Landscape and Urban Planning 118 (2013) 1–9

Contents lists available at SciVerse ScienceDirect

Landscape and Urban Planning

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

Research paper

A visitor use monitoring approach on the Half Dome cables to reduce crowding and inform park planning decisions in Yosemite National Park

David Pettebone[a,*], Bret Meldrum[a,1], Colin Leslie[a,2], Steven R. Lawson[b,3], Peter Newman[c,4], Nathan Reigner[d,5], Adam Gibson[e,6]

[a] Yosemite National Park, Visitor Use and Social Science Branch, Resources Management and Science Division, El Portal, CA 95318, United States
[b] Resource Systems Group Inc., 55 Railroad Row, White River Junction, VT 05001, United States
[c] Human Dimensions of Natural Resources, Colorado State University, 233 Forestry Building, Fort Collins, CO 80523, United States
[d] Rubenstein College of Natural Resources, University of Vermont, Burlington, VT 05405, United States
[e] Utah State University, 5215 Old Main Hill, Logan, UT 84322-5215, United States

HIGHLIGHTS

- Visitor use regulation and/or limits are a contentious issue on federal public lands.
- We developed empirical relationships between visitor use levels and evaluative conditions.
- Understanding of these relationships can be used to communicate with the public.

ARTICLE INFO

Article history:
Received 11 June 2012
Received in revised form 7 May 2013
Accepted 9 May 2013

Keywords:
Visitor use management
Park planning
User carrying capacity
Adaptive management

ABSTRACT

Regulating visitor access, in the form of user limits, on public lands is a contentious issue. Although visitor use limits have been instituted to manage a variety of recreation activities in national parks there is little research that has successfully demonstrated relationships between visitor use levels and evaluative conditions (e.g. visitor perceptions of crowding). The lack of empirical understanding of relationships between use levels and evaluative conditions brings into question the efficacy of use limits to achieve management objectives. This paper describes a research and monitoring program that identifies clear management objectives and definitive visitor use pattern relationships to manage visitor use on Half Dome in Yosemite National Park to inform the development of the Half Dome Trail Stewardship Plan that established a permit system to limit visitor use on and around Half Dome. Automated visitor counters were used to collect trail use level data and photographic documentation was used to collect people-at-one-time (PAOT) data on the cable route. Regression analyses yielded strong relationships between these data and show that 400 people per day significantly reduces crowded conditions and preserves unimpeded travel on the Half Dome cables. The approach and results developed in this project provide a basis for future monitoring to promote adaptive management of visitor use on Half Dome in order to ensure that management objectives related to quality visitor experiences and safety are met.
Published by Elsevier B.V.

* Corresponding author. Present address: Rocky Mountain National Park, 1000 Highway 36, Estes Park, CO 80517, United States. Tel.: +1 970 586 1321; fax: +1 970 586 3014.
E-mail addresses: david_pettebone@nps.gov (D. Pettebone), bret_meldrum@nps.gov (B. Meldrum), colin_leslie@nps.gov, coffeeclimber@gmail.com (C. Leslie), slawson@rsginc.com (S.R. Lawson), pnewman@warnercnr.colostate.edu (P. Newman), Nathan.Reigner@uvm.edu (N. Reigner), adam.gibson@usu.edu (A. Gibson).
[1] Tel.: +1 209 379 1216.
[2] Present address: Human Dimensions of Natural Resources, Colorado State University, 233 Forestry Building, Fort Collins, CO 80523, United States. Tel.: +1 707 616 7741.
[3] Tel.: +1 802 299 4999.
[4] Tel.: +1 970 491 2839.
[5] Tel.: +1 202 258 5146.
[6] Tel.: +1 435 797 3818.

0169-2046/$ – see front matter. Published by Elsevier B.V.
http://dx.doi.org/10.1016/j.landurbplan.2013.05.001

1. Introduction

Regulating visitor access, in the form of user limits, on public lands is a contentious issue. Controversy over limiting visitor use on public lands stems largely from the public's desire for access, concerns about the equitability of permitting systems, unclear rationale's about the need for use limits, and questions about the efficacy of use limits to actually achieve management goals (Arnberger & Haider, 2007; Beunen, Regnerus, & Jaarsma, 2008; McCool, 2001; Hall, 2001; Hall & Cole, 2000). Despite the contentiousness of this issue park administrators sometimes need to consider visitor use limitations as a means to manage visitor use in order to protect resources, preserve the quality of visitors' experience, and/or to fulfill legal mandates (Arnberger & Haider, 2007; Haas, 2003; McCool & Stankey, 2001).

Land managers who are considering visitor use limits require research to understand the implications and efficacies of use limits to achieve management goals. Previous research has attempted to understand how evaluative measures, such as visitor perceptions of crowding, are affected by different levels of visitor use (e.g. trail use counts) using statistical modeling with use levels as an independent variable and visitor perceptions of crowding as a dependent variable. A review of 25 studies of this nature reveals generally weak statistical relationships between these variables (Manning, 2011). Studies that have yielded stronger statistical relationships between these variables find that use levels are among a variety of variables that affect visitor perceptions of crowding including visitors' expectations and feelings (Hammit, McDonald, & Noe 1984; Heberlein & Vaske 1977), situational variables (Arnberger & Haider 2007; Tarrant & English, 1996), and temporal aspects of a visit (Arnberger & Haider 2007; Tarrant & English, 1996). The lack of empirical evidence to describe the relationship between use levels and evaluative variables, such as crowding, is a vexing problem for park managers because managers who desire to improve park visitors' experience by addressing crowded conditions have unclear guidance to achieve this goal (Tarrant & English, 1996).

Understanding the efficacy of use limits to achieve management objectives is important because use limits can be an important tool to manage user capacity. User capacity is generally defined as the type and amount of visitor use that is compatible with the management prescriptions for an area (Whitaker, Shelby, Manning, Cole, & Haas, 2011). Park planners tasked to determine user capacities need relevant and reliable information from which to consider the opportunities and constraints as well as the implications of various levels of visitor use. In particular, identifying salient variables that park managers can control is necessary to determine if management actions, such as use limits, will successfully achieve user capacity goals. However, it is rare that park managers have the data or tools to link these types of data (Tarrant & English, 1996).

The failure to define relationships between use levels and impacts can undermine support for use limitations from park administrators and also complicates communication to the public about the need for use limits (McCool, 2001). Fundamentally, the lack of empirical support about relationships between use levels and impacts leads to questions about the efficacy of use limits to actually achieve management objectives. Little work has been published that evaluates the effectiveness of use limits to meet visitor experience quality goals sought out in parks and protected areas (Manning, 2011; McCool, 2001). This lack of evaluation adds to the controversial nature of use limits and hampers the ability for park managers to learn from previous research and planning efforts related to user capacity (McCool, 2001; Freimund & Cole, 2001).

Here we describe a research and monitoring program that identifies clear management objectives and variables that park managers can control (i.e. daily trail use counts and people-at-one-time (PAOT)) to manage visitor use on Half Dome in Yosemite National Park (YNP). The approach described in this paper does not attempt to understand how visitor perceptions of evaluative variables, such as crowding, are affected by levels of visitor use (e.g. trail use counts). Rather, the goal of this approach is to operationalize a visitor use management program to maintain prescribed experiential conditions by understanding how user density (i.e. PAOT) is related to daily use levels (i.e. daily trail use counts). Specifically, this study examines how proxy variables of evaluative variables (e.g. PAOT) are related to variables that park managers can control (e.g. trail use levels) in order to provide park managers information needed to develop management strategies to maintain desired travel and social conditions on the Half Dome cable route.

This work provided YNP administrators strong empirical support needed to understand and weigh the implications of alternative management actions related to regulating visitor use during the development of the Half Dome Trail Stewardship Plan (NPS, 2012) that established a permit system to limit visitor use on and around Half Dome. Understanding relationships between daily use levels and user density and how evaluative data, such as visitor perceptions of crowding and unimpeded travel along the cable route, are related provided decision makers insights about potential management actions as well as a clear rationale to communicate with the public. Moreover, empirical understanding of relationships between visitor use levels and evaluative data are a strong base to monitor progress toward operationalizing management objectives and achieving acceptable experiential conditions, key components of adaptive management planning frameworks (Manning, 2011; NPS, 1997).

2. Background

YNP is centrally located in the Sierra Nevada mountain range in California, United States of America (USA) and protects 285,151 ha of rugged mountain terrain. YNP has some of the most spectacular scenery in the NPS and views of glacier carved valleys can be seen from many locations throughout the park. People from around the world come to experience YNP and visitation reached approximately 4 million visitors in 2010 (NPS, 2010). Half Dome is one of the most popular attraction sites in the park and in recent years upwards of 60,000 visitors attempt to summit this scenic peak annually.

The two-mile Half Dome trail which leads to the Half Dome cables is typically accessed via the Vernal Fall/Mist Trail and the other trails within the Nevada Fall Corridor, totaling to an approximately 16-mile round trip hike (Fig. 1). The cable route can also be accessed as a minor detour off the popular John Muir Trail that begins in Yosemite Valley and terminates at Mt. Whitney 215 miles to the south. A number of other trailheads within YNP may also lead hikers to the Half Dome trail. In addition, there are nearly 50 technical rock climbing routes of varying difficulty that ascend the vertical face of Half Dome as well as its more sloping shoulders and technical rock climbers typically use the Half Dome cable route to descend from the summit.

Half Dome is one of the most iconic features representing YNP and the NPS. Its signature silhouette can be found on numerous logos both regionally and internationally. Previous to the park's recent visitor use management actions, Half Dome's popularity attracts hundreds, and sometimes over one-thousand, people per day attempting to summit the peak during summer months (Lawson, Choi, Reigner, Newman, & Gibson, 2009). This high level of use is a concern to Yosemite park administrators because of potential negative effects of crowding to the visitor experience and visitor safety. Half Dome is in designated wilderness, and while there is little precedence to manage visitor use in wilderness areas based on

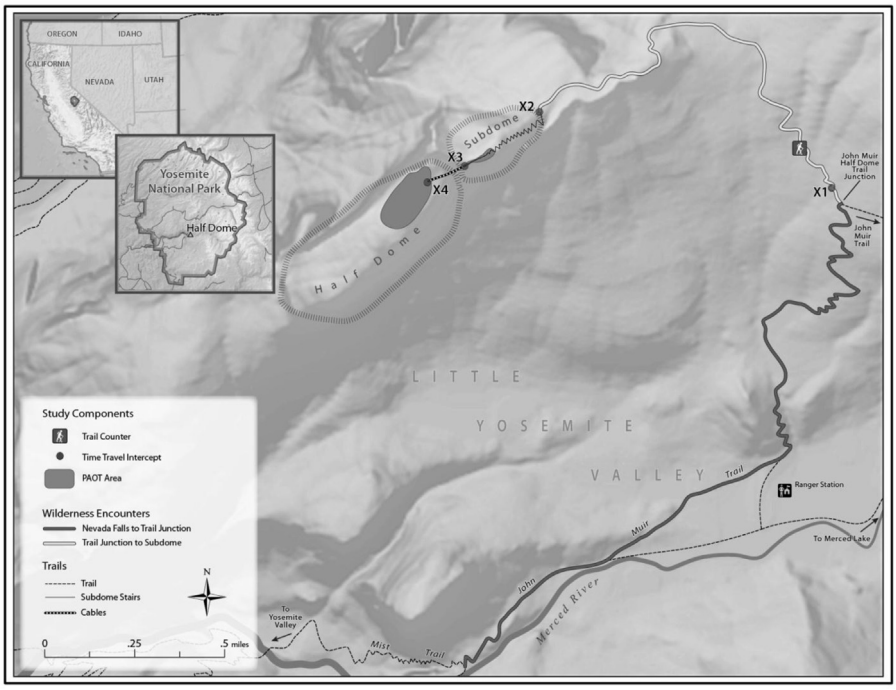

Fig. 1. Half Dome study area.

visitor safety concerns Half Dome in YNP presents a unique set of circumstances and concerns for park management.

In 1919, the Sierra Club installed the "cable route" to provide access for visitors to gain the summit of Half Dome without requiring the use of technical rock climbing equipment. The cable route consists of two parallel steel cables extending its entire length, forming a double handrail. The cables are approximately 3′ apart, are supported off the ground by steel stanchions spaced at intervals of approximately 10′, and extend approximately 600′ at an average grade of 100%. Typically, the stanchions are installed in late May when the trail is relatively free of snow and are removed in October.

Today the cable route on Half Dome is one of the most popular backcountry hikes in all of Yosemite and in recent years visitor use has increased steadily (Fig. 2). For example, in 1994 about 575 people per day attempted to summit Half Dome, and by 2008, average daily use was about 630 people per day with over 1300 people documented attempting the summit on the busiest day of the year (Lawson, Choi, et al., 2009; Lawson, Newman, Choi, Pettebone, & Meldrum, 2009). A recent visitor survey indicates that current levels of visitor use on the Half Dome cables are regularly above thresholds where visitors feel that crowded conditions negatively affect both their experiences and safety (Lawson, Choi, et al., 2009; Lawson, Newman, et al., 2009).

Park administrators are particularly concerned about safety on the cable route because many visitors come to YNP unprepared or unaware of potential hazards, some of which require assistance from NPS search and rescue (SAR) services. In 2005, Yosemite National Park (YNP) accounted for 10% of all NPS SAR operations and spent nearly $5 million dollars on SAR operations (Heggie & Amundson, 2009). High levels of use on Half Dome are a concern to Yosemite park managers because there have been five fatal falls from the cable route since 2006. Three of these falls occurred during the summer season when the cable stanchions were installed and two of the falls occurred during the winter and spring months when the stanchions were removed. Of the three summertime falls, two falls occurred during inclement weather when the granite surface of the cable route was wet and traction was at a minimum. This suggests that safety on the cable route is potentially related to weather conditions in addition to overall use levels. Weather in the Sierra Nevada mountain range can deteriorate quickly and the current high level of visitor use on Half Dome increases the chance of a catastrophic incident during a storm event. Crowded conditions on the cable route can also trigger "coping" behaviors (Hammitt, Patterson, & Michael, 1991; Nieuwenhuysm, Pijper, Oudejans, & Bakker, 2008; Shafer & Hammitt, 2009) such as visitors traveling

Fig. 2. Photograph of crowded conditions on Half Dome cable route.

outside of the cables to avoid crowded conditions and exposing themselves to greater risk of an unarrested fall (Lawson, Choi, et al., 2009; Lawson, Newman, et al., 2009).

Due to concerns for visitor safety, YNP managers developed an emergency interim system in 2010 to mitigate high levels of visitor use occurring on Saturdays and holidays, the highest levels of use documented in previous years. The design of the permit system was based on study findings from Lawson and others (2009) including: (1) on average, about 400 visitors per day hiked up the Half Dome trail on Sunday–Friday; (2) on average, about 700 visitors per day hiked up the Half Dome trail on Saturdays and holidays; (3) visitor travel on the cable route is impeded when there are more than 30 PAOT on the cable route; and (4) visitors perceive unacceptable levels of crowding when there are about 70 PAOT on the cable route. Thus, in 2010 visitors were required to obtain a permit in order to attempt to summit Half Dome via the cable route on Fridays, Saturdays, Sundays, and holidays.

Permits were required on Fridays and Sundays to account for potential temporal recreational displacement across a typical extended weekend. This allowed for both an exploration of visitor travel pattern change as a result of the permit and the least possible regulatory burden on visitors. Visitor use on Half Dome in 2008 on Sundays through Fridays was about 416 people/day and based on anecdotal evidence YNP managers estimated that 400 people attempting to summit Half Dome per day would result in no more than approximately 30 PAOT on the cable route and preserve unimpeded travel conditions. Thus, 400 Half Dome permits were issued for each Friday, Saturday, Sunday, and holiday in 2010 that the cable route was open to the public.

3. Conceptual approach

YNP researchers took a conceptual approach to monitoring visitor use conditions on the cable route steeped in logic of previous adaptive management planning frameworks (Manning, 2011; NPS, 1997). Specifically, four important steps were defined to develop monitoring methods to comprehensively inform management decisions about visitor use on the Half Dome cable route: (1) identify management objectives; (2) develop salient and quantitative variables that reflect the essence of management objectives; (3) collect data about variables of interest (i.e. proxies for management objectives); and (4) develop quantitative relationships between known visitor use levels and variables that represent management objectives to inform visitor use capacity related decisions. This framework was used to guide monitoring efforts in order to develop quantitative relationships between visitor use levels and park management objectives. Moreover, this is a hypothesis driven approach that tests for statistically significant quantitative relationships between known use levels and variables of interest. Specifically:

H_1. Daily visitor use levels on the Half Dome trail are positively correlated to PAOT on the Half Dome cable route.

H_0. Positive, quantitative relationships between visitor use levels and PAOT on the Half Dome cable route do not exist.

The outcome of this effort directly informs quantitative visitor use capacity estimation and management. Rejecting H_0 suggests quantitative relationships between visitor use levels and management objectives exist and the implications of various visitor use levels on specific management objectives can be determined. Failing to reject H_0 suggests no relationship between visitor use levels and management objectives exist and that limits to regulate visitor use may not mitigate negative impacts to management objectives. Thus, this research as a whole is a test of the efficacy of limiting visitor use as a means to address management objectives.

This approach was developed collaboratively with YNP wilderness staff, YNP social science staff, YNP compliance staff, and subject matter experts in universities and the NPS to produce the following framework from which research methods were developed. First, the objectives for managing visitor use on Half Dome are: (1) provide an environment where visitors can manage their own risk (i.e. maintain visitor use levels where travel along the cable route is not impeded by other visitors) and (2) maintain visitor use levels that are not perceived by visitors as "crowded" (Lawson, Choi, et al., 2009; Lawson, Newman, et al., 2009).

Second, PAOT on the cable route was identified by park staff and researchers as the variable that represent management objectives because research from 2008 results suggest that it can serve as a proxy for impeded and unimpeded travel and crowding on the cables (Lawson, Choi, et al., 2009; Lawson, Newman, et al., 2009). That is, below a certain PAOT threshold, visitors are generally able to move unimpeded by congestion and manage their own risk, and above that threshold, visitors become impeded by the presence of others, and consequently are less able to manage their own risk. Similarly, visitor evaluations of crowding based on various PAOT levels were determined by Lawson, Choi, et al. (2009) and Lawson, Newman, et al. (2009).

Third, data were collected during the 2008 and 2010 seasons to understand visitor use conditions before and after management actions were implemented on Half Dome, respectively. These data provided park planners clear understanding of the implications of unregulated use as well as use limits on management objectives.

Fourth, quantitative relationships between visitor use levels and conditions were estimated to determine (1) if daily trail use levels were related to use density (PAOT) conditions on Half Dome, and in turn, management objectives, and (2) how different levels of visitor use relate to management objectives. The steps outlined here provide a systematic approach to determine the efficacy of the 2010 interim permit system to provide desired management objectives.

4. Analytical approach

Two approaches have been developed to estimate relationships between visitor use levels and management objectives: computer simulation modeling and statistical modeling using regression analysis. Both approaches can be applied to a variety of different recreation settings including river rafting, overnight backcountry hiking, and day use attraction sites. Moreover, these approaches provide a robust set of information about the timing and levels of use and their relationship to various measures of crowding such as PAOT or people-per-viewscape (PPV).

Cole (2005) provides a thorough overview of computer simulation modeling, including a number of cases studies. For example, positive linear relationships were found between camp encounters per party-night and the number of party-nights in early computer simulation modeling work to inform overnight wilderness trailhead quotas (Schechter & Lucas, 1978; Van Wagtendonk, 1979). More recently computer simulation modeling has been used to estimate relationships between visitor use levels and social standards for the number of PAOT at attraction sites (estimated from on-site visitor surveys). This approach has been used in a number of national parks (NP) including Arches NP (Manning, Lime, Hof, & Freimund, 1995), Isle Royale NP (Lawson & Manning, 2003), Acadia NP (Wang & Manning, 1999), Rocky Mountain NP (Lawson et al., 2011), and YNP (Lawson, Choi, et al., 2009; Lawson, Newman, et al., 2009; Manning Valliere, Wang, Lawson, & Newman, 2003). Outputs from these simulation models are quantitative in nature and provide managers with information that integrates descriptive data (i.e. visitor use levels) with prescriptive data (i.e. evaluative data about social conditions such as crowding). However,

computer simulation modeling can be expensive, time consuming, and technically difficult to develop (Hallo & Manning, 2009).

A second but less published approach to describe relationships between use levels and variables that represent management objectives is statistical modeling using regression analysis. For example, Tombaugh and Love (1964) examined the relationship between automated traffic counter estimates and the total number of visitors in United Stated Forest Service campgrounds as estimated by field personnel. Results from correlation analyses showed strong relationships ($r = 0.807$). Similarly, Wagar and Thalheimer (1969) used traffic counts from automated vehicle counters to explain the variability in site visitation from observational sampling. More recently, Jacobi (1997) used regression analysis to develop relationships between automated monitor counts and census counts of visitor use along the Carriage Roads in Acadia NP.

Regression analysis has also been used successfully to estimate quantitative relationships between inbound vehicles and visitor use levels at attraction sites in National Park units (Lawson, Newman, et al., 2009; Pettebone, 2009). Similarly, Broom and Hall (2010) used regression analysis to estimate the number of intergroup trail encounters based on the number of visitor arrivals at a trailhead. The research presented in this paper builds on these previous studies to estimate relationships between known visitor use levels and visitor use conditions at attraction sites and along trails. For illustrative purposes, the following sections detail the sampling and statistical modeling analysis to quantitatively estimate relationships between daily trail use levels and PAOT on the cable route on Half Dome. The outcome of this research provided YNP managers with information to understand how different levels of daily visitor use on Half Dome affect management objectives to reduce crowding and improve safety conditions on the Half Dome cable route.

5. Methods

5.1. Photographic documentation of PAOT on the cable route

PAOT on the Half Dome cable route was recorded using repeat photography on 13 randomly selected days from June 25, 2010 through September 2, 2010. The protocols for photographic documentation of visitor use on the Half Dome Cable Route were based on previous research conducted by Lawson and others (2009). Photographs were recorded from the subdome and captured visitor use on the 600 ft portion of the cable route visible from this vantage point. Photographic observations were recorded in 20 min intervals from 9:00 am to 4:00 pm which produced 21 photographs per day to estimate PAOT on the cables throughout the day. A total of 266 photographs were recorded in 2010.

5.2. Automated visitor counters

One TRAFx active infrared monitors (Canmore, Canada) and one Eco-Counter was used to estimate visitor use on the Half Dome trail approximately one-quarter mile beyond the junction with the John Muir Trail (Fig. 1). The TRAFx monitor system is comprised of a single infrared scope connected to a small memory unit. The monitor registers a count when the scope detects the infrared signature of a warm moving object (i.e. a passing hiker). For security of the equipment, TRAFx units were mounted inside steel boxes mounted to trees adjacent to the trail with ¾ in. steel strapping. The TRAFx monitor was installed on June 23 and collected data continuously (i.e. 24 h per day, 7 days per week) until September 14. Additionally, an Eco-Counter automated counter (Lannion, France) was installed at the same study location. The Eco-Counter monitoring system detects and quantifies the direction of a hiker's travel in addition to overall hiker counts. Thus, the direction of hiker travel was estimated using the data from the Eco-Counter. Direction of travel needs to be estimated because the number of visitor *arrivals* to a location is used as a proxy for the total number of visitors to an area. The Eco-Counter was installed on July 22 and collected data until September 14. Specific methods to calibrate automated monitors from direct observation are described in Pettebone, Newman, and Lawson (2010).

5.3. Regression analyses

Statistical relationships were developed between daily visitor counts collected via automated counters on the trail to Half Dome and PAOT on the Half Dome cable route. The most parsimonious models were identified and are reported in this paper. Outliers due to the leverage of any single data point were determined using Cook's test. In addition, residuals from all regression analyses were examined for normality using tests for skew and kurtosis. All statistical models reported in this paper exhibited no significant leverage and residuals were normally distributed.

5.4. Permit enforcement

Daily permits were rationed between day users (300 permits) and overnight wilderness users (100 permits). On each permit day a member of the YNP wilderness staff was stationed at the base of Half Dome's subdome to ensure each visitor approaching Half Dome had a permit. It is important to note that permits were transferable between individuals and visitors who obtained a permit but did not use their permit for any reason could give their permit to someone else. Many groups who arrived at the base of the subdome had extra permits from individuals in their party who did not complete the trip and returned unused permits to the wilderness staff member to redistribute to other hikers seeking to summit Half Dome but did not have permits. Additionally, many groups reserved permits on consecutive days to minimize any weather constraints on their trip, and this phenomenon also served as a daily permit surplus. Wilderness staff who checked permits at the subdome communicated to the authors that all visitors who arrived at the subdome either had a permit or were given a permit by the wilderness staff member that was returned by other groups. Thus, no visitors who hiked to the base of the subdome were excluded from attempting to summit Half Dome on permit days in 2010.

6. Results

For these analyses *average* and *maximum* PAOT on the cable route reflect visitor use on the cables from 9:00 am to 4:00 pm. Daily arrivals on the Half Dome trail were entered as the independent variable and PAOT variables were entered as dependent variables into the regression models. Simple ordinary least squares (OLS) models produced the best fits for estimating relationships between daily visitor use and PAOT on the cable route.

Strong statistical relationships were found between daily visitor arrivals at the Half Dome junction and (1) *average* PAOT on the cable route ($F(1,10) = 131.2$, $p < .05$, $R^2 = 0.9292$) and (2) *maximum* observed PAOT on the cable route ($F(1,10) = 63.98$, $p < .05$, $R^2 = 0.8648$) (Table 1). The minimum arrival count collected by the automated counter for this analysis was 240 and the maximum count was 871. The coefficient of these models (β) can be interpreted as follows: for every 100 additional visitor arrivals at the Half Dome trail junction *average* PAOT on the cable route increases by about 9 (.085) and *maximum* PAOT on the cable route increases by about 15 (.152). In other words, *maximum* PAOT on the cable route increases at a higher rate than *average* PAOT on the cable

Table 1
Model parameters to estimate average and maximum PAOT on the Half Dome cable route from daily arrival counts at the Half Dome trail junction.

Variable	β	*SE*	*p*
Average PAOT			
Intercept	−10.229	3.858	0.024
Daily arrivals	0.085	0.007	<0.001
Maximum PAOT			
Intercept	−10.038	9.883	0.334
Daily arrivals	0.152	0.019	<0.001

route based on the number of visitors arriving at the Half Dome trail junction.

These results indicate that PAOT on the cables is strongly related to the number of daily Half Dome hikers and that unimpeded travel conditions are violated during periods of *maximum* PAOT that are related to relatively low numbers of daily Half Dome hikers (i.e. ~300 arrivals). Average PAOT on the cable route violates unimpeded travel conditions at moderate levels of visitor arrivals at the Half Dome junction (i.e. ~500 arrivals). The relationship between the number of daily Half Dome hikers and PAOT on the cable route is depicted in Fig. 3. The standard for unimpeded travel conditions on the cable route and the visitor standard for perceptions of safety and crowding are included in Fig. 3 to allow comparison between the number of people using the Half Dome trail per day and desired management conditions on the cable route. Error bars that represent the 95% confidence interval are included with predicted values for maximum and average PAOT.

7. Discussion

7.1. Conceptual approach

The results of this work provide quantitative user capacity numbers to reduce crowding and improve visitor safety on the Half Dome Cable Route and are based on an adaptive management approach. The analytical approach taken in this project is different than previous efforts to find relationships between use levels (trails counts) and evaluative conditions (crowding) in that previous research has attempted to define the relationship between use levels and evaluative conditions used some form of statistical modeling with use levels as an independent variable and perceptions of crowding as a dependent variable. This study did not attempt to find this particular relationship but rather the proxy relationship between use levels and PAOT (i.e. the metric used to evaluate unimpeded travel and crowding on the cables). The statistical relationship describes the relationship within Half Dome's trail system and applied a static evaluative standard (i.e. 30 PAOT related unimpeded travel and 70 PAOT related to crowding) to consider the effect of different levels of use density on social conditions on the Half Dome Cable Route. These results were derived from relatively easy to measure variables using automated visitor counters and direct human observation.

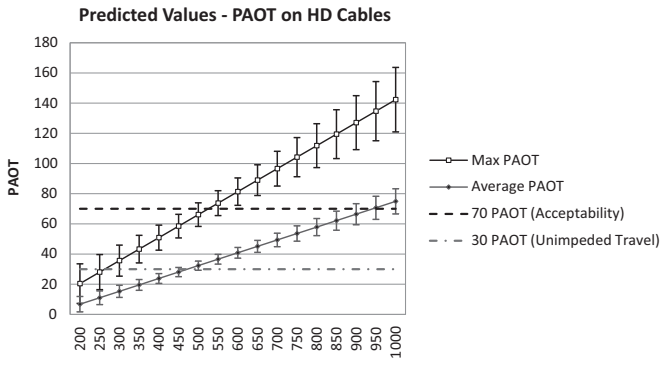

Fig. 3. Predicted values for PAOT on the Half Dome cable route.

The approach described in this paper to understand how daily use levels is related to user density (i.e. PAOT) is a novel approach toward operationalizing visitor capacity because it attempts to understand how proxy variables of evaluative variables (e.g. PAOT) are related to variables that managers can control (e.g. trail counts) in order to provide information needed to develop management strategies to maintain desired travel and social conditions. Moreover, this approach toward monitoring and managing visitor use lends itself well to evaluation as suggested by McCool (2001) who applied concepts suggested by Brewer (1973):

(1) Is the approach based on *conceptual soundness*? Specifically, is there a definitive relationship between use level and impact? Are social and biophysical conditions stable? Has a normative definition of carrying capacity been established?
(2) Is the approach *technically sound*? In other words, does it translate into practice well?
(3) Is it *ethical*? Who wins and who loses?
(4) Is the approach *pragmatic*? Does it work?

We believe the approach to manage and monitor visitor use on the Half Dome Cable Route described in this paper satisfies these definitions for conceptual and technical soundness as well as pragmatism. Specifically, statistically strong empirical relationships (*conceptual soundness*) between daily visitor use levels and proxy variables of social conditions (i.e. PAOT) were found that could be controlled by park managers both administratively using a permitting system (*technically sound*) and through enforcement by ranger staff (*pragmatic*). The question of *ethics* (i.e. equitability) is addressed in the Half Dome Trail Stewardship Plan (NPS, 2012) through a National Environmental Policy Act (NEPA) compliant public process.

7.2. Management implications

To be clear, specifying a prescriptive standard of 30 PAOT on the cables does not ensure that visitors will be safe when traveling along the cable route, however, it preserves a recreational setting where visitors can act upon a choice to ascend or descend the cables as they desire. This is a marked improvement over the unregulated system where the high volume of visitors on the cable route restricted visitors' opportunity to act upon a decision to descend for any reason (e.g. concerns about the weather, fear, or poor experience).

The 2010 Half Dome permit system allowed up to 400 visitors per day to access the subdome and the summit of Half Dome, however, average daily use (estimated from the automated visitor counters) on Half Dome was approximately 300 visitors/day. The regression model developed in this study predicts an average of about 24 PAOT on the cables corresponding to 400 visitors/day, and a mean of 15 PAOT on the cables corresponding to 300 visitors/day; both well below the PAOT thresholds of 30 and 70. However, predicted values for maximum PAOT on the cables corresponding to 400 visitors/day is about 50 and for 300 visitors/day is estimated to be about 35 PAOT. These results directly informed the Half Dome Stewardship planning effort and influenced, in part, the decision to limit daily use to 300 visitors/day, 7 days/week, in order to ensure that objectives to reduce crowding and safety are met (NPS, 2012). Moreover, these findings illustrate the need to carefully consider the metrics (i.e. averages vs. maximums) and temporal distributions from which to determine if management objectives are met.

Table 2
Estimated visitor use levels on Half Dome and trails near Half Dome.

