graefe, & Taff, 2019). The majority of this work, however, has used point data to map the spatial distribution of visitation. Sonter, Watson, Wood, and Ricketts (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, Kim, Lee, Lee, & Andrada, 2019; Sinclair et al., 2020), metropolitan area (e.g., Donahue et al., 2018; Hamstead et al., 2018; Heikinheimo et al., 2020; Li, Li, Li, & Long, 2020; Song, Richards, & Tan, 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; 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, Geijzendorffer, Václavík, Poulin, & Ziv, 2019), parameterize models of visitor flows (Orsi & Geneletti, 2013), and quantify the value of parks and protected areas (Sinclair, Ghermandi, & Sheela, 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, Campbell, Svendsen, & McMillen, 2019; Muñoz, Hausner, Runge, Brown, & Daigle, 2020; Retka et al., 2019; Vaz et al., 2019; Vieira, Bragagnolo, Correia, Malhado, & Ladle, 2018; Yoshimura & Hiura, 2017), or inequitable access to (Martinez-Harms et al., 2018), 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 is 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, Wood, & Smith, 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, Tenkanen, & Toivonen, 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 (2006–2014) as the reported visitation from each land management agency. We limited the time period for our investigation to the years between 2006 and 2014 because the *Panoramio* API only provides data between 2006 and 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:

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

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[1] 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.

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. 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

[1] 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.

Table 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	1,469	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.

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.

As shown in Table 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 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, Wood, and Smith (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.

The regression models revealed substantial differences in the ability of PUDs to proxy reported visitation across the three types of public lands (Fig. 1; Table 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. $\geq$ 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

Table 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.

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 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 Fig. 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 $I = 0.427$; $p < 0.01$).

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 Fig. 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 Fig. 4. All maps have been made publicly available at [https://doi.org/10.3886/E131163V1].

Local indicators of spatial association are shown in Fig. 5. The map illustrates high-high areas (cells with high PUD counts surrounded by

Table 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.

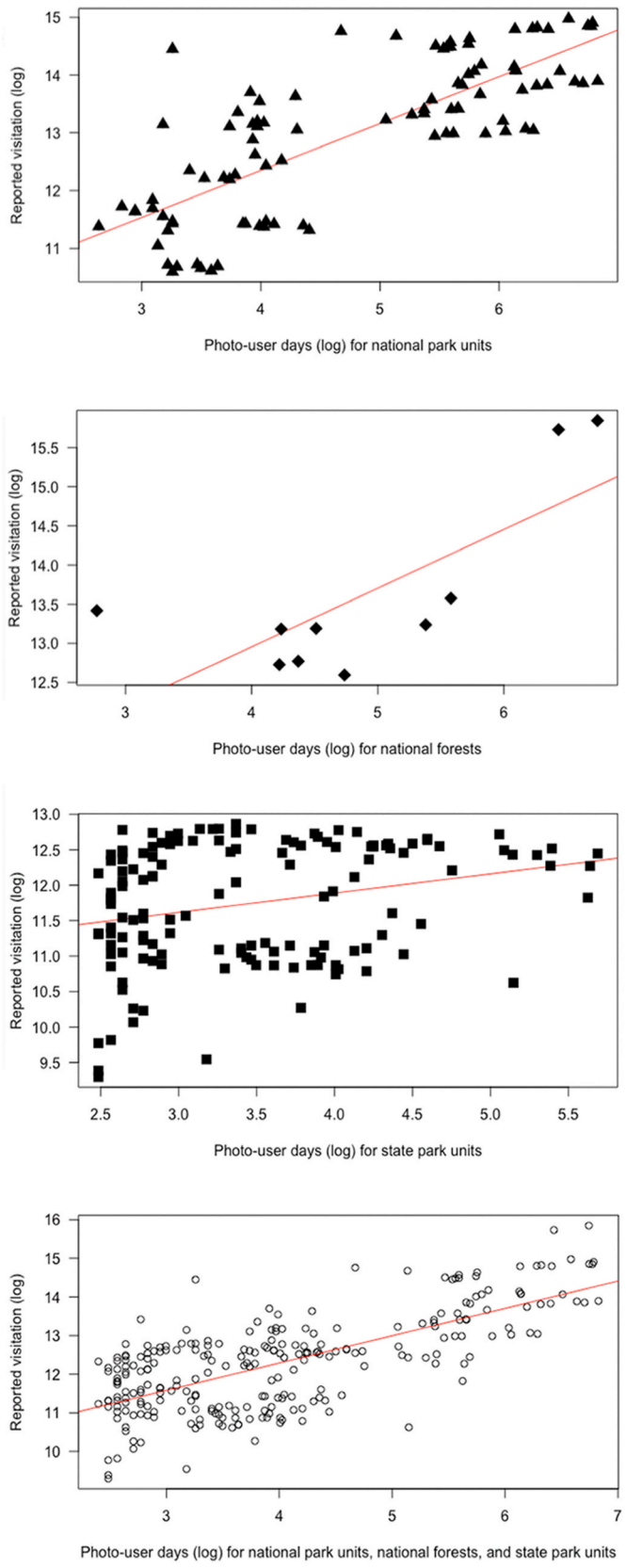

Fig. 1. Association between reported visitation and photo-user-days for National Park Service units (a), national forests (b), state park units (c), and all three land management agencies combined (d).

