Applied Geography 93 (2018) 92–102

Contents lists available at ScienceDirect

Applied Geography

journal homepage: www.elsevier.com/locate/apgeog

A GPS tracking study of recreationists in an Alaskan protected area

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ARTICLE INFO

Keywords:
Recreation
GPS tracking
Protected areas
Social-ecological data
Public land management
Alaska

ABSTRACT

Understanding human movement and behavior in parks and protected areas is an integral part of managing social-ecological systems. In particular, spatial travel patterns of recreationists and their impacts on ecosystems have been studied in many protected area contexts. However, there is limited knowledge of recreation behavior in areas with little to no infrastructure or without formal trail systems. Drawing from Global Positioning System (GPS) tracking data, we identified travel patterns of recreationists in a nearly trail-less backcountry setting in Alaska. Specifically, we investigated the spatial and temporal dynamics of recreation use in relation to resource conditions experienced in Denali National Park and Preserve during the high-use season of 2016. We observed that recreationists' travel routes were heavily concentrated along the Denali Park Road and exhibited different spatial patterns for day and overnight backcountry use. Also, informal campsite locations, delineated using multi-day GPS tracking data, showed uneven distributions within the park. This study provides recommendations for public land management agencies in the US and highlights the need for more systematic evaluations of concentrated use in parks and protected areas.

1. Introduction

Public land management agencies are challenged to accommodate recreational activities in parks and protected areas with increased demand for public resources and associated environmental degradation. Understanding spatial patterns of human use is particularly important for making informed decisions about how best to sustain ecosystems and human well-being across spatial scales (Eagles & McCool, 2002; Margules & Pressey, 2000). However, little is known about on-ground travel patterns across protected landscapes such as federally designated Wilderness. These locations are difficult to access and often encompass large areas far from population centers (D'Antonio et al., 2010). Further, travel patterns are difficult to record in remote areas because recreational activities often occur off trail without managed paths to guide human use. A stronger understanding of the spatial dynamics of human behavior in remote protected areas is needed to direct management attention to high priority locations (Bagstad, Reed, & Semmens, 2016; Korpilo, Virtanen, & Lehvävirta, 2017) and integrate biophysical and social science information into decision-making (van Riper, Kyle, Sherrouse, & Bagstad, 2017).

Global Positioning System (GPS) visitor tracking is a well-researched method for documenting spatial patterns of human use in parks and protected areas (Beeco & Hallo, 2014; Kidd et al., 2015; McGehee et al., 2013). Numerous researchers have lauded the advancements of GPS tracking in relation to previous methods (Bauder, 2015; Beeco & Brown, 2013; Orellana, Bregt, Ligtenberg, & Wachowicz, 2012; Shoval & Isaacson, 2009) due to this tool's ability to record temporal and spatial patterns of human movement in natural and built environments (Beeco, Hallo, & Brownlee, 2014). GPS tracking research has been applied in public land management contexts given its potential to support agency decisions related to balancing resource protection and human use across spatial scales (Beeco, Hallo, & Giumetti, 2013; D'Antonio, Monz, Newman, & Lawson, 2013; Edwards, Dickson, & Griffin, 2010; Taczanowska, González, & Garcia-Massó, 2014). Specifically, GPS tracking methods have been employed to document human impacts on the environment from activities such as hiking (Kidd et al., 2015; Wimpey & Marion, 2011) and camping (Cole, 2004; Leung & Marion, 2004).

This study incorporated GPS visitor tracking and survey methods to better understand backcountry recreation use in Denali National Park and Preserve (Denali). GPS units were used to collect precise and accurate estimates of travel patterns, avoid recall bias, and bridge the gap between reported and actual use. Diverging from most GPS tracking research focused on formal trail and road systems (Hallo et al., 2012),

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https://doi.org/10.1016/j.apgeog.2018.02.011
Received 30 October 2017; Received in revised form 6 February 2018; Accepted 13 February 2018

the backcountry recreationists examined in this study traversed a nearly trail-less landscape, making human use in this context less predictable and more difficult to document. Moreover, this research expanded upon existing GPS tracking literature by capturing multiple-day trips and identifying informal campsite locations in the backcountry. In identifying spatial clusters of both hiking routes and campsite locations, the present study illuminated areas that may be subject to environmental degradation and addressed management concerns about crowding and informal trail creation (Abbe & Burrows, 2014; Marion, Leung, & Nepal, 2006). Understanding the spatial and temporal patterns of day and overnight use in protected areas such as Denali is important for resource planning and management, as well as refining knowledge of how best to capture the dynamics of spatial behavior.

2. Literature review

2.1. Space-time methods

Space-time travel patterns provide valuable information for land management agencies responsible for optimizing experiences for the public while minimizing environmental degradation. Researchers and managers have developed a number of methods to assess travel patterns and understand visitor behavior in parks and protected areas (Manning, 2011). Traditional data collection has involved visitor recollection, automated trail or vehicle counters, and researcher observations. For example, previous research has relied on surveys (Anderson, 1971), paper diaries (Stewart & Cole, 2001), and other techniques by asking visitors to recall where they went and how much time they spent in different locations (Hallo, Manning, Valliere, & Budruck, 2004; Kidd et al., 2015). Automated technologies such as trail and vehicle counters have also been employed to document use patterns (D'Antonio et al., 2010). In addition, counters have generated high quantities of visitor use data and are relatively inexpensive. Advanced counter technology is available to detect the direction of travel and distinguish between use type (Greene-Roesel, Diogenes, Ragland, & Lindau, 2008).

Although a range of tracking methods have been developed, previous work has highlighted several limitations (D'Antonio et al., 2010; Kidd et al., 2015). For instance, travel recollection requires extensive time and consideration from respondents, which can be cognitively burdensome and result in low survey completion rates (Hallo et al., 2004). In addition, reported activities may yield data that are influenced by an individual's knowledge of the area (van Riper & Kyle, 2014), study design (e.g., sites highlighted on a map) (D'Antonio et al., 2013), or social judgment bias (Birnbaum & Stegner, 1979). Counter technology can relieve burden from both the researcher and respondent and be camouflaged to not disrupt the visitor experience (Cessford & Muhar, 2003; James & Ripley, 1963; Leonard, 1980). However, the spatial richness of this technique is often limited to conditions at fixed points, and researchers and managers cannot identify complex spatial distribution and density patterns. Lastly, observational studies are more reliable and less burdensome for the respondent but require a considerable investment of researchers' time and resources (Arnberger, Haider, & Brandenburg, 2005).

2.2. GPS visitor tracking

GPS technology captures on-ground travel patterns to provide insight into the densities, flows, and distributions of human movements. Studies that use GPS technology to understand use often require respondents to carry small, unobtrusive units that are returned after their visit and converted into a spatially-rich dataset (Edwards & Griffin, 2013). The spatial and temporal data received from GPS units is increasingly more accurate, detailed, and complete (Beeco & Brown, 2013; D'Antonio et al., 2010; Edwards & Griffin, 2013; Kidd et al., 2015). Further, this method requires little additional time and resources from participants and researchers (Edwards & Griffin, 2013). In a study comparing the efficacy of visitor self-reported data and GPS-derived data, results indicated that the GPS method recorded more accurate data, elicited a lower refusal rate, and was more efficient overall than the self-reporting method (Hallo et al., 2004); it was "not humanly or technologically feasible" to obtain similar results that the GPS units produced using self-reported methods (p. 172).

GPS tracking methods have been applied in an array of disciplines and geographic areas. Previous research in geography, tourism, and recreation ecology has relied on tracking to understand spatial patterns of tourists and recreationists (Bauder, 2015; Beeco & Brown, 2013; Edwards & Griffin, 2013; Edwards et al., 2010; Modsching, Kramer, Gretzel, & Hagen, 2006; Orellana et al., 2012; Shoval & Isaacson, 2009; Shoval, 2008; Wolf, Hagenloh, & Croft, 2012), with particular focus on human use patterns in parks and protected areas (Hallo & Manning, 2010; Hallo et al., 2004). Distance traveled, time spent in a particular area, destinations visited, and use concentrations contribute to a comprehensive understanding of human use across protected landscapes. Spatial data can also be linked to survey, interview, and value mapping data to understand the theoretical and practical implications of human use in natural resource management contexts (Beeco et al., 2014; Evans & Jones, 2011; Pettersson & Zillinger, 2011; Plieninger, Dijks, Oteros-Rozas, & Bieling, 2013; van Riper et al., 2017).

2.3. Ecological impacts of dispersed use

Tracking technology has been used for monitoring human impacts on natural resources such as wildlife, water, soil, and vegetation (Hammitt, Cole, & Monz, 2015; Monz, Pickering, & Hadwen, 2013). Overlaying use patterns on ecological conditions enables resource management agencies to identify the current and future impacts of recreational activities (Leung & Marion, 2000; Monz et al., 2013). Previous research indicates the distribution of recreation use tends to be uneven. High-use areas carry implications for ecological disturbance as recreationists tend to concentrate along linkages such as trails or roadways and at nodes such as facilities or campsites, which can cause environmental impacts such as soil compaction, erosion, and vegetation destruction (Hammitt et al., 2015; Manning, 1979, 2011). Though, areas of low or dispersed use also warrant particular attention. The development of the use-impact curve (Hammitt et al., 2015) and other function models that describe ecosystem responses to recreation use (Monz et al., 2013) indicate initial use results in the majority of impact on an environment, especially vegetated surfaces. Thus, concentration of dispersed use is particularly problematic because short-term impacts can have long-lasting effects. In addition, impact from recreation use is especially concerning for areas that have a sensitive resource base such as tundra or alpine vegetation with fragile species and a short growing season (Goonan, 2009; Whinam & Chilcott, 1999; van Riper, Manning & Reigner, 2010).

Areas that adopt dispersed use strategies to manage ecosystems encourage recreationists to spread out and recreate on undisturbed terrain. Dispersal strategies are only effective, however, where "use intensities are low, vegetation types are durable, and [users] practice Leave No Trace techniques" (Cole & Monz, 2004, p. 83). If these criteria are not met, negative outcomes (i.e., informal trails and campsite formation) can arise. Informal trails, also known as 'social' trails, are visitor-created trails that form with repeated foot traffic along the same path. Informal trails might begin as a shortcut or as a game trail eventually used by humans. When vegetation is trampled and soil is compacted, a more desirable path is created, which encourages future use of unmanaged paths (Hammitt et al., 2015). These informal trails are arguably the most widespread environmental consequence of recreation use (Monz, Cole, Leung, & Marion, 2010). They can potentially change species composition and advance soil erosion (Monz et al., 2010).

Previous GPS tracking research has focused attention on the creation of informal trails caused by activities such as hiking, backpacking, mountain biking, horse-back riding, and climbing (Korpilo et al., 2017; Marion & Leung, 2001; Pickering, Hill, Newsome, & Leung, 2010). Tracking human use lends itself to proactive management by addressing areas of concentrated use before informal trails begin to form. Also, this information provides insight on how existing informal trail systems might be changing or shifting over time. Some work has pointed to the presence of informal trail systems that detract from a person's solitude in a wilderness setting (Lawson & Manning, 2001), while other work has assessed the role of informal trails in increasing the frequency of potentially harmful human-wildlife interactions (Toubman & Burrows, 2015). Protected areas and public land management agencies have extensive informal trail monitoring protocols; however, with few exceptions (e.g., Goonan, 2009; Lawhon, Taff, & Schwartz, 2016; Wimpey & Marion, 2011), little research has been done to analyze informal trail system development, use patterns, and messaging techniques within vulnerable and remote natural areas.

A bulk of previous research on recreation impacts in dispersed-use settings has been conducted in the context of campsites (Cole & Monz, 2004; Leung & Marion, 2004; Price, Blacketer, & Brownlee, 2018). In dispersed-use areas, users are urged to camp on durable surfaces and in locations where evidence of previous use is absent in order to avoid visible campsite formation. Led by Cole (1981), this line of research indicates that successful dispersed camping is difficult to achieve because environmental impacts can occur very quickly with low levels of use. Adverse environmental impacts of camping include disturbance or loss of vegetation cover, degradation of soils, tree damage, and improperly disposed human waste (Leung & Marion, 2004). The recovery of impacted sites is very slow. Cole (1981) suggested that some alpine areas might take up to 1000 years to recover. In a more recent study, Cole and Monz (2004) concluded that particularly fragile sites should not be camped on more than once every ten years to avoid the proliferation of an established campsite. Past management strategies that address campsite formation in the backcountry have focused on concentrating the areas where camping is allowed or closing off certain areas. To avoid drastic backcountry management approaches that exclude recreation entirely, GPS tracking can help managers anticipate the environmental impacts of popular or repetitively-used campsite locations. Thus, backcountry activities (i.e., camping) can be discouraged in known areas of relatively concentrated use.

2.4. Study objectives

This study used GPS tracking methods to examine day and overnight backcountry use patterns in Denali National Park and Preserve. Specifically, we highlighted popular routes, access points, and campsite locations within the protected area. Three objectives guided this research: 1) examine the distribution and density of backcountry recreation use, 2) compare the distribution and density of use between overnight and day recreationists, and 3) analyze the distribution and density of campsites in relation to viewshed and land-cover. This study advances the GPS tracking literature by capturing spatial patterns of multi-day backcountry trips and applying visitor tracking methods in a nearly trail-less context. Further, the study provides insight on visitor use to inform public land management agencies that aim to balance resource protection and visitor experiences in parks and protected areas.

3. Methods

3.1. Study site

Denali National Park and Preserve is located in southcentral Alaska, covering a six million-acre subarctic landscape in the Alaskan Interior (see Fig. 1). The protected area harbors an abundance of large mammals, including grizzly bears, wolves, and ungulates, as well as a diversity of alpine flora and fauna (Abbe & Burrows, 2014; Ritter, 2007). The Alaskan Range transects the park's landscape, including wide valleys, braided river systems, and panoramic mountain views. The symbolic and near geographical center of this Park and Preserve is Denali, which is the highest peak in North America, reaching 20,310 feet (NPS, 2017). The National Park Service (NPS) manages the six million-acre National Park and Preserve classified as a UNESCO Biosphere Reserve. This region has been managed and protected since 1917 when two million acres were set aside to serve as a wildlife refuge for the threatened Dall sheep (*Ovis dalli*). When Denali expanded its boundaries to its current size of six million acres through the 1980 Alaska National Interest Land Conservation Act (ANILCA), federal Wilderness designation was overlaid on the original park boundary (NPS, 2006). Within these 2 million acres, the Park is mandated to preserve specifically defined characteristics of wilderness, in accordance with the Wilderness Act of 1964. Wilderness characteristics include: pristine and intact landscapes, untrammeled and undeveloped, solitude and quietude (ability to be surrounded by natural sounds), and no motorized access (NPS, 2006).

The NPS designates lands in Denali as frontcountry or backcountry. The backcountry in Denali includes all park and preserve lands with the exception of the 92-mile road corridor, the maintained campgrounds, and day use areas (see Fig. 1). The developed 'frontcountry' areas host activities such as hiking on maintained trails, taking guided bus trips along the park road, and touring the visitor centers while the backcountry allows for more remote and wilderness-like activities such as packrafting and off-trail backpacking and camping (Patterson & Hammitt, 1990). Backcountry recreationists use the park road as a common launching point into the backcountry and can start their trip from anywhere – with the exception of temporary wildlife closures – along the park road. Recreationists are in the backcountry once they are at least ½ mile outside of the park road corridor. The backcountry in Denali is segmented into eighty-seven backcountry units that serve as mechanisms for managing the protected area. A quota system limits the number of people in any given backcountry unit, ranging from two to twelve users per night. In this way, the system facilitates dispersion to avoid environmental degradation and maintain solitude. Backcountry visitation in Denali has remained fairly stable over the past decade (Abbe & Burrows, 2014) with 1600 backcountry permits issued on an annual basis. Given that recreation use has exceeded 500,000 annual visits in recent years, backcountry users represent a relatively small proportion of annual visitation (NPS, 2015). Visitors that come to the park as part of a cruise tour package or select a concessions operated bus tour along the park road make up the bulk of park visitation (Keller, 2017).

3.2. Visitor tracking and surveying

Spatial data were collected during the 2016 peak season (June–August) in Denali from day (N = 178) and overnight (N = 113) backcountry recreationists (see Fig. 2). Day users were participants in guided hikes called 'Discovery Tours.' These groups typically consisted of 8–10 recreationists. NPS interpretive rangers led these hikes twice a day during the peak season. Rangers were asked to carry Trackstick II GPS loggers and return the units to NPS staff after their hikes. If the Trackstick resulted in missing data for more than 1/4 of the hike, rangers completed hand-drawn routes on the standard NPS-issued quads given to each ranger at the start of their guide season to estimate the correct route taken. The hand-drawn routes were in turn digitized using the polyline tool in GIS software. After cleaning these data, tracks were stored as both.gpx and shapefiles and shared by NPS staff for analysis.

In addition to assessing day use through the collection of data from NPS rangers, university field technicians collected overnight data from unguided backcountry recreationists during the same time period. These individuals came to the park with their own trip itinerary, restricted only by the overnight quotas specific to each backcountry unit.

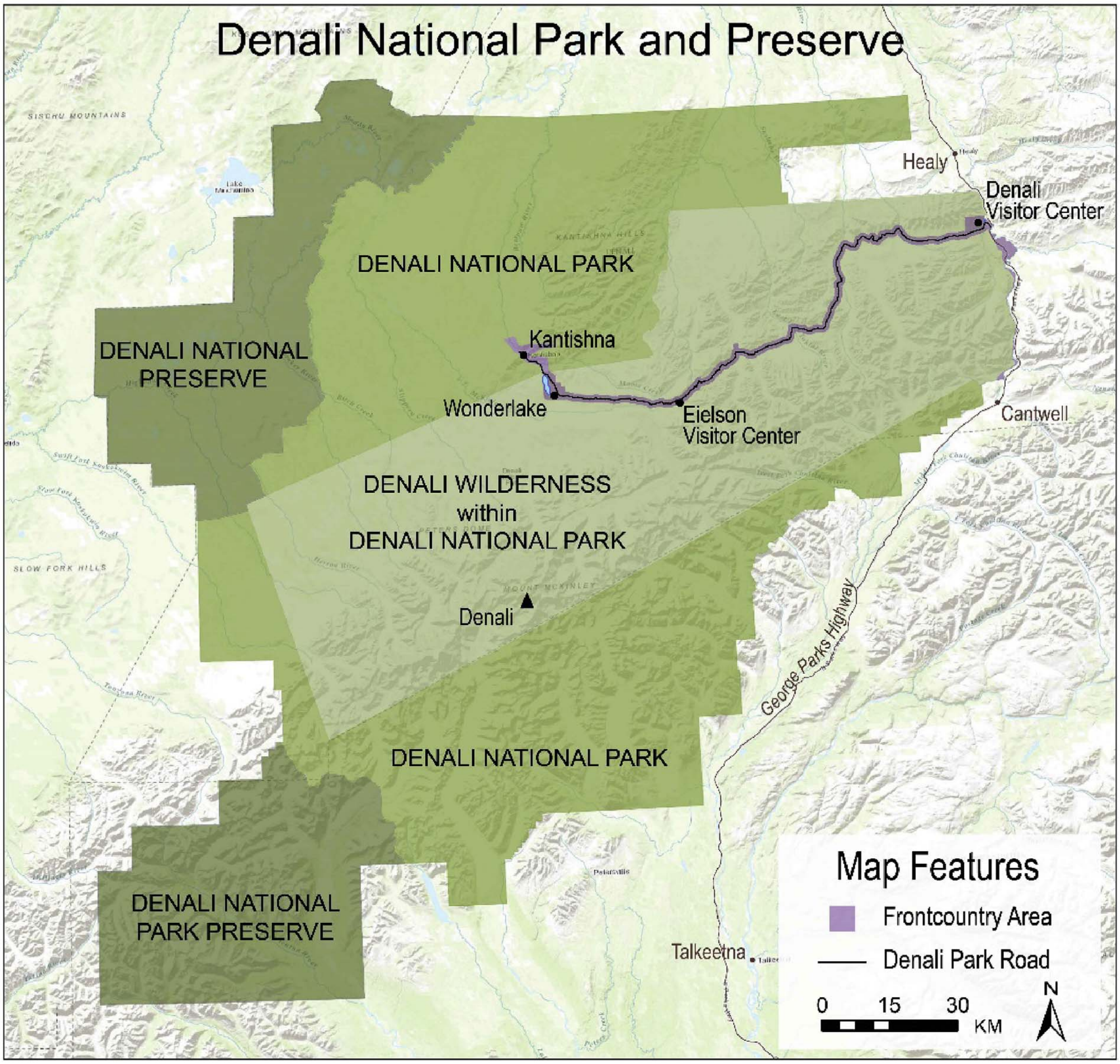

Fig. 1. Study map designating backcountry (green) and frontcountry (light purple) areas (Sources: DENA BCMP - Management Zones, 2008; ESRI Basemap, 2017). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

The field technicians collected data on both weekdays and weekends and during the day and evening to represent the diversity of user groups. During the survey periods, all groups that received backcountry permits were asked to participate in the study. Upon agreement, field technicians administered a Canmore GT-740 FL GPS unit to each group. In line with previous research, the GPS units were set to mark waypoints at 15-second intervals (Beeco et al., 2013, 2014; D'Antonio et al., 2010; Kidd et al., 2015; White, Brownlee, Furman, & Beeco, 2015). Positional error of the GPS units was not calculated, in part because previous research indicated calibration was not necessary for research focused on travel routes rather than small spatial scales of visitor use (D'Antonio et al., 2010). Also, past work found these units to be one of the most spatially accurate models, with an observed accuracy of 3.1 meters (White, 2014). Beyond their validated use in other studies, one of the advantages of the Canmore units is their extended battery life, which was particularly important given the multi-day trips taken in the backcountry of Denali. Of the 147 GPS units distributed to 132 backcountry groups, respondents returned all but three units (97.96%). Once the overnight groups returned from the backcountry, technicians administered a follow-up survey to gather trip characteristics and sociodemographic information.

For the overnight user sample, survey and GPS data were extracted and saved on a weekly basis. Following the summer field season, the spatial data points were uploaded to ArcGIS 10.4, transformed from WGS 1984 to the NAD 1983 Alaska Albers coordinate system, and converted to lines using the 'point to line' conversion tool in ArcGIS (Beeco et al., 2013). Fifteen tracks were found to have incomplete or missing data in ArcGIS and were removed from the sample. Spatial cleaning accounted for GPS error and clusters that formed when groups stopped movement but the GPS kept recording (see Fig. 3). Cleaning the data allowed for reporting a more accurate measurement of total distance traveled by the backcountry groups (Beeco & Hallo, 2014). To measure the differences between uncleaned and cleaned GPS tracks, a paired-samples *t*-test was performed. The test showed that cleaning the GPS data reduced route distances for each trip by a mean distance of 7.6 kilometers ($t = 11.523$, $p < 0.001$). Campsites were delineated using the time-stamp attribute associated with each GPS point, and a point was assigned to the place where groups stayed at night. Campsites at formal campgrounds managed by the park concessionaire were not recorded. Thus, the campsite locations represented in this study were informal campsite locations selected by recreationists while in the backcountry. The sample size for overnight recreationists was 113 GPS

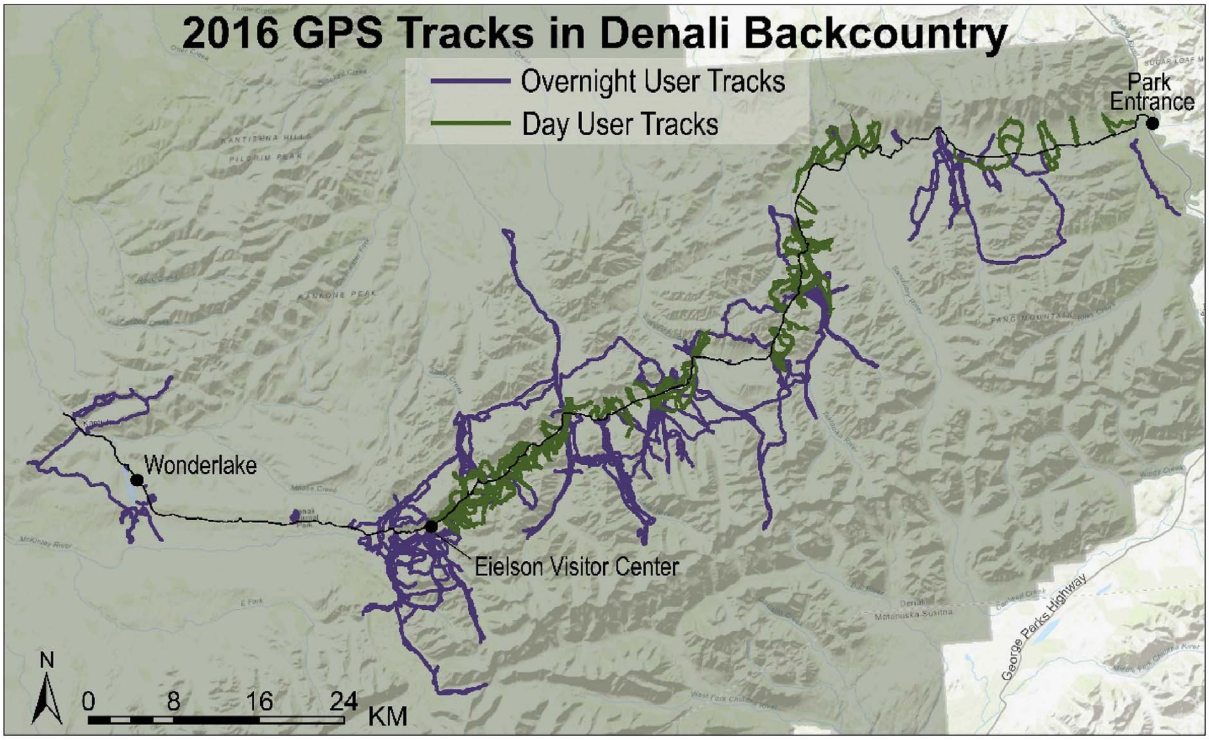

Fig. 2. Spatial distribution of backcountry GPS Tracks (N = 291) (Sources: DENA Roads, 2009; ESRI Basemap, 2017).

tracks, representing 113 different groups and 203 campsite locations.

3.3. Analysis of GPS data

After cleaning and preparing the data for analysis, the GPS tracks and survey data were examined using ArcGIS 10.4 (see Table 1) and SPSS 24 software. Guided by the first objective, the spatial distribution and density of recreation use were studied using the first two analyses listed in Table 1. First, a kernel density estimation in ArcGIS transformed the line data into a continuous surface of values to visually display the local density of GPS tracks. The bandwidth was set at five kilometers for all kernel density analyses. Second, the distribution of access points into the backcountry was analyzed by: a) converting the park road feature into a route using the 'create routes' tool, b) locating each groups' access locations along the park road with the 'local features along routes' tool, and c) executing a 'point density' analysis to visualize the distribution of access along the Denali Park Road. Following the second objective, kernel density maps were generated to compare the distributions of day and overnight use, and independent samples t-tests were used to assess differences in trip characteristics, including length of trip (Beeco & Brown, 2013), total distance traveled (Edwards & Griffin, 2013), furthest distance from the park road (Korpilo et al., 2017), and group size (Beeco & Hallo, 2014). Objective three was carried out using a land-cover overlay, viewshed analysis, and kernel density estimation. After converting the Denali land-cover layer from raster to polygon, a spatial join was performed to determine which types of land-cover surfaces were used for camping. Similarly, using the ArcGIS 'viewshed' tool, campsites within the park road viewshed were spatially located and mapped to display which campsites were visible from the park road.

4. Results

4.1. Trip characteristics

The socio-demographic characteristics of respondents aligned with demographics reported by other protected areas in the U.S (Alessa et al., 2008; Hallo et al., 2012). Over sixty percent of respondents (62.2%, N = 156) completed a survey following their backcountry trip. Results indicated the majority of respondents were male (64.7%) and

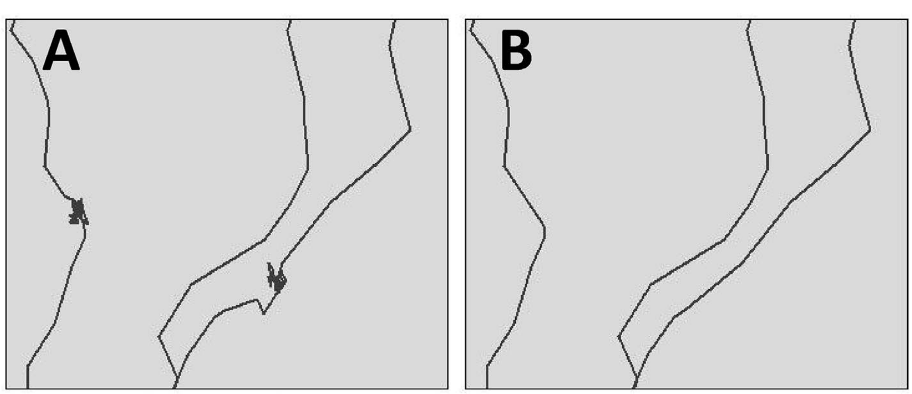

Fig. 3. Visual cleaning of spatial data: a) Uncleaned GPS tracks and b) Cleaned GPS tracks.

Table 1
GIS analysis of route and campsite data.

Element	Variable	Research Questions	Spatial Analyst Tool(s)	Description of Analysis
Route	Density	Where were areas of low density and/ or high density of visitors tracks located?	• Point to Line Conversion • Kernel Density	The GPS point layer was converted into a line layer. Spatial diffusion of GPS routes was analyzed using kernel density estimation (KDE) (Korpilo et al., 2017).
	Access Point Distribution	Where do users access the backcountry? How is access to the park distributed?	• Create Routes • Locate Features Along Routes • Point Density	The park road access corridor was converted into a route layer, and point features were located along the road to capture where backcountry users departed from the park road and moved into the backcountry.
	Land-Cover Overlay	On what types of surfaces do most users camp?	• Raster to Polygon Conversion • Spatial Join	A Denali land-cover layer, including 23 land-cover classifications, was spatially joined to backcountry campsite locations (Marion & Cole, 1996).
Campsite	Viewshed Analysis	Which campsites were located within the Park Road Viewshed?	• Viewshed • Select by Location	The viewshed tool calculated the raster cells that were visible from the park road (Carver, Comber, McMorran, & Nutter, 2012). Campsites within the viewshed were spatially selected and mapped.
	Density	Where were low and/or high density areas located?	• Kernel Density	The campsite data were analyzed using kernel density estimation to show concentration of use (Alessa, Kliskey, & Brown, 2008).

the distribution of age was unimodal ($M = 31.48$; $SD = 9.62$) with the majority (53.9%) being between 20 and 30 years old. Survey respondents were educated beyond the U.S. average with almost 80% reported having obtained a four-year college degree or higher. Annual income was nearly even among the income brackets evaluated. Most respondents (85.6%) reported a primary residence in the U.S. while western Europeans were the second largest group of respondents. A total of 93.1% identified as White or Caucasian, and 3% were Hispanic or Latino.

To address the first and second objectives, we analyzed the travel patterns of backcountry use in Denali, focusing first on basic trip characteristics. On average, respondents spent 1.74 days ($SD = 1.26$) in the backcountry with the lengthiest trip lasting ten days. Distance varied greatly, in that the mean distance traveled was 9.56 kilometers ($SD = 10.25$). Mileage was right-skewed given that the majority of trips were under 5.5 kilometers (Median = 5.32). The range of backcountry trips extended from 0.63 to 60.08 kilometers. The furthest distance traveled from the park road was variable, in that the furthest any group hiked from the road was 18.21 kilometers, but on average, respondents ventured a straight-line distance of 2.62 kilometers from the park road ($SD = 2.78$). A comparison between day and overnight trip characteristics using independent samples t-tests determined whether the respondents differed in total trip length in Denali's backcountry and distance traveled per day (see Table 2). Overnight trips in the backcountry were significantly longer ($M = 2.89$ days, $SD = 1.37$) than day trips ($M = 1.00$ days, $SD = 0.00$, $p \leq .001$). Respondents on overnight trips also hiked further distances while they were in the backcountry, averaging 13.53 more kilometers per trip than those on day trips ($p \leq .001$). Similarly, respondents on multi-day trips traveled more remotely into the backcountry, averaging a distance of 4.67 kilometers from the park road access corridor, compared to 1.33 kilometers traveled by respondents on day trips ($p \leq .001$).

Table 2
Comparison between day (N = 178) and overnight (N = 113) trip characteristics.

Variable	Day Users M(SD)	Overnight Users M (SD)	t-stat (df)
Length of trip (days)	1.00 (0.00)	2.89 (1.37)	14.68* (112)
Trip distance (kilometers)	4.30 (1.75)	17.84 (12.26)	14.51* (289)
Furthest distance from park road (kilometers)	1.33 (0.61)	4.67 (3.46)	12.58* (289)
Group size	–	2.26 (1.14)	–

*$p \leq .001$.

4.2. GPS route analysis

Spatial patterns of backcountry use were derived from the 291 GPS tracks collected for analysis. Results from a kernel density analysis showed several trends (see Fig. 4). First, backcountry respondents occupied a relatively small portion of the park. Specifically, use was concentrated tightly along the park road corridor, and the highest levels of use were located within the middle section of the park road. Second, distinct 'hotspots' emerged, defined as areas with an unusually high number of events (e.g., GPS tracks, campsites). The kernel density analysis of data from the pooled sample showed five hotspots with particularly dense concentrations of GPS tracks. Third, the shape and intensity of use was markedly different between day and overnight recreationists. The day use distribution was less widespread and more tightly concentrated along the road than overnight use. Day use tended to concentrate directly over the park road, exhibiting more uniformed distributions on both the north and south sides of this access corridor. By contrast, overnight use was spread across a greater area, revealed a more irregular shape, and the hotspots deviated slightly to the south side of the road, indicating that the majority of backcountry recreationists hiked in areas south of the park road.

Access points into the backcountry were examined along the park road. Although recreationists in Denali could start their trip from nearly anywhere along the park road, access into the backcountry was unevenly distributed (Fig. 5). As shown in the graph, the section at miles 65–70 of the park road had the highest number of access points (n = 25, 19.1%). Over one third (37.5%) of backcountry recreationists were concentrated within only 10% of the park road (i.e., between miles 65–70 and miles 50–55), and 84.0% of access points were located between mile markers 30 and 75. Again, use was concentrated along the middle section of the park road. At the most dense locations, there were approximately six access points per mile (see Fig. 5), though the most dense areas were limited to only several sections of the park road. Most sections were used very little or not at all to access the backcountry.

4.3. Campsite data analysis

In response to the third study objective, we assessed 203 campsite locations in relation to other social-ecological data including land-cover and viewshed data layers. Results from the land-cover analysis showed that campsites were located on 14 different land-cover types found in the park (see Table 3), and the majority camped on vegetated surfaces (see Fig. 6a). Low shrub birch-ericaceous-willow, dwarf shrub, bareground, and spare vegetation were the top four land-cover types among backcountry recreationists. Over half of the campsites recorded were

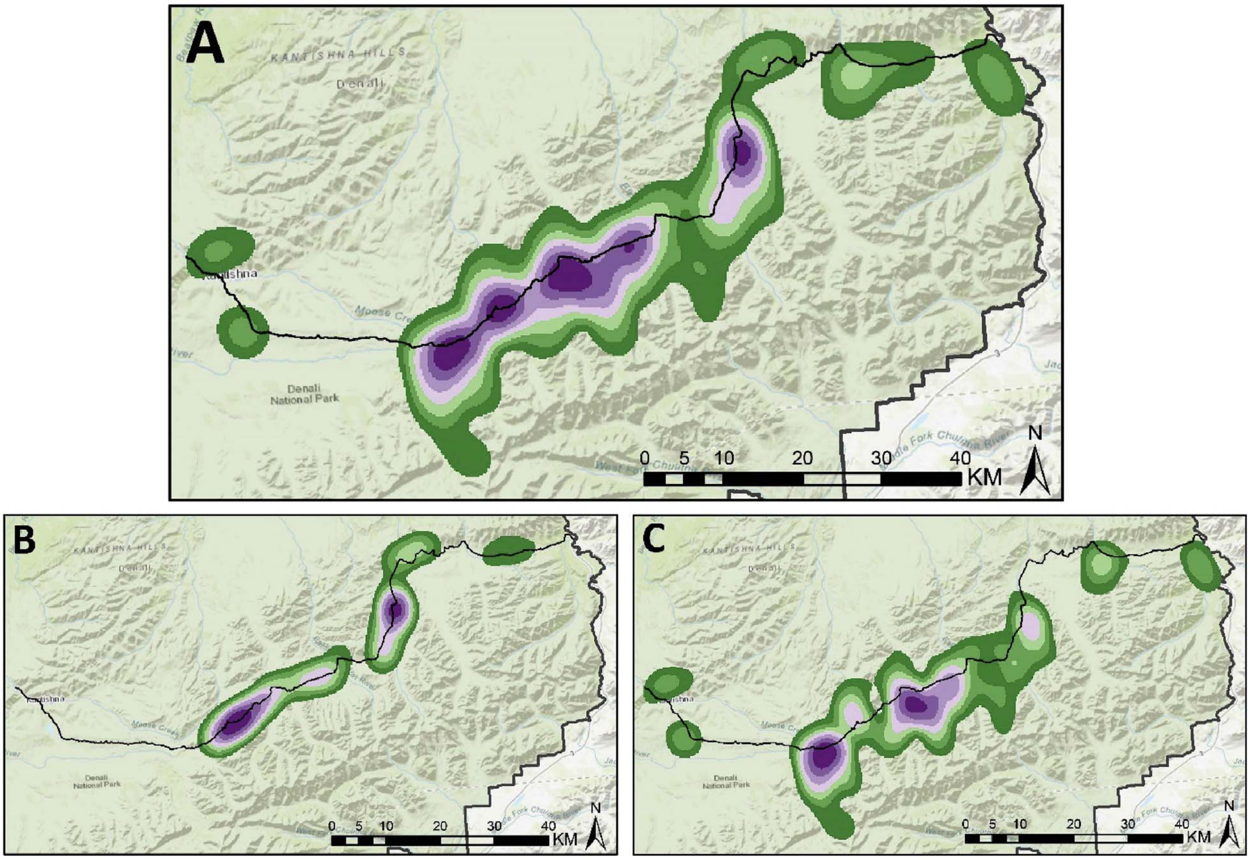

Fig. 4. Density of backcountry use within Denali National Park and Preserve: a) use density of all backcountry tracks, b) day use density, c) overnight use density (5 km. bandwidth) (Sources: DENA Roads, 2009; ESRI Basemap, 2017).

within sight of the park road (see Fig. 6b) although campsites within the viewshed of the road are prohibited by Denali's Backcountry Management Plan to preserve other wilderness experiences. However, these locations were on average just 272 meters from being out of the park road viewshed ($SD = 282$, N = 103). Similar to the route data, a kernel density estimation was used to analyze the campsite data (see Fig. 6c and d). The campsite distribution paralleled the distribution of overnight use, including the irregular shape with hotspots emerging in the middle and south sections of the park road. Fig. 6d shows the most dense and largest hotspot at a smaller scale to illustrate the distance between campsites. Three areas in this region had more than one campsite within 100 meters (see Fig. 6d).

5. Discussion

The purpose of this study was to better understand the spatial and temporal patterns of day and overnight backcountry use in Denali National Park and Preserve, Alaska. Characteristics that define this park, particularly its large size and trail-less qualities, make understanding travel patterns difficult. However, GPS tracking technologies provided an efficient and data-rich method for recording patterns of backcountry use. The results of the study suggested recreationists were highly concentrated along the park road and clustered within specific areas. Although Denali's backcountry management plans encourage wide-spread dispersion of backpackers to reduce social-ecological impacts, this study indicated that use tends to be concentrated. Specifically, analysis of GPS tracks highlighted a number of hotspots, the majority of which were located within several kilometers of the park road. Results also showed that mileage, length of trip, and distance from the park road differed greatly between day and overnight users. Finally, the majority of campsites recorded in the study were found on vegetated surfaces, were within the viewshed of the park road, and exhibited comparable density patterns to the route data. These spatial use patterns aid public land management agencies, particularly those in Alaska, in the strategy and prioritization of management decisions.

Several on-ground conditions may have influenced the backcountry travel patterns that emerged in our study. First, hiking conditions in Denali were easiest in higher elevations above the tree line, and as indicated in Fig. 5, use was generally greater in higher elevations. Second, backcountry unit quotas directly influenced campsite locations. With some backcountry units being much smaller than others, particularly on the south side of the park road, more recreationists can travel in this area because the north side units were larger but still had the same limiting quotas. Third, recreationists may have been drawn towards similar landscape features or to areas with evidence of prior use. These patterns likely directed recreationists to specific locations such as those in Fig. 6d. Finally, several temporary wildlife closures prohibited recreationists from accessing specific areas of the backcountry.

The spatial dynamics of human use support management decisions in numerous ways (see Table 4). In particular, knowledge of where recreationists travel within protected areas is imperative for anticipating areas of social and ecological concern (Beeco et al., 2013; D'Antonio et al., 2013). For example, hotspots - spatial clusters of route and campsite locations - were identified to prioritize backcountry monitoring efforts (Alessa et al., 2008; Korpilo et al., 2017). Although this study did not directly identify informal trails, the particularly high-use areas that were highlighted indicate that informal trails are most likely to form in these locations. Moreover, the backcountry use maps generated from this study can be compared with known informal trail systems to understand spatial behavior changes over time. Identification of informal trails should be of particular ecological concern for public land management agencies, as they are the most extensive

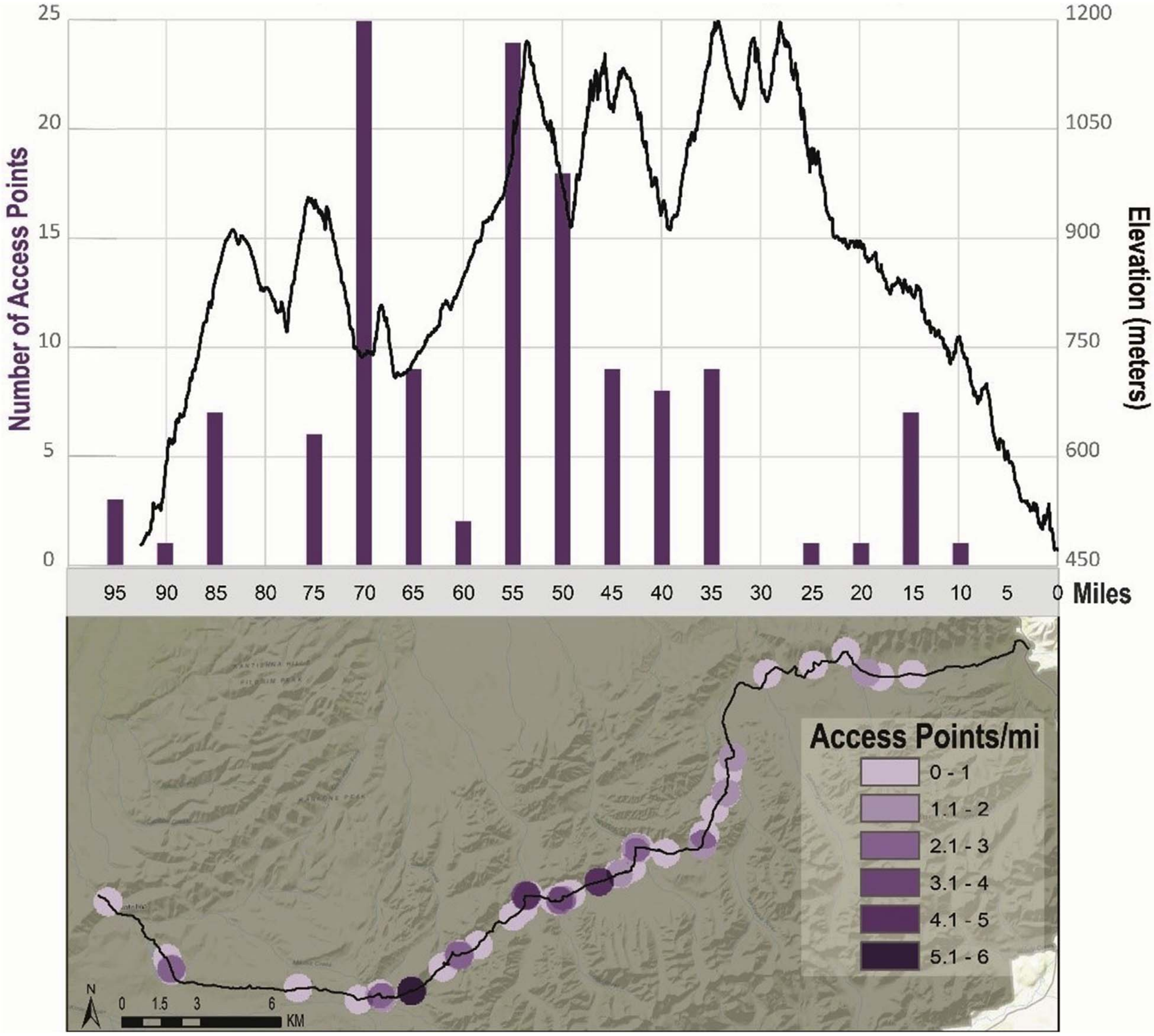

Fig. 5. Frequency distribution (above figure) and spatial distribution (below figure) of access points along the park road (N = 113) (Sources: DENA Roads, 2009; ESRI Basemap, 2017).

Table 3
Campsites located on different land-cover types (N = 203).

Land-Cover Classification	Frequency	Percent
Low Shrub Birch-Ericaceous-Willow	47	23.2%
Dwarf Shrub	38	18.7%
Bare Ground	36	17.7%
Sparse Vegetation	34	16.7%
Low Shrub-Sedge	16	7.9%
Dwarf Shrub-Rock	9	4.4%
Stunted Spruce	6	3.0%
Shadow-Indeterminate	5	2.5%
Closed Low Shrub Birch	4	2.0%
Open-Woodland Spruce	3	1.5%
Alder	1	0.5%
Broadleaf	1	0.5%
Dense-Open Spruce	1	0.5%
Wet Herbaceous	1	0.5%
Willow	1	0.5%

impacts from recreation use (Monz et al., 2010). Informal trails detract from solitary wilderness experience, which is particularly important in the context of Denali, given the park's "Find Your Own Trail" motto.

Integrating spatial use alongside other datasets is a powerful way to advance knowledge of the complexities present in social-ecological relationships. Future research that employs GPS tracking methods should consider coupling spatial data with in-depth survey data (Pettersson & Zillinger, 2011) and/or biophysical layers such as species richness (Alessa et al., 2008), land-cover (van Riper et al., 2017), and soil composition (Marion & Cole, 1996) to gain a more complete understanding of human-environment interactions. Also, our assessment of campsites within the park road viewshed can be extended in future research by applying tracking data to assessments of visitor compliance with park rules and regulations. As evidenced by the technology utilized for this research, the capabilities of GPS tracking will allow researchers and mangers to capture more detailed and complete use patterns for multi-day trips.

5.1. Limitations

There were methodological challenges that should be considered when designing GPS tracking research in protected areas. First, some groups returned units without any data. In most cases, groups failed to turn on the units, or the batteries did not last for the duration of the trip. Future research should carefully consider the technological limitations of GPS units, particularly battery-life, reliability, and ease of use. Korpilo et al. (2017) bypassed some of these methodological limitations by tracking use with personal smartphones; however, this

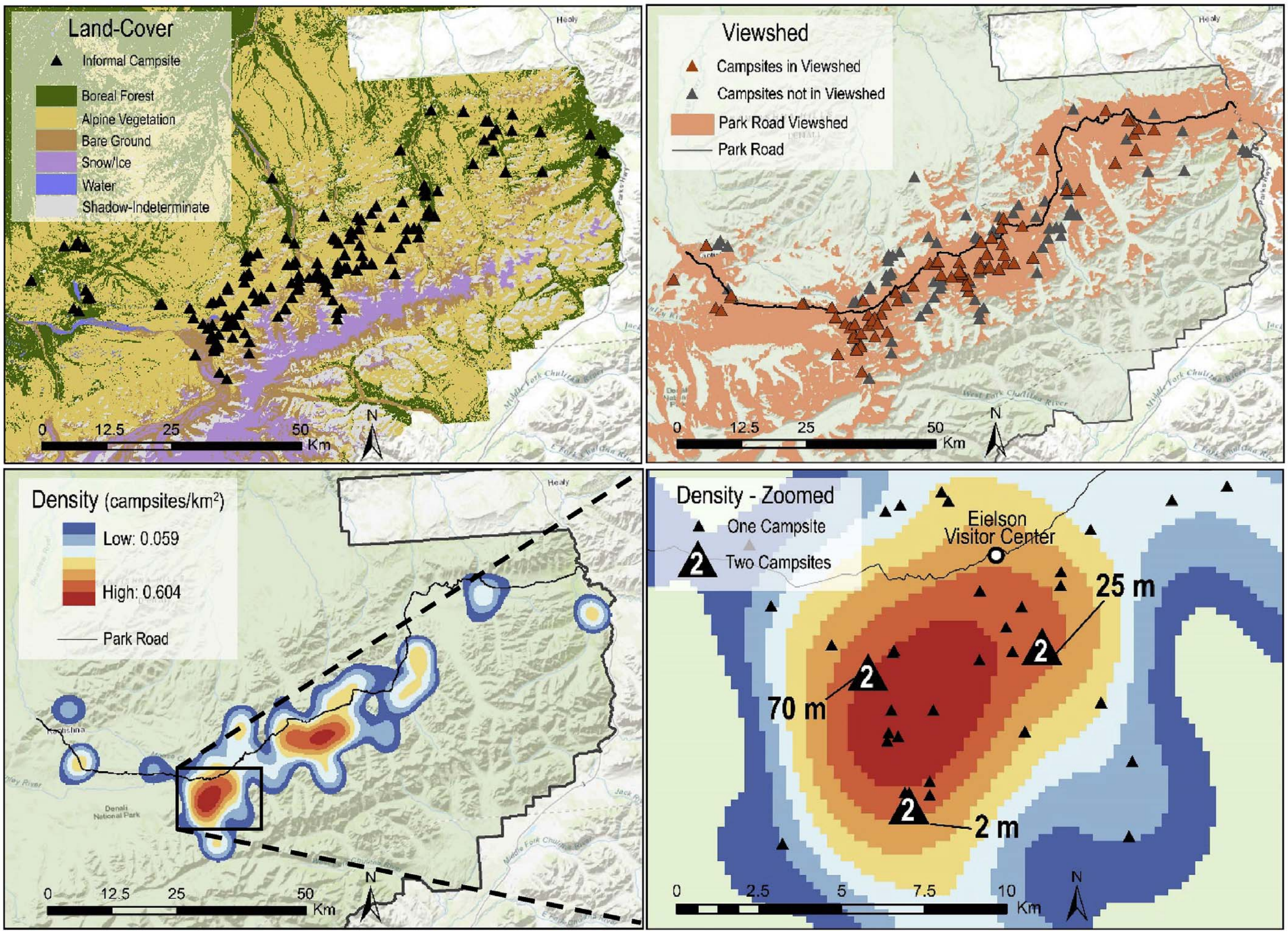

Fig. 6. Analyses with campsite data (clockwise from top-left): a) overlay with land-cover data, b) identification of campsites within the park road viewshed, c) density of highest concentrated area, showing distance between campsites, d) kernel density analysis of campsites (5 km. bandwidth) (Sources: DENA Landcover, 2008; DENA Roads, 2009; DENA Park Road Viewshed Analysis, 2011; ESRI Basemap, 2017).

method is limited by battery life and skepticism about using personal phones for research. A second methodological limitation of the study is that GPS tracks were cleaned manually, which was labor intensive and may have generated errors. Although researchers took steps to maintain consistency, an automatic cleaning process would be more efficient and accurate.

The study presented several other noteworthy limitations. Two different GPS unit models were used to measure overnight and day use, because day use data collection was managed by the NPS. Therefore, discrepancies in accuracy existed and should be taken into consideration when interpreting the study findings. Additionally, spatial scale discrepancies existed in the campsite viewshed analysis. Although the 'Park rule' is that tents must be out of sight of the road, the campsite points showed where GPS units (rather than tents) were located. A GPS unit may have been attached to a backpack, at a food site, or in a bear can, items that must be kept over 100 meters away from sleeping quarters. A final limiting factor of the study was that the subgroups used for this research did not represent all park visitors. Day users represented only ranger-led hikes and did not account for independent day hikes into the backcountry, though anecdotally, few

Table 4
Management implications derived from GPS tracking results.

Findings	Disciplinary focus	Implications for Management and Opportunities for Future Research
1. Multiple hotspots of use were identified as areas of social and ecological concern.	Social and Ecological	Hotspot locations should be prioritized in backcountry monitoring efforts to locate areas for potential informal trail creation or campsite formation.
2. Almost 40% of launching points were within 10% of the park road.	Ecological	Future efforts in protected areas such as Denali should continue to inventory informal trail systems, especially at the most common access points identified in this study.
3. Only 18% of campsites were located on a durable surface (e.g., 'bare ground' land-cover).	Ecological	Backcountry education should emphasize the ecological impacts of campsites. Future research can overlay additional biophysical layers (i.e., species richness) on GPS tracks to quantify social-ecological relationships.
4. Over half of all campsites were visible from the park road.	Social	In an effort to maintain a wilderness experience for all Denali visitors, the park should emphasize the importance of keeping tents out-of-sight from the park road.
5. The GPS tracking sticks used in this study provided detailed spatial data for multiple-day trips.	Technological	Management of Denali and other protected areas can use similar field equipment to capture use for multiple-day trips. Future research should monitor use in different seasons and engage with different groups to generate a more complete picture of human use patterns.

recreationists took unguided day trips. Moreover, the spatial data in this study reflected use in the peak summer season but did not incorporate visitors in shoulder seasons, winter users, or mountaineering groups who access the park from a secondary region.

6. Conclusion

The use of GPS technology demonstrates one approach for developing robust and comprehensive models of human use in relation to on-ground conditions experienced in nature-based contexts such as protected areas. In Denali's nearly trail-less landscape, we explicitly quantified the spatial and temporal dynamics of recreational activities. Given that behavioral patterns in remote settings are less predictable and rarely researched, the multi-day trips documented in this study provide new evidence for public land management agencies to make more informed decisions about recreational impacts. Moreover, we related human use patterns to biophysical conditions such as land-cover and viewshed to better understand how recreationists are interacting with the environment. This information is in turn used to identify high and low priority places that warrant managerial attention. The continued development of spatial tools available for enhancing management of parks and protected areas has important implications for balancing environmental sustainability and human well-being.

Acknowledgements

The authors are grateful for Jessica Toubman, John Brueck, and Dave Schirokauer from the National Park Service for their assistance throughout this project. Many thanks to Clinton Lum, Saachi Kuwayama and Sadia Sabrina for their various contributions to the project, including data collection, data entry, and conceptual guidance on various phases of the writing process. This research was financially supported by the University of Illinois at Urbana-Champaign Campus Research Board Grant Number: RB16092.

References

Abbe, J. D., & Burrows, R. (2014). *Denali national park and preserve state of the backcountry – 2012. Natural resource report NPS/DENA/NRR—2014/865.* Fort Collins, Colorado: National Park Service.

Alessa, L., Kliskey, A., & Brown, G. (2008). Social – ecological hotspots mapping: A spatial approach for identifying coupled social – ecological space. *Landscape and Urban Planning, 85*, 27–39.

Anderson, J. (1971). Space-time budgets and activity studies in urban geography and planning. *Environment and Planning A, 3*(4), 353–368.

Arnberger, A., Haider, W., & Brandenburg, C. (2005). Evaluating visitor-monitoring techniques: A comparison of counting and video observation data. *Environmental Management, 36*(2), 317–327.

Bagstad, K., Reed, J., & Semmens, D. (2016). Linking biophysical models and public preferences for ecosystem service assessments: A case study for the southern rocky mountains. *Regional Environmental Change, 16*(7), 2005–2018.

Bauder, M. (2015). Using GPS supported speed analysis to determine spatial visitor behaviour. *International Journal of Tourism Research, 17*(4), 337–346.

Beeco, J., & Brown, G. (2013). Integrating space, spatial tools, and spatial analysis into the human dimensions of parks and outdoor recreation. *Applied Geography, 38*, 76–85.

Beeco, J., & Hallo, J. (2014). GPS tracking of visitor use: Factors influencing visitor spatial behavior on a complex trail system. *Journal of Park and Recreation, 32*(2), 43–61.

Beeco, J., Hallo, J., & Brownlee, M. (2014). GPS visitor tracking and recreation suitability mapping: Tools for understanding and managing visitor use. *Landscape and Urban Planning, 127*, 136–145.

Beeco, J., Hallo, J., & Giumetti, G. (2013). The importance of spatial nested data in understanding the relationship between visitor use and landscape impacts. *Applied Geography, 45*, 147–157.

Birnbaum, M., & Stegner, S. (1979). Source credibility in social judgment: Bias, expertise, and the judge's point of view. *Journal of Personality and Social Pschology, 37*(1), 48–74.

Carver, S., Comber, A., McMorran, R., & Nutter, S. (2012). A GIS model for mapping spatial patterns and distribution of wild land in Scotland. *Landscape and Urban Planning, 104*(3), 395–409.

Cessford, G., & Muhar, A. (2003). Monitoring options for visitor numbers in national parks and natural areas. *Journal for Nature Conservation, 11*(4), 240–250.

Cole, D. N. (1981). Managing ecological impacts at wilderness campsites: An evaluation of techniques. *Journal of Forestry, 79*(2), 86–89.

Cole, D. N. (2004). Impacts of hiking and camping on soils and vegetation: A review. *Environmental impacts of ecotourism,* 41–60.

Cole, D. N., & Monz, C. A. (2004). Spatial patterns of recreation impact on experimental campsites. *Journal of Environmental Management, 70*(1), 73–84.

D'Antonio, A., Monz, C., Lawson, S., Newman, P., Pettebone, D., & Courtemanch, A. (2010). GPS-based measurements of backcountry visitors in parks and protected areas: Examples of methods and applications from three case studies. *Journal of Park and Recreation Administration, 28*(3), 42–60.

D'Antonio, A., Monz, C., Newman, P., & Lawson, S. (2013). Enhancing the utility of visitor impact assessment in parks and protected areas: A combined social–ecological approach. *Journal of Environmental Management, 124*, 72–81.

Eagles, P., & McCool, S. (2002). *Tourism in national parks and protected areas: Planning and management.* CABI.

Edwards, D., Dickson, T., & Griffin, T. (2010). Tracking the urban visitor: Methods for examining tourists' spatial behaviour and visual representations. *Cultural Tourism,* 104–114.

Edwards, D., & Griffin, T. (2013). Understanding tourists' spatial behaviour: GPS tracking as an aid to sustainable destination management. *Journal of Sustainable Tourism, 21*(4), 580–595.

Evans, J., & Jones, P. (2011). The walking interview: Methodology, mobility and place. *Applied Geography, 31*(2), 849–858.

Goonan, K. A. (2009). *Protecting natural resources and the visitor experience on mountain summits in the northern forest: A framework for management.* Burlington: M.S., University of Vermont.

Greene-Roesel, R., Diogenes, M. C., Ragland, D. R., & Lindau, L. A. (2008). *Effectiveness of a commercially available automated pedestrian counting device in urban environments: Comparison with manual counts.* Safe Transportation Research & Education Center.

Hallo, J., Beeco, J., Goetcheus, C., McGee, J., McGehee, N., & Norman, W. (2012). GPS as a method for assessing spatial and temporal use distributions of nature-based tourists. *Journal of Travel Research, 51*(5), 591–606.

Hallo, J. C., & Manning, R. E. (2010). Analysis of the social carrying capacity of a national park scenic road. *International Journal of Sustainable Transportation, 4*(2), 75–94.

Hallo, J. C., Manning, R. E., Valliere, W., & Budruck, M. (2004). A case study comparison of visitor self-reported and GPS recorded travel routes. *Proceedings of the 2004 northeastern recreation research symposium* (pp. 172–177). .

Hammitt, W., Cole, D., & Monz, C. (2015). *Wildland recreation: Ecology and management.* John Wiley & Sons.

James, G. A., & Ripley, T. H. (1963). Instructions for using traffic counters to estimate recreation visits and use. *Res. Pap. SE-3*Asheville, NC: US Department of Agriculture, Forest Service, Southeastern Forest Experiment Station 14 p., 3.

Keller, R. (2017). *Denali year visitation in review. Denali national park and preserve.* Fort Collins, Colorado: U.S. Department of Interior – National Park Service.

Kidd, A. M., Monz, C., D'Antonio, A., Manning, R. E., Reigner, N., Goonan, K. A., & Jacobi, C. (2015). The effect of minimum impact education on visitor spatial behavior in parks and protected areas: An experimental investigation using GPS-based tracking. *Journal of Environmental Management, 162*, 53–62.

Korpilo, S., Virtanen, T., & Lehvävirta, S. (2017). Smartphone GPS tracking—inexpensive and efficient data collection on recreational movement. *Landscape and Urban Planning, 157*, 608–617.

Lawhon, B., Taff, B. D., & Schwartz, F. (2016). *Undesignated trail management and messaging study report*Boulder, Colorado: The City of Boulder, Department of Open Space and Mountain Parks.

Lawson, S., & Manning, R. (2001). Solitude versus access: A study of tradeoffs in outdoor recreation using indifference curve analysis. *Leisure Sciences, 23*, 179–191.

Leonard, R. (1980). *Management guidelines for monitoring use on backcountry trails, Vol. 286*. Dept. of Agriculture, Forest Service, Northeastern Forest Experiment Station.

Leung, Y., & Marion, J. (2000). Recreation impacts and management in wilderness: A state-of-knowledge review. *USDA forest service proceedings RMRS-P-15-VOL-5. 2000* (pp. 23–48). .

Leung, Y. F., & Marion, J. L. (2004). Managing impacts of camping. *Environmental Impacts of Ecotourism,* 245–258.

Manning, R. E. (1979). Impacts of recreation on riparian soils and vegetation. *Journal of the American Water Resources Association, 15*(1), 30–43.

Manning, R. E. (2011). *Studies in outdoor Recreation: Search and research for satisfaction* (3rd ed.). Oregon State University Press.

Margules, C., & Pressey, R. (2000). Systematic conservation planning. *Nature, 405*, 243–253.

Marion, J., & Cole, D. (1996). Spatial and temporal variation in soil and vegetation impacts on campsites. *Ecological Applications, 6*(2), 520–530.

Marion, J., & Leung, Y. (2001). Trail resource impacts and an examination of alternative assessment techniques. *Journal of Park and Recreation Administration, 19*(3), 17–37.

Marion, J., Leung, Y., & Nepal, S. (2006). Monitoring trail conditions: New methodological considerations. *The George Wright Forum, 23*(2), 36–49.

McGehee, N. G., Boley, B. B., Hallo, J. C., McGee, J. A., Norman, W., Oh, C.-O., & Goetcheus, C. (2013). Doing sustainability: An application of an inter-disciplinary and mixed-method approach to a regional sustainable tourism project. *Journal of Sustainable Tourism, 21*(3), 355–375.

Modsching, M., Kramer, R., Gretzel, U., & Hagen, K. (2006). Capturing the beaten paths: A novel method for analysing tourists' spatial behaviour at an urban destination. *Information and Communication Technologies in Tourism,* 75–86.

Monz, C. A., Cole, D. N., Leung, Y.-F., & Marion, J. L. (2010). Sustaining visitor use in protected Areas: Future opportunities in recreation ecology research based on the USA experience. *Environmental Management, 45*(3), 551–562.

Monz, C. A., Pickering, C. M., & Hadwen, W. L. (2013). Recent advances in recreation ecology and the implications of different relationships between recreation use and ecological impacts. *Frontiers in Ecology and the Environment, 11*(8), 441–446.

National Park Service (2006). *Denali backcountry management plan. Denali national park and preserve.* Fort Collins, Colorado: U.S. Department of the Interior – National Park Service.

National Park Service (2015). Denali NP & PRES: Annual park recreation visitation (1904-last calendar year). Retrieved from https://irma.nps.gov/Stats/SSRSReports/ParkSpecificReports/AnnualParkRecreationVisitation(1904-LastCalendar Year)?Park=DENA.

National Park Service (2017). *Administrative boundaries of national park system units 9/30/2017-national geospatial data asset (NGDA) NPS national parks dataset.* NPS - Land Resources Division.

Orellana, D., Bregt, A., Ligtenberg, A., & Wachowicz, M. (2012). Exploring visitor movement patterns in natural recreational areas. *Tourism Management, 33*, 672–682.

Patterson, M. E., & Hammitt, W. E. (1990). Backcountry encounter norms, actual reported encounters, and their relationship to wilderness solitude. *Journal of Leisure Research, 22*(3), 259.

Pettersson, R., & Zillinger, M. (2011). Time and space in event behaviour: Tracking visitors by GPS. *Tourism Geographies, 13*(1), 1–20.

Pickering, C., Hill, W., Newsome, D., & Leung, Y. (2010). Comparing hiking, mountain biking and horse riding impacts on vegetation and soils in Australia and the United States of America. *Journal of Environmental Management, 91*(3), 551–562.

Plieninger, T., Dijks, S., Oteros-Rozas, E., & Bieling, C. (2013). Assessing, mapping, and quantifying cultural ecosystem services at community level. *Land Use Policy, 33*, 118–129.

Price, S., Blacketer, M., & Brownlee, M. (2018). The influence of place attachment on campers' evaluation of ecological site impacts. *Journal of Outdoor Recreation and Tourism, 21*, 30–38.

van Riper, C., & Kyle, G. (2014). Understanding the internal processes of behavioral engagement in a national park: A latent variable path analysis of the value-belief-norm theory. *Journal of Environmental Psychology, 38*, 288–297.

van Riper, C., Kyle, G., Sherrouse, B., & Bagstad, K. (2017). Toward an integrated understanding of perceived biodiversity values and environmental conditions in a national park. *Ecological Indicators, 72*, 278–287.

van Riper, C. J., Manning, R. E., & Reigner, N. (2010). Perceived impacts of outdoor recreation on the summit of cascade mountain, New York. *Adirondack Journal of Environmental Studies, 16*(1), 8.

Ritter, J. L. (2007). *Species distribution models for Denali national park and preserve, Alaska* (Master's thesis). University of Alaska Fairbanks.

Shoval, N. (2008). Tracking technologies and urban analysis. *Cities, 25*, 21–28.

Shoval, N., & Isaacson, M. (2009). *Tourist mobility and advanced tracking technologies.* New York: Taylor and Francis.

Stewart, W. P., & Cole, D. N. (2001). Number of encounters and experience quality in Grand Canyon backcountry: Consistently negative and weak relationships. *Journal of Leisure Research, 33*(1), 106.

Taczanowska, K., González, L., & Garcia-Massó, X. (2014). Evaluating the structure and use of hiking trails in recreational areas using a mixed GPS tracking and graph theory approach. *Applied Geography, 55*, 184–192.

Toubman, J., & Burrows, R. (2015). *State of the backcountry report. Denali national park and preserve.* Fort Collins, Colorado: U.S. Department of Interior – National Park Service.

Whinam, J., & Chilcott, N. (1999). Impacts of trampling on alpine environments in central Tasmania. *Journal of Environmental Management, 57*(3), 205–220.

White, K. (2014). *Climber access trail mapping and GPS visitor tracking in Indian Creek Utah*Master's Thesis. University of Utah.

White, K., Brownlee, M., Furman, N., & Beeco, A. (2015). *Climber access trail mapping and GPS visitor tracking in Indian Creek Utah*Technical report submitted to the U.S.. Bureau of Land Management: Monticello Utah Field Office.

Wimpey, J., & Marion, J. (2011). A spatial exploration of informal trail networks within Great Falls Park, VA. *Journal of Environmental Management, 93*(3), 1012–1022.

Wolf, I., Hagenloh, G., & Croft, D. (2012). Visitor monitoring along roads and hiking trails: How to determine usage levels in tourist sites. *Tourism Management, 33*(1), 16–28.