Monitoring and Managing Recreational Use in Backcountry Landscapes Using Computer-Based Simulation Modeling

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Abstract: In the United States, legislation dictates that wilderness areas should be managed to, among other things, provide recreational visitors with opportunities for solitude. The growing popularity of outdoor recreation in backcountry settings presents managers with challenges in their efforts to achieve this objective. Recent research suggests that computer-based simulation modeling is an effective tool for helping to address the challenges associated with managing visitor use in backcountry and wilderness settings. This paper describes the development and application of a computer-based simulation model of recreational use in the John Muir Wilderness Area in the Sierra Nevada Mountains of California, USA. The results of the study demonstrate how simulation modeling can be used as a tool for understanding existing visitor use patterns within the John Muir Wilderness Areas and estimating the effects of alternative management practices on visitor flows and visitor use conditions.

Introduction

In the United States, legislation dictates that Wilderness Areas should be managed to, among other things, provide recreational visitors with "opportunities for solitude or a primitive and unconfined type of recreation" (Wilderness Act of 1964). However, the growing popularity of outdoor recreation in backcountry settings threatens the ability of wilderness managers to achieve these objectives. For example, increasing recreational use of wilderness areas can result in perceived crowding and increasing conflict among different types of users (e.g., hikers and packstock) (Manning, 1999). These problems are exacerbated by the fact that backcountry recreation use tends to be concentrated both spatially and temporally (Hendee & Dawson, 2002, Lucas 1980). For example, most wilderness areas are used most heavily during the summer, and within the summer months, use can be heavier on the weekends than during weekdays. Similarly, recreational use tends to concentrate geographically along established hiking trails/routes, along the periphery rather than within the interior of an area, and close to desirable natural features (e.g., water bodies, scenic views).

Rules and regulations designed to manage recreation-related impacts such as crowding, conflict, and damage to natural resources can diminish visitors' sense of spontaneity and freedom, thus eroding the primitive and unconfined nature of the wilderness experience (Cole et al. 1987). Managers are faced with the challenge of preventing and mitigating recreation-related impacts to wilderness with the most unobtrusive, indirect, light-handed means possible (Hendee & Dawson 2002). That is, managers are expected to identify the "minimum tool" required to achieved desired conditions within wilderness. Consequently, decisions about how to manage recreational use of wilderness are complex.

Recent research suggests that computer-based simulation modeling is an effective tool for helping to address the challenges associated with managing visitor use in backcountry and wilderness settings (Daniel & Gimblett 2000, Gimblett et al. 2000, Lawson & Manning 2003a, 2003b, Lawson et al. 2003a, Lawson et al. 2003b, Wang & Manning 1999). For example, simulation modeling can be used to describe existing visitor use conditions. That is, given current management practices and existing levels of visitor use, where and when is visitor use occurring? By providing managers with detailed information about how visitors are currently using the area, this baseline information can assist managers in identify "trouble spots" or "bottlenecks", as well as areas that may be capable of accommodating additional use. Simulation modeling can also be used to monitor the condition of "hard to measure" indicator variables (Lawson et al. 2003a, Wang & Manning 1999). For example, how many encounters do backpacking visitors have with other groups per day while hiking? How many nights do visitors camp within sight of other groups? In addition, simulation modeling can be used to test the potential effectiveness of alternative management practices in a manner that is more comprehensive, less costly, and less politically risky than on-the-ground trial and error (Lawson & Manning 2003a, 2003b). For example, what effect does a permit quota have on the number of encounters visitors have with other groups while hiking? How would the number of hiking encounters change as a result of redistributing use from heavily used trailheads to less commonly used entry points? These capabilities make computer-based simulation modeling an effective tool for assisting managers in identifying recreation-related problems and evaluating the effectiveness and costs to visitors of potential solutions to these problems.

This paper describes the development and application of a computer-based simulation model of recreational use in the John Muir Wilderness Area in the Sierra Nevada Mountains of California, USA. The paper describes data collection methods, simulation model design, development and validation of outputs related to visitor use, and evaluation of alternative backcountry visitor use management practices. The results of the study demonstrate how simulation modeling can be used as a tool for understanding existing visitor use patterns within the John Muir Wilderness Area and estimating the effects of alternative management practices on the condition of crowding-related indicators of quality.

Description of Study Area

In this study a computer-based simulation model of recreation use was developed for a portion of the Humphrey's Basin area of the John Muir Wilderness Area. The John Muir Wilderness covers 584,000 acres in the Sierra and Inyo National Forests, in the Sierra Nevada Mountains of California. The area is characterized by snow-capped mountains with hundreds of lakes and streams and lush meadows. Lower elevation slopes are covered with stands of Jeffrey Pine, incense cedar, white and red fir and lodgepole pine. The higher elevations are barren granite with many glacially carved lakes.

Data Collection

Visitor Characteristics

During the 1999 visitor use season, diary questionnaires were distributed to backcountry visitors in the John Muir Wilderness. Questionnaires were distributed at trailhead self-registration stations and at ranger stations when visitors picked up their agency-issued permit. Randomly selected self-registration stations were periodically attended by data collectors who distributed diaries to visitor groups and collected completed questionnaires from groups as they finished their trips. In addition, questionnaires were distributed by commercial packstock outfitters, following instructions given by the research team.

The diary questionnaire included a series of questions concerning group and trip characteristics and a map of trails and natural features. Respondents were instructed to record their route of travel during their visit, including the trailhead(s) where they started and ended their trip, and their camping location on each night of their trip. Respondents were also asked to report the duration of their visit, the number of people in their party, and their mode of travel. The response rate for the Humphrey's Basin area of the John Muir Wilderness was 32.2%, resulting in a total of 324 competed diaries.

Site Characteristics

Trail Network

Data concerning the trail network within the study area were provided by the USFS Inyo National Forest in Bishop California as a GIS overlay. These data were supplemented with information from a campground inventory completed in the summers of 1999 and 2000. The data included all trail segments and intersections within the study area.

Campsite Clusters

"Campsite clusters" were created from the visitor surveys by grouping visitor reported camping locations based on proximity and common access. A single campsite cluster was comprised of all reported camping locations that were within a (subjectively determined) reasonable distance of each other. The campsite clusters were used to determine camping encounters within the travel simulation model. Specifically, groups camping in campsites within the same campsite cluster were considered to be within close enough proximity to have had a camping encounter with each other.

Travel Simulation Model Design

The data described in the previous section of this paper were used as inputs in the construction of a dynamic travel simulation model. The travel simulation model was developed using Extend software, and a duplicate model was developed using RBSim2 software (see Lawson et al. 2003a and Itami et al. 2004 for a detailed description of Extend and RBSim2, respectively). The scope of this paper will be limited to discussing the results of the Extend travel simulation model. However, additional research conducted by the authors of this paper found no statistically significant differences between the outputs of the Extend and RBSim2 travel simulation models of the study area.

The travel simulation model was designed to simulate backpacking use within a section of the Humphrey's Basin area during the peak summer months of the visitor use season. Data concerning trips starting before July 1, 1999 and after September 30, 1999 were excluded from the simulation. Furthermore, data concerning packstock trips and day trips were excluded from the simulation. This resulted in a total of 190 useable trip itineraries included as inputs into the travel simulation model.

The Humphrey's Basin travel simulation model is a probabilisitic steady state simulation (Law & Kelton 2000). Steady state simulations are designed to model a system during the period when it reaches its full operating level (e.g., during the peak period of the visitor use season). Consequently, steady state simulations require a "warm up" period to reach the target steady state operating level. Furthermore, steady state simulations require substantial replication (e.g., simulated visitor use days) in order to obtain reliable outputs that are not biased by short-term effects of the probabilisitic components within the model.

In this study, the travel simulation model is designed to model visitor use patterns and the effect of alternative management practices on visitor use-related conditions during the busiest period of the visitor use season. In all of the simulations conducted in this study, the model was run for a total of 2000 simulated visitor days. The first 500 days of each simulation were dropped from the study analyses in order to avoid potential start-up effects within the simulation. The outputs from the remaining 1500 days were used to generate the data reported in this study.

The travel simulation model is designed to allow the user to manipulate several parameters within the model. This feature of the model allows the user to estimate the effect of alternative management practices and visitor use scenarios on visitor use densities and hiking and camping encounters within the study area. For example, the model is designed to allow the user to control the number and timing of trips starting each day from each of the three entry points into the study area. This capability allows the user to design simulations that test the potential effect of increasing total use levels, trailhead quotas, and temporal and spatial redistribution of visitor use on crowding-related indicators of quality within the study area.

Simulation Analysis

Outputs

A series of simulations were conducted to generate a common set of outputs concerning visitor use densities and hiking and camping encounters. The common data generated within this series of simulations included:

1) Average hiking use per day, by trail segment.

Average hiking use per day is calculated for each trail segment by summing the number of groups that pass through each trail segment during the course of the simulation and dividing by the total number of days simulated.

2) Average hiking encounters per group per day, by trail segment.

Hiking encounters are calculated for each trail segment on each day that at least one group passes along the trail segment. Two types of hiking encounters were calculated within the simulation model. "Overtaking encounters" are defined as one group passing another group while travelling in the same direction along the trail. "Meeting encounters" are defined as two groups passing each other while travelling along the trail in opposite directions. The average number of hiking encounters per group per day is calculated for each trail segment by summing the total number of hiking encounters along the trail segment throughout the simulation and dividing by the number of groups that hiked the trail segment during the simulation.

3) Average camping use per night, by campsite cluster.

Average camping use per night is calculated for each campsite cluster by counting the number of groups at the campsite cluster each night of the simulation and dividing by the total number of nights simulated.

4) Average camping encounters per group per night, by campsite cluster.

Average camping encounters per group per night are calculated for each night that a campsite cluster is occupied by one or more parties. A camping encounter is defined as the number of other groups camping in the same campsite cluster on the same simulated night. The average number of camping encounters per group per night is calculated for each campsite cluster by summing the total number of campsite encounters throughout the simulation and dividing by the total number of groups that camped at the campsite cluster during the simulation.

Baseline Simulation

The first simulation conducted with the travel simulation model developed in this study was designed to generate the outputs described above based on existing visitor use levels in the study area observed during the 1999 sampling period. This simulation is referred to as the 1X simulation throughout the remainder of this paper.

Increasing Visitor Use Simulation

A second simulation was conducted to estimate the potential effect of increased visitor use of the study area on visitor use densities and encounters along trail segments and within campsite clusters. Within this simulation, the average number of trip starts per day was increased from baseline levels by 400% at each of the three trailheads in the study area. The outputs described above were generated for this scenario. This simulation run is referred to throughout the remainder of this paper as the 4X simulation.

Maximum Allowable Use Simulation

A series of simulations were conducted to demonstrate the capability of travel simulation modeling to assist managers in estimating the total daily use that can be accommodated within an area without violating crowding-related standards of quality. Specifically, this series of simulations was designed to estimate the maximum level of use that could be accommodated in the study area without the number of groups in a selected campsite exceeding five for more than 5% of nights (a potential standard of quality for camping use density). This was done by incrementally increasing or decreasing the simulated use levels evenly across the three entry points until the result "converged" on the desired level of campsite cluster use (Lawson et al. 2003a). This analysis illustrates how simulation modeling can be used to establish trailhead quotas to achieve desired social conditions within a wilderness area, and is referred to as the maximum allowable use simulation throughout the remainder of the paper.

Validation

Outputs concerning campsite cluster use generated in the 1X simulation were used as the basis for validating the travel simulation model output reported in this study. Specifically, the distribution of campsite cluster use derived from the camping locations reported in the trip diaries was compared to the distribution of campsite cluster use estimated in the 1X simulation (for a more detailed description of the validation methods used in this study see Law and Kelton 2000).

Results

Simulated Use Levels: 1X and 4X Simulations

Table 1 reports the mean number of simulated trip starts per day by trailhead for the 1X and 4X simulations. The trailheads are differentiated with a code number that was assigned to them during the data collection process. As the data in Table 1 suggest, the baseline level of visitor use in the study area is relatively low, with an average of less than two trip starts per day from the most heavily used of the three trailheads (Trailhead 93). Even with a 400% increase in visitor use, two of the three trailheads would have less than one trip start per day into the Humphrey's Basin area.

Table 1. Simulated mean number of backpacking trip starts per day, by trailhead.

Simulated mean trip starts per day, by trailhead - 1x simulation		
trailhead 93 1.89	trailhead 94 0.01	trailhead 999 0.14
Simulated mean trip starts per day, by trailhead - 4x simulation		
trailhead 93 7.61	trailhead 94 0.04	trailhead 999 0.56

Camping Use and Encounters, by Campsite Cluster: 1x And 4x Simulations

Table 2 reports average camping use per night and average camping encounters per group per night, by campsite cluster for the 1X and 4X simulations. Results of the 1X simulation suggest that under existing conditions, camping densities are low throughout the entire study area. In all of the campsite clusters within the study area, there is an average of less than one camping group per night. Similarly, the data suggest that under existing conditions, very few visitors encounter other groups while camping.

The 4X simulation results suggest that if use were to increase by 400% at each of the three trailheads in the study area, visitors who camp within campsite clusters 7 and 37 would encounter an average of three other groups per night. Furthermore , visitor use densities and camping encounters would be moderately high in several other campsite clusters, including clusters 42, 44, 46, and 47. However, throughout the remainder of the study area, camping densities and encounters would remain relatively low.

Table 2. Average camping use and encounters, by campsite cluster – 1X and 4X simulations.

Campsite Cluster ID	1X Avg. Use Per Night	1X Avg. Encounters Per Group Per Night	4X Avg. Use Per Night	4x Avg. Encounters Per Group Per Night
7	0.86	0.90	3.43	3.40
36	0.12	0.14	0.47	0.44
37	0.74	0.75	3.04	3.01
38	0.05	0.06	0.22	0.28
39	0.15	0.12	0.52	0.51
40	0.05	0.03	0.21	0.19
41	0.26	0.22	0.95	0.90
42	0.32	0.33	1.44	1.41
44	0.44	0.43	1.84	1.93
45	0.13	0.12	0.66	0.65
46	0.48	0.51	1.90	1.89
47	0.31	0.25	1.21	1.12
48	0.14	0.14	0.56	0.59
49	0.04	0.00	0.13	0.14
50	0.12	0.15	0.46	0.47
51	0.07	0.04	0.25	0.26
52	0.02	0.00	0.08	0.10
53	0.04	0.10	0.18	0.14
56	0.10	0.09	0.33	0.39
57	0.14	0.13	0.60	0.61
80	0.11	0.09	0.42	0.46
81	0.07	0.02	0.25	0.23

Hiking Use and Encounters, by Trail Segment: 1X and 4X Simulations

Table 3 reports average hiking use per day and average hiking encounters per group per day, by trail segment for the 1X and 4X simulations. Results of the 1X simulation suggest that, under existing conditions, hiking densities are low throughout most of the study area, with moderate levels of visitor use along several trail segments (e.g., trail segments 2, 4, 5, 9, 10, 11). In addition, there are very few hiking encounters among groups under existing conditions.

Table 3. Average hiking use and encounters, by trail segment – 1X and 4X simulations.

Trail Segment ID	1x Avg. Use per Day	1x Avg. Encounters per Group per Day	4x Avg. Use per Day	4x Avg. Encounters per Group per Day
2	3.51	0.20	14.02	0.75
3	0.08	0.00	0.35	0.00
4	3.51	0.11	14.02	0.42
5	3.43	0.34	13.75	1.48
6	0.58	0.03	2.35	0.11
7	0.14	0.03	0.55	0.06
8	0.04	0.00	0.18	0.01
9	3.35	0.11	13.41	0.40
10	3.28	0.10	13.17	0.40
11	3.20	0.05	12.83	0.17
12	0.12	0.00	0.42	0.02
13	0.20	0.01	0.86	0.04
14	0.80	0.04	3.31	0.16
15	2.95	0.20	11.72	0.80
16	1.10	0.02	4.56	0.06
17	2.47	0.11	9.77	0.42
18	2.41	0.05	9.61	0.19
19	0.15	0.01	0.62	0.05
20	0.99	0.01	4.13	0.07
21	0.90	0.03	3.70	0.10
22	0.77	0.06	3.21	0.20
23	0.09	0.00	0.43	0.03
24	0.13	0.01	0.49	0.05
25	2.31	0.07	9.16	0.27
26	0.15	0.02	0.50	0.04
27	1.08	0.06	4.47	0.22
28	0.15	0.01	0.68	0.08
29	0.45	0.02	1.93	0.08
30	1.29	0.01	5.34	0.02
31	0.68	0.03	2.77	0.12
32	0.63	0.05	2.61	0.18
33	0.04	0.00	0.16	0.02
34	1.87	0.09	7.22	0.37
35	0.07	0.00	0.26	0.03
36	1.43	0.08	5.54	0.30
37	0.29	0.02	1.13	0.07
38	0.88	0.06	3.66	0.35
39	1.29	0.21	5.03	0.76
40	0.22	0.01	0.84	0.04
41	1.25	0.07	4.87	0.35
132	0.06	0.00	0.26	0.02

Results of the 4X simulation suggest that while hiking densities would increase along several trail segments in the study area if use were to increase 4-fold at each of the trailheads, hiking encounters would remain low throughout the trail network. In fact, the model estimates that hikers along only one trail segment (segment 5) would have an average of more than 1 encounter per group per day.

Maximum Allowable Use Simulation

As stated earlier, simulation modeling can be used to help managers estimate the impact of alternative policy decisions related to visitor use and visitor flows within a recreation area. Table 4 reports the results of a series of simulations designed to estimate the maximum amount of use that could be accommodated in the study area without the number of groups camping within a selected campsite cluster exceeding 5 more than 5% of nights. The results of this simulation suggest that use could be dramatically increased from existing levels without exceeding this standard. While the standard and campsite cluster selected for this analysis are hypothetical, the analysis demonstrates the capability of computer-based simulation modeling to assist managers in estimating the total daily use that can be accommodated within an area without violating crowding-related standards of quality.

Table 4. Maximum allowable use for hypothetical camping use density standard.

Simulated mean trip starts per day, by trailhead – cg 46 use <= 5 groups 95% of nights			
	trailhead 93	trailhead 94	trailhead 999
Mean=	10.95	0.06	0.78
95% c.i.=	[10.80, 11.10]	[0.05, 0.08]	[0.74, 0.82]

Validation of Simulation Model Output

Table 5 reports the paired-t confidence interval for the difference between the distribution of campsite cluster use reported in the visitor survey and the 1X simulated trips. The results suggest that the data generated by the travel simulation model are valid estimates of visitor use conditions within the study area.

Table 5. Travel simulation model validation results.

	Reported trips vs. Simulated trips
Mean difference	0
95% c.i.	0.00 +/- [0,0]

Conclusion

The study described in this paper illustrates the potential usefulness of computer-based simulation modeling in monitoring and managing recreational use in backcountry and wilderness landscapes. Dispersed recreation in such areas is inherently difficult to observe directly. However, by collecting representative data on recreational use levels and patterns by means of trailhead counts and a diary survey of a sample of visitor groups, a simulation model was developed to estimate detailed levels and patterns of visitor use. The model developed for the Humphrey's Basin area informs managers about levels of use and resulting encounters at all trail segments and campsite clusters within the study area, and this information can be used for several purposes, including identifying potential bottlenecks or congested sites, scheduling maintenance and patrol activities, and educating visitors about the conditions they are likely to experience.

The simulation model of Humphrey's Basin can also be used for monitoring purposes. Monitoring is becoming increasingly important in park and wilderness planning and management, and plays a vital role in application of the Limits of Acceptable Change (LAC) (Stankey et al. 1985) and Visitor Experience and Resource Protection (VERP) (Manning 2001, National Park Service 1997) frameworks developed and used by the U.S. Forest Service and U.S. National Park Service, respectively. These frameworks require formulation of indicators and standards of quality for resource and experiential conditions in parks and wilderness. Indicator variables must be monitored to help ensure that standards of quality are maintained. The simulation model developed for Humphrey's Basin can be used to monitor crowding-related indicator variables such as trail and campsite encounters. Trailhead counts (gathered on a periodic basis by means of automatic trail counters, self-registration stations, or permit data) can be used to run the model and estimate trail and campsite encounters. Moreover, the model can be used in a more "proactive" way by estimating the total daily use that can be accommodated without violating crowding-related standards of quality. In this way, a trailhead quota or permit system could be designed to ensure that crowding-related standards of quality are maintained. The Humphrey's Basin model estimates that visitor use could be substantially increased without violating a camping encounter standard of 5 more than 5% of the time.

Finally, travel simulation model can be used to test the potential effectiveness of management practices, such as those designed to reduce trail and campsite encounters. For example, travel simulation modeling provides managers with a tool to estimate the potential effect of redistributing use among entry points to a wilderness area, or altering the temporal distribution of use on visitor flows and visitor use-related conditions. While the level of visitor use in the Humphrey's Basin area is too low to demonstrate this capability of travel simulation modeling, several other studies have illustrated this (Manning & Potter 1984, McCool et al. 1977, Potter & Manning 1984, Smith & Krutilla 1976, Underhill et al. 1986, Van Wagtendonk & Coho 1986, Wang & Manning 1999). For example, in a study at Isle Royale National Park, a travel simulation model was developed to test the effectiveness of a range of management practices designed to reduce crowding within the Park's backcountry campgrounds (Lawson & Manning 2003a, 2003b). Travel simulation results from the study suggest that redistributing use among the entry points to the Park's backcountry would not be an effective strategy for reducing crowding in backcountry campgrounds. These findings assisted managers in identifying management practices that would effectively reduce campground crowding, while avoiding the costs associated with instituting potentially ineffective management policies. Findings from a travel simulation model of visitor use along the Appalachian Trail suggest that the number of hiking encounters along the Trail could be reduced by altering the number and timing of arrivals at various trailheads (Manning & Potter 1984, Potter & Manning 1984). In fact, spatial and temporal redistributions of use along a section of the trail were found to be more effective at reducing the number of hiking and camping encounters than across-the-board use limits. In such cases, simulation modeling is a useful tool for optimizing the design of trailhead quota systems and/or information and education programs that redistribute use across starting locations and starting times.

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