Table 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.

Table 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.

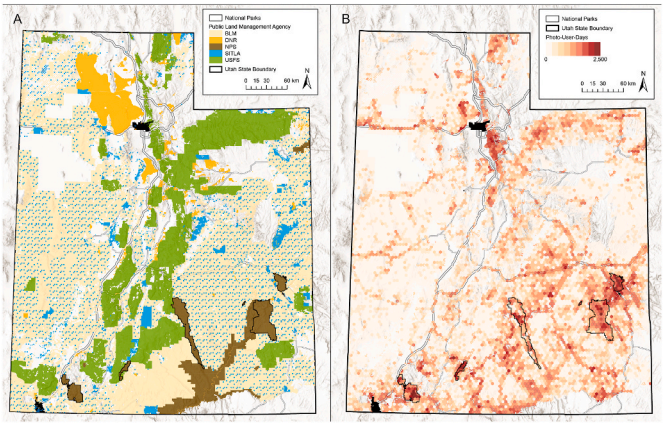

Fig. 2. Public lands accessible for outdoor recreation in Utah by management agency (a) and photo-user-days aggregated by a 5-km grid across these lands (b).

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

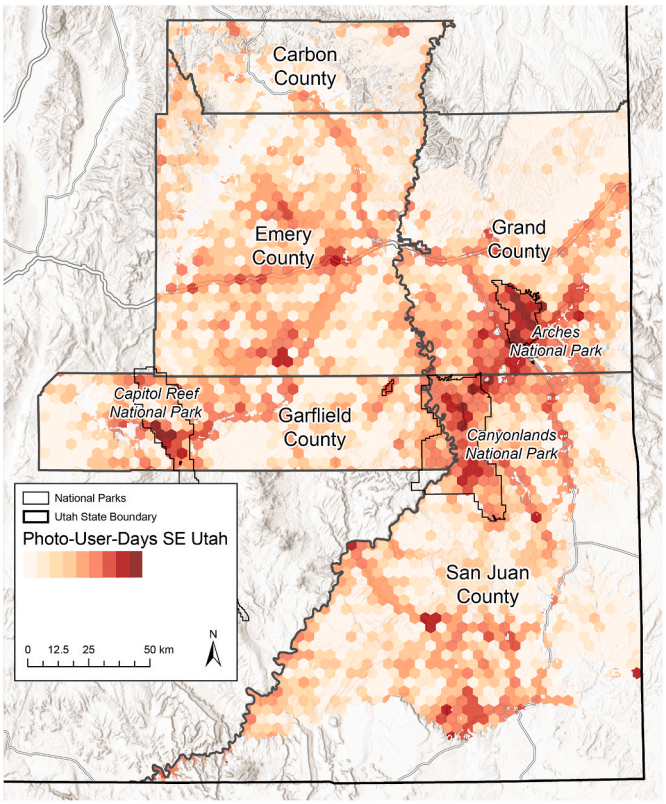

Fig. 3. Photo-user-days aggregated by a 5-km grid across public lands within the southeastern region of Utah.

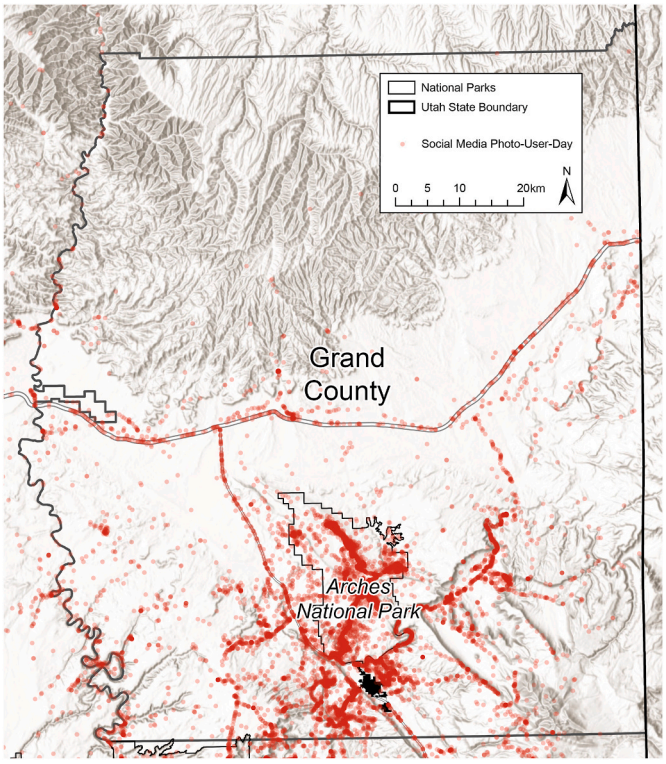

Fig. 4. Photo-user-days on public lands within Grand County, Utah.

