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Understanding visitors' spatial behavior: a review of spatial applications in parks

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ABSTRACT

The integration of spatial concepts with social science data in natural resource management has progressed rapidly over the past 15 years. There is now a foundational understanding, and supporting empirical work, that recreational use at parks and protected areas (PPAs) is a spatially conditioned process. To better understand visitor's spatial behavior, we present an updated review of the incorporation of space into human dimensions of natural resources research; what it has illuminated about human behavior, human values, and PPA management; how spatially related social science data are being integrated with other resource issues; and identify knowledge gaps and propose future directions for research. Overall, our review suggests that the examination of spatially related social science data are only in their infancy because of rapidly evolving technology which continues to advance the value of this type of research. Additionally, the geographic scope of studies often determines the applicability of the findings. For example, participatory mapping methods are typically used for macro-level PPA management applications such as infrastructure planning while visitor data logging are often used for more localized visitor management applications. Therefore, one significant advancement over the past five years has been the incorporation of multiple methods in single studies.

摘要

在过去15年中，空间概念与自然资源管理中的社会科学数据的整合取得了快速地进展。现在有一个基本的认识，并且有实证工作支持，即在公园和保护区(PPAs)的娱乐利用是一个受空间制约的过程。为了更好地理解游客的空间行为，我们提供了一个更新版的文献综述，将空间纳入自然资源研究的人类维度研究之中。该综述阐述了人类行为、人类价值观和公园及保护地管理；空间相关的社会科学数据如何与其他资源问题进行整合；该综述识别了知识缺口，并提出未来的研究方向。总的来说，我们的综述表明，对空间相关社会科学数据的研究还处于起步阶段，这是因为快速发展的技术不断提升了这类研究的价值。此外，研究的地理范围常常决定了研究结果的适用性。例如，参与式绘图方法通常用于基础设施规划等宏观尺度的公园及保护地管理，而访问者记录数据

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关键词
公园；保护区；游客行为；空间分析；GIS （地理信息系统）；GPS（全球定位系统）；PPGIS（公众参与式地理信息系统）

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通常用于更小范围的游客管理领域。因此, 在过去的五年里, 一个重要的进步是将多种方法结合到单个的研究中。

Introduction

Recreation in parks and protected areas (PPAs) is a spatially conditioned process that affects visitors' experiences and impacts to biophysical resources (Beeco & Brown, 2013; Beeco, Hallo, English, & Giumetti, 2013). A spatially conditioned process is a relationship between space and a human-related phenomena. Beeco and Brown (2013) identified how nature-based recreation is a spatially conditioned process because of the visitor interaction with space within a PPA. Specifically, the physical terrain structure, along with anthropogenic infrastructures, affects the spatial trajectory of visitors leading to spatial diffusion—where visitors concentrate in specific areas. Beyond the physical behavioral aspect of PPA visitors, their spatial behavior is manifested from a complex psychological dynamic that includes values, motivations, beliefs, attitudes, and norms. Visitor use distribution impacts experiential factors, natural resources, and cultural resources, which are all directly related to where visitors travel. Finally, managers also use space to segment visitor use through management zones and spatial segmentation practices.

Spatial behavior is also strongly connected to time, hence the jargon term 'spatiotemporal' (Birenboim, Anton-Clavé, Russo, & Shoval, 2013). Hägerstrand (1970, 1973) stated that time is an essential aspect of spatial behavior, because time-budgets affect spatial movements. Spatiotemporal data are important for managers of PPAs to understand: how much time visitors spend in specific locations, the distribution of visitors, the identification, evaluation and evolution of possible resource impacts, and where and when mitigation of problems may be prevented (D'Antonio & Monz, 2016). Consequently, this information can help managers effectively manage for social, environmental, cultural, and managerial impacts. This knowledge can reduce PPA management spending and staff time. Hence, it is critical to assess not only the spatial component of visitors' travel patterns, but to investigate the temporal factor in conjunction with spatial data, hence the importance of spatiotemporal research in PPAs.

The advances of the integration of spatial concepts with social science data in natural resources management has progressed rapidly over the past 15 years. Thus, the purpose of this article is to review spatial applications in PPAs that conducted research within the scope of understanding visitors' spatial behavior. This state of knowledge review serves as a concise consolidation of research conducted to explain visitors' spatial behaviors and the methods employed. Beeco and Brown (2013) conducted a similar review, although not congruent, in which the incorporation of space into PPA research was reviewed, along with concepts, methods, gap analyses, and lastly proposals for future research were provided. This article builds on the review of Beeco and Brown (2013) and primarily focuses on research done since 2013, which includes research that explored a single method and the affiliated outcomes, along with how researchers have ingeniously combined multiple methods to gain a rich understanding into visitors' spatial behavior. The Beeco and Brown (2013) paper found that research had mostly described spatial behavior instead of explaining spatial behavior and therefore focused largely on methodical approaches.

A framework for spatial research in PPAs

This review begins with an organizing framework for describing spatial research conducted in PPAs (Figure 1). Row 1 of Figure 1 displays four general spatial processes—diffusion, interaction, impacts, and segmentation—that are presented as organizing categories for understanding how space is applied to measuring, predicting, and managing visitor use in PPAs. Spatial diffusion describes where visitors go, spatial interaction describes why visitors go there, spatial impacts identity resources that may be affected, and spatial segmentation identifies how space can be managed. Row 2 provides examples of spatial operations that have been performed on visitor spatial data including cluster, density, proximity, overlay, and network analyses. The spatial operations are a means to examine and assess spatial data to inform a range of PPA applications (Row 3) such as physical infrastructure design and management (facilities, roads, trails, and information services), the management of visitor social behavior (experiences, conflict, crowding), and the management of PPA areas and features (levels of service, zoning).

The framework is intended to be organizational and illustrative, not exhaustive of all categories and relationships. Multiple spatial processes and operations are typically used when analyzing spatial data for a given PPA management application. For simplicity, the framework depicts a one-to-one relational hierarchy, however, a more accurate graphical representation would show multiple arrows connecting spatial operations to multiple PPA management applications. For example, at its most basic Global Positioning System (GPS), data are used to understand where visitor's travel

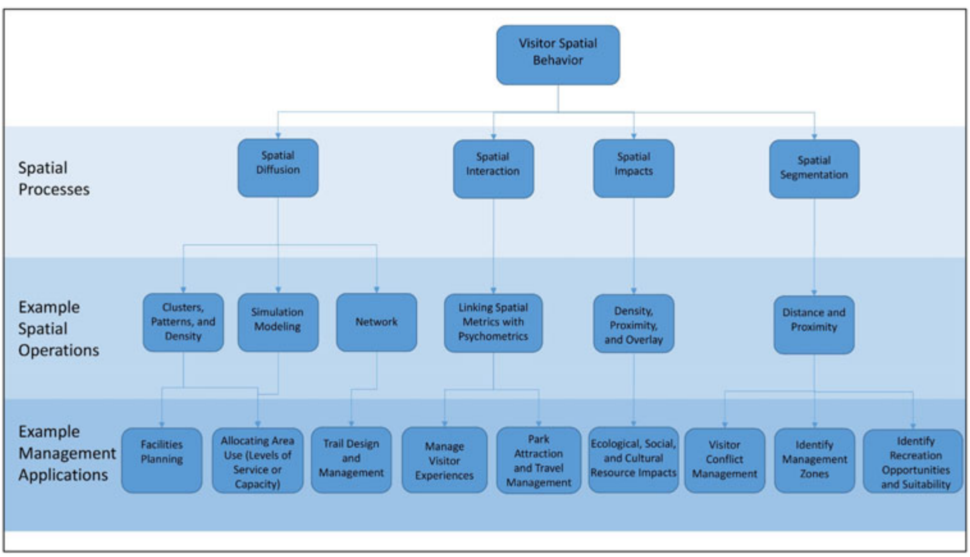

Figure 1. A framework for understanding spatial behavior in parks and protected areas management. Source: Authors.

(spatial diffusion) and often analyzed using a density measure. However, that same data could be linked with survey data to understand why visitors are traveling to certain places at certain times (spatial interaction). Further, the findings from this analysis could then inform management zones, a spatial/temporal zoning regime, trail design and management, and facilities planning.

Spatial data—data logging versus user-generated content

Locational data for visitor activities and behaviors in PPAs fall into two general categories—data that is captured through GPS loggers or remote-sensing equipment (e.g. cameras, aerial imagery) and data provided directly by visitors who identify locations on a map, either hardcopy or digital. This latter method is typically described as public participation Geographic Information Systems (PPGIS) or volunteered geographic information (VGI) systems. Data loggers can provide accurate locations of visitor use over time using GPS tracks while remote-sensing equipment can provide location information about PPA use at a single point in time. PPGIS and VGI systems typically capture PPA spatial data from users during or after their visits and have the advantage of providing greater context for the spatial data generated from user descriptions.

Over the past five years the greatest advances in methodology have come from innovatively combining and cross validating spatial methods rather than the development of new approaches. The use of GPS data loggers solely for descriptive analysis is rarely sufficient to help managers of PPAs, but as described below, combining GPS data loggers with questionnaires, using GPS to cross-validate other data, and using GPS data to determine assessment indicators are three examples of creatively achieving results. Similarly, PPGIS and VGI systems alone may not generate sufficient spatial data at a scale that is adequate for the management of specific features or areas within a PPA. The combination of spatial data collection methods can generate spatial information to inform PPA management at multiple scales, from park feature and trail management, to larger area zoning for visitor experience and resource protection.

Spatial diffusion

Spatial diffusion is the geographical pattern of spatial distribution (Beeco & Brown, 2013). The locations people visit, their travel routes, and the amount of time spent at these locations are some of the most basic, but relevant, data on recreation (Hallo et al., 2012). Multiple methods have been used to better understand how visitors travel through space in PPAs.

Recent advancements in GPS technology have made it possible to collect spatio-temporal data with affordable devices that collect high-resolution and accurate time-space data (Birenboim et al., 2013). The GPS data loggers are an effective device that record waypoint position at regular time intervals in its internal memory. These devices are small (some models are approximately the size of a thumb drive), typically waterproof, can be carried in a pocket, and purchased at an affordable price. Accordingly, GPS data loggers have regularly been featured as a tool to further gain knowledge about visitor use management in PPAs (Beeco & Hallo, 2014; Beeco, Hallo,

& Brownlee, 2014; D'Antonio & Monz, 2016; D'Antonio et al., 2010; Kidd et al., 2015). Even though GPS data loggers are commonly used as one method for understanding visitors' behavior, the methods of analysis are underdeveloped (Beeco & Brown, 2013; Beeco & Hallo, 2014), and can gain richness by being combined with social data.

Most of the GPS studies in PPAs have largely focused on the utility of GPS technology and mapping visitor travel patterns. These studies are usually limited to visual analyses such as mapping, point densities, or overlays and descriptions of clustering and pattern analysis (Beeco & Hallo, 2014; Zheng, Huang, & Li, 2017). Fortunately, there is high potentiality to investigate inventive research questions that categorize GPS attribute data into specific classifications that help describe a fuller understanding of visitor travel patterns, and the implications visitor travel patterns have on other knowledge and on management implications. More recent studies have done just that—used GPS to better understand human behavior.

A popular setting that draws researchers to use GPS data loggers is recreational trail activity. Taczanowska et al. (2014) combined graph theory with GPS data to assess the functionality of a trail network in Austria. Graph theory, which has marginally been applied to PPAs, is applicable for understanding properties and functions of networks, and is useful for evaluating overall trail connectivity and the relative importance of trail intersections (Gross & Yellen, 2006). This two-pronged approach, utilized by Taczanowska et al. (2014), determined that the official trail network does not strongly correspond with hikers' behavior, that a network of informal trails encourages hikers to leave official trails, and connectivity indices produced from graph theory are an efficient method to measure change to a trail network.

Another study coupled GPS data loggers and questionnaires to analyze how visitors travel within and through a complex trail network (Beeco & Hallo, 2014). The study operationalized travel patterns into three distinct (but overlapping) measures: total distance traveled, number of zones (areas) encountered, distance (Euclidean) from start, and time spent using the trail system. This study generally found (in a more-to-less order) that mountain bikers, horseback riders, runners, and then hikers travel the most miles, encountered the most zones, and traveled the furthest from the starting point. These results also suggest that horseback riders stayed significantly longer on the trails than all other groups.

GPS tracking of visitor use in PPAs has challenged some theoretical assumptions in visitor use. Studies performing simulation modeling assume the temporal or spatial distribution of visitor use remains constant even as use levels rise in the study areas modeled (Lawson, Hallo, & Manning, 2008). Using GPS to measure visitor dispersion patterns, D'Antonio and Monz (2016) indicated that this assumption is only valid for some recreational settings. Visitor spatial behavior (i.e., dispersal away from hardened surfaces) varied with use level in areas that had a single attraction point or feature for visitors to view (i.e. 'view sites').

Innovative application of analyses have also taught us more about how visitors are distributed through time and space in PPAs. Point density analysis has become a popular tool to determine where visitors are 'dense' within a PPA. Point density analysis is possible because GPS data loggers are programmed to take a waypoint at a pre-determined interval, such as recording a waypoint every five seconds. These

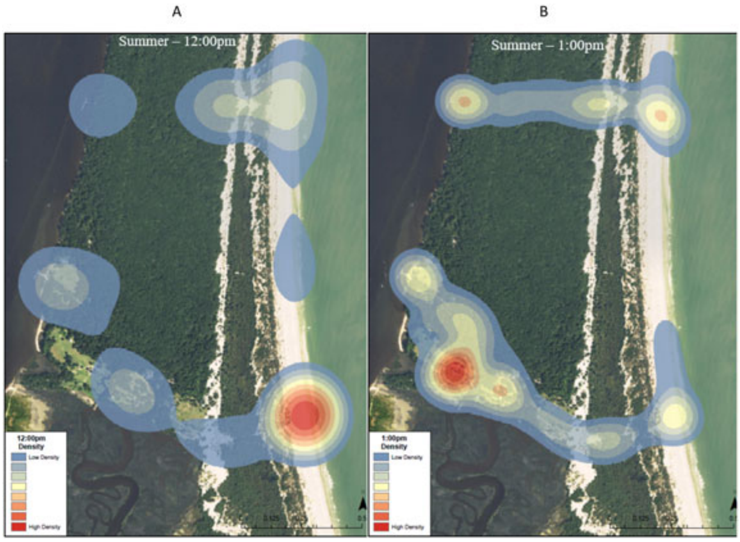

Figure 2. Point density display of 12 noon (A) and 1:00 PM. (B) waypoints collected during the summer of 2016 at Cumberland Island National Seashore (Peterson, Brownlee, & Sharp, 2017).

waypoints recorded by the GPS data logger are connected to form tracks using GIS software, such as ArcGIS. The waypoint data can be used to analyze point data density. Density analysis can be assessed at numerous scales, such as by season or by hour. Point density analysis by season will display seasonal densities of point data gathered by GPS data loggers. Hourly point density analysis is a smaller scale that can display density patterns for each hour of the day. For example, using point density analysis it is possible to assess the density of summer visitors at each hour of each day. This would result in a density display for spring data for 9:00 am, 10:00 am, 11:00 am, etc., for each day of the week for each season. This would show managers where visitors are dense within the PPA for each hour of the day for each day of the week for summer data. Figure 2 illustrates point density maps at 12:00 noon and 1:00 pm for data collected during the summer of 2016 with GPS data loggers at Cumberland Island National Seashore. Stratifying data are useful for managers to gain enhanced understanding of the visitor population. Similarly, kernel density estimation could also be used and has other advantages, including it has a smoothing effect that produces a clean display and is a non-parametric process on which each point is looked at uniquely and no underlying distribution is assumed.

Line density is a tool that can be employed to analyze the density of tracks. Line density is similar to point density, but instead of being applied to point features, line density is applied to linear features, such as a travel routes. Line density is a tool that has not been employed as often as point density. Point density has become more popular due to its analysis of individual waypoints and thus resulting in a more detailed analysis versus analyzing all the waypoints together that form a continuous track. A line density analysis was conducted of trail users that was segmented by user groups (Beeco et al., 2013). The line density analysis revealed drastically different travel

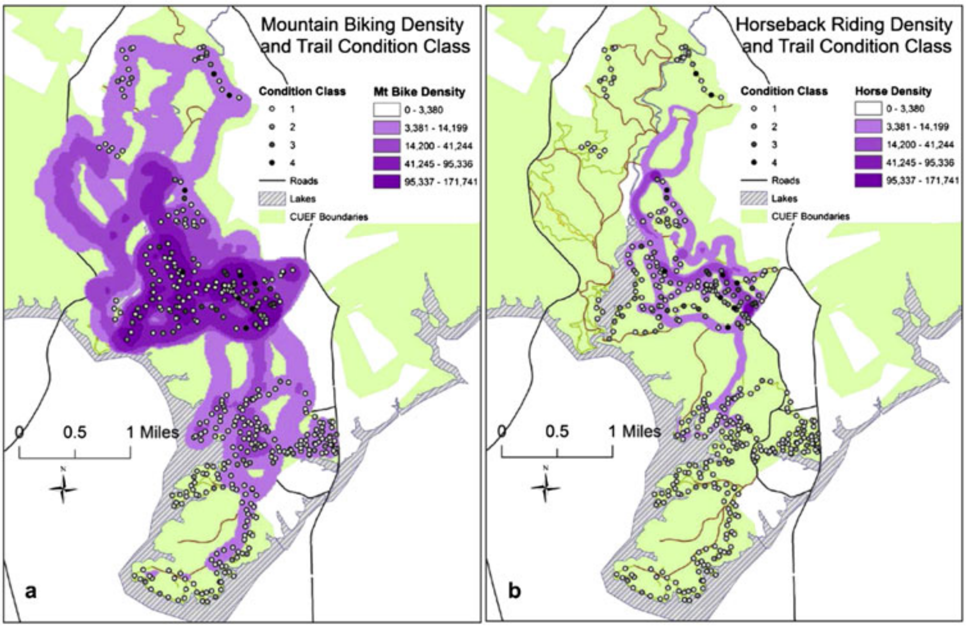

Figure 3. Line density analysis of travel patterns of mountain bikers and horseback riders (Beeco et al., 2013).

patterns for mountain bikers versus horseback users (Figure 3; Beeco et al., 2013; note that this is the same overall project cited as Beeco & Hallo, 2014).

Another approach to understanding visitor use patterns has been to examine phenomena at different scales. Balmford et al., (2015) analyzed visitor spatial behavior at a macro level to model predicted visitation variation of international PPAs. The researchers built several variables into their model schema: visitation rates, local population size, PPA remoteness, PPA natural attractiveness, and national income. Generalized linear models were constructed to predict variation in PPA visitation. The model data were used to make inferences about visitation and economic significance. This research was the first of its type to illuminate the scale of PPA visitation and the economic significance. The pinnacle inference that was revealed is that for the amount of visitation to PPAs, they are insufficiently funded, which suggest that if PPAs were substantially more funded, there would consequently be higher economic expansion at PPAs and their surrounding local areas.

As opposed to macro level analyses, micro-level analyses have also been conducted. GPS data loggers are a worthy tool for also analyzing walking speed of visitors at PPAs. Bauder (2015) analyzed tourists' velocity to interpret tourists' behavior. This study analyzed various groups that may have different walking speeds, such as age, gender, and traveling with children. This study coupled GPS data loggers with questionnaires to identify and isolate some of the factors that influence tourists' spatial behavior. These methods are valuable for comparing visitors' spatial behavior before, after, and during managerial actions. Analyzing visitors' velocities enable researchers to determine what spatial areas are causing visitors to slow their walking velocity and what areas are causing visitors to increase their walking velocity. Bauder (2015) created three meter circles of the study area, and mean speed for all points within each three meter circle was calculated. This type of analysis can be combined with questionnaire data to obtain differences in visitor groups and to investigate factors that underpin visitors' spatial behavior. Additionally, this type of analysis can be implemented before and after management actions. Speed analysis is a strong method to assess the attractiveness of a site within a PPA.

Additionally, while the vast majority of these studies have employed GPS data loggers, we would be remiss if we did not mention advances in tracking using mobile phones. Mobile positioning data can be used to measure visitor flows at a destination. Raun, Ahas, and Tiru (2016) used log files consisting of the location coordinates of mobile phones from Estonia's largest mobile network operator to measure visitor flows. Passive mobile positioning data files are stored automatically in the memory of mobile network operators and contains roaming data. 'Roaming' refers to situations where mobile phones registered in a particular country can be used outside that country (e.g. a mobile phone registered in the US being used in Canada) for outgoing and incoming calls, sending and receiving short message services (SMSs) and using internet data services (Ahas, Aasa, Mark, Pae, & Kull, 2007). This method of tracking visitors can analyze the behavior of international tourists at the country level at relatively low cost and is suitable for macro-scale research. However, sole use of mobile positioning data fails to provide additional information about the visitor besides the country of origin and travel patterns.

Another emerging line of research to understand visitor travel patterns is the use of social media. Researchers have utilized geo-tagged social media data to analyze tourist flows in Italy. Chua, Servillo, Marcheggiani, and Moere (2016) used geo-tagged Twitter data that was collected from Twitter's application programming interfaces (API). The researchers organized tweets by account and by time to create a time-ordered collection of geotagged tweets. The researchers applied this data to a visualization tool they developed called Flowsampler (Chua, Marcheggiani, Servillo, & Moere, 2014). This tool produces flow maps that can be filtered across four variables: time, direction of travel, number of trips, and demographic group. Although tourist flow knowledge is derived from numerous sources, the authors concluded that geo-tagged social media data are a valuable source that contributes to knowledge of tourist flow patterns. However, when using data acquired from social media, it is important to be strongly aware of the limitation of this data. For example, this type of data is not validated by ground truth verification, which means biases may be present in the data. Additionally, not all tourists use social media, nor are tourists providing geo-tagged data to social media at all times to fully understand tourists' itineraries.

The use of PPGIS for land use planning and management has grown significantly over the last two decades (Brown & Kyttä, 2018). These systems provide user-generated spatial data for a wide range of PPA attributes ranging from recreational activities to place values and management preferences. The majority of PPGIS studies involve sampling of households and/or on-site visitors to PPAs where participants place markers on a map identifying attribute locations. PPGIS systems have been implemented for different types of PPAs including national parks (Brown & Weber, 2013;

Engen et al., 2017; Pietilä & Kangas, 2015; van Riper, Kyle, Sutton, Barnes, & Sherrouse, 2012; Wolf, Wohlfart, Brown, & Lasa, 2015), national forests (Brown, 2013; Brown & Reed, 2009; Clement & Cheng, 2011), and conservation areas (Brown & Weber, 2013). PPGIS data are analyzed to show the diffusion of spatial attributes within the PPA, identifying areas of intensity and clustering of activities and place values. Unlike GPS systems, PPGIS data indirectly measure visitor spatial behavior through marker locations. At a PPA-wide scale, these spatial patterns of use, values, and preferences can be used to identify facility needs, the spatial locations of potential user conflict, and to delineate areas for more specific uses (management zones).

Volunteered Geographic Information (VGI) systems are becoming popular to study the movement of people engaged in recreation. Using tracking applications installed on mobile devices and webshare services (e.g. sports tracker, Strava, GPSies.com, and wikiloc), people share routes, experiences and georeferenced photos in online platforms (Campelo & Mendes, 2016; Heesch & Langdon, 2017; Oksanen, Bergman, Sainio, & Westerholm, 2015; Santos, Mendes, & Vasco, 2016). Korpilo, Virtanen, and Lehvävirta (2017) demonstrate the utility of available and voluntarily collected smartphone GPS self-tracking data for applications in urban forest management by locating spatial clustering of off-trail movement in intensively used areas—'hotspot analysis'. This low-cost participatory data collection approach using smartphone GPS tracking is relatively accurate (Haddad, Kelly, Leinonen, & Saarinen, 2014; Korpilo et al., 2017), and mitigates possible concerns affecting participants' spatial behavior due to their awareness of researcher supplied GPS data loggers (Wolf et al., 2015). Overlaying user-generated maps with official land record datasets, roads, and habitat charts help PPA managers identify where trespassing occurs, where informal/illegal trails exist and where ecological impacts may happen (Campelo & Mendes, 2016). However, VGI may be limited to only collecting information related to visitors' movement patterns. PPA managers also need to understand visitors' route choice motives. Therefore, VGI data needs to be linked with other instruments (e.g. survey data) to gain more knowledge of the visitors' profiles and environmental features that may influence their spatial behavior in PPAs (Korpilo et al., 2017).

Korpilo, Virtanen, Saukkonen, and Lehvävirta (2018) advanced the research conducted by Korpilo et al. (2017) by combining smartphone GPS tracking and questionnaires to study visitor behavior at an urban park in Helsinki, Finland. The researchers utilized public PPGIS from 'MyDynamicForest' to gather spatiotemporal data. The researchers determined that different activity types were associated with distinctive travel patterns. Runners and cyclists predominantly stayed on formal trails. Mountain bikers were found to concentrate around a few informal trails when traveling away from formal trails. Walkers and dog walkers were found to travel off-trail the most frequently. Off-trail behavior was found to be caused by an affinity for scenic views, exploration, and viewing flora and fauna.

GPS tracking has also been used as a cross-validation tool for other spatial methods of measuring visitor distribution. Wolf et al. (2015), used PPGIS mapping and GPS data loggers to monitor mountain bikers in Australia. Participants identified and marked locations on a map (either online or paper map) about perceived place attributes like riding frequency, popularity and issues on specific trail tracks. The collected GPS data were then used to cross-validate the results from PPGIS mapping. The study revealed a strong positive correlation between the ranked tracks from the PPGIS mapping and GPS tracking, thereby implying the validity of the PPGIS method for estimating future use at specific locations (Wolf et al., 2015).

Spatial interactions

Spatial interaction processes are evident when one area of space affects other areas of space (Beeco & Brown, 2013). Another way of considering this is how do visitors affect their own travel patterns and other's travel patterns? This is essentially the 'why' visitors are traveling the way they travel. Because this question directly addresses visitor behavior, early research suggests complicated answers. Logically, there are two approaches here. First, what is it about visitors' characteristics, motivations, and goals that affect spatial behavior? Second, how do certain visitor behaviors affect other visitors' behaviors? Connected to both of these approaches is how does time affect visitor use patterns?

The use of typologies was one way Beeco and Brown (2013) identified how researchers had approached this first question. At that time, there had been some theoretical and qualitative approaches (non-spatial), but few that assessed visitor behavior spatially. Two types of approaches to assess visitor typologies have emerged: non-spatial and spatial approaches (Beeco et al., 2013). Non-spatial approaches group visitors using psychological measures, such as values, attitudes, and motivations, and then use spatial data to determine whether these psychological measures reflect differences in spatial behaviors. The second method is to group visitors according to how they travel through space (Beeco et al., 2013; McKercher, Wong, & Lau, 2006), and then use measures (e.g. psychological) to try and understand those patterns.

Beeco et al. (2013) matched non-spatial tourist characteristics with spatial movement patterns. The study linked self-reported travel style of two visitor typologies identified in the literature, wanderers and planners (McKercher et al., 2006), with visitor travel patterns at Blue Ridge Parkway in Virginia. The study revealed that travel style (of wanderers and planners) had no significant effect on actual travel patterns. This means that regardless of whether participants were wanderers, planners, or a little of both, they used the same routes and visited the same locations for approximately the same time duration.

Presently, there is growing interest in categorizing visitors by relying on visitors' spatial patterns. For example, Kidd et al. (2018) classified visitors based on vehicular behavior along the Moose-Wilson corridor of Grand Teton National Park. Vehicle behavior variables (e.g. trip start and end time, location and duration of stops along the corridor etc.) were extracted from the GPS tracks and exploratory factor analysis conducted (Kidd et al., 2018). Cluster analysis was then performed to determine the factors that were deemed important for specific visitor types. By incorporating survey data, the study suggested three types of visitors: opportunistic commuters, wildlife/scenery viewers, and hikers. At the same site, by tracking visitors' vehicular patterns, Newton, Newman, Taff, D'Antonio, and Monz (2017) simultaneously examined space and time statistics to better understand visitor flow. The space-time cube tool was used to create bins representing a location and time, and correlated stopped points within the study area. Hot spot analysis was then conducted to identify significant hot and cold spots. The study found four categories of statistically significant cold spots. They were likely influenced by the presence of wildlife along the road, the number of pull offs, the number of cars on the road, and availability of parking. Also, the study found that there was a significant decrease in stopping point counts over time.

Another approach to use is to analyze how motivations and visitor use characteristics influence visitor use patterns. One study used GPS data loggers and questionnaires to analyze how visitors traveled within and throughout a complex trail network (Beeco & Hallo, 2014). This is the same study that operationalized travel patterns into three distinct (but overlapping) measures: total distance traveled, number of zones (areas) encountered, distance (Euclidean) from start, and time spent using the trail system. The study surveyed mountain bikers, horseback riders, runners, and hikers. This study measured self-report ability/skill, finding that the more ability/skill reported, the more miles they traveled, zones they encountered, further they ventured from the trailhead, and the longer they stayed. The researchers also determined factors that displayed a positive relationship with trip time (number of years visiting, group size, and motivations to develop skills), and factors that displayed a negative relationship with trip time (number of visits over the past 12 months, gender, and motivations for physical exercise).

Secondly, an assumption in recreation ecology is that as visitor use increases and places become crowded, visitors will disperse leading to potentially greater resource changes (Hammitt & Cole, 1998). GPS studies that tracked visitor use indicated that visitor dispersion in response to use level may remain unchanged and conversely in some cases decreasing use levels may result in increased visitor dispersal (D'Antonio & Monz, 2016). Therefore, a better understanding of the relationship between visitor use level and visitor spatial behavior will help managers better predict the potential for resource change under changing use levels.

Another assumption that has been both challenged and supported is that repeat visitors travel differently than other visitors. This was found not to be supported for visitors traveling for recreation throughout a marine park, in northwestern Australia. In the study, visitors were intercepted and asked to identify beach access points, their length of stay, and the location of their furthest traveled site from a place of accommodation for recreation purposes. Visitor responses were mapped and analyzed. The study found no significant differences between first time and repeat visitors on distances traveled by foot from beach access locations to shore recreation sites. However, when vehicles were used as mode of travel from a place of accommodation to beach access locations differences were observed between them. Also, first time visitors who stay for 1–3 days were reported to travel further (Smallwood, Beckley, & Moore, 2012). Also, the Beeco and Hallo's (2014) paper previously cited found that self-reported knowledge of the destination resulted in greater use distribution across an entire trail system regardless of group type (hikers, runners, mountain bikers, and horseback riders).

Lastly, an approach to the third question (how does time interact with behavior) examines the travel patterns of visitors based on demographic characteristics such as age or group composition. Space has been a popular research focus, however, the temporal attribute has not received as much attention. The space-time budget concept has received the most attention (Fennel, 1996). The concept suggests that the amount of time visitors have allotted to their recreational experience will determine the amount of space they can travel through. Research in PPAs have focused more nominally on time-budgets and more specifically on other time-related variables. Schamel and Job (2017) modeled the walking times of different hiker groups in reaching different zones at Germany's alpine Berchtesgaden National Park (BNP). This study focused more directly on walking speeds by age. The park is geographically divided into two zones: the core zone and the buffer zone. The study matched visitor surveys and GPS-loggers information to identify the travel patterns of different hikers from access areas such as parking areas to the buffer and core zones (i.e. intra-area accessibility). The results suggest that day use groups with children and groups of older visitors may access fewer trails. For example, at an average hiking time of about three hours, visitors aged 60 may need to stay overnight to access the core zone that is further away from parking areas. Therefore, if older visitors do not extend their time-budgets, the buffer zone may experience significant levels of use. The concentration of visitors in this zone may lead to crowding and diminished recreational experiences. Another study (Beeco & Hallo, 2014) found that recreational trail users differed in the time they spent recreating depending upon group type—specifically, horseback riders spent significantly longer at the destination than hikers, runners, and mountain bikers.

Spatial impacts

Understanding the relationship between visitor movements and various impacts offers tremendous potential for managers to efficiently remedy potential problems. Currently, examining the relationship between visitor use with impacts to trails and wildlife have seen the most attention. However, examining economic impacts (mostly from tourists) and social interactions (e.g. crowding and conflict) are currently under explored topics.

One study examined the relationship between amount of use, type of use, and trail conditions by tracking visitor use using GPS (Beeco et al., 2013). A total of 396 trail conditions points were measured on 76-trail segments throughout the trail system. The number of routes that crossed each point (including the user type) were counted. This allowed the researchers to link amount of use, type of use, and trail conditions at 396 points throughout the trail system. While controlling for trail design (e.g. trail slope), results suggest that horseback riders created the most impacts, while mountain bikers, trail runners, and hikers had minimal effects. This finding supported prior findings (Hammitt & Cole, 1998; Pickering, Hill, Newsome, & Leung, 2010), but used a vastly different method. Additionally, this study also identified how spatial-nested data (also called spatial auto-correlation) can bias results, and provides one method for dealing with this type of data.

Coppes and Braunisch (2013) used spatial modeling for research done in the Black Forest of Germany to predict where recreationalists were most likely to travel off trail, and determined what environmental factors were the most likely to trigger this off-trail behavior. The researchers investigated three types of factors influencing off-trail behavior: topography, forest structure, and infrastructure needs (such as signage) across three types of winter recreationists: cross-country skiers, hikers, and snowshoe users. Trail signage was found to be the most influential trigger that led to off-trail behavior. The research revealed that if a summer trail, which was closed for winter, had visibly posted signage, then recreationists were likely to leave the winter trail and follow the closed summer trail. The steepness of the terrain (slope) was the second most influential factor triggering off-trail behavior, and proved to be a deterrent. The researchers used MAXENT software program to model environmental conditions, including trail infrastructure, location, direction, and types of tracks that led off trail for the three types of winter recreationists analyzed in the study. MAXENT enabled the researchers to plot the probability of off-trail behavior as a function of each variable. The models were overlaid with sensitive wildlife areas to determine conflict areas. The primary implication of this research is that it reduces the locations managers need to monitor recreationists from entering sensitive wildlife areas.

GPS tracking was employed by Kidd et al. (2015) to investigate whether educational strategies were effective at compelling hikers to stay on formal trails. Spatial analysis revealed statistically significant differences among educational treatments that encouraged hikers to stay on formal trails. The treatments included the following educational strategies: personal contact educational message, an ecological-based message, and an amenity-based message. Both the ecological-based message and the amenity-based message were posted on signs. Spatial behavior was analyzed in ArcGIS by creating a four meter buffer around each trail. Visitor's tracks that went beyond the four meter buffer were deemed to display off-trail behavior. The distance traveled from formal trails was calculated using Euclidean distance for tracks that displayed off-trail behavior. Euclidean distances were compared for the educational treatments using ANOVA calculations. The researchers determined that trail markings and trail directional signage were persuasive at encouraging hikers to stay on formal trails. The ecological-based message and the amenity-based message were found to be ineffective, and that the trail markings and trail directional signage was adequate. Personal contact was found to be the most effective for resource impact education. The researchers also analyzed a summit area to see if hikers were hiking off trail around the summit area to assess the effectiveness of each educational treatment. The researchers employed the Directional Distribution tool in ArcGIS to calculate the spatial extent of distribution of off-trail behavior for the summit area. This tool determines a distribution center and creates standard deviational ellipses around the distribution center. The researchers chose to employ an ellipse constructed from one standard deviation, which depicted 68% of all off-trail waypoints for the summit area. The researchers constructed an ellipse for each educational treatment and then calculated the total spatial area of each ellipse to enable direct comparison.

GPS technology has also provided increased insights into how wildlife respond to human activity. In order to understand recreational conflict between visitors and wildlife, GPS tracking of visitor use was used at a key marine turtle rookery island in Greece (Katselidis, Schofield, Stamou, Dimopoulos, & Pantis, 2013). Employing GPS, the study recorded turtle nesting locations, locations of all anthropogenic features (e.g.

permanent beach umbrellas), and beach locations that had high visitor use. The overlap in the distribution of nests with the area used by beach visitors was determined by measuring the number of nests located in areas of recorded beach visitor use and then overlaying the GPS data for the two data sets. The study also calculated the probability of nests occurring in designated beach furniture zones (Katselidis et al., 2013).

D'Antonio and Monz (2016) examined the relationship between visitor use levels and spatial behavior at multiple backcountry recreation destinations. This research illuminated two primary conclusions: (1) instead of visitors dispersing more as visitor use levels increase, dispersion was more likely when low use periods were prominent; and (2) visitor use levels may be a less important influence of ecological change than visitor behavior (as mentioned previously in this article). The researchers employed infrared trail counters and GPS data loggers. The infrared trail counters determined visitor use levels. The waypoints produced by the GPS data loggers were analyzed for dispersion. The GPS waypoints were grouped into high use and low use as determined by the infrared trail counters. The GPS waypoints were then used to calculate a median center. The median center was used to produce a standard deviational ellipse around each median center that was fit to one standard deviation. The standard deviational ellipses were compared for the two groupings of use level across multiple backcountry destinations. The researchers also calculated average Euclidean distance from the median center for the two use level groupings (high use and low use levels) at each backcountry site analyzed. These averages were compared using two-sample *t* tests. The average Euclidean distances were then standardized for comparison across sites.

Wolf, Brown, and Wohlfart (2017) used both PPGIS and GPS methods in a study to identify visitor conflict potential between different trail users, with a specific focus on mountain bikers and horse riders. The PPGIS data mapped concurrent trail usage intensity (validated by GPS data) to predict potential conflict locations over a large study area to identity trails of greatest concern. The responses to survey questions that accompanied spatial mapping revealed that the trail conflict was somewhat asymmetrical, with horse riders expressing more conflict than mountain bikers. The conflict was based on differences in visitor behavior characteristics such as intensity of activity styles and personal attachment to specific trails. The largest number of intra-activity conflicts (i.e. conflict within the same trail user group) was also mapped along high-usage horse and mountain bike trails. The results indicated that intra-activity conflicts were localized and many high-usage trails were not identified for conflict. Thus, high trail usage was not necessarily a good predictor of intra-activity trail conflict given the infrequent and localized nature of the conflict. The authors noted that PPGIS methods functions as a diagnostic to identify trail segments that would benefit from more site-specific investigation and management.

Tracking visitors in PPAs has also been extended to hunting. Hunting in public lands or private leased forestland remains a popular recreational activity in the US (Mingie, Poudyal, Bowker, Mengak & Siry, 2017). It is necessary to provide spatial data on the behavior of hunters and their impact on the hunted population (Brøseth & Pedersen, 2000). Understanding how hunters behave while hunting and their spatial distribution across different habitats may aid PPA managers to more efficiently achieve management objectives. For example, Gross, Cohen, Prebyl, and Chamberlain (2015), tracked the movements of wild turkey hunters at Tunica Hills Wildlife Management Area in Louisiana, and found that hunting locations were centered near access points such as roads and parking lots. The study also estimated that 75% of hunting activity occurred on less than 10% of the study area. Therefore, spatial-temporal data can be used by PPA managers to make decisions about creating hunter access and opportunities while attempting to maintain high-quality hunting experiences (Gross et al., 2015). Likewise, managers may be able to identify habitats where wildlife species are at greater risk and adjust their management accordingly (Stedman et al., 2004). GPS tracking also provides opportunities to measure hunter behavior in public lands that have different management restrictions. For example, hunter movement in public areas managed with lottery hunting as opposed to areas with open-access hunting.

The spatial movement of wildlife has been tracked to compare the relative effect of different recreational activities. Marchand et al. (2014) contrasted the behavioral metrics of the Mediterranean mouflon in three contiguous areas in southern France that had varying levels of hunting and hiking pressures. Specifically, the researchers tracked movement sinuosity, habitat use, and activity pattern of 66 collared mouflon between 2003 and 2012. Study findings showed that mouflon that were less disturbed did not display any direct or indirect response to the presence of hikers. Contrastingly, hunting was highly disruptive. There were immediate responses in terms of less sinuous movements and decreased daytime activities, and a delayed compensatory response in terms of increased movement sinuosity, use of foraging areas, and activity level during nighttime. The effects of hunting were extended to animals living in the wildlife reserve, where no hunting occurred. Animals displayed modified daily activity budget during hunting period, though less pronounced than in the hunted areas. The study suggests that non-lethal forms of recreation may have less impact on wildlife. Further, during breeding periods and in adverse climatic seasons, recreational activities in protected areas should be restricted to reduce ecological impacts.

Spatial segmentation

Spatial segmentation is the partitioning of a formerly homogenous region into two or more sub-regions. This is a common management practice in PPA where management may have many different zones for managing visitor use. Additionally, recreation specific activities are often zoned to prevent recreational conflict by only allowing certain users to access certain areas.

Visitors' movement patterns may be used to define ecological and recreation zones. Miller, Vaske, Squires, Olson, and Roberts (2017) used GPS to track motorized and non-motorized use to demonstrate the complexity of recreation zoning and conflict in the Vail Pass Winter Recreation Area in Colorado. GPS data collected in the study identified areas of mixed non-motorized and motorized use. The study concluded that there was higher interpersonal conflict among respondents who traveled in areas of mixed-use, compared with those traveling outside mixed-use areas. Therefore, PPA managers may use spatiotemporal visitor flow information to develop indicators and thresholds for recreation conflict based on historical use patterns for the area, topographic features, and access routes for different visitor groups (Miller et al., 2017).

To reduce socio-ecological impacts, backcountry management plans often encourage the dispersal of visitors. However, by tracking backcountry recreationists in Denali, Stamberger, van Riper, Keller, Brownlee, and Rose (2018) suggest that visitors tend to be clustered and highly concentrated along the park road. Land cover analysis indicated that only a few (18%) of overnight backpackers camped on durable surfaces. Also, despite Denali's Backcountry Management Plan prohibiting campsites within the viewshed of the park road, a large proportion of campsites were visible. Therefore, to preserve the wilderness experience, managers at Denali may use the study findings to prioritize actions such as developing backcountry education programs to minimize socio-ecological impacts.

Recreation Suitability Mapping (RSM) is a GIS approach that seeks to inform visitor use or recreation zoning regimes. RSM often couples terrain conditions with social data, which determines the areas most suitable for specific recreational activities, and the relationships that exist between terrain attributes and social preferences (Kliskey, 2000). RSM methods quantify areas of recreational worth through weighting social preferences for terrain conditions, and coupling those weightings with measurements of physical conditions for the area that is being studied (Kliskey, 2000). Using RSM, it is possible to couple social data with such terrain features as percent of tree cover, or miles of single-track trail, which can then be coupled with social preferences determined through questionnaires that quantify the relationships between social preferences and terrain conditions, and to produce maps of these relationships (Beeco et al., 2014). For example, a hiker might prefer an area that has vistas, proximity to water, trails that are steep, and proximity to known wildlife habitats. The degree that these physical conditions exist is measured in the field and then coupled with the social preference weightings resulting in quantified relationships between social preferences and terrain conditions. Ultimately, RSM techniques can be used to map areas of recreation value in accordance to visitors' preferences. The implications of RSM help managers to zone PPAs, assess the suitability of an area for specific activities, and to understand the relationships between resource conditions and experiential outcomes (Aklıbaşında & Bulut, 2014; Beeco et al., 2013). Additionally, using RSM techniques, researchers can map place-experience interactions for multiple user groups. Each user group can be mapped as a layer, and then researchers can combine all the layers together to determine where there are overlapping attributes (Goodchild, Anselin, Appelbaum, & Harthorn, 2000).

Beeco et al. (2014) integrated GPS visitor tracking and RSM. The researchers mapped visitor use preferences to determine recreational suitability models for competing recreational groups (hikers, trail runners, mountain bikers, and horseback riders). The researchers produced suitability maps of the North Forest of the Clemson Experimental Forest in South Carolina. The maps displayed which areas of the forest were most suitable for recreational groups. The suitability zones were constructed through quantifying suitability values for each recreational group. Examples of the variables used to calculate the suitability values were questionnaire preference ratings of trail slope, proximity to water, length of trail, land cover type, trail width, trail surface, and condition of trail.

RSM has been employed to map experiential elements along the northern Appalachian Trail for long-distance hikers (Peterson, Brownlee, & Marion, 2018). The relationships between trail-tread conditions and specific experiential elements of long-distance hiking were weighted and quantified from questionnaire data. These data were combined with the extent that trail-tread conditions were present along five-kilometer sections of the northern Appalachian Trail. The researchers produced maps of where specific experiences were likely to occur along the northern Appalachian Trail. This was the first time that RSM had been applied to a restricted recreational corridor, and was efficient in comparing experiential elements of various trail sections along the Appalachian Trail, and quantifying the relationships between trail-tread conditions and experiential elements of long-distance hikers of the Appalachian Trail. The pinnacle management implication of this technique is that it provides managers with data to manage for trail sustainability and a quality hiking experience. Additionally, this research can be used in the future as a method to design sustainable trail networks that produce intentional experiential outcomes, such as level of challenge.

At a PPA-wide scale, PPGIS methods can be used to determine whether spatial segmentation occurs among different PPA visitor groups. For example, Muñoz, Hausner, Brown, Runge, and Fauchald (in press) found that local, domestic, and international visitors to Jotunheimen National Park and Utladalen Protected Landscape in Norway spatially self-segregate to some degree with local users emphasizing harvesting and cultural identity park uses compared to tourists. These results can help inform strategies to avoid visitor conflict or reduce overuse through spatial zoning or information and marketing aimed at the different visitor groups. The authors suggested that given the spatial self-segregation results, increased tourism in PPAs may be possible without degrading the values and experiences desired by local users.

Conclusions

This state of knowledge review discussed many articles which all contributed to the advancement of knowledge of understanding visitors' spatial behavior. Some research illuminated specific findings, while other research revealed effective techniques and broad outcomes. The geographic scope of the research often determines the applicability of the findings. Participatory mapping methods are typically used for macro-level PPA management applications such as infrastructure planning and zoning while visitor data logging are typically used for more localized visitor management applications such as modifying visitor behavior in specific areas of the PPA. One of the largest advancements over the past five years has been the incorporation of multiple methods in single studies. Generally, these types of studies used some form of tracking in combination with another method. Moreover, some studies employed GPS technology to validate research findings of previous studies that did not utilize GPS technology or to validate other methods such as PPGIS or VGI. It is important for research of visitors' spatial behavior to combine multiple approaches to gain a robustness of insight. Mapping visitor travel patterns is not sufficient without context as it does not provide comprehensive information to managers. Researchers need to combine several types of analyses to develop thorough knowledge of visitors' spatial behavior. Data from

GPS data loggers supply enough data to map visitor travel patterns, conduct time allocation analysis, conduct sequence analysis, conduct speed analysis, and conduct density analyses at various temporal scale (such as hourly point density analysis). Additionally, this information is useful for managers to assess crowding, the impact intensity of visitors, and creation of use-zones. Furthermore, the potential of more methods is high as more innovative research questions are generated, and as techniques are combined in which social data are also utilized.

Another general finding is that spatial research with respect to visitor use management is being conducted world-wide. While most studies were conducted in the United States and Australia, studies have been conducted Asia and Europe as well. Despite the steady growth in nature-based tourism in developing economies such as countries in Africa and South America, there is little evidence of spatial research for visitor use management purposes (Shoval & Ahas, 2016). Spatial research in protected areas in this part of the world has been limited to wildlife monitoring (e.g. Abrahms et al., 2016; O'Connor, Butt, & Foufopoulos, 2016). Therefore, recreation managers may largely be unaware of where visitors go, how much time they spend, what activities they undertake, and the how they interact with resources. To better manage visitor experiences, recreation managers need to track visitors' movements.

Understanding human behavior, values, and management

There are many site-specific conditions and characteristics that influence visitors' spatial behavior. Coupling any spatial method with social data is a necessity towards understanding visitors' spatial behavior when visiting a PPA. Questionnaire data provide a contextual tool for determining the 'why' behind spatial behavior, such as group type, motivations, and familiarity with the site.

Specific findings about human spatial behavior in PPAs have seen rapid development. Many of these findings depend on a single study and warrant more research, while some other findings have coalesced through multiple studies. Below is a list of findings that have been derived from studies cited above:

- The connectivity of a trail network influences visitors' off trail behavior
- Trails should lead to attractions, such as scenic vistas, to reduce off trail behavior
- Educational approaches to influencing visitors' spatial behavior have a range of effectiveness
- Visitor dispersion is likely influenced by the concentration of visitor use and may have an inverse relationship
- Visitor's familiarity with a site influences travel patterns—visiting different locations and having higher distribution across an area
- Grouping by non-spatial typologies may not predict spatial behavior
- Activity type influences visitor spatial behavior
- Visitor characteristics, such as motivations or abilities, can influence visitor spatial behavior
- Visitor use levels may be a weaker predictor of ecological change compared to visitor behavior

- Visitor spatial/temporal segmentation continues to be an appropriate management technique to reduce conflict

Integration with other resource issues

As mentioned in Beeco and Brown (2013), space is an excellent platform for integrating different aspects of natural resource management. One example of this was the study related to turtle nesting, where researchers overlapped the distribution of nests with visitor use areas to better protect turtle nesting. However, the studies identified here generally revealed a lack of combining spatially related social science data with other natural resources issues.

One area ripe for development in this application is soundscapes in natural areas. A reported increase in visitation densities at many US parks (National Park Service, 2016) and discussions on managing visitor experiences (Kim & Shelby, 2011) has led to calls to manage the noise generated by visitors. Mennitt and Fristup (2016), constructed a regression model that predicted sound levels across the continental United States, based upon both natural (e.g. land cover type) and non-natural (e.g. roads) considerations. This model also used an algorithm for removing anthropogenic contributions of noise so that estimated natural conditions could be compared to existing conditions. This model was developed by researchers in and partners of the Natural Sounds and Night Skies Division of the US National Park Service to assist in park planning efforts. Further, standardized modeling tools such as Aviation Environmental Design Tool (2017) and Federal Highway Traffic Noise Model (Menge, Rossano, Anderson, & Bajdek, 1998) used by the US Department of Transportation have regularly been used to model the noise from overflights and road traffic, many times at National Park Service units. Both of these models produce spatial or temporal-spatial models of noise, which can be used to inform visitor use planning or determine if management actions (such as public shuttles) are having the desired benefits in noise reduction for visitors. While these models are now beginning to be used to inform visitor use management, the visitor, space, and noise line of research is only just beginning. One of the reasons for this delay is likely the level of expertise and software to run these models.

Gaps and future directions of research

This review illustrates that the theme of understanding visitors' spatial behavior still has growth to make. As technology continues to develop, easier field methods, and more intuitive computer programs will make this toolset available and efficient for more researchers, even if they are not trained to use GIS. This means that spatiotemporal models of visitors' travel patterns are going to become more exact, more available, and thus more useful for managers to correctly comprehend how visitors are behaving and what is causing those behaviors.

First, there should not be an over reliance on GPS data to track visitors. While GPS data provide a rich data source, researchers should also be looking to camera data, infrared trail counter data, and remote sensing imagery, when GPS may not prove practical. All researchers should be looking towards conducting comprehensive visitor behavior investigations, which will further validate the findings and provide a more accurate description of visitors' spatial behavior for PPA managers. For example, the use of macro-level PPGIS and VGI methods, in combination with tracking data, can illuminate visitor motivations by identifying the specific values and experiences that visitors seek.

Second, most of the tracking studies have heavily relied on the assumption that group behavior is dependent on whomever fills out the questionnaire. Most of these studies used methods to address this assumption, such as asking the person in the group with the 'nearest birthday' to complete the questionnaire. However, it is likely that the group as a whole influence spatial travel patterns, whether that includes resting at a scenic vista while hiking or choices in which attractions to visit. Therefore, future research efforts should seek to determine the effects of group dynamics and decision making on travel behavior.

Third, a better understanding of how time relates to space is needed. Currently, space-time budgets have been the focal point of this research (Beeco & Brown, 2013; Fennel, 1996). In space-time budgets, visitors must make decisions about what to see and where to visit based upon the time they have allotted. While space-time budgets continue to be a line of research in tourism, few studies have applied this concept to PPAs with respect to travel patterns. Further, because this has really been the only approach to understanding time, other approaches may prove fruitful.

Fourth, many of the studies listed above also contributed to theoretical, statistical, or methodological advances. Graph theory, spatial nesting (spatial autocorrelation), and tracking use through cell phones are specific examples of this type of progress. More focus on these contributions is needed. Specifically, the tracking of mobile positioning data enviably leads to a discussion about 'big data'. Future research efforts will likely be addressing how big data can assist visitor use management and understanding visitor travel patterns. This area of research is currently very limited, but has vast opportunities. Application of spatial theory is worthy to form valid scientific hypotheses, yet the employment of spatial theory has been under-stated.

Fifth, there are research dimensions where spatial analysis are still lacking, yet may be truly beneficial. For example, recreational boating (RB) is one of the major water-based activities in the United States. Participation in RB is considered to be substantial, with 36% of US households participating in it annually (National Marine Manufacturers Association [NMMA], 2017). In water-based recreation, such as lakes and rivers, recreational use is extremely contained by the physical presence of water, yet like other recreational activities, high level of participation in RB may lead to undesirable conditions. Overcrowding in public waterways may result in displacement with boaters and other recreationists dispersing to other lakes or locations (Gyllenskog, 1996; Kuentzel & Heberlein, 2003; Robertson & Regula, 1994; Tseng et al., 2009). Recreation managers should therefore strive to understand visitor experiences so as to decide on appropriate management responses like where to establish new boating facilities and crafting policy that minimizes conflict between RB and other waterway users. RB spatial information provides baseline information important for managing public lands and waters. Information such as total distance traveled, furthest distance from shore, vessel speed, and turning angle can be recorded using GPS devices to classify RB typologies. This can help to simulate recreational boats' trajectory in a GIS model for boating traffic analysis (Pelot & Wu, 2007).

Therefore, in closing, spatial research related to visitor use management in PPAs is expanding rapidly and contributing to our knowledge about visitors' spatial behavior. Perhaps, more importantly, we believe that this rapidly developing line of research is only in its infancy because of quickly evolving technology and the continued demonstrated value this line of research is providing.

Disclosure statement

No potential conflict of interest was reported by the authors.

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