Journal of Environmental Management 170 (2016) 79–87

Contents lists available at ScienceDirect

Journal of Environmental Management

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

Research article

The influence of visitor use levels on visitor spatial behavior in off-trail areas of dispersed recreation use

Ashley D'Antonio [a, *], Christopher Monz [b]

[a] Department of Environment and Society, Utah State University, 5215 Old Main Hill, Logan, UT 84322, USA
[b] Department of Environment and Society, The Ecology Center, Utah State University, 5215 Old Main Hill, Logan, UT 84322, USA

ARTICLE INFO

Article history:
Received 23 September 2015
Received in revised form
5 January 2016
Accepted 9 January 2016
Available online 21 January 2016

Keywords:
GPS tracking
Visitor behavior
Recreation management
Dispersed recreation
Visitor use levels

ABSTRACT

A variety of social and ecological factors influence the level and extent of ecological change that occurs in a park or protected area. Understanding these factors and how they are interrelated can help managers prevent undesirable ecological impacts, especially in areas without formal trails and visitor sites. This study examines the relationship between levels of visitor use and spatial patterns of visitor behavior at a variety of backcountry recreation destinations. Current assumptions in both the literature and simulation modeling efforts assume that visitor behavior either does not change with use level or that visitors are more likely to disperse at high levels of visitor use. Using visitor counts and GPS tracks of visitor behavior in locations where visitors could disperse off-trail, we found that visitors' spatial behavior does vary with visitor use level in some recreation settings, however the patterns of visitor behavior observed in this study are sometimes contrary to current generalizations. When visitor behavior does vary with use level, visitors are dispersing more at low levels of visitor use not when use level is high. Overall, these findings suggest that in certain situations the amount of visitor use at a recreation destination may be a less important driver of ecological change than visitor behavior.

1. Introduction

Recreation use in parks and protected areas inevitably leads to some level of ecological change (Hammitt et al., 2015). Managers of parks and protected areas are charged with mitigating these ecological changes while simultaneously providing visitors with opportunities for high quality recreation experiences. The level of resource change that occurs in a park or protected area is influenced by a variety of social and ecological factors including: current environmental conditions, ecosystem type, visitor use levels, the timing of visitor use, the type of visitor use, and visitor behavior (Hammitt et al., 2015; Monz et al., 2013; Pickering, 2010). Managers can influence some of these factors through actions such as limiting use, hardening the environment against impact, directing visitors to desirable locations (based on the Recreation Opportunity Spectrum), and encouraging minimum-impact visitor behavior (Cole, 2008). The field of recreation ecology is focused on understanding the factors that drive resource change in an effort to help develop effective management strategies that mitigate undesirable ecological impacts while continuing to provide for recreation experiences (Monz et al., 2013).

Much of the ecological change and recreation impacts that are of concern to managers are occurring off of hardened surfaces and in areas where visitors disperse off-trail. Visitor use on hardened surfaces is important from a social and managerial standpoint but these hardened areas are designed to be buffered against undesirable ecological change. The relationship between visitor use and ecological change is generally considered curvilinear; meaning initial use causes a disproportionate amount of ecological change (Hammitt et al., 2015; Monz et al., 2013). Therefore, visitor behavior that results in visitors leaving hardening surfaces and entering disperse use areas, where visitor use rarely or never occurs, can have significant ecological consequences (Hammitt et al., 2015).

Recreation ecologists and park and protected area managers have developed a variety of measurement and monitoring techniques that are used to evaluate the factors that influence the level of resource change both on and off-trail. The current environmental conditions of a recreation area can be measured using monitoring and assessment techniques such as ground surveys of the level and extent of visitor use impacts (e.g. vegetation loss, soil erosion,

* Corresponding author.
E-mail addresses: ashleydantonio@gmail.com (A. D'Antonio), chris.monz@usu.edu (C. Monz).

http://dx.doi.org/10.1016/j.jenvman.2016.01.011
0301-4797/

informal trail formation, etc.), trampling studies, and trail assessments (D'Antonio et al., 2013; Marion and Leung, 2011; Monz et al., 2010; Wimpey and Marion, 2010). Indirect measurement techniques, such as automatic trail counters and traffic counters, are frequently used to quantify visitor use levels and the timing of visitor use (Cessford and Muhar, 2003; Watson et al., 2000). More direct measurement techniques, such as visitor surveys, are needed to assess the type of visitor use and visitor behaviors.

Survey methodology is often applied in parks and protected areas to gather specific, descriptive visitor information such as activity type (Manning, 2010). Survey techniques can also be employed to understand visitor behavior through the use of trip logs or diaries or by having the visitor recall their activities (Wolf et al., 2012). However, these survey methods are often somewhat inaccurate, subject to bias, and time intensive for the visitor. Unobtrusive observational techniques (Walden-Schreiner and Leung, 2013), where researchers watch and record visitor behavior, may be more accurate than surveys but are often prohibitively expensive and time intensive (Arnberger et al., 2005; Park et al., 2008). Alternatively, recent advances in Geographic Information Systems (GIS) and Global Positioning Systems (GPS) technology allows for visitors' spatial behavior to be more accurately and robustly measured, mapped and analyzed (D'Antonio et al., 2010; Hallo et al., 2005).

GPS tracking techniques have been employed in various park settings to measure visitor behavior (Beeco and Brown, 2013; Beeco et al., 2014; D'Antonio et al., 2013; Hallo et al., 2012; Taczanowska et al., 2014). A common approach is to select a random sample of visitors who voluntarily carry GPS units with them during their recreation visit and return the unit upon departure. With little input of time or effort on the part of the visitor, researchers are able to gather a large and detailed record of visitor movement patterns at a particular recreation location (D'Antonio et al., 2010; Wolf et al., 2012). Analysis in GIS can then be used to describe spatial patterns of visitor behavior. Hallo et al. (2012) demonstrated, through the use of GPS-tracks from visitors to the Blueridge Parkway, that spatial statistics in ArcGIS can be used to examine the dispersion and patterns of visitor use. In Acadia National Park, Kidd et al. (2015) explored whether visitor dispersion and off-trail behavior varied in response to interpretative messages by GPS tracking hikers and experimentally exposing hikers to different types of messaging.

GPS-based measurement techniques and GIS analysis are useful in describing the current social and ecological components of recreation use but are inherently static, i.e., the descriptive data collected represents a "snapshot in time" and may or may not be representative of future conditions, especially as social, ecological, or management conditions change. The need for more predictive capacity in recreation management led to the development of simulation modeling techniques (Gimblett and Skov-Petersen, 2008; Lawson et al., 2003). Simulation modeling efforts provide managers with a proactive management tool which allows them to "experiment" with different management techniques and visitor use scenarios (Lawson et al., 2003).

Despite their predictive power, current simulation modeling efforts do have their limitations. For example, models often assume that there is no change in the temporal or spatial distribution of visitor use (Wang and Manning, 1999). Most simulation models of recreation use assume that visitor travel routes do not change under different use levels (Wang and Manning, 1999); meaning that visitors do not change their spatial behavior in response to the visitors (or lack of visitors) around them. Yet, conventional thought in recreation ecology and park and protected area management assumes that as visitor use increases visitors spread out; potentially increasing the extent of ecological change (Cole, 1994). These two assumptions exist because the interrelationship between visitor behavior and other social factors of ecological change has never been empirically examined. By operating under the assumption that visitor behavior is constant, even during varying social settings, current simulation models and generalizations in the field of recreation ecology may inaccurately predict future levels of ecological change.

This study addresses the following question: does visitor behavior, specifically spatial behavior of day-use hikers, in off-trail areas of disperse use vary with visitor use level and/or setting characteristics? By combining indirect measures of visitor use (visitor counts) with direct measures of visitor spatial behavior (GPS-tracks of hikers) across a variety of recreational and managerial settings this study assessed how visitor dispersion in off-trail areas varies by use level. Consequently, this study tested current assumptions about visitor behavior, the results of which will better inform future simulation modeling efforts, and provide a better understanding of the interrelatedness of the factors that influence resource change.

2. Methods

2.1. Study sites

2.1.1. Study sites as a spectrum of opportunities

Given that the social, ecological, and managerial aspects of a recreation area can influence visitor behavior, a variety of recreation locations were chosen to include in this study (Table 1 and Fig. 5). This series of study sites represents popular hiking destinations across a spectrum of recreational opportunities, visitor use levels, and levels of visitor management. The specific recreation destinations where chosen for inclusion in this study because at all locations visitors have the potential to disperse into off-trail areas once they reach a specific recreation destination. Each study site and recreation destination will be described in detail here in order to outline the unique ecological, social, and/or managerial setting of each location.

2.1.2. Yosemite National Park, CA: El Capitan Meadow and Tuolumne Meadows

Yosemite National Park (YOSE) is located in the Sierra Nevada region of California and is only a few hours from the San Francisco Bay, Sacramento, and San Jose metropolitan areas. YOSE's proximity to city centers makes it one of the most visited national parks in the United States. In 2014, YOSE received approximately 3.8 million visitors (National Park Service, 2015a). The acreage of meadow habitat in YOSE has been cut in half since the late 1800s due to both ecological and anthropogenic forces and the level of management varies by individual meadow (Walden-Schreiner and Leung, 2013).

One of the least managed meadows in YOSE is El Capitan Meadow. El Capitan Meadow is located at the west end of Yosemite Valley and provides views of El Capitan for photography or scoping climbing routes. In 2011 when GPS tracking occurred in the meadow, El Capitan Meadow received approximately 300 visitors per day (Monz et al., 2012). A popular recreation corridor in YOSE is Tioga Pass (also State Route 120). Tioga Pass bisects Tuolumne Meadows; one of the highest elevation meadows in the Sierra Nevadas (NPS, 2015b). During 2011, Tuolumne Meadows received approximately 120 visitors entering the meadow areas per day. Tuolumne Meadows is used as a "picnic" or resting spot for those patronizing the Tuolumne Meadows Store. A few designated trails can be accessed from the Tuolumne Meadows Visitors Center and Tuolumne Meadows Store. However, there is minimal interpretative or informative material at these trailheads.

Table 1
Data collection efforts at each recreation destination. Only GPS tracks of visitors that visited the recreation destination were included in the analysis. Therefore, the number of high use and low use tracks does not equal the total number of GPS tracks collected at each study site.

Rec destination	Destination type	Response rate	Average GPS positional error (m)	Number of visitor GPS tracks		
				Total collected in overall study	High use	Low use
El Capitan Meadow	Meadow/View site	71%	1.7	98	45	45
Tuolumne Meadows	Meadow	65%	0.7	108	25	25
Alberta Falls	Waterfall/View site	80%	6.4	301	68	37
Emerald Lake	Lakeshore	80%	6.4	301	23	14
Mt. Evans	Mountain Summit	97%	N/A	2248	76	93
Mt. Bierstadt	Mountain Summit	97%	N/A	1051	105	80
Phelps Lake	Lakeshore	93%	1.7	500	113	98

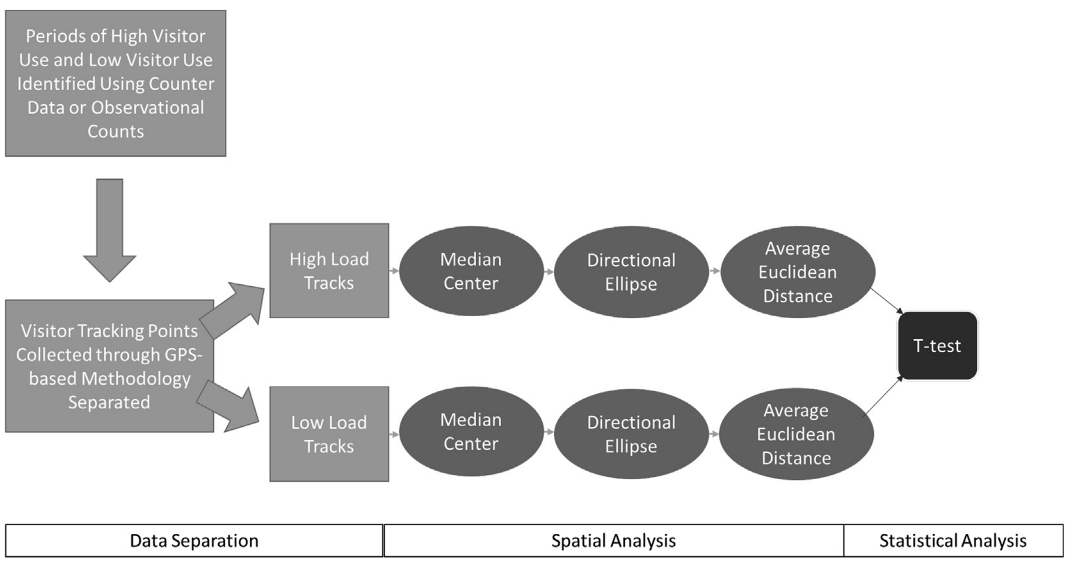

Fig. 1. Conceptual diagram of the analysis steps taken in this study. Each step was repeated at each recreation destination listed in Table 1.

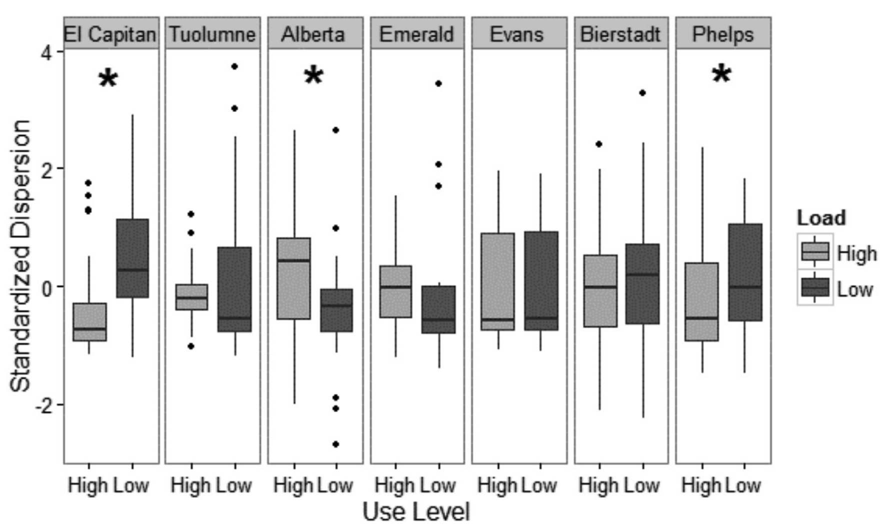

Fig. 2. Standardized, average, overall visitor dispersion at each recreation destination. Asterisks indicate recreation destinations where a statistically significant ($p \leq 0.05$) difference was observed between overall visitor dispersion at high and low levels of visitor use.

2.1.3. Rocky Mountain National Park, CO: Alberta Falls and Emerald Lake, Bear Lake Road Corridor

Rocky Mountain National Park (ROMO) is located in the Front Range of Colorado. Like YOSE, ROMO is also located relatively close to metropolitan areas (Denver, Boulder, and Fort Collins). In 2014, ROMO received approximately 3.4 million visitors (NPS, 2015a). Previous studies (Newman et al., 2010) found that the shuttle bus system to the Bear Lake Road Corridor was being utilized in a manner that was delivering large numbers of visitors to high capacity trails leading to low capacity destinations. Two of these

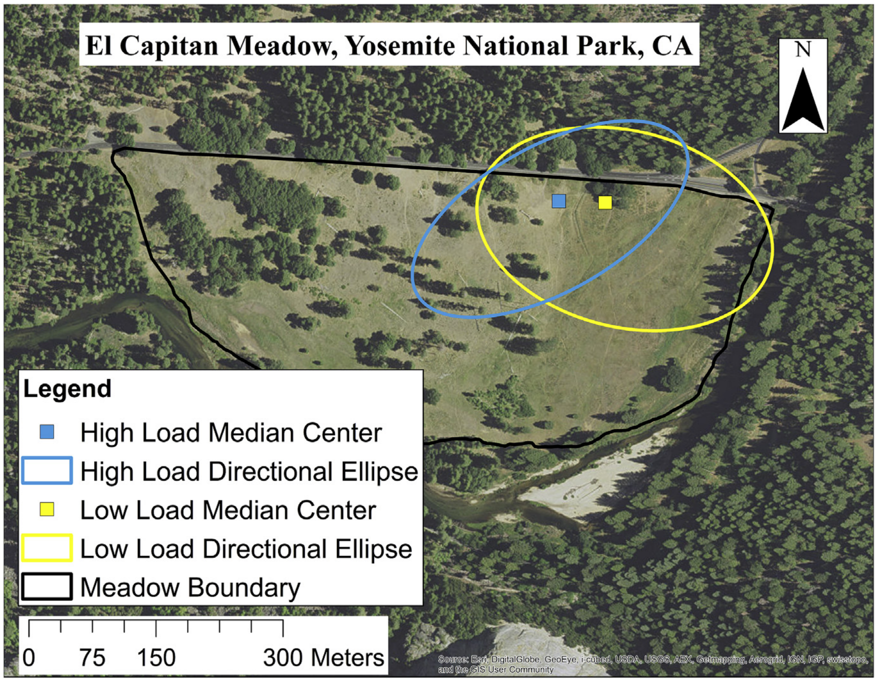

Fig. 3. Descriptive metrics of overall visitor dispersion at El Capitan Meadow. Here the high load median center point and low load median center point are located in different locations. The standard deviational ellipses are of very difference size, shape, and orientation.

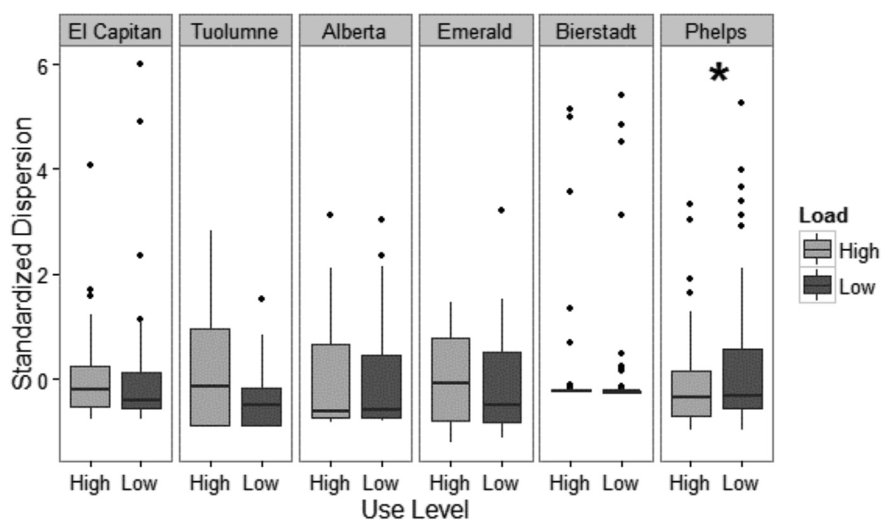

Fig. 4. Standardized, average, overall visitor dispersion away from hardened surfaces at each recreation destination. Asterisks indicate recreation destinations where a statistically significant ($p \leq 0.05$) difference was observed between dispersion away from hardened surfaces at high and low levels of visitor use.

relatively low capacity sites in the Bear Lake Road Corridor are Alberta Falls and Emerald Lake. Alberta Falls is a 30-foot waterfall on Glacier Creek located about 1 mile from the Granite Gorge Trailhead. In 2008 when GPS tracking occurred in the Bear Lake Road Corridor, Alberta Falls received approximately 1300 visitors per day (Newman et al., 2010). There is a moderate amount of management at Alberta Falls including rocks lining the edge of the designated trail as subtle reminders to stay on-trail. There is also a sign asking visitors to stay on the trail at one of the most popular view sites at Alberta Falls. Compared to the hike to Alberta Falls, Emerald Lake is one of the more difficult day hikes in the Bear Lake Road Corridor. Emerald Lake is located 1.8 miles from the Bear Lake Trailhead. During 2008, approximately 1000 visitors per day hiked to Emerald Lake. There is very little management at Emerald Lake; although visitors are presented with a Leave-No-Trace focused interpretative sign at the Bear Lake Trailhead and pass a variety of “stay on the trail” signs as they hike to Emerald Lake.

2.1.4. Arapaho-Roosevelt National Forest, CO: Mt. Evans and Mt. Bierstadt, Mt. Evans Wilderness Area

Arapaho-Roosevelt National Forest (ARNF) is also located in the Front Range of Colorado. The Mt. Evans Wilderness Area and Guanella Pass are popular recreation areas in ARNF. These locations are easily accessed from population centers of the Colorado Front Range. Mt. Evans (14,265′) is one of 54 “Fourteeners” found in Colorado and is located very close to Denver. The highly managed

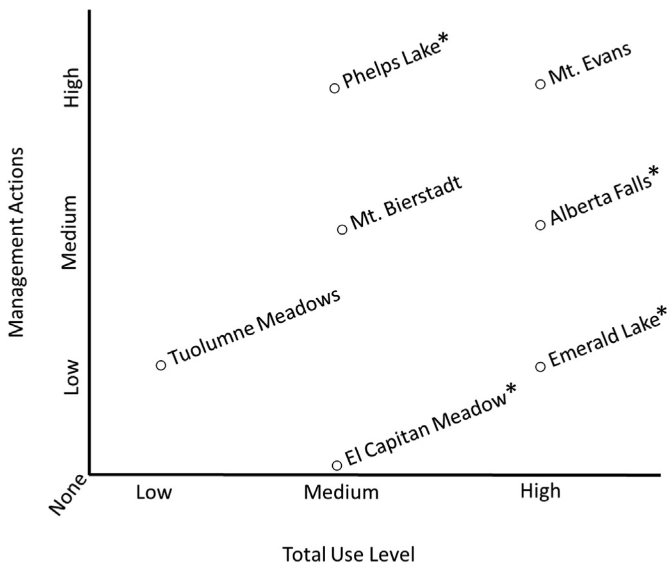

Fig. 5. Graph of matrix from Table 1. Locations where a statistically significant difference was found between overall visitor dispersion during periods of high and overall visitor dispersion during periods of low use are identified by an asterisk.

Mount Evans Scenic Byway, the highest paved road in the North America, allows vehicular traffic to reach the peak of the mountain during the summer months when the road is opened. Approximately 120,000 visitors use the Mount Evans Scenic Byway each year (USDA Forest Service, 2014) and, in 2012, approximately 650 visitors per day hiked the short trail to the peak of Mt. Evans (Resource Systems Group, Inc., 2013a). The Guanella Pass Scenic Byway is also in the Mt. Evans Wilderness Area and originates in the town of Georgetown, Colorado. One popular hiking destination along the Guanella Pass Scenic Byway is Mt. Bierstadt. Mt. Bierstadt (14,065′) is another easily accessible "Fourteener". The summit of Mt. Bierstadt is only 3 miles from the trailhead parking lot at Guanella Pass. When GPS tracking occurred in ARNF in 2012, approximately 300 visitors hiked to Mt. Bierstadt per day (RSG, 2013b). The trail to the summit of Mt. Bierstadt passes through wetland habitat where boardwalks have been installed to prevent vegetation damage.

2.1.5. *Grand Teton National Park, WY: Phelps Lake, Laurence S. Rockefeller preserve, Moose-Wilson road corridor*

Grand Teton National Park (GRTE) is located in northwestern Wyoming just south of Yellowstone National Park and north of Jackson, Wyoming. In 2014, Grand Teton National Park received approximately 2.8 million visitors (NPS, 2015a). That same year, using a rustic stretch of road, approximately 5400 visitors per day accessed the Moose-Wilson corridor (MWC) of GRTE (Monz et al., 2014). The most popular destination in the MWC is the Laurance S. Rockefeller (LSR) Preserve (Monz et al., 2014). The LSR Preserve is highly managed and includes a parking lot that is maintained at a capacity of approximately 50 vehicles. Phelps Lake is a key destination that can be accessed from the LSR Preserve and during the summer of 2013 approximately 300 visitors reach the shore of Phelps Lake per day. The shore of Phelps Lake has been hardened to prevent visitor impacts to the southern lakeshore. However, any use off of these hardened surfaces has the potential to lead to ecological changes to sensitive lakeshore vegetation.

2.2. *Dispersion analysis*

A GPS tracking methodology, as outlined in D'Antonio et al. (2010), was employed at all study sites (Table 1) to measure visitor spatial behavior in both on and off-trail locations. A representative, random sample of visitors was collected at each study site by intercepting visitors at random time intervals during the sampling period and asking these groups to participate in the study. Only one GPS unit was given per group of visitors and GPS units were handed out by researchers at trailheads or, in the case of the meadow sites, researchers moved along the perimeter of the meadow to intercept visitors at random intervals. Sampling occurred throughout the day and on both weekdays and weekend days (Table 1). Position data were collected at 15 s intervals and GPS tracks were saved as point features for analysis in ArcGIS so that each visitor's hiking path was represented by a series of points. The 15 s interval was chosen because it provided an adequate resolution of visitor behavior (i.e we could see where visitors traveled off-trail even they did not travel for or remain off-trail for a long period of time) but produced a dataset that was still reasonable in size for data cleaning, processing, and analysis. Prior to analysis, all GPS-based tracking data was checked for non-response bias and cleaned to remove any positional error. No response bias was found and error was minimal at these site due to the open nature of the canopy at most of the recreation destinations in the study (Table 1).

Standard visitor estimation techniques using infra-red counters (Pettebone et al., 2009) or observational techniques (in YOSE only) were used to determine levels of visitor use at all recreation destinations from each study site. Only those visitors who traveled to the specific recreation destinations were included in the final dataset of GPS tracks collected at each study site. At most study sites, full GPS-tracks were edited to include only visitor behavior that occurred at the recreation destination where dispersed, off-trail behavior was observed by researchers and reported by managers.

A series of analysis steps were taken at each recreation destination to examine how visitor spatial behavior in off-trail areas of dispersed use varies by use levels (Fig. 1). First, visitor use level distributions were examined and destination-specific periods of relatively "high use" and "low use" were determined based on these distributions. For ARNF, only daily visitor use counts were available. For ROMO, YOSE, and GRTE, both daily and hourly visitor counts were available but at both of these locations weekend and weekday use levels were equal. Therefore, at ROMO, YOSE, and GRTE, hourly counts were used to identify periods of high and low use. Once times of high visitor use and low visitor use were determined, then visitor GPS tracking points were separated into those points collected during periods of high use, or "High Load Points," and points collected during periods of low use or "Low Load Points."

This separation resulted in two datasets per recreation destination (Table 1). These two datasets were the inputs for subsequent analyses. Tools in ArcGIS were used to examine the dispersion characteristics of both the High Load Points and Low Load Points at each recreation destination. In this case, dispersion was defined as the spatial pattern of visitor behavior as visitors spread out (or did not spread out) across the recreation destination area. For each dataset and using built-in tools in ArcGIS, the median center point was calculated and then a one standard deviation standard deviational ellipse was generated (Hallo et al., 2012). The median center point identifies where the visitor tracking points are most concentrated; visually identifying the geographic center of the point cloud that represents visitor behavior. The standard deviational ellipse is used to display the overall dispersion of the point cloud of visitor tracking data as well as any directional tendencies of the data. The area and perimeter of each standard deviational ellipse was calculated to compare size and shape of the ellipses. Both the median center point and the standard deviational ellipse provide visual indicators of any differences in dispersion between the High Load Points and the Low Load Points.

In order to quantitatively examine visitor dispersion in response to visitor use levels, Euclidean distance measures were calculated in ArcGIS (Kidd et al., 2015). Euclidean distances describe how far visitors traveled from a point of interest. For each of the two datasets at each recreation destination, Euclidean distance measures were calculated from all data points in the dataset to the median center point of that dataset. Additionally, Euclidean distance measures were calculated to determine the distance visitors dispersed from hardened surfaces such as designated trails or sites. The average Euclidean distance from hardened surfaces indicates the potential for ecological consequences as a result of visitor dispersion into off-trail areas. At most of the study sites, the positional error associated with the GPS tracks was estimated and ranged from 0.7 m to a maximum of 6.4 m with an average across all study sites of 3 m (Table 1). In order to correct for positional error, an error buffer was generated around the hardened surface layer in GIS and Euclidean distances were calculated to the buffer edge.

The average Euclidean distances from the median center point and hardened sites were calculated. These averages were compared using two-sample t-tests (p-value ≤ 0.05) conducted in the open-source software and programming language R. After these statistical analysis, Euclidean distance measures were standardized for the purposes of comparison across sites. The result of the destination-level dispersion analyses described here were compared across study sites to see if the level of management action or other setting characteristics may be influencing how visitor behavior changes in response to visitor use levels. The average Euclidean distance to the median center point describes overall visitor dispersion in response to use levels.

3. Results

3.1. Response rate, sampling effort, and sample size

Response rates for the GPS-based tracking methodology at the various study sites varied from a lowest value of 65% in Tuolumne Meadows to 97% at both sites in ARNF (Table 1). Given the relatively high response rates at each study site and a successful, random sample of overall use at each site, the GPS-based tracking data is considered to be a representative sample of day-use visitors to each recreation destination. The total number of GPS tracks collected at each study varied from a low of 98 in El Capitan Meadow to over 2000 at Mt. Evans (Table 1). The total number of visitor tracks collected during periods of low use varied from 14 at Emerald Lake to 98 at Phelps Lake (Table 1). The total number of visitor tracks collected during periods of high use varied from 23 at Emerald Lake to 113 at Phelps Lake (Table 1). The final sample size for each dataset is a reflection of overall sampling effort at each study location and well as a reflection of the amount of visitor use that occurs at each recreation destination.

3.2. Differences in overall dispersion

There was not a statistically significant difference in overall visitor dispersion in response to visitor use level observed at the summit of Mt Evans ($t\,(145) = -0.0007$, $p = 0.999$), the summit of Mt. Bierstadt ($t\,(183) = -0.6409$, $p = 0.522$), in Tuolumne Meadows ($t\,(18) = 0.4373$, $p = 0.667$), or at Emerald Lake ($t\,(17) = 0.0401$, $p = 0.968$) (Fig. 2). At all of these recreation destinations, no difference was found between the average Euclidean distance from the median center point of the High Load Points and the Low Load Points.

For Mt. Evans, Mt. Bierstadt, and Tuolumne Meadows the size (in meters squared), shape, and location of the standard deviational ellipse were visually similar for both High Load Points and Low Load Points. The spatial location of the median center point for the High Load Points and Low Load Points was also very similar for these three locations. In the case of Tuolumne Meadows, the two median center points were located in the exact same location.

At Emerald Lake, although there was no difference found between the average Euclidean distance from the median center point for the High Load Points and the Low Load Points, the location, size and shape of the standard deviational ellipse differed visually. During periods of low use, visitors tended to disperse more to the north of the designated trail. More “outlier” visitor behavior, where a few visitors traveled unusually far from the median, occurred during periods of low use. During periods of high use, visitors tended to disperse more to the south of the designated trail.

At El Capitan Meadow ($t\,(27) = -2.874$, $p = 0.008$), Alberta Falls ($t\,(79) = 2.8685$, $p = 0.005$), and Phelps Lake ($t\,(204) = -2.1907$, $p = 0.029$), a statistically significant difference was found in average dispersion away from the median center point between the High Load Points and the Low Load Points (Fig. 2). At El Capitan Meadow and Phelps Lake visitors tended to disperse less during periods of high visitor use; contrary to conventional thinking about how visitors react to crowding. In other words, GPS-tracked visitors tended to cluster more at these sites when there were other visitors present at the recreation destination. At El Capitan Meadow and Phelps Lake, visitors disperse more overall during periods of low visitor use. Meaning, when there were potentially fewer other visitors around, GPS-tracked visitors tended to wander farther overall. However, at Alberta Falls, the opposite trend was observed with visitors dispersing more during periods of high use as compared to periods of low use. Visitor dispersion at Alberta Falls is more in-line with current assumptions about how visitors behave in response to visitor use.

The median center point locations as well as the geometry of the standard deviational ellipses also indicate differences in dispersion at different use levels at El Captain Meadow, Alberta Falls, and Phelps Lake. At El Capitan, the High Load and Low Load median center points were in different locations within the meadow boundary and the size, shape, and orientation of the standard deviational ellipses differed (Fig. 3). The standard deviational ellipse for the Low Load Points was larger than the standard deviational ellipse of the High Load Points. At Phelps Lake, the standard deviational ellipses were of similar size and orientation but the median center points were in different locations along the lakeshore. The standard deviational ellipses were also of similar geometry and orientation at Alberta Falls, but like Phelps Lake, the median center points were in different locations.

3.3. Differences in dispersion from hardened surfaces

As with the overall dispersion analysis, there was no statistically significant difference in visitor dispersion away from hardened surfaces in response to visitor use level observed at the summit of Mt. Bierstadt ($t\,(119) = 0.2529$, $p = 0.800$), in Tuolumne Meadows ($t\,(46) = 1.8439$, $p = 0.071$), in El Capitan Meadows ($t\,(114) = -0.0417$, $p = 0.966$), at Alberta Falls ($t\,(65) = -0.0262$, $p = 0.979$), or at Emerald Lake ($t\,(21) = -0.2155$, $p = 0.831$) (Fig. 4). Mt. Evans was not included in the analysis of dispersion from hardened surfaces as accurate trail layers were not available. The only site where the average Euclidean distance dispersed off of hardened surfaces varied with use levels was at Phelps Lake ($t\,(201) = -2.1155$,

$p = 0.036$). During periods of low visitor use, GPS-tracked visitors dispersed farther from hardened surfaces than during periods of high visitor use.

The total distances that visitors dispersed from hardened surfaces and into off-trail areas varied by study site and was influenced by the size and location of the study site. The greatest dispersion distances were observed in the two meadow recreation destinations, Tuolumne and El Capitan Meadow. Visitors also dispersed an average of approximately 35 m away from the designated trail at Alberta Falls. At Mt. Bierstadt and Emerald Lake, visitors dispersed an average of approximately 8–9 m away from designated trails. The lowest dispersion distance off of hardened surfaces was observed at Phelps Lake. Phelps Lake was the only site which contained hardened visitor sites in addition to hardened trails, with visitors on average dispersing approximately 4–5 m off of these hardened areas.

4. Discussion

4.1. Overall findings

Results from this study indicate that: 1) visitor spatial behavior in off-trail areas does vary with visitor use level in some recreation settings, 2) visitor spatial behavior can vary in ways that are contrary to what is currently assumed in the literature, and 3) visitor spatial behavior in response to use level varies in ways that are ecologically important. Each of these points will be discussed in greater detail results and the management implications of these findings will be discussed.

4.2. Visitor behavior: use levels and recreation sites

Whether or not visitor behavior varies with use level is dependent on the recreation location (Fig. 5). Overall dispersion, as measured and analyzed in this study, serves as an indicator of how visitors respond spatially to the social setting at the recreation destination (the presence of other visitors around them). Measures of dispersion away from hardened surfaces indicates how visitors respond to one component of the managerial setting of the recreation destination. Our results suggest that visitor use level does not influence how far visitors travel off-trail into areas of disperse use. However, once off-trail in some recreation settings, visitor dispersion appears to be influenced by visitor use level.

Overall visitor dispersion and dispersion away from hardened surfaces did not vary with use level at Tuolumne Meadows, Mt. Evans, Mt. Bierstadt, or at Emerald Lake. At Emerald Lake, although differences in dispersion were not statistically significant the standard deviational ellipses suggest the direction that visitors disperse may vary with use level. At El Capitan Meadow, Alberta Falls, and Phelps Lake overall visitor dispersion varied with use levels. Dispersion away from hardened surfaces only varied with use levels at Phelps Lake; the site with the highest level of management action related to hardened surfaces.

More generally, the recreation destinations where visitor behavior did not vary with use levels were one of the two meadow locations and the two mountain summit locations. The destinations where visitor behavior did vary with use levels could all be considered "view sites" or destinations that had a single feature that was the attraction point for visitors. At El Capitan Meadow many visitors went to the meadow to view and photograph El Capitan. At Alberta Falls, visitors were drawn to the destination to view and photograph the falls. At Emerald Lake, visitors are drawn to the lake shore and the views of nearby mountain summits. At Phelps Lake, the southern shore provides one of the best views of the lake and associated canyons.

4.3. Implications of observed spatial behaviors

The patterns of dispersion observed in this study are contradictory to the current assumptions of visitor spatial behavior held in both simulation modeling efforts and the recreation ecology literature. Current simulation modeling efforts assume that visitor use is constant in space (Lawson et al., 2003). Results from this study indicate that this assumption is only valid for some recreation settings such as mountain summits and some meadow locations. At the lakeshore and view sites examined in this study, visitor behavior varied with use level. Simulation models that are modeling visitor behavior at lakeshores or viewsites may be building models that are inaccurate representations of visitor behavior at these recreation destinations. The level of importance of this inaccuracy will depend on the management questions being examined in the simulation model.

Unlike in simulation modeling, conventional thinking in recreation ecology and parks and protected area management assumes that visitor use is not constant. The assumption has been that as visitor use increases and recreation destinations become more crowded with visitors, visitor use will spread out (Cole, 1994). As visitor use disperses, then the extent of potential ecological change increases. At only one site in this study, Alberta Falls, were visitors observed to disperse more at levels of high visitor use. At all other sites, visitor dispersion either did not change in response to use level or the opposite pattern was observed. A more complete understanding of the relationship between visitor use level and visitor behavior will help recreation ecologists and managers better predict the potential for resource change under varying use scenarios.

In this study, we were only examining the influence of visitor use levels on visitor behavior. However, other social factors not examined in this study could also be influencing the spatial patterns observed or could help further explain these spatial patterns. Social science surveys could help clarify what social factors (visitor motivations, social norms, demographics, behavior of other visitors, etc.) are important drivers of visitor dispersion. Pairing GPS-based visitor behavior data with survey data would provide a means of understanding not only how people move spatially but why visitors behave the way they do and what ecological and/or managerial aspects of the environment are driving their behavior.

4.4. Visitor behavior and ecological significance

Visitor use is arguably the most studied factor influencing ecological change (Monz et al., 2013). The relationship between the level of visitor use and the amount of ecological change is characterized by various models, but is often described as a curvilinear response, i.e., that low levels of use cause a disproportionate amount of resource change in a given area. At high use levels there is proportionally less impact as compared to initial disturbance. Overall, the use-impact relationship indicates that initial disturbance in undisturbed sites causes proportionally more resource change. Results from this study indicate that at certain recreation locations, low use may have the potential to lead to increases in the spatial extent of ecological change. At low use levels, as visitors tend to disperse more overall, visitors may be more likely to enter previously undisturbed areas.

And although, at some sites, the differences observed in visitor behavior may appear relatively small in positional space (Fig. 3), these differences may be important at the ecological scale. There is potential to combine these results with ecological data that describes current resource conditions and the ecology of the site in a way that is predictive in nature. The findings from this study suggest that visitor behavior is an important driver of ecological change but that the amount of impact that may result from visitor behavior is site-specific. Combining spatial behavior assessments, like those presented here, with ecological data—such as vegetation susceptibility—would create a social-ecological model of recreation use. This model could then clarify the ecological significance of the differences of visitor dispersion in response to visitor use level that are observed in this study. A social-ecological model of recreation use could not only inform management actions but also potentially provide insight into the use-impact relationship.

4.5. Management implications and modeling efforts

Whether or not visitors disperse under different use levels appears to be dependent on the managerial conditions of the study site. At some recreation destinations current management and simulation modeling assumptions were supported but at other recreation destinations these assumptions were violated. Visitor behavior is not uniform in time and space, even at a single recreation destination, but from these findings some reasonable generalizations can be made and incorporated into future simulation modeling efforts and management strategies. Identifying the type of recreation destination, level of management action at the destination, and the obviousness of the activities afforded by that location can help managers and simulation modelers predict how visitor spatial behavior may vary with use level at that site. Further studies could examine the most effective management actions for reducing undesirable ecological change by reducing visitor dispersion in response to use level.

Another important implication of this work is that visitor behavior may be more important than visitor use numbers when managing for ecological change. For example, at El Capitan Meadow, visitors dispersed less at high use levels. This pattern indicates that El Capitan Meadow could potentially have increased off-trail use without increasing ecological impacts as long as visitors continue to disperse less at these high use levels. Therefore, management efforts that focus on encouraging low-impact visitor behavior (such as educational programs like Leave No Trace) may be effective at preventing or mitigating resource change. In some recreation scenarios, indirect management techniques like education could be more influential in protecting ecological resources in off-trail areas than managing visitor numbers in those same areas.

5. Conclusions

Overall the findings from this study show that, in terms of ecological change, visitor spatial behavior may be a more important driver than the levels of visitor use. Certain recreation destinations may be able to support high levels of visitor use without an increase in the extent or level of ecological change in off-trail areas. Additionally, the factors that influence the level of resource change at a recreation destination may be interrelated and feedback on one another. This study represents a first step at exploring the influence of social and managerial factors on visitor behavior in disperse use areas. Findings from studies examining patterns of visitor behavior and their interrelatedness with other drivers of resource change can be incorporated into ecological modeling efforts that predict where and to what extent resource change may occur in off-trail areas.

Future studies including additional types of recreation destinations are needed to solidify these generalizations and clarify the role and importance of environmental and managerial setting characteristics and normative responses in driving visitor behavior. Social science surveys could also help identify other mitigating factors influencing these patterns of behavior and explain the spatial patterns observed in this study. The combined use of indirect and direct measurement techniques, especially GPS tracking, allows for the exploration of the interrelatedness of the factors that influence ecological change (Beeco and Brown, 2013). A better understanding of how visitors behave in off-trail areas can help managers, recreation ecologists, and simulation modelers make more accurate predictions about the potential for undesirable ecological change to occur at a recreation destination.

Acknowledgments

The authors are grateful to the S.J. and Jessie E. Quinney Foundation, Yosemite National Park, Rocky Mountain National Park, Grand Teton National Park, Arapaho–Roosevelt National Forest, and the Utah Agricultural Experiment Station for providing the funding for this research. The authors thank Steve Lawson and Brett Kiser from Research Systems Group, Inc, as well as Todd Newburger from Yosemite National Park for providing some of the data used in this paper. Special thanks to Annie Weiler and the numerous other field technicians who assisted with data collection on these projects.

References

Arnberger, A., Haider, W., Brandenburg, C., 2005. Evaluating visitor-monitoring techniques: a comparison of counting and video observation data. Environ. Manag. 36, 317–327.

Beeco, J.A., Brown, G., 2013. Integrating space, spatial tools, and spatial analysis into the human dimensions of parks and outdoor recreation. Appl. Geogr. 38, 76–85.

Beeco, J.A., Hallo, J.C., Brownlee, M.T., 2014. GPS visitor tracking and recreation suitability mapping: tools for understanding and managing visitor use. Landsc. Urban Plan. 127, 136–145.

Cessford, G.R., Muhar, A., 2003. Monitoring options for visitor numbers in national parks and natural areas. J. Nat. Conserv. 11, 240–250.

Cole, D.N., 1994. Backcountry impact management: lessons from research. Trends 31, 10–14.

Cole, D.N., 2008. Ecological impacts of wilderness recreation and their management. In: Dawson, C.P., Hendee, J.C. (Eds.), Wilderness Management: Stewardship and Protection of Resources and Values, fourth ed. Fulcrum Press, Golden, pp. 395–438.

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. J. Park Recreat. Adm. 28, 42–60.

D'Antonio, A., Monz, C., Newman, P., Lawson, S., Taff, D., 2013. Enhancing the utility of visitor impact assessment in parks and protected areas: a combined social–ecological approach. J. Environ. Manag. 124, 72–81.

Gimblett, H.R., Skov-Petersen, H., 2008. Monitoring, Simulation, and Management of Visitor Landscapes. University of Arizona Press, Tucson.

Hallo, J.C., Manning, R.E., Valliere, W., Budruk, M., 2005. A case study comparison of visitor self-reported and GPS recorded travel routes. In: Proceedings of the 2004 Northeastern Recreation Research Symposium. US Department of Agriculture, Forest Service, Northeastern Research Station, Newtown Square, pp. 172–177.

Hallo, J.C., Beeco, J.A., Goetcheus, C., McGee, J., McGehee, N.G., Norman, W.C., 2012. GPS as a method for assessing spatial and temporal use distributions of nature-based tourists. J. Travel Res. 51, 591–606.

Hammitt, W.E., Cole, D.N., Monz, C.A., 2015. Wildland Recreation: Ecology and Management. John Wiley & Sons, Hoboken.

Kidd, A., Monz, C., D'Antonio, A., Manning, R.E., Reigner, N., Goonan, K., Jacobi, C., 2015. The effects of minimum impact education on visitor behavior: an experimental investigation using GPS-based tracking. J. Environ. Manag. 162, 53–62.

Lawson, S.R., Manning, R.E., Valliere, W.A., Wang, B., 2003. Proactive monitoring and adaptive management of social carrying capacity in Arches National Park: an application of computer simulation modeling. J. Environ. Manag. 68, 305–313.

Manning, R.E., 2010. Studies in Outdoor Recreation: Search and Research for Satisfaction. Oregon State Univ. Press, Corvallis.

Marion, J.L., Leung, Y.F., 2011. Indicators and protocols for monitoring impacts of formal and informal trails in protected areas. J. Tour. Leis. Stud. 17, 215–236.

Monz, C.A., Marion, J.L., Goonan, K.A., Manning, R.E., Wimpey, J., Carr, C., 2010. Assessment and monitoring of recreation impacts and resource conditions on mountain summits: examples from the Northern Forest, USA. Mt. Res. Dev. 30, 332–343.

Monz, C.A., D'Antonio, A., Newburger, T., 2012. Yosemite National Park Meadows Environments Visitor Tracking Study. National Park Service Report. Utah State University, Logan, UT.

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. Front. Ecol. Environ. 11, 441–446.

Monz, C.A., D'Antonio, A., Hesslip, K., 2014. Moose-Wilson Corridor Use Levels,

Types, Patterns, and Impacts in Grand Teton National Park. National Park Service Technical Report. Utah State University, Logan, UT.
National Park Service, 2015a. Visitor Use Data. Available from: https://irma.nps.gov/Stats/.
National Park Service, 2015b. Yosemite National Park Meadows. Available from: http://www.nps.gov/yose/naturescience/meadows.htm.
Newman, P., Lawson, S., Monz, C., 2010. Integrated Approach to Transportation and Visitor Use Management at Rocky Mountain National Park. National Park Service Report, Estes Park, CO, pp. 72–105.
Park, L.O., Manning, R.E., Marion, J.L., Lawson, S.R., Jacobi, C., 2008. Managing visitor impacts in parks: a multi-method study of the effectiveness of alternative management practices. J. Park Recreat. Adm. 26, 97–121.
Pettebone, D., Newman, P., Theobald, D.M., 2009. A comparison of sampling designs for monitoring recreational trail impacts in Rocky Mountain National Park. Environ. Manag. 43, 523–532.
Pickering, C.M., 2010. Ten factors that affect the severity of environmental impacts of visitors in protected areas. Ambio 39, 70–77.
Resource Systems Group Inc, 2013a. ARNF Transportation System Alternative Study: Summary of Data Findings. Mount Evans Recreation Area, Summer 2012. Technical Memo 3.2.
Resource Systems Group Inc, 2013b. ARNF Transportation System Alternative Study: Summary of Data Findings. Guanella Pass Scenic Byway, Summer 2012. Technical Memo 3.3.
Taczanowska, K., González, L.M., Garcia-Massó, X., Muhar, A., Brandenburg, C., Toca-Herrera, J.L., 2014. Evaluating the structure and use of hiking trails in recreational areas using a mixed GPS tracking and graph theory approach. Appl. Geogr. 55, 184–192.
USDA Forest Service, 2014. Mount Evans Wilderness. Available from: http://www.fs.usda.gov/recarea/psicc/recarea/?recid=80756.
Walden-Schreiner, C., Leung, Y.F., 2013. Spatially characterizing visitor use and its association with informal trails in Yosemite valley meadows. Environ. Manag. 52, 163–178.
Wang, B., Manning, R.E., 1999. Computer simulation modeling for recreation management: a study on carriage road use in Acadia National Park, Maine, USA. Environ. Manag. 23, 193–203.
Watson, A.E., Cole, D.N., Turner, D.L., Reynolds, P.S., 2000. Wilderness Recreation Use Estimation: a Handbook of Methods and Systems. USDA Forest Service General Technical Report RMRS-GTR-56. Rocky Mountain Research Station, Ogden, UT.
Wimpey, J., Marion, J.L., 2010. The influence of use, environmental and managerial factors on the width of recreational trails. J. Environ. Manag. 91, 2028–2037.
Wolf, I.D., Hagenloh, G., Croft, D.B., 2012. Visitor monitoring along roads and hiking trails: how to determine usage levels in tourist sites. Tour. Manag. 33, 16–28.