Daily visitor use	Average cable PAOT	Maximum cable PAOT	Average summit PAOT	Maximum summit PAOT	Inter-group trail encounters: Nevada falls to the Half Dome trail junction	Inter-group trail encounters: Half Dome trail junction to the subdome
100	N/A[a]	N/A[a]	N/A[a]	N/A[a]	10.96	8.25
150	N/A[a]	N/A[a]	N/A[a]	N/A[a]	12.26	9.74
200	6.80	20.44	11.51	29.96	13.71	11.49
250	11.06	28.05	15.09	35.41	15.33	13.55
300	15.32	**35.67**	18.68	40.87	17.15	15.98
350	19.58	**43.29**	22.27	46.32	19.18	18.86
400	23.83	**50.91**	25.85	51.78	21.45	22.24
450	28.09	**58.53**	29.44	57.23	23.99	26.24
500	**32.35**	**66.15**	33.03	62.69	26.83	30.96
550	**36.61**	73.77	36.62	68.14	30.01	36.52
600	**40.87**	81.38	40.20	73.60	33.56	43.08
650	**45.12**	89.00	43.79	79.05	37.54	50.82
700	**49.38**	96.62	47.38	84.50	41.99	59.95
750	**53.64**	104.24	50.96	89.96	46.96	70.73
800	**57.90**	111.86	54.55	95.41	52.52	83.44
850	**62.16**	119.48	58.14	100.87	58.74	98.43
900	**66.41**	127.09	61.72	106.32	65.70	116.12

Note: Values in bold black indicate PAOT values that exceed 30 that impede visitor travel times on the cable route. Values in bold gray indicate PAOT values of 70 that exceed visitor perceptions of safe and acceptable experiential conditions on the cable route.

[a] Predicted values are beyond the practical limits of these data and produce negative values.

The approach and results developed in this project provide a basis for future monitoring to promote adaptive management of visitor use on Half Dome in order to ensure that management objectives related to quality visitor experiences and safety are met. The proposed "hypothesis driven" framework used to develop this research provides empirical evidence that regulating visitor use can reduce PAOT on the Half Dome cable route within thresholds that are consistent with management objectives for visitor experience and safety on Half Dome.

7.3. Comprehensive daily use level comparison

It is worth noting that further regression analyses were conducted to estimate the relationship between daily trail use levels and (1) PAOT on the summit and (2) inter-group trail encounters along the Half Dome trail below the subdome. Data were collected for PAOT on the summit because it can serve as a proxy for crowding and safety (i.e. potential mass evacuation in the case of an emergency such as a building thunder storm or lightning strike). Inter-group trail encounter data were documented because group encounter rates are a common measure of crowding and were selected in order to understand how overall visitor use levels affect visitor experience along trails that provide access to Half Dome (Broom & Hall, 2010; Chichetti & Smith, 1973; Patterson & Hammit, 1990; Roggenbuck, Williams, & Watson, 1993).

Similar to the Half Dome Cable Route analysis, strong statistical relationships were found among these variables, however, evaluative measures of social conditions (e.g. crowding) for these locations have not been collected. The strong relationships between the daily trail use levels and these proxy variables suggest that evaluative data for these locations can be related to daily trail use levels similar to the analysis described for the Half Dome Cable Route. A comprehensive comparison of PAOT and inter-group encounter rates along trails at various daily use levels are presented in Table 2. The information in Table 2 provides park administrators an easy to read and understandable summary of the effects of different visitor use levels on variables of concern (i.e. potential monitoring indicators). This table allows park managers to consider the trade-offs and implications of allowing or restricting different visitor use levels on Half Dome and can be used to communicate the rationale for a particular decision to the public.

These estimates of PAOT and encounter rates are based on the regression models for each relative measure of visitor use condition (i.e. PAOT or encounter rate). The information in this table is reflective of conditions found in 2010 under the three-day per week permit system. Any changes to the visitor management system on Half Dome in the future may change the specific statistical relationships found in this study; therefore, it is imperative that monitoring accompany any changes in visitor management on Half Dome in order to ensure that resultant visitor use conditions continue to meet YNP management objectives for visitor safety and experience, and to guide adaptations to visitor management if they do not.

7.4. Limitations

It is important to recognize that the approach taken here does not fully consider all of the various influences that influence social conditions related to visitor use on Half Dome. For example, the photo based simulation conducted in 2008 asked visitors to evaluate their user density on the cable route based on their immediate experience. Arnberger and Haider (2007) termed this approach as "actual measures" of crowding as compared to "global measures" of crowding that ask repeat visitors to aggregate their previous experiences and estimate crowding for a recreation area. They found that "global measures" of crowding were significantly higher than "actual measures". Thus, crowding evaluations for the cables may be higher for repeat visitors than is estimated for this study. Similarly, visitor expectations have consistently been shown to affect perceptions of crowding (Shelby, 1980) and it should be recognized that not all visitors will find the conditions on the Half Dome cables as not crowded. However, it can be expected that use density will be more consistently predictable under the permit system in order to inform visitors' expectations.

7.5. Further applications of this approach

The concepts of crowding, carrying capacity, and use limits have been examined more thoroughly in the USA than other countries, largely due to mandates required by various legislation such as the Wilderness Act of 1964 and the Organic Act of 1916 (Arnberger & Haider, 2007). For example, the Wilderness Act provides language that defines specific social conditions (i.e. outstanding

opportunities for solitude or primitive and unconfined recreation) to be preserved in designated wilderness areas. However, impacts to social conditions, such as crowding, have recently become a concern in highly used parks and recreation areas internationally and a topic of inquiry among international researchers (Arnberger & Mann, 2008).

The research and monitoring approach described in this paper are applicable to any park or protected area where managers need to manage user capacity and may consider use limits. Essentially, the approach described in this paper empirically defines the relationship between use levels at an entrance point (e.g. trailheads) and use density of a geographically discrete recreation use area (e.g. attraction site). Evaluations of crowding at the recreation site were estimated using social science survey methods that applied a visual simulation approach to determine visitors' evaluations of different use levels. Standards that satisfied management objectives for visitor experience were then derived based on quantitative data. Appropriate entrance use levels (e.g. trail use levels) were then determined for the recreation area based on: (1) the use level relationship between the entrance point and the recreation area, and (2) the standard derived from the visitor survey. This approach can be used at attraction points in parks and protected areas and potentially on popular via ferrata cable routes that are becoming crowded in order to achieve management objectives for visitor experience.

8. Conclusion

Half Dome is an iconic attraction in YNP and in recent years has received very high levels of visitor use. High levels of visitor use are a concern for YNP managers because of potentially unsafe conditions and impacts to the visitor experience. This research suggests that the strong interrelationship between daily use levels and specific use conditions (i.e. PAOT on the cables) on and around Half Dome can be used to determine visitor use capacities that will achieve park management objectives for safety and quality visitor experiences. The research described in this paper followed a systematic process based in adaptive management in order to ensure that the data collected accurately described current visitor use conditions and their implications relative to management objectives. A clearly defined management objective (i.e. free flow travel conditions) provides a concise measure from which to consider the implications of various levels of visitor use on Half Dome. Furthermore, ensuring free flow conditions on the cable route allow visitors a predictable experience on the cables. Although it is impossible for park and protected area management to completely eliminate potentially unsafe conditions, establishing use limits that maintain unimpeded travel is an improvement over conditions caused by unregulated visitor use and corresponding crowding-related delays on the cables. The data highlighted in this paper were used to inform long term management of visitor use on Half Dome in a current National Environmental Policy Act (NEPA) planning and compliance effort. The protocols and results from this study provided a basis to derive impacts within a NEPA compliance document and serve as a foundation from which to monitor visitor use conditions on Half Dome resulting from management actions and in relation to management objectives.

References

Arneberger, A., & Haider, W. (2007). A comparison of global and actual measures of perceived crowding of urban forest visitors. *Journal of Leisure Research*, *39*(4), 668–685.

Arnberger, A., & Mann, C. (2008). Crowding in European forests: A review of recent research and implications for forest management and policy. *Forestry*, *81*(4), 559–571.

Beunen, R., Regnerus, H. D., & Jaarsma, C. F. (2008). Gateways as a means of visitor management in national parks and protected areas. *Tourism Management*, *29*, 138–145.

Brewer, G. D. (1973). *Politicians, bureaucrats, and the consultant. A critique of urban problem solving*. New York, NY: Basic Books.

Broom, T. J., & Hall, T. E. (2010). *An assessment of indirect measures for the social indicator of encounters in the Tuolumne Meadows area of Yosemite National Park. Report for Yosemite National Park*. Moscow: University of Idaho, College of Natural Resources Department of Conservation Social Sciences.

Cicchetti, C. J., & Smith, V. K. (1973). Congestion, quality deterioration, and optimal use: Wilderness recreation in the Spanish Peaks primitive area. *Social Science Research*, *2*(1), 15–30.

Cole, D. N. (2005). *Computer simulation modeling of recreation use: Current status, case studies, and future directions. General Technical Report (RMRS-GTR-143)*. Missoula, MT: USDA, Forest Service, Rocky Mountain Research Station.

Freimund, W. A., & Cole, D. N. (2001). Use density, visitor experience, and limiting recreational use in wilderness: Progress to date and research needs. In W. A. Freimund, & D. N. Cole (Eds.), *Visitor use density and wilderness experience: Proceedings of a workshop (Proceedings RMRS-P-20)* June 1–3, 2000, Missoula, MT, (pp. 3–8). Ogden, UT: USDA Forest Service, Rocky Mountain Research Station.

Hall, T. E. (2001). Use limits in wilderness: Assumptions and gaps in knowledge. In W. A. Freimund, & D. N. Cole (Eds.), *Visitor use density and wilderness experience: Proceedings of a workshop (Proceedings RMRS-P-20)* June 1–3, 2000, Missoula, MT, (pp. 39–48). Ogden, UT: USDA Forest Service, Rocky Mountain Research Station.

Hall, T. E., & Cole, D. N. (2000). An expanded perspective on displacement: A longitudinal study of visitors to two wildernesses in the Cascade Mountains of Oregon. In S. F. McCool, D. N. Cole, W. T. Borrie, & J. O'Loughlin (Eds.), *Wilderness science in a time of change conference* (Vol. 4) (pp. 113–121). Fort Collins, CO: USDA Forest Service, Rocky Mountain Research Station.

Hallo, J. C., & Manning, R. E. (2009). Transportation and recreation: A case study of visitor driving for pleasure at Acadia National Park. *Journal of Transport Geography*, *17*, 491–499.

Hammit, W. E., McDonald, C. D., & Noe, F. P. (1984). Use level and encounters: Important variables of perceived crowding among nonspecialized recreationists. *Journal of Leisure Research*, *16*, 1–8.

Hammitt, W. E., Patterson, M. E., & Michael, E. (1991). Coping behavior to avoid visitor encounters: Its relationship to wildland privacy. *Journal of Leisure Research*, *23*(3), 225–237.

Haas, G. (2003). Applying judicial doctrine to visitor capacity decision making. *Society & Natural Resources: An International Journal*, *16*(8), 741–750.

Herberlein, T., & Vaske, J. (1977). *Crowding and visitor conflict in the Bois Brule River*. Paul, MN: University of Wisconsin, Water Resources Center Tech Re NC-28 St.

Heggie, T., & Amundson, M. (2009). Dead men walking: Search and rescue in US national parks. *Wilderness and Environmental Medicine*, *20*, 244–249.

Jacobi, C. (1997, December). Monitoring carrying capacity on Acadia National Park carriage roads: 1997. *Acadia National Park Natural Resources Report 97-11*.

Lawson, S., Choi, J., Reigner, N., Newman, P., & Gibson, A. (2009). *Half Dome cables monitoring and visitor use estimation final report. Study Report*. Yosemite National Park.

Lawson, S., Chamberlain, R., Choi, J., Swanson, B., Kiser, B., Newman, P., Monz, C., Pettebone, D., & Gamble, L. (2011). Modeling the effects of shuttle service on transportation system performance and quality of visitor experience in Rocky Mountain National Park. *Transportation Research Board*, *2244*, 97–106.

Lawson, S. R., & Manning, R. E. (2003). Research to guide management of backcountry camping at Isle Royale National Park: Part I. Descriptive research. *Journal of Park and Recreation Administration*, *21*, 22–42.

Lawson, S., Newman, P., Choi, J., Pettebone, D., & Meldrum, B. (2009). Integrated transportation and user capacity research in Yosemite National Park, the numbers game. *Transportation Research Board*, *2119*, 83–91.

Manning, R. (2011). (3rd ed., pp.). *Studies in outdoor recreation: Search and research for satisfaction* Corvalis, Oregon: Oregon State University.

Manning, R. E., Lime, D., Hof, M., & Freimund, W. (1995). The visitor experience and resource protection (VERP) process: The application of carrying capacity to Arches National Park. *George Wright Forum*, *12*, 41–55.

Manning, R., Valliere, W., Wang, B., Lawson, S., & Newman, P. (2003). Estimating day use social carrying capacity in Yosemite National Park. *Leisure: The Journal of the Canadian Association for Leisure Studies*, *27*(1–2), 77–102.

McCool, S. F. (2001). Limiting recreational use in wilderness: Research issues and management challenges in appraising their effectiveness. In W. A. Freimund, & D. N. Cole (Eds.), *Visitor use density and wilderness experience: Proceedings of a workshop (Proceedings RMRS-P-20)* June 1–3, 2000, Missoula, MT, (pp. 49–55). Ogden, UT: USDA Forest Service, Rocky Mountain Research Station.

McCool, S. F., & Stankey, G. H. (2001). Managing access to wildlands for recreation in the USA: Background and issues relevant to sustaining tourism. *Journal of Sustainable Tourism*, *9*(5), 389–399.

National Park Service. (1997). *VERP: The visitor experience and resource protection (VERP) framework-a handbook for planners and managers*. Denver, CO: Denver Service Center.

National Park Service. (2010). *NPS Stats, National Park Service public use statistics office*. Retrieved from http://www.nature.nps.gov/stats

National Park Service. (2012). *Half Dome trail stewardship plan environmental assessment*. Retrieved from http://www.nps.gov/yose/parkmgmt/upload/halfdomeea.pdf

Nieuwenhuysm, A., Pijper, J., Oudejans, R., & Bakker, F. (2008). The influence of anxiety on visual attention in climbing. *Journal of Sport and Exercise Psychology*, *30*, 171–185.

Patterson, M. E., & Hammitt, W. E. (1990). Backcountry encounter norms, actual reported encounters, and their relationship to wilderness solitude. *Leisure Research*, *22*(3), 259–275.

Pettebone, D. (2009). *Quantifying and modeling visitor use in Yosemite National Park and Rocky Mountain National Park*. Colorado State University (Doctoral dissertation).
Pettebone, D., Newman, P., & Lawson, S. (2010). Estimating visitor use at attraction sites and trailheads in Yosemite National Park using automated visitor counters. *Landscape and Urban Planning*, *97*, 229–238.
Roggenbuck, J., Williams, D., & Watson, A. (1993). Defining acceptable conditions in wilderness. *Environmental Management*, *3*(1), 187–197.
Schecter, M., & Lucas, R. C. (1978). *Simulation of recreational use for park and wilderness management.* Baltimore, MD: John Hopkins University Press.
Shafer, S. C., & Hammitt, W. E. (2009). Congruency among experience dimensions, condition indicators, and coping behaviors in wilderness. *Leisure Sciences*, *17*(4), 263–279.
Shelby, B. (1980). Crowding models for backcountry recreation. *Land Economics*, *56*, 43–55.
Tarrant, M. A., & English, D. B. K. (1996). A crowding based model of social carrying capacity: Applications for whitewater boating use. *Journal of Leisure Research*, *28*(3), 155–168.
Tombaugh, L., & Love, L. (1964). *Estimating number of visitors to national forest campgrounds. Research Note (RM-17)*. Fort Collins, CO: USDA, Forest Service, Rocky Mountain Forest and Range Experiment Station.
Van Wagtendonk, J. W. (1979). Use of a wilderness simulator for decisions. In R. M. Linn (Ed.), *Proceedings of the First Conference on Scientific Research in the National Parks, November 9–12, 1976, New Orleans, LA. Transactions and Proceedings Series 5* (Vol. 1) (pp. 1039–1040). Washington, DC: U.S. Department of the Interior, National Park Service.
Wagar, J. A., & Thallheimer, J. (1969). *Trial results of net count procedures for estimating visitor use at developed recreation sites. Research Note (INT-105)*. Ogden, UT: USDA, Forest Service, Intermountain Forest and Range Experiment Station.
Wang, B., & Manning, R. E. (1999). Computer simulation modeling for recreation management: A study on carriage road use in Acadia National Park, Maine, USA. *Environmental Management*, *23*(2), 193–203.
Whitaker, D., Shelby, B., Manning, R., Cole, D., & Haas, G. (2011). Capacity reconsidered: Finding consensus and clarifying differences. *Journal of Park and Recreation Administration*, *29*(1), 1–20.

Dr. David Pettebone is currently the Wilderness Program Manager for Rocky Mountain National Park in Colorado. Previously, he was a Social Scientist for Yosemite National Park in the Resource Management and Science division. He has conducted visitor use related research in various national parks for 6 years. His research has focuses on understanding visitor travel networks throughout parks and protected areas and the resulting changes to visitor experiences and resource conditions. He has also previously worked on NPS trail maintenance crews in King's Canyon NP, Yosemite NP, Big Bend NP, and Rocky Mountain NP. Dr. Pettebone received his Ph.D. and Master's Degrees in Human Dimensions of Natural Resources from Colorado State University.

Bret Meldrum is the Branch Chief for the Visitor Use and Social Science Branch in the Resources Management and Science Division at Yosemite National Park. He holds a B.S. in Recreation, Parks and Tourism Resources from West Virginia University, M.S. in Conservation Social Sciences from the University of Idaho, and is currently a Ph.D. Student in Natural Resource Studies at the University of Arizona. Bret has previously worked as a research assistant for the NPS Social Science Division's Park Studies Unit and as the monitoring coordinator for Yosemite's Visitor Use and Impact Monitoring Program. He has also held positions abroad focusing on international tourism development and protected area management in Nepal.

Colin Leslie is a social science technician in Yosemite's Visitor Use and Social Science branch. Colin holds a B.S. in Geography from Humboldt State University. Colin administered a survey of local residents in Tibet as part of his undergraduate degree. He will begin work toward a Master's Degree this fall at Colorado State University in the Human Dimensions of Natural Resources program.

Dr. Steven R. Lawson is a senior project consultant and leads RSG's Public Lands Planning and Management services. He has conducted research in national parks throughout the United States for 12 years, with a focus on indicator-based adaptive management and planning of recreation carrying capacity. His projects address nationally significant issues, including carrying capacity planning in Yosemite and Acadia National parks; scenic air tour management in Haleakala and Hawaii Volcanoes National parks; and alternative transportation planning in Rocky Mountain and Yosemite National parks. Dr. Lawson received his Ph.D. in natural resources from the University of Vermont.

Dr. Peter Newman is Associate Dean of Academic Affairs, Warner College of Natural Resources, Colorado State University, and an associate professor of protected areas management. His research focuses on the human dimensions of natural resource management and social carrying capacity decision-making in the context of protected areas management. He also worked as an NPS ranger in the Division of Resources Management in Yosemite and as a naturalist/instructor for the Yosemite Institute. Dr. Newman received his PhD in natural resources from the University of Vermont.

Nathan Reigner is a doctoral student in the Park Studies Laboratory. Nathan earned his M.S. in Forestry within the Natural Resources Recreation program at Virginia Tech in 2008. He earned a B.A. in 2001 from Gettysburg College in Anthropology and Sociology. His master's research applied the Theory of Planned Behavior to understand and influence depreciative visitor use at the 'Ohe'o Pools in Haleakala National Park. Nathan's research interests encompass outdoor recreation motivations, the relationships that individuals form with nature through their recreation experiences, and how those relationships influence natural resource decision-making in protected areas and communities.

Dr. Adam Gibson is a professor at Utah State University. His research focuses on human dimensions of natural resources and issues that deal with visitor use management and capacity. His doctoral work examined methodological issues with current survey approaches and recommendations to improve visual based approaches in visitor surveys. Dr.Gibson received his PhD from Colorado State University.