GPS-based measurements of backcountry visitors in parks and protected areas: Examples of methods and applications from three...
GPS-Based Measurements of Backcountry Visitors in Parks and Protected Areas: Examples of Methods and Applications from Three Case Studies

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EXECUTIVE SUMMARY: Understanding the spatial pattern of visitor use in parks is essential for protecting park resources and visitor experiences. Information on the specific locations and intensity of use can provide an important “early warning” of locations of potential visitor resource impact and of times and places where visitor density is suggestive of crowding and other experience issues. Past studies have traditionally used techniques such as automated visitor counters, observational methodologies, and survey techniques to gain an understanding of the spatial component of visitor use behavior and of visitor use intensity. However, these methods have various limitations including logistical considerations and the reliability and accuracy of the techniques. This research reports on recent methodological advances in three studies where global positioning system (GPS) tracking methodologies was used to determine the locations and densities of visitor use along trail corridors. GPS-based methods were used in the Tuolumne Meadows trail system of Yosemite National Park to understand visitor use at this popular hiking destination, within the Bear Lake Corridor of Rocky Mountain National Park to examine the spatial patterns of visitor use, and in the Teton Range to measure the frequency, timing, and intensity of winter backcountry recreation. Findings from these studies suggest that GPS tracking methodology holds significant promise. GPS-based methods can be used to gather both spatial and temporal information about visitors in a variety of protected area management situations. The data resulting from GPS strategies are ample, detailed, and more accurate spatially than data collected using traditional methodologies. GPS tracking methodology has the potential to be combined with other data sources, such as visitor surveys and recreation ecology assessments, to provide an important use-related context to these approaches. Overall, GPS tracking can be used to gain information vital to the understanding of several contemporary
issues in protected area management such as visitor experience and natural resource impacts, visitor-wildlife concerns, and visitor soundscape experiences.

KEYWORDS: Global positioning system, visitor use patterns, visitor behavior, visitor use estimation, recreation management

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Participation in outdoor recreation and visitation to parks and protected areas has increased over recent decades in the United States (Cordell, 2008) and worldwide (De Lacy & Whitmore, 2006). As the number of visitors to parks and protected areas increases, there is potential for the expansion and proliferation of recreation resource impact and diminished visitor experience (Hammit & Cole, 1998; Manning, 1999). From a resource perspective, the extent of impact is influenced by the type, amount, location, and spatial and temporal distribution of visitor use (Hammit & Cole, 1998; Newsome, Moore, & Dowling, 2002; Monz, Cole, Marion, & Leung, 2010). As such, managers often find it useful to understand several attributes of visitor use including the number of visitors in an area or system, spatial patterns of visitor use, and visitor behavior as possible “early warnings” of resource change. Similar strategies can be employed from a visitor experience perspective, as understanding use is suggestive of issues of crowding and diminished visitor experiences. Managers can also utilize information related to visitor use to better understand the relationship between impact and use, understand trends, assign priorities for management action and facility development, and as input for statistical and simulation models of visitor use (Lawson, 2006; Leonard, Echelberger, Plumley, & Van Meter, 1980). A thorough understanding of visitor use levels and patterns can contribute to a more complete understanding of many important issues in protected area management involving visitor experience and resource protection priorities.

Past research examining visitor use has focused primarily on estimating use levels. Developed approaches can be categorized as self-counting methods, direct-count methods, and indirect-count methods (Hollenhorst, Whisman, & Ewert, 1992; Watson, Cole, Turner, & Reynolds, 2000). The earliest counting techniques used by managers of parks and protected areas were self-counting techniques such as voluntary registration, self-issued
permits, and, in some locations, mandatory permits (Wenger & Gregerson, 1964; Wag, 1969; James, 1971; Hendee & Lucas, 1973; Hollenhorst et al., 1992). However, self-counting techniques are subject to inaccuracies due to noncompliance by visitors and, in order to accurately estimate use, managers must make adjustments for noncompliance and calibrate accordingly (Thorsell, 1967; Echelberger, Leonard, & Plumley, 1981; Leatherberry & Lime, 1981). Self-registration and self-issued or mandatory permits are often best used in areas where access to lands is restricted (Muhar, Arnberger, & Brandenburg, 2000). The information collected from self-counting techniques is useful but often lacks descriptive information such as visitor use patterns, visitor characteristics, motivations, and behavior.

Direct counting methods such as observational techniques and surveys can provide managers with use estimations as well as more detailed information related to visitor use patterns and behavior. Observational techniques, whether roaming or stationary, have the advantage of being unobtrusive and demand no time on visitors (Schreuder, Tyre, & James, 1975; Hollenhorst et al., 1992; Schaick & van der Spek, 2008). However, these methodologies are time consuming for staff and are subject to a variety of accuracy issues (Arnberger, Haider, & Brandenburg, 2005). Observational data are frequently dependent on the training of a large team of technicians, and the accuracy of results relies on inter-observer reliability (Park, Manning, Marion, Lawson, & Jacobi, 2008). Observational studies provide visual interpretations of visitor behavior and thus lack non-visual demographical data and detailed information related to visitor itineraries or motivations (Shoval & Issacson, 2007).

Survey techniques, however, can provide some of this lacking information regarding visitor use patterns, demographics, detailed itineraries, and visitor motivations (James & Harper, 1965; Kovacs, 1970). Surveys are particularly useful in situations of dispersed visitor use where observational techniques may not be feasible (Cushwa & McGimmes, 1963; James & Henley 1968; Hollenhorst et al., 1992). However, survey methodology demands a significant time investment from visitors and is susceptible to issues of accuracy (Hallo, Manning, Valliere, & Budruk, 2005). Often surveys examining visitor use patterns will require participants to recall characteristics of their visit, introducing opportunities for inaccuracies and biased results (Park et al., 2008). Visitor diaries may reduce issues of recall bias but require an even higher demand on visitor time than other survey techniques (Shoval & Issacon, 2007). Finally, the data entry and analysis resulting from survey-based studies can be extremely time consuming and tedious (Hallo et al., 2005).

As automated technology for counting visitors became available in the late 1960s, indirect-counting techniques became widely used in parks and protected areas to estimate visitor use levels. Indirect-counting techniques include pressure plates, automatic trail counters using photoelectric technology, and electronic vehicle counters (James & Ripley, 1963; Leonard et al., 1980; Hollenhorst et al., 1992). The use of automated counters is commonplace as they are relatively inexpensive and easy to set up and maintain (Watson et al., 2000). Recent technological advances in dual and array passive infrared technology have allowed automatic trail counters to collect information related to visitor use patterns, such as speed and direction, as well as use estimates. However, these counters are expensive and can be sensitive to temperature changes in the environment (Greene-Roesel, Diogenes, Ragland, & Lindau, 2008). While the data from counters are clearly useful, even with technological advances, counters alone cannot provide specifics such as visitor demographics or specific visitor itineraries (Arrowsmith & Chhetri, 2003; O’Connor, Zerger, & Itami, 2005). Visitor counter methodology is also subject to confounding factors such as accuracy, calibration, and battery life (Pettebone, 2009).

In order for managers to make the most informed management actions, detailed, specific information about both visitor use intensity and patterns is required. Moreover,
many contemporary issues in protected area management are more thoroughly understood with a detailed examination of visitor use patterns. Although self-counting, direct-counting, and indirect-counting approaches can provide useful information to managers, research using global positioning system (GPS) technology has shown significant promise in providing more detailed data from which to examine visitor use patterns and intensity, as well as visitor flows and densities (Hallo et al., 2005; O’Connor et al., 2000). Recent studies have used GPS tracking methodologies to collect information on the spatial extent, patterns, and intensity of visitor use (Lai, Li, Chan, & Kwong, 2007; Ligtenburg, van Marwijk, Moelans, & Kuijpers, 2008). These studies indicate that the information collected using GPS-based technology is more accurate, more detailed, and more robust than data collected from traditional methodologies (Hallo et al., 2005). Compared to observational and survey techniques, GPS-based methodologies require minimal time demands on the visitor and less training of staff for data collection (Hallo et al., 2005).

GPS-based approaches can also provide data that has been heretofore difficult to collect. First, in many protected area situations, visitors departing from designated trails and sites are of increasing management concern. Short of observational studies, no techniques are readily available to determine the spatial extent and duration of off-trail use. GPS-based measurements provide results with enough detail to examine relatively small-scale visitor movements both on and off-trail. Second, precise information about visitor use levels and patterns is helpful in developing and validating computer models that are becoming a more common tool to identify visitor flows in parks and protected areas (e.g., Lawson, 2006). These data have traditionally been measured via survey methods, which have limited spatial and temporal precision due to recall bias and limits to visitors’ knowledge of areas studied. GPS approaches can be used to collect modeling inputs and have the potential to be more reliable and accurate data sources.

This study reports on the development of GPS-based measurements of visitor use patterns through the examination of three case studies that utilized GPS tracking methodologies; a visitor tracking study in Yosemite National Park, a day-use visitor tracking study in the Bear Lake Corridor of Rocky Mountain National Park, and a winter recreation study in the Teton Range of Wyoming. In the course of these investigations, we conducted extensive tracking of visitors via random sampling at trailheads in each study area and developed accuracy-checking procedures to minimize positional errors associated with the current, available GPS technology. Our goal in this paper is to illustrate the utility of GPS tracking as a means of gaining further understanding of several important protected area management issues.

**Method**

**Study Areas**

**Yosemite National Park.** Yosemite National Park (YNP) is located in the Sierra Nevada range of California approximately 240 km east of the San Francisco Bay area. As one of the most visited parks in the United States, YNP receives over 3.5 million visitors annually (National Park Service, 2009). While the majority of park use is concentrated in Yosemite Valley, the Tuolumne Meadows area of the park offers visitors opportunities for day hiking, backpacking, rock climbing, and fishing in an alpine environment. Trailheads in the Tuolumne Meadows area of the park provide access to vast areas of congressionally designated Wilderness and are accessed via Tioga Road, which is a National Scenic Byway.

The National Park Service is conducting transportation and visitor use planning activities throughout the park, including collecting information to understand relationships among vehicle traffic volumes, visitor use levels in locations throughout the park, the
quality of visitors’ experiences, and park resource conditions. To support park planning, GPS-based tracking data were collected during summer 2009 to measure visitor use patterns in Tuolumne. Specifically, research technicians were stationed at five trailheads along Tioga Road and recruited visitor groups to participate in the study (see Figure 1). In addition, infrared trail counters were installed at each of the five trailhead locations to measure daily trailhead visitation.

**Rocky Mountain National Park.** Rocky Mountain National Park (RMNP) is located in north central Colorado, approximately 160 km from the Denver metropolitan area. RMNP receives over 3 million visitors per year (National Park Service, 2009). One of the most popular destinations within RMNP is the Bear Lake Road Corridor, which provides access to many alpine lakes and is a popular destination for day users, backpackers, and boulderers. In 1998, due to the high level of use in the Bear Lake Road Corridor, RMNP created a shuttle bus system to service the area (Gamble, Lawson, Monz, & Newman, 2007). Ridership on the shuttle bus to the Bear Lake Road Corridor has increased substantially since its installment, resulting in apparent increased visitation to hiking destinations in this corridor.

GPS-based tracking methodologies were performed at three trailheads served by the shuttle bus in the Bear Lake Road Corridor; Bear Lake, Glacier Gorge, and Bierstadt Lake. Participants in the study were asked to complete an optional survey at the end of their hike that gathered information on crowding and visitor behavior in response to crowding.

**The Teton Range.** Grand Teton National Park (GTNP) receives 2.5 million visitors annually and is located in Northwestern Wyoming bordered by Yellowstone National Park and two National Forest Service units. To the east and south of GTNP is the Bridger-Teton National Forest (BTNF) and to the west of GTNP is the Caribou-Targhee National Forest (CTNF).

The Teton Range supports the smallest native bighorn sheep population in Wyoming. Due to anthropogenic disturbance at lower elevations, the Teton Range bighorn sheep (Ovis canadensis) herd resides year-round at high elevation in the Teton Range (Kauffman & Courtemanch, 2009). Although nearly all of the bighorn sheep winter range falls within designated Wilderness, where motorized recreation is prohibited, non-motorized recreation such as backcountry skiing is popular. Participation in backcountry skiing is rapidly increasing in the Teton Range and has the potential to influence bighorn sheep winter habitat use patterns (Kauffman & Courtemanch, 2009).

Trail counter and GPS-based tracking data were collected at seven popular backcountry access points in the Teton Range from January to April of the 2009 winter recreation season. These access points included three backcountry gates at Jackson Hole Mountain Resort (where skiers enter BTNF and GNTP), Death Canyon trailhead in GTNP, Bradley-Taggart Lake trailhead in GTNP, and Teton Canyon and Grand Targhee access points to backcountry skiing in CTNF. For the purpose of this paper, we will focus on the visitor tracking data collected at the Death Canyon and Bradley-Taggart Lake trailheads in GTNP (see Figure 2).

**GPS-Based Data Collection and Data Analysis**

In all three case studies, GPS data on visitor routes were recorded using recreation-grade Garmin GPS 60 units (Table 1). GPS 60 models have 28 hours of battery life, storage of 1MB, and are Wide Area Augmentation System (WAAS) enabled allowing for signal corrections and improved real-time accuracy. Each Garmin GPS 60 model costs approximately $190, can store track logs up to 10,000 points, and is cited by the manufacture as having a positional accuracy of within 15 meters 95% of the time (Garmin Ltd., 2010). Visitors were randomly intercepted at each trailhead according to a sampling
protocol of random days stratified by time of day and weekend and weekdays. All visitors were asked to voluntarily participate and only day use visitors were sampled. One GPS unit was given to a volunteer in each group and the visitor was asked to carry the unit clipped on to the outside of their pack for the duration of their hike or ski. The GPS unit recorded location points at 15-second intervals in YNP and RMNP or 5-second intervals in GTNP. A shorter time interval was used in GTNP to account for skiers’ greater speed of travel as compared to the hikers tracked in YNP and RMNP. The units were returned at the end of the visitor’s trip to technicians positioned at all possible exit trailheads. In the case of trailheads in the GTNP, the GPS units could also be returned to a labeled drop box found at all possible exit trailheads.

No units were broken, lost, or stolen in YNP or RMNP for a return rate of 100%. In GTNP two of the 10 units were lost out of a total of 108 samples. Each study site varied in topography and vegetation cover, which can affect signal reception. However, overall the unique environmental conditions at each study site did not interfere significantly with data collection. In YNP, GPS tracking occurred mostly in high-elevation meadows with little canopy cover. The conditions in YNP resulted in very few missing or corrupt tracks; 199 usable tracks out of 212 total tracks collected. In RMNP, the Bear Lake Road Corridor is located in a subalpine ecosystem with dense to sparse tree cover and large cirque walls at some of the subalpine lakes. Due to the areas of dense tree cover and mountainous environment, 301 usable tracks were collected out of 350 total tracks in RMNP. In GTNP, the backcountry ski routes range in elevation from approximately 2,000 meters to 3,500 meters. The majority of backcountry skiing occurs on the east slope of the Teton Range, which is characterized by steep, open slopes and deep canyons. At low elevations, there is significant conifer cover in many areas, but the cover did not affect GPS unit satellite reception. Occasionally, GPS units missed locations while visitors were travelling in very deep, narrow canyons. In GTNP, most problems that occurred with GPS reception was usually due to visitors moving GPS units to inside their backpacks during their trip or problems with low batteries due to colder conditions.

To account for any possible site-specific, positional error associated with recreation grade GPS measures, calibration techniques were employed in RMNP and the Teton Range. Calibration also allowed for a verification of the accuracies calculated and displayed by the Garmin GPS 60, as no information on this process is available from the manufacturer due to the proprietary nature of the software. In RMNP, a sub-meter Trimble GeoXT GPS unit

<table>
<thead>
<tr>
<th>Study Site</th>
<th>Data Collection Dates</th>
<th>Number of GPS Units Used</th>
<th>Response Rate</th>
<th>Number of Visitor Tracks Collected</th>
<th>GPS Positional Error Estimate (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yosemite</td>
<td>July 2009 (10 days)</td>
<td>30</td>
<td>82%</td>
<td>199</td>
<td>N/A</td>
</tr>
<tr>
<td>Rocky Mountain</td>
<td>July - August 2008 (13 days)</td>
<td>20</td>
<td>80%</td>
<td>301</td>
<td>6.40</td>
</tr>
<tr>
<td>Grand Teton</td>
<td>January - April 2009 (27 days)</td>
<td>10</td>
<td>90%</td>
<td>108</td>
<td>3.67</td>
</tr>
</tbody>
</table>

Table 1. GPS sampling characteristics by study site.
was used to map a calibration track along the center of the designated trail at each sampled trailhead. Before each sampling day began, a randomly selected Garmin GPS 60 unit was used to record the same calibration track. Upon completion of data collection, all of the calibration tracks from Garmin GPS 60 units were compared to the high accuracy tracks assessed by the Trimble in ArcGIS software. A Euclidean distance measure (a straight line distance measure between two points) was used to determine the average positional error for each Garmin 60 GPS track. These error measures were then averaged to determine the overall positional error estimate for the Garmin GPS 60 during the sampling period (Table 1).

In the Teton Range, due to logistical differences from RMNP, a slightly different calibration technique was used. At each trailhead sampled, a high accuracy point was recorded using a Trimble GeoXT GPS unit. At the start of each sampling day, a Garmin 60 GPS unit was randomly selected and 75 points were recorded at the same location at which the calibration point was recorded. A Euclidean distance was then calculated from each point recorded by the Garmin 60 GPS units to the calibration point; these values were averaged to determine the overall positional error (Table 1). No calibration methodologies were performed in YNP due to our previous experience with the method and because the project goal was to examine visitor travel routes rather than small spatial scale visitor use issues.

The dataset resulting from GPS-based tracking methodologies is a series of point data that can then be examined in a geographic information system (GIS). When examined spatially, these data inherently combine visitor use levels and certain behavioral aspects, such as visitors pausing or congregating in one location. The data also includes additional attributes such as time, speed, and elevation. Analysis of the point data yields information on visitor densities and temporal and spatial patterns. When combined with visitor surveys and total use estimation techniques, these data provide an important and highly accurate picture of visitor use and behavior.

Visitor Use Estimation Data Collection and Data Analysis

GPS-based measures can be used to supplement traditional visitor use estimation techniques. As such, total visitor use was estimated at selected attraction sites and trailheads in YNP and RMNP using active infrared automated monitors. These devices are commonly used by researchers and park managers to monitor recreation use levels in protected natural areas because they are relatively easy to install and operate. (Bates, Wallace, & Vaske, 2007; Gracia-Longares, 2005; Pettebone, Newman, Beaton, Stack, & Gibson, 2008; Vaske & Donnelly, 2007).

Similar approaches were used in both parks. For example, in RMNP, TrailMaster™1550 active infrared monitors were deployed at seven locations in the Bear Lake area to estimate visitor use at attraction sites and trailheads. At each study site, 10 hours of direct observation data were collected to calibrate results specific to each device. Based on the calibrations for each device, seasonal, daily, and hourly visitor use was estimated for each study site. Estimates of visitor use were combined with data collected via GPS to determine spatially detailed total seasonal use along the Bear Lake trail system (Pettebone, 2009).

Results and Discussion

Spatial Aspects of Visitor Use

The GPS techniques employed in the three studies allow for the examination of spatial patterns of visitor use at a much more detailed level than is possible through observational or survey techniques. At the relatively large spatial scale of a park or management unit,
GPS-based tracking data can be mapped to show the extent of use within the system (Figures 1 and 2). For example, in YNP, visitors were tracked within the Tuolumne Meadows trail system and mapping of these data indicate the spatial extent of day use hikers originating from the Tuolumne visitor center trailheads (Figure 1). This information is relevant to managers in providing a thorough understanding of the nature of hiking use in this trail system. The detail provided by GPS-based techniques, even at a large spatial scale, is greater than that which could be provided by traditional techniques, which typically provide only total use on trail segments where they are located.

Information on the overall spatial extent of visitation is also particularly valuable in situations where the visitor use patterns are not as predictable—where most of the visitation is occurring off of a designated trail system. This is illustrated in the analysis of data collected in the GTNP study of backcountry skiers (Figure 2). Data of this kind are useful in identifying locations, densities, and temporal patterns of off-trail use and, in this case, are able to be directly compared with GPS-collared wildlife locations and habitat use patterns. GPS tracking data can be easily incorporated into statistical models as a predictor variable of wildlife distribution.

The spatial components of the backcountry skier tracks (distance of backcountry travel routes, of varying densities, to GPS-collared bighorn sheep locations) can be included, along with several additional predictor variables, into a resource selection function (RSF) modeling procedure for winter habitat use (Sawyer et al., 2006). In GTNP, visitor use data was collected concurrently with GPS-collared bighorn sheep data. In future work, the detailed location data from both bighorn sheep and backcountry visitors will allow for the determination of how various spatial and temporal patterns of backcountry skiing affect bighorn sheep winter habitat use. Winter backcountry recreation will be included as a predictor variable in the RSF (as distance to backcountry use areas of varying densities of use) to determine if bighorn sheep avoid backcountry recreation routes, even if these areas have been identified by the RSF as suitable winter habitat. Specifically, the RSF can determine if a threshold of visitor use at which bighorn sheep abandon suitable winter habitat areas exists. These modeling procedures are especially useful to wildlife managers to identify areas of potential interaction between recreationists and wildlife.

The detail associated with GPS tracking data, where positional errors can be estimated, also allows for analysis at smaller spatial scales such as destination points. In these cases, examination of particular aspects of visitor behavior, including waiting times at the destination point and examination of off-trail use may be particularly relevant to managing for visitor experience and resource protection. In the case of RMNP, the error calculated from the calibration procedures was used to create a 12.8m buffer around designated trails. All visitor points within the buffer were considered to be “on trail.” Specific points of interest can then be examined more closely to explore the details of visitor use in these dispersed-use settings. For example, in RMNP, off-trail use was examined at Alberta Falls (Figure 3). Off-trail use can be given further context when combined with GPS-recorded visitor impacts such as visitor created trails and sites. The combination of visitor-impact data and GPS tracking data can highlight how visitors are accessing off trail areas and how visitors are using areas that have already experienced resource change.

Understanding the typical spatial patterns of visitor use can inform decisions related to designated trail management. Also, by understanding spatial patterns of off-trail use, managers can evaluate the effectiveness of current management techniques to discourage off-trail use. The level of accuracy and detail provided by GPS-based measures, at both the large and small spatial scale, allows managers to identify and focus on areas of most concern for resource change and diminished visitor experience. Traditional techniques, such as observational studies and survey methodologies may not provide the same level of detail or accuracy, especially in situations of dispersed visitor use.
Figure 1. Extent of hiking use originating from trailheads in Tuolumne Meadows trail system in YNP. Stars mark trailheads where sampling occurred.
Figure 2. Extent of backcountry ski use from trailheads in GTNP. Stars make trailheads where sampling occurred.
Density Analysis

Visitor point data can be used to calculate a density of visitor tracking points. High visitor densities can be caused by overall high levels of use or by a few visitors staying in an area for an extended period of time. Visitor use density can be examined at a system-wide level to highlight areas of high use that can then be analyzed at a more detailed level (Figure 4). Once sites for further investigation are identified, a density analysis can be completed for popular hiking destinations such as Dog Lake in YNP (Figure 5). A density analysis of the visitors tracked to Dog Lake show that the highest densities of points are found where the designated trail first connects to the lake and at various spots along the edge of Dog Lake. The density analysis also shows that there is concentrated use at an area off of the designated trail on the northwest shore of Dog Lake. Managers can use density analyses to highlight areas that may be at risk for changes to resource conditions or diminished visitor experience from crowding or conflict. Further analysis can be performed using the same GPS-based tracking data to examine temporal and spatial patterns at these areas to better understand visitor behavior at these popular destinations.

Temporal Aspects of Visitor Use

GPS units record visitor location at a selected time interval. As such, the tracking data can be analyzed to better understand the temporal patterns of visitor use in an area. At the large scale, characteristics for an entire visit can be determined. For example, visitor-tracking data were used to determine the average time visitors spent in each study area (Table 2). Visitors spent the most time in the GTNP system, averaging 6 hours and 28 minutes. In YNP, the visitors tracked spent an average of 5 hours and 20 minutes in the Tuolumne Meadows trail system. While in RMNP, visitors spent an average of 2 hours and 30 minutes in the Bear Lake Road Corridor trail system. An examination of the temporal
Figure 4. Density analysis of visitor use points in the Tuolumne Meadows trail system in YNP.

<table>
<thead>
<tr>
<th>Location</th>
<th>Average Total Time in Area (h:mm)</th>
<th>Max Time in Area (h:mm)</th>
<th>Min Time in Area (h:mm)</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tuolumne Meadows (Yosemite)</td>
<td>5:20</td>
<td>11:08</td>
<td>0:29</td>
<td>2.33</td>
</tr>
<tr>
<td>Bear Lake (Rocky Mountain)</td>
<td>2:30</td>
<td>8:00</td>
<td>0:04</td>
<td>0.07</td>
</tr>
<tr>
<td>Grand Teton</td>
<td>6:28</td>
<td>13:52</td>
<td>0:32</td>
<td>2.51</td>
</tr>
</tbody>
</table>
Large-scale temporal data can also be integrated with other studies. For example, the temporal aspects of visitor hikes collected in RMNP were used in combination with a transportation noise model of the park to understand visitors' experiences of the park's soundscape. Specifically, the GPS visitor data and maps of transportation-related noise levels were analyzed spatially. GIS spatial statistics were applied to these data to estimate the amount of time and distance visitors must hike from trailheads away from the transportation corridor to experience natural sounds. Estimates were also generated for the proportion of visitors who experience at least 15 minutes of natural sounds and quiet. At the time of the study, the National Park Service had not defined a threshold for road noise, beyond which natural sounds and quiet are compromised. Thus, a range of example road noise thresholds were evaluated to estimate the proportion of visitors who experience at least 15 minutes of natural sounds and quiet. The example road noise thresholds used in the analysis include ≤25 dBA (nighttime ambient natural sound level measured in the study), ≤30 dBA and ≤35 dBA (daytime ambient natural sound levels), and ≤65 dBA (the level at which noise interferes with conversational tones).

Temporal patterns of use can also be examined at a small scale such as at specific sites of interest. In RMNP, visitors frequently travel off-trail in an area of dispersed use adjacent to Alberta Falls (Figure 2). By using the positional error calculated from calibration techniques to eliminate all on trail use from the analysis and using the temporal

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**Figure 5. Density analysis of visitor use points at Dog Lake in Tuolumne Meadows, YNP.**
data collected from the GPS units, it was determined that 46% of visitors that were tracked traveling along the Glacier Gorge trail left the designated trail adjacent to Alberta Falls and spent, on average, 17 minutes off trail. Visitor use can also be analyzed by the distance traveled from the designated trail, for example at Alberta Falls, the area of dispersed use was split into two off-trail zones; one near the designated trail and one far from the designated trail. The data resulting from this analysis can then be incorporated in modeling efforts to examine dispersed use within off trail areas.

Integration with Visitor Use Estimation and Survey Techniques

Estimates of use level are important for managers in terms of informing issues such as the potential for resource change and experiential impacts such as crowding. Automatic counter data can be combined with GPS-based measurements to gain a better understanding of visitor use for popular destinations. For example, in RMNP, automatic visitor counters were placed on the trailheads that were sampled using GPS-based methodologies. An automatic visitor counter was placed at the Bear Lake trailhead, which provides access to the Emerald Lake trail and three alpine lakes. From the GPS-based measures recorded and the visitor counters, it can be determined that 28% of visitors traveled to a destination along the Emerald Lake trail. The average seasonal use for the Bear Lake trailhead, as determined by the automated visitor counters can then be combined with the GPS-based results of travel to destinations along the Emerald Lake trail to estimate overall seasonal use patterns along the designated trail.

Strategic placement of automatic visitor counters can also be combined with GPS-based measures to determine use levels at specific areas of visitor interest or off-trail destinations. GPS-based measurements provide an additional layer of detail to traditional visitor use-estimation techniques, which can only provide an estimate of use level at the specific location of the counter mechanism. GPS-tracking methodologies can provide information regarding exactly where visitors are going and the routes that visitors are using to get to their destinations.

GPS-based tracking data can effectively provide spatial and temporal data and be used to complement automated visitor counters in use estimation, but the resulting dataset does not contain any information about visitor characteristics. However, the visitor-tracking methodologies discussed here can be combined with traditional survey techniques. In RMNP, visitors who participated in the GPS-based visitor tracking study were asked to complete a short survey following their hike. The surveys were coded so that individual GPS tracks could be linked to the visitor’s survey (Table 3). For example, Euclidean distance calculations were computed for individual visitors and the average distance that each individual traveled off of the designated trail can be calculated (Table 3). Visitors were asked whether or not they hiked off-trail to avoid feeling crowded with results showing that some visitors who answered ‘no’ to this question were recorded as traveling off-trail. The combination of survey and GPS-based techniques allows for a comparison between reported behavior by visitors and actual, measured behaviors.

It is possible that some visitors hiked off-trail for reasons other than feeling crowded and thus answered ‘no’ to this question on the survey; however, the combination of GPS-based methodology with survey techniques provides a means of combining individual visitor behavior with visitor characteristics. Survey techniques allow for the stratification of GPS-based tracking data by visitor characteristics, such as knowledge of Leave No Trace practices or activity type, and for comparisons of visitor behavior across groups. The combination of survey results with GPS-based methodology allows managers to examine visitor use patterns stratified by user group. This information could further understanding of the needs and behaviors of different groups and how to target certain user groups based on behavior.
Table 3. Survey results from randomly selected visitors at the Glacier Gorge Trailhead at RMNP.

<table>
<thead>
<tr>
<th>Visitor ID</th>
<th>Distance Visitor Traveled Off-Trail</th>
<th>Hike Off-Trail To Avoid Feeling Crowded?</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Min (m)</td>
<td>Max (m)</td>
</tr>
<tr>
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*Euclidian distance calculated to trail buffer

Conclusion

GPS-based tracking methodologies provide accurate and detailed datasets that offer information that cannot be practically collected using traditional methods for estimating visitor use. GPS methodologies are an established means of gathering spatial and behavioral information in the wildlife sciences (Bowmen, Kochanny, Demarais, & Leopold, 2000; Burger & Shaffer, 2008; Rutter, 2007) and provide very valuable information to wildlife managers. This research shows that GPS methods can be employed successfully to further understand visitor use in park and protected area management.

GPS approaches do present some challenges and limitations. Logistically, an effective methodology needs to be devised to administer and retrieve the GPS units used (Schaick & van der Spek, 2008). In complicated trail systems, to ensure a high return rate of units, it is important to have technicians or drop boxes located at all possible exit locations. Also, each unit should be labeled with instructions regarding how to return the unit in the event that the visitor cannot find a technician or drop box. The battery life and data storage of the units employed in this study is a limitation if GPS-based methodology is to be utilized in a backcountry, multi-day trip setting, but technology is being developed that will work in this situation as well (Rupf, Koechli, Haider, Skov-Petersen, & Probstl, 2010).

The issue of positional error and satellite reception can become a problem in certain environmental settings, and therefore calibration techniques can be helpful to quantify the site-specific error associated with the tracking data. Recent GPS technological advances have resulted in more sensitive, accurate handheld units such as the Garmin GPS 60Cx and GPS 60 CSx. However, the use of these updated units in GPS-based studies may be less feasible as they are more expensive than less sophisticated units and have a shorter battery life (Garmin Ltd., 2010). Regardless, as GPS technology continues to improve, calibration and accuracy issues may become less of a concern.

Data processing and analysis are also significant considerations, as the approaches illustrated require some knowledge of GIS to edit and analyze the data collected. Recently developed extensions for ArcMap (a GIS software program) allow for quick and easy importation of large numbers of GPS tracks into a GIS environment. Once in a GIS environment, a basic knowledge of ArcGIS is required for the data-cleaning process as corrupt files are easily identified and many of the analysis presented here (point density,
straight line distance calculations, time analyses) can be completed using available tools in ArcMap (Schaick & van der Spek, 2008). An overriding concern is that the approach illustrated here, particularly the density analysis, is a result of both visitor use levels and visitor behavior—high-point densities can be the result of either high total use or visitors pausing and congregating while the GPS is collecting data. These point densities were applicable for the larger social and ecological projects for which these methods were developed, but other investigators may be interested in assessing use and behavior independently. In this case, some additional methodological development is needed.

Despite these limitations, GPS-based methodologies have clear advantages and applications. The time demand on visitors is minimal and less training is required for staff to conduct a GPS-based tracking study compared to other techniques. In the case studies presented, there were low refusal rates for participation that resulted in very ample datasets being collected in a relatively short period of time. GPS technology allows for the examination of subtle visitor movements such as off-trail use that would be difficult or even impossible to measure accurately with traditional techniques. GPS-based tracking datasets contain valuable descriptive data such as time, speed, direction, and elevation and the method produces potentially less biased datasets compared to observational studies, diaries, and survey techniques. The case studies presented demonstrate just a few examples of analysis that can be conducted using GPS-based tracks. Other possible data analyses techniques include time series analysis, three-dimensional displays of density, analysis of visitor speed, and stratification of results by activity type characteristics (Schaick & van der Spek, 2008).

As demonstrated through the case studies examined in this paper, the methods presented can be implemented in a range of settings to address a variety of managerial issues or problems. There is potential for the information provided by GPS-based techniques to lead to more informed management decisions due to the high levels of accuracy and detail that cannot be practically collected using traditional methodologies. Future implementation and development of the techniques presented here can serve to expand the utility and worthiness of the GPS-based measures as an emerging technique to understand visitor use in parks and protected areas.

References


James, G. A. (1971). *Inventorying recreation use*. In proceedings from the forest recreation symposium, Syracuse, NY (78-95). Northeast Forest Experiment Station, Upper Darby, PA.