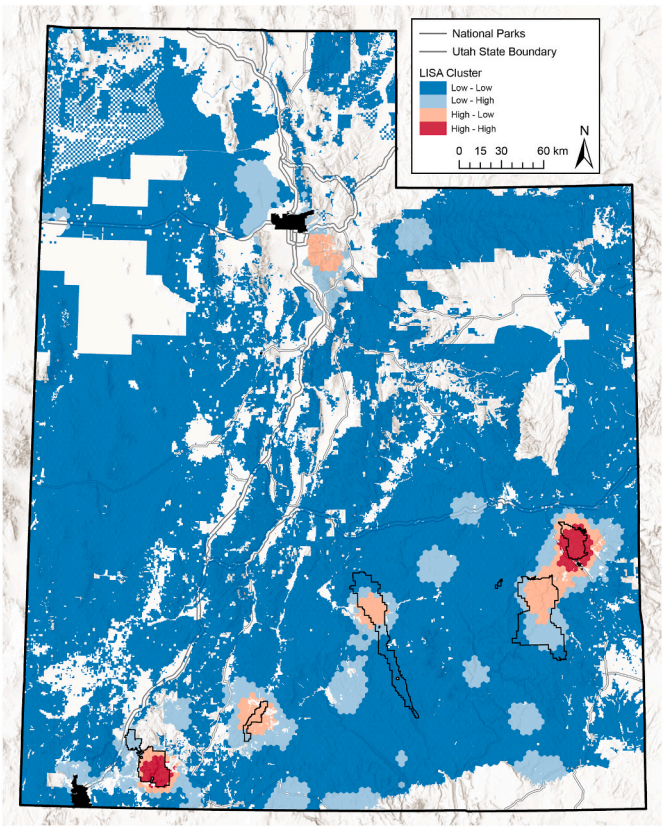

Fig. 5. Local Indicators of Spatial Association (LISA) categories of photo-user-days across public lands within Utah.

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.

The percentage of land managed by each agency within the four LISA categories is shown in Table 7. Over 90% of Bureau of Land Management

Table 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.

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 7).

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, Leung, and Tateosian (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, White, Bowker, & Winter, 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, Barbieri, Wilhelm Stanis, Aguilar, & Smith, 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, Leung, & Tateosian, 2018; Walden-Schreiner, Rossi, et al., 2018). 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, Kim, & Jakus, 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 (Fig. 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

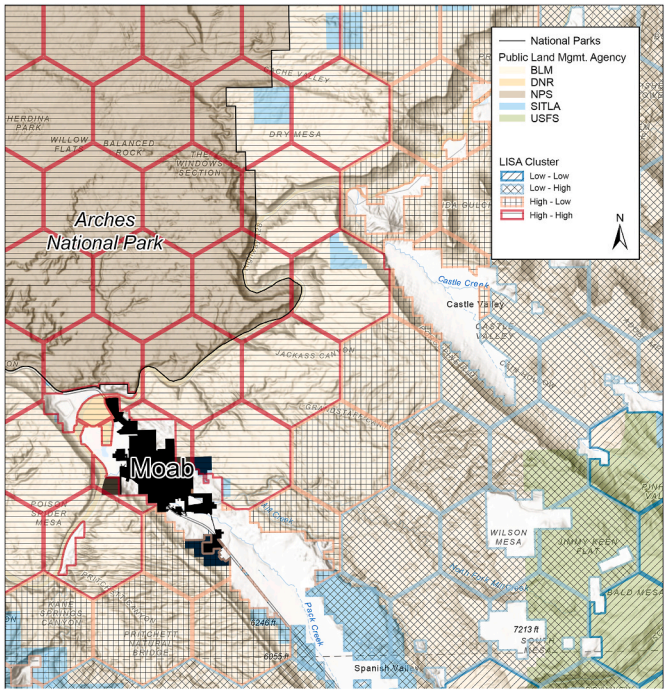

Fig. 6. Local Indicators of Spatial Association (LISA) categories of photo-user-days across public lands around Moab, Utah.

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 (Fig. 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.

At the smallest spatial scale investigated (the county), our analysis highlights locally relevant patterns of visitation (Fig. 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, Cole, & Monz, 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, Wood, & Smith, 2020). This is a well-documented limitation within this line of research (Wilkins, Wood, & Smith, 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. *Explanatory* research which investigates 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, Albert, Rota, & Giné, 2019; McCreary et al., 2020; Wartmann, Tieskens, van Zanten, & Verburg, 2019). 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).

Author statement

Hongchao Zhang: Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Writing – Original Draft, Visualization. **Derek van Berkel**: Resources, Data Curation, Writing – Review and Editing. **Peter D. Howe**: Writing – Review and Editing; **Zachary D. Miller**: Writing – Review and Editing; **Jordan W. Smith**: Conceptualization, Methodology, Writing – Reviewing and Editing, Visualization, Supervision, Project administration, Funding acquisition.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.apgeog.2021.102389.

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