Computer Simulation as a Tool for Planning and Management of Visitor Use in Protected Natural Areas

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The United Nations Environment Programme's Principles on Implementation of Sustainable Tourism suggest that implementing sustainable tourism must include monitoring visitor use of protected natural areas and directing it to areas where the environmental and social impacts of tourism are minimised. Thus, sustainable tourism management requires information about the spatial and temporal flow of visitor use in protected natural areas to help identify potential tourism-related threats to the natural and cultural resources of an area and the quality of visitors' experiences. Recent research has identified at least four ways in which simulation modelling of visitor use can facilitate more informed planning and management of sustainable tourism in protected natural areas, including (1) describing existing visitor use flows; (2) monitoring the condition of 'hard to measure' indicator variables; (3) testing the effectiveness of alternative visitor use management practices; and (4) guiding the design of research on public attitudes. The purpose of this paper is to demonstrate, using findings from studies conducted in the Inyo National Forest and Isle Royale National Park, USA, each of these four potential contributions of computer simulation to sustainable tourism management and planning. The paper concludes with an assessment of the limitations of existing applications of computer simulation to nature-based tourism and recommendations for future research.

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Introduction

The popularity of tourism in protected natural areas has grown tremendously in the last several decades and visitor use of these areas has reached record levels in recent years. For example, the United States National Park System received nearly 300 million recreational visits in 2004 (http://www2.nature.nps.gov/stats/), while the United States National Forests received over 200 million visits in 2002 (http://www.fs.fed.us/ recreation/programs/nvum/). This represents both an opportunity and a challenge for sustainable tourism planning and management in protected natural areas. The opportunity is to provide visitors with outstanding experiences that help build public support for protected natural areas. The challenge is to protect the natural and cultural resources of these areas and the quality of visitors' experiences in the face of increasing visitor use. For example, high levels of visitor use can lead

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to trail erosion, loss of ground cover vegetation at and around campsites, extensive networks of social trails, and disturbance of wildlife (Hammitt & Cole, 1998). In addition, increased visitor use of these areas can cause crowding and conflict, degrading the quality of visitors' experiences (Manning, 1999).

The United Nations Environment Programme's Principles on Implementation of Sustainable Tourism (http://www.uneptie.org/pc/tourism/policy/principles.htm) underscore the significance of balancing public interest in visiting protected natural areas with protecting the natural, cultural, and historical resources of these areas. In particular, the UNEP Principles suggest that implementing sustainable tourism must include monitoring visitor use of protected areas and directing it to areas where the environmental and social impacts of tourism are minimised. Thus, sustainable tourism management requires information about the spatial and temporal flow of visitor use in protected natural areas. For example, information about visitor use patterns can help managers identify potential tourism-related threats to the natural and cultural resources of an area and the quality of visitors' experiences. While in some cases it may be possible to monitor visitor flows through on-the-ground observation, this is inherently difficult in larger protected areas that receive more dispersed use. Consequently, monitoring and managing visitor use in protected natural areas is both challenging and important.

Recent research suggests that computer-based simulation modelling is an effective tool for facilitating the planning and management of nature-based tourism (Daniel & Gimblett, 2000; Gimblett *et al.*, 2000; Lawson & Manning, 2003a; Lawson *et al.*, 2003; Wang & Manning, 1999). This research has identified at least four ways in which simulation modelling of visitor use can facilitate more informed planning and management.

(1) *Simulation modelling can be used to describe existing visitor use conditions that are inherently difficult to observe*. As noted above, protected natural areas are often large in size and have multiple points of access, thus visitor use of these areas is often dispersed over a large area and can be difficult to observe on the ground. Consequently, what little information managers of protected natural areas have about visitor use is often limited to arrival counts at trailheads or access points and relatively imprecise itinerary data (Watson *et al.*, 2000). A benefit of computer simulation is that relatively easy to collect information (i.e. visitor use information collected at trailheads, parking areas, visitor centres, etc.) can be used as inputs to a computer simulation model to provide managers with precise estimates of visitor use both on the *periphery* as well as in the *interior* of protected natural areas. The spatially and temporally explicit information about existing visitor use patterns derived from computer simulation models can assist managers in identifying 'trouble spots' or 'bottlenecks', as well as areas that may be capable of accommodating additional use. For example, does visitor use tend to concentrate in certain locations or at certain times within a protected natural area which may lead to crowding or conflicts among different types of visitors? Is visitor use occurring within zones that contain fragile ecological resources or wildlife habitat that are highly sensitive to recreation use?

(2) *Simulation modelling can be used to monitor the condition of 'hard to measure' indicator variables* (Lawson *et al.*, 2003; Wang & Manning, 1999). For example, how many encounters do backpacking visitors have with other groups per day while hiking? How does the number of people at a popular attraction site change throughout the course of a day or visitor use season and with increasing or decreasing levels of total visitor use?

(3) *Simulation modelling can be used to test the 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). For example, what effect does a permit quota have on the number of encounters visitors have with other groups while hiking? Could congested conditions be alleviated by shifting some use to other parts of a recreation area or other periods of time? How many new campsites would need to be built in order to ensure that visitors do not have to share campsites with other people not in their group? How do alternative transportation systems affect the density of visitor use along trails and at attraction sites? How does the addition of a new trail or road affect the number of encounters visitors have with other groups while hiking?

(4) *Simulation modelling data can be used to guide the design of more realistic research on public attitudes concerning the management of visitor use in protected natural areas* (Lawson & Manning, 2003b; Lawson *et al.*, 2003). For example, visitor survey methods including stated choice and related stated preference methods have been used to assess public attitudes concerning how to balance tradeoffs associated with managing visitor use in protected natural areas (Lawson & Manning, 2001, 2002; Manning & Lawson, 2002; Newman *et al.*, 2005). A potential limitation of conventional visitor survey methods is that respondents are asked to evaluate *hypothetical* visitor use management alternatives derived intuitively rather than empirically. Descriptive data, generated from a computer simulation model, can be used to guide the design of visitor survey questions that measure public attitudes about realistic, empirically derived management scenarios.

The purpose of this paper is to demonstrate, using empirical data from studies conducted in the Inyo National Forest and Isle Royale National Park, USA, the four broad uses of computer simulation modelling for sustainable tourism management and planning outlined in the preceding paragraphs. The comprehensive treatment of this topic represents a new contribution to the literature designed to benefit practitioners and academics alike. The paper concludes with an assessment of the limitations of existing applications of computer simulation to nature-based tourism and recommendations for future research.

Computer Simulation of Visitor Use in Protected Natural Areas

Simulation modelling is a computer-based simplification of a real world system. Simulation models are designed to imitate a system as it operates over time, and are a useful tool for observing and experimenting with the components and interactions of a system that are too complex to observe directly (Wang & Manning, 1999). Modelling approaches that are dynamic, discrete, and stochastic are best suited for simulating visitor use in protected natural areas, since most outdoor recreation systems (e.g. trail networks, campgrounds, scenic roads, etc.) possess these characteristics. Dynamic models are those that represent the internal interactions of a system as they change over time (Banks *et al.*, 2001). For example, a simulation model designed to track the number of parties using a campground each night of the visitor use season would be considered a dynamic model. Dynamic models in which the values of variables change at separated points of time, when an event occurs, are referred to as discrete-event simulation models (Banks *et al.*, 2001). Simulation of a campground is a good example of a discrete-event model, since the number of groups camping in a campground changes only when an event occurs (i.e. a camping group arrives or departs). In contrast, the values of variables in a continuous model change continuously over time. A model of stream flow is a good example of a continuous simulation model, in that stream flow changes continuously over time (Wang & Manning, 1999). In a stochastic simulation model, some of the components of the system being modelled are based on probability distributions, in order to account for variation within the system (Banks *et al.*, 2001). For example, the number of parties starting a backcountry camping trip into a protected natural area varies from day to day, throughout the visitor use season. To account for this variability, a stochastic simulation model generates simulated backcountry camping groups based on an empirical or theoretical probability distribution.

The first generation of simulation modelling applications to outdoor recreation was introduced in the 1970s, and continued through the mid-1980s (Van Wagtendonk, 2003). The modelling approach used during this time, referred to as the Wilderness Travel Simulation Model (WTSM), was designed to represent a protected natural area's entire travel network, including entry points, trails, campsites, and attraction sites (Van Wagtendonk, 2003). Inputs used in the development of the WTSM included information about the number of groups entering the area at each entry point, the travel routes of visitor groups, total use levels, group sizes, and modes of travel (e.g. backpacking, horseback). Outputs from the WTSM included estimates of the number and location of encounters between visitor groups (Wang & Manning, 1999). Output concerning encounters derived from the WTSM was designed to differentiate among different types of encounters. For example, information generated by the WTSM included estimates of the number of meeting encounters, overtaking encounters, and encounters among different types of visitor groups (e.g. horseback riding groups and hiking groups).

The earliest applications of the WTSM were designed to simulate trail and campsite conditions in large protected natural areas, including the Spanish Peaks Wilderness Area, Montana, USA (Smith & Krutilla, 1976) and the Desolation Wilderness, California, USA (Shechter & Lucas, 1978). Subsequent applications of the WTSM included simulation of whitewater recreation on the Green and Yampa Rivers in Dinosaur National Monument, USA (McCool *et al.*, 1977) and modelling of the effect of Glen Canyon Dam operations on whitewater boating on the Colorado River through Grand Canyon National Park, USA (Underhill *et al.*, 1986). The WTSM was also used to simulate visitor use on a section of the Appalachian Trail, a long-distance hiking trail in the eastern United States (Manning & Potter, 1984; Potter & Manning, 1984).

Despite the potential benefits of the WTSM, it fell into disuse largely due to the cost and difficulty of running simulations with the computer technology that was available at the time (Van Wagtendonk, 2003). Recent advances in computing technology have made computer simulation modelling more accessible and affordable (Pidd, 1992). For example, the WTSM required the use of mainframe computers to run simulations. Today, desktop computers are capable of running computer simulations with relatively limited processing time required and at a much lower financial cost. Furthermore, while the WTSM required the user to be capable of computer programming, today's simulation software allows users to develop complex simulations without writing computer code.

With improved computer simulation capabilities, a second generation of applications of simulation modelling to nature-based tourism management and planning has emerged in recent years, including two related approaches. One approach, referred to as the Recreation Behaviour Simulator (RBSim2), combines computer simulation modelling with artificial intelligence technologies and geographic information systems (GIS) to simulate visitor use in protected natural areas (Daniel & Gimblett, 2000; Gimblett *et al.*, 2001). The second approach uses Extend software, developed by Imagine That, Incorporated, to develop probabilistic, discrete-event simulations, similar to the WTSM (Law & Kelton, 2000). The Extend simulation approach has been applied in several US national parks to track visitor travel patterns and to assist managers in monitoring and managing social carrying capacity (Lawson & Manning, 2003a,2003b; Lawson *et al.*, 2003; Wang & Manning, 1999). This paper presents empirical data from studies using Extend simulation modelling in the Inyo National Forest and Isle Royale National Park, USA to demonstrate the four broad uses of computer simulation for sustainable tourism management and planning described in the introduction.

Computer Simulation of Visitor Use in the Inyo National Forest

The John Muir Wilderness covers 584,000 acres in the Sierra and Inyo National Forests, in the Sierra Nevada Mountains of California, USA. The area can be characterised as an alpine environment, with backcountry camping opportunities alongside high elevation lakes and in alpine meadows (USFS, 2001). Backpacking and horseback riding trips constitute the majority of visitor use of the area; however, day use occurs in the area as well. A computer-based simulation model of visitor use was developed for a portion of the Humphrey's Basin area of the John Muir Wilderness Area. Data used to develop the computer simulation model of visitor use in Humphrey's Basin included information about visitors' trip characteristics obtained from a visitor survey conducted during the 1999 visitor use season by the University of Arizona. Survey 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 simulated trail and camping network was constructed using GIS data obtained from the Inyo National Forest and the University of Arizona. For more information about the simulation model design and analysis methods used in this study, refer to Lawson *et al*. (2006).

Generating spatially explicit estimates of existing visitor use

A series of experiments was conducted with the simulation model of visitor use in Humphrey's Basin to address the objectives of the original study, including an experiment referred to in this paper as the 'Baseline Simulation'. The 'Baseline Simulation' was designed to generate spatially explicit estimates of hiking and camping use in the area under existing visitor use levels and management practices (the existing level of visitor use in the study area is assumed to be equal to the number of groups that completed the diary questionnaire during July, August and September 1999 and does not include horseback riding use). The specific outputs generated by the 'Baseline Simulation' included: (1) Average hiking use per day, by trail segment, and (2) Average camping use per night, by camping location. For the purposes of this paper, only the outputs related to hiking use will be presented. Refer to Lawson *et al.* (2006) for additional information about the simulation outputs.

The results of the 'Baseline Simulation' presented in Table 1 suggest that under existing conditions, hiking densities are low throughout most of the study area,

Table 1 Average hiking use, by trail segment – baseline simulation

Trail ID	*Mean use*[a]	*Trail ID (cont.)*	*Mean use*[a] *(cont.)*
2	3.51	23	0.09
3	0.08	24	0.13
4	3.51	25	2.31
5	3.43	26	0.15
6	0.58	27	1.08
7	0.14	28	0.15
8	0.04	29	0.45
9	3.35	30	1.29
10	3.28	31	0.68
11	3.20	32	0.63
12	0.12	33	0.04
13	0.20	34	1.87
14	0.80	35	0.07
15	2.95	36	1.43
16	1.10	37	0.29
17	2.47	38	0.88
18	2.41	39	1.29
19	0.15	40	0.22
20	0.99	41	1.25
21	0.90	132	0.06
22	0.77		

[a] Mean number of hiking groups per day

with moderate levels of visitor use along several trail segments. These results illustrate how computer simulation can be used to provide managers with spatially explicit outputs that describe existing visitor use levels and patterns. Contemporary nature-based tourism planning frameworks including the Limits of Acceptable Change (LAC) (Stankey *et al.*, 1985) and Visitor Experience and Resource Protection (VERP) (Manning, 2001; National Park Service, 1997) rely on a zoning approach that involves prescribing alternative visitor use, resource, and management conditions for different sections of a protected area (Manning, 1999). The objective of zoning is to provide visitors with a diversity of recreation opportunities and to provide guidance for visitor use and related management decisions. The spatially explicit nature of computer simulation outputs like those generated in the 'Baseline Simulation' helps managers to assess the extent to which existing visitor use is consistent with management zoning prescriptions.

The map in Figure 1 portrays the spatial distribution of hiking use within the study area for the 'Baseline Simulation'. While the data in Table 1 suggest that use throughout the study area is low, the map shows the *relative* density of hiking use. Specifically, thicker lines on the map correspond to higher use trail segments, while thinner lines correspond to lower use segments. To generate the map of baseline visitor use, tabular computer simulation outputs were exported to a GIS database. In this way, the geo-referenced estimates of visitor use generated by the simulation model allow managers to integrate information about visitor use patterns with other resource data to perform land suitability and overlay analyses.

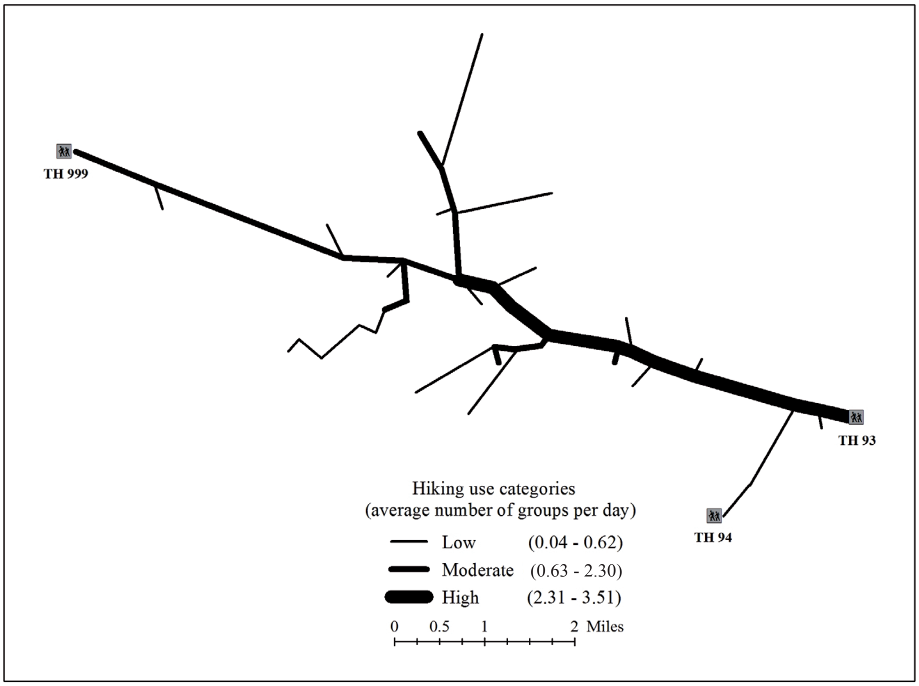

Figure 1 Spatial distribution of hiking use – baseline simulation

Monitoring the condition of 'hard to measure' indicator variables

Nature-based tourism planning and management frameworks, including LAC and VERP, are operationalised through the formulation of indicators and standards of quality, and monitoring of indicators to 'trigger' management action when standards are exceeded or at risk of being exceeded. Due to the dispersed nature of visitor use in protected natural areas, indicators of quality related to visitors' experiences are often difficult to monitor through on-the-ground observation. Estimates of hiking encounters generated in the 'Baseline Simulation' of visitor use in the Inyo National Forest illustrate how 'hard to measure' indicators, such as the number of hiking and camping encounters visitors have with other groups, can be monitored given existing use levels and management practices (Table 2). The data suggest that under existing conditions, very few visitors encounter other groups while hiking in the Humphrey's Basin area of the Inyo National Forest.

In addition to providing managers with a tool to establish baseline measures of indicators of quality, the computer simulation model provides a means to conduct

Table 2 Average hiking encounters, by trail segment – baseline simulation

Trail ID	*Mean encounters*[a]	*Trail ID (cont.)*	*Mean encounters*[a] *(cont.)*
2	0.20	23	0.00
3	0.00	24	0.01
4	0.11	25	0.07
5	0.34	26	0.02
6	0.03	27	0.06
7	0.03	28	0.01
8	0.00	29	0.02
9	0.11	30	0.01
10	0.10	31	0.03
11	0.05	32	0.05
12	0.00	33	0.00
13	0.01	34	0.09
14	0.04	35	0.00
15	0.20	36	0.08
16	0.02	37	0.02
17	0.11	38	0.06
18	0.05	39	0.21
19	0.01	40	0.01
20	0.01	41	0.07
21	0.03	132	0.00
22	0.06		

[a] Mean number of hiking encounters per group per use day

ongoing monitoring of 'hard to measure' indicators. For example, managers could use periodic trailhead counts as inputs to a computer simulation model to generate estimates of hiking and camping encounters as use of an area changes over time. To demonstrate this concept, the Inyo National Forest simulation model was used to estimate the number of hiking and camping encounters among visitors in the study area as a result of a four-fold increase in the total number of people taking trips in the area. Specifically, an experiment was conducted with the computer simulation model in which the average number of groups starting trips into the study area per day was increased from baseline levels by 400% at each trailhead (referred to in this paper as the 'Increasing Use Simulation'). The results of the 'Increasing Use Simulation' reported in Table 3 demonstrate how computer simulation could be used as part of an ongoing monitoring programme to estimate changes in the condition of indicators of quality associated with changes in the total use of an area in a more comprehensive, efficient, and precise manner than might be possible through on-the-ground observation alone.

Table 3 Average hiking encounters, by trail segment – increasing use simulation

Trail ID	*Mean encounters*[a]	*Trail ID (cont.)*	*Mean encounters*[a] *(cont.)*
2	0.75	23	0.03
3	0.00	24	0.05
4	0.42	25	0.27
5	1.48	26	0.04
6	0.11	27	0.22
7	0.06	28	0.08
8	0.01	29	0.08
9	0.40	30	0.02
10	0.40	31	0.12
11	0.17	32	0.18
12	0.02	33	0.02
13	0.04	34	0.37
14	0.16	35	0.03
15	0.80	36	0.30
16	0.06	37	0.07
17	0.42	38	0.35
18	0.19	39	0.76
19	0.05	40	0.04
20	0.07	41	0.35
21	0.10	132	0.02
22	0.20		

[a] Mean number of hiking encounters per group per use day

Table 4 Maximum allowable use, by trailhead, for hypothetical camping use density standard

TH 93	*TH 94*	*TH 999*
10.95 [a] [10.80, 11.10] [b]	0.06 [a] [0.05, 0.08][b]	0.78 [a] [0.74, 0.82] [b]

[a] Simulated mean number of trip starts per day
[b] 95% confidence interval for simulated mean number of trip starts per day

Conventional monitoring protocols rely on field observations to detect when standards of quality are exceeded, or are at risk of being exceeded as a result of increasing visitor use levels. A more 'proactive' approach would be to estimate the amount of visitor use that an area can accommodate without violating crowding-related standards of quality. This information could be used to design management strategies, such as a trailhead quota or permit system, that ensure that crowding-related standards of quality are maintained. An experiment was conducted with the Inyo National Forest model to demonstrate how computer simulation can improve the ability of managers to conduct a monitoring programme that facilitates this 'proactive' management approach. This experiment, referred to as the 'Maximum Allowable Use' simulation, 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 (an arbitrarily selected 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 into the study area until the result 'converged' on the desired level of camping use in the selected campsite (Lawson, Manning, *et al.*, 2003). The results of this analysis, presented in Table 4, illustrate how simulation modelling can be used to establish trailhead quotas to achieve desired social conditions within a protected natural area.

Computer Simulation of Backcountry Camping Use at Isle Royale National Park

Isle Royale National Park is located in the northwest corner of Lake Superior, approximately 75 miles from Houghton, Michigan, USA and 20 miles from Grand Portage, Minnesota, USA. The park has a system of 36 campgrounds, with a total of 244 designated tent and shelter sites dispersed along a network of 165 miles of trails. Primary visitor use activities at the park, which is open to visitors from mid-April until the end of October, include hiking and camping (Farrell & Marion, 1998). Backcountry camping permit data from the 2001 visitor use season were used to construct a computer simulation model of backcountry camping use to assist park staff with the development of a Wilderness and Backcountry Management Plan. For information about the simulation model design and analysis methods used in this study, refer to Lawson and Manning (2003a).

Testing the effectiveness of alternative management practices

Isle Royale National Park requires that visitors obtain a permit for backcountry camping in the park; however, there is no limit on the number of permits issued during the visitor use season. Furthermore, visitors are not required to follow prescribed or fixed itineraries. This management approach, coupled with increased backcountry visitation at the park, has resulted in campground capacities commonly being exceeded during peak periods of the visitor use season. Campers who arrive at full campgrounds are asked to share campsites with other groups, and most campers surveyed indicated that having to double up with other camping groups detracted from the quality of their experience (Pierskalla *et al.*, 1996, 1997).

As part of the park's effort to develop a Wilderness and Backcountry Management Plan, park staff generated a list of potential management actions designed to reduce or eliminate campsite sharing in the park. While park staff were able to generate a relatively comprehensive list of management strategies, they lacked information to estimate the effectiveness of alternative management practices at achieving desired camping conditions. For example, to what extent would use limits have to be imposed to achieve alternative levels of campsite sharing? Could campsite sharing be eliminated by adding new campsites to the park, rather than by limiting use? If so, how many additional campsites would be needed, and where would they need to be located? Would campsite sharing be eliminated if visitors were required to follow prescribed itineraries? The computer simulation of backcountry camping use at Isle Royale National Park was used to assist park staff in answering these and related questions.

Table 5 summarises the results of simulation experiments conducted to estimate the current extent of campsite sharing in the park and to estimate the effectiveness of alternative strategies for reducing or eliminating campsite sharing. The alternatives outlined in Table 5 were selected for analysis with the simulation model because they reflect a range of management approaches that emphasise campsite solitude, visitor freedoms, public access, and facility development to varying degrees and were alternatives the park was considering at the time of the study.

Simulation results for the 'Status Quo' alternative suggest that under the park's current management approach, an average of about 9% of groups are required to share campsites per night during July and August, with 24% sharing during the busiest two weeks of this period (Table 5). Less than 1% of groups are estimated to share sites during the low use period of the season (April to June and September to November).

Under the 'Permit Quota' alternative, no new campsites would be constructed and visitors would not be required to follow prescribed itineraries. However, the average number of permits issued per day during July and August would be reduced to ensure that an average of no more than 5% of groups share campsites per night (a standard for campsite sharing the park was considering at the time of the study). Results of the simulated 'Permit Quota' alternative suggest that the park would need to reduce visitor use during July and August by nearly 25% to ensure that an average of no more than 5% of groups share campsites per night.

To avoid the controversy associated with limiting use, park managers could instead attempt to reduce campsite sharing by requiring visitors to follow prescribed, fixed camping itineraries. Under this approach, everyone who wanted to take a backcountry camping trip would be able to obtain a permit to do so and no new campsites would be constructed. However, visitors would potentially have fewer choices of itineraries and would lose the freedom to spontaneously alter their camping itinerary during the course of their trip. The results of the simulated 'Fixed Itineraries' alternative suggest that, by requiring visitors to follow prescribed camping itineraries, the park could actually increase the number of permits issued to visitors by approximately 30%, while at the same time virtually eliminate campsite sharing (Table 5).

At the time of the study, park staff were considering building new campsites as one option to eliminate or reduce campsite sharing. In fact, the park's recently adopted General Management Plan allows for construction of up to 13 additional campsites in specific campgrounds. If the park were to adopt this 'Campsite Construction' alternative, the simulation results suggest that, without instituting any limits on use or requiring visitors to follow prescribed itineraries, campsite sharing could be reduced by about 2%, resulting in an average of approximately 7% of groups sharing campsites per night.

As the results of the simulated 'Status Quo' alternative indicate, campsite sharing is a problem primarily during the months of July and August, while there is virtually no campsite sharing during the low use period of the season. Further, results of the 'Permit Quota' alternative suggested that park managers would need to reduce the number of permits issued during July and August by about 25% to ensure that an average of no more than 5% of groups share sites per night. However, rather than turning those visitors away completely, park managers could shift 'surplus' peak season use to the low use period of the season (assuming these displaced peak season visitors would be willing to visit the park during the low use period of the season). This 'Temporal Redistribution' approach would allow managers to maintain season-wide visitor use levels, reduce campsite sharing during July and August, avoid building new campsites, and maintain visitors' freedom with respect to camping itineraries. Results of the simulated 'Temporal Redistribution' alternative suggest that campsite sharing would increase from an average of approximately 0.4% of groups per night during the low use period of the season, to just over 1% of groups per night (Table 5).

Designing realistic questions for visitor survey research

The results of the computer simulation experiments presented in Table 5 provide Isle Royale National Park staff with estimates of the effectiveness of alternative management practices designed to reduce or eliminate campsite sharing in the park that may be more precise than intuitive judgements. While this descriptive information is informative, park staff are still faced with difficult decisions concerning the most appropriate strategies for managing backcountry camping. These decisions require managers to reconcile tradeoffs among potentially competing wilderness values. For example, do the costs in visitor freedoms and spontaneity associated with a fixed itinerary system outweigh the benefits of increasing public access to the park and eliminating or substantially reducing campsite sharing? Is it in the public's interest to limit backcountry camping use during the peak period of the season in order to minimise campsite sharing? Is it acceptable to shift a percentage of peak season use to the low use period of the season, or does the historically low use period of the season offer a type of wilderness experience that should be preserved? While these judgements must

Table 5 Management alternatives quantified based on simulation model output [a]

Wilderness values	*Status Quo*	*Permit quota*	*Fixed itineraries*	*Campsite construction*	*Temporal redistribution*
Public Access	Current use	22% reduction in July/ August use	30% increase in July/ August use	Current use	Current use (shift 22% of peak)
Facility Development	No new campsites	No new campsites	No new campsites	13 new campsites	No new campsites
Visitor Freedom	No fixed itineraries	No fixed itineraries	Fixed itineraries	No fixed itineraries	No fixed itineraries
Camping Solitude July and August	9% of groups share sites/night	5% of groups share sites/night	<1% of groups share sites/night	7% of groups share sites/night	5% of groups share sites/night
Camping Solitude Low Use Period	0.4% of groups share sites/night	0.4% of groups share sites/night	<1% of groups share sites/night [b]	<1% of groups share sites/night	1.4% of groups share sites/night

[a] *Source*: Lawson, Mayo-Kiely *et al*. (2003)
[b] Assumes permits are issued to achieve 80% occupancy rate to adjust for non-compliance

Table 6 Preference proportions for management alternatives [a]

Status Quo	*Permit quota*	*Fixed itineraries*	*Campsite construction*
Current use (39 permits/day)	22% reduction in use (31 permits/day)	30% increase in use (52 permits/day)	Current use (39 permits/day)
No new campsites	No new campsites	No new campsites	70 new campsites
No fixed itineraries	No fixed itineraries	Fixed itineraries	No fixed itineraries
9% of groups share campsites/night	5% of groups share campsites/night	<1% of groups share campsites/night[b]	<1% of groups share campsites/night
36%	39%	6%	19%

[a] *Source*: Lawson, MayoKiely *et al*. (2003)
[b] Assumes permits are issued to achieve 80% occupancy rate to adjust for non-compliance

ultimately be made by managers, information derived from visitor surveys concerning the public's perceptions of what constitutes appropriate management can help inform these judgements. Computer simulation results, like those presented in Table 5, can be used to design survey questions that ask respondents to evaluate the appropriateness of realistic, feasible alternatives based on empirical data, rather than hypothetical scenarios based on best guesses.

The simulation results presented in Table 5 formed the basis of a visitor survey conducted at Isle Royale National Park during the 2002 visitor use season (Lawson & Manning, 2003b). The visitor survey was designed to assess public attitudes toward management alternatives derived from the simulation model. Results of the visitor survey provide managers with estimates of the proportion of current visitors that would support alternative strategies for managing backcountry camping (Table 6). Each alternative in Table 6 is defined in terms of the amount of backcountry camping use permitted, the number of new campsites constructed, whether visitors are required to follow a prescribed itinerary, and the extent of campsite sharing during July and August. The last row of Table 6 reports the proportion of visitors estimated to support each alternative. The results suggest that the greatest support among visitors is for the 'Status Quo' and 'Permit Quota' options, with 36% and 39% of visitors estimated to support each of these alternatives, respectively. While the 'Campsite Construction' alternative is less popular than the 'Status Quo' and 'Permit Quota' alternatives, the stated choice model estimates that nearly 20% of visitors would support this option. The 'Fixed Itineraries' alternative is substantially less favourable to visitors than any of the other alternatives, with just over 5% of visitors estimated to support this option. These findings suggest that visitors would prefer to tolerate some amount of campsite sharing in order to ensure that the park does not build a large number of new campsites or require visitors to follow prescribed, fixed itineraries.

Discussion

The empirical data presented in this paper suggest that computer simulation may be an effective tool for helping to inform sustainable tourism planning and management in protected natural areas. As the study results from the Inyo National Forest suggest, computer simulation provides managers with detailed information about the spatial and temporal characteristics of visitor use in a manner that may be more comprehensive, precise, and efficient than on-the-ground observation alone. While the data gathered to develop the computer simulation models presented in this paper describe some elements of the existing visitor use conditions in the study areas (e.g. when, where and how many people enter the area, and where they go), it is when these data are used as inputs to a computer simulation model that a comprehensive picture of existing visitor use conditions is generated. For example, the data collected to develop the computer simulation models presented in this paper do not describe the timing and location of interactions among visitor groups, but when they are input into computer simulation models they can be used to generate estimates of hiking and camping encounters. Simulation outputs like those presented in this study can be exported to a GIS database and used to produce maps of existing visitor use levels as they vary across space and time. These data can be integrated with resource data, including information about sensitive resources, wildlife habitats and patterns, and threatened and endangered species to guide future management and planning of protected natural areas.

Results of the Inyo National Forest study also illustrate how computer simulation can improve nature-based tourism planners' and managers' monitoring capabilities by providing them with a tool to estimate 'hard to measure' indicators of quality (e.g. backcountry hiking and camping encounters). In particular, a commonly used monitoring strategy is to identify variables that are relatively easy to measure that can be used to estimate harder to measure variables. For example, some monitoring programmes have used parking lot counts to make rough estimates of the total number of people using a recreation area. Similarly, computer simulation models can be constructed from relatively easy to measure inputs, such as trailhead counts, to generate output data that would be difficult and costly to collect. Outputs from the Inyo National Forest simulation model not only help monitor indicators of quality under existing visitor use conditions, but, as the 'Increasing Use Simulation' demonstrates, also allow managers to estimate the effect of projected use levels and trends on indicators of quality. In this way, computer simulation modelling can facilitate managers' ability to implement pre-emptive management practices to ensure standards of quality are not exceeded.

Study results from Isle Royale National Park demonstrate how computer simulation can be used to experiment with alternative management practices to assess their potential effectiveness at achieving management goals and objectives. At Isle Royale, park managers were faced with the difficult task of deciding how to reduce or eliminate campsite sharing in a manner that optimises tradeoffs among camping solitude, public access, visitor freedom, and limited facility development. The Isle Royale computer simulation model provided park staff with a means to assess the implications of alternative management practices. This information not only assisted park staff in making decisions about how to manage backcountry camping use at the park, it also served as a useful communication tool with the public.

The study findings from Isle Royale National Park also demonstrate how computer simulation results can be used to guide the development of realistic visitor survey questions designed to inform managers about the public's attitudes toward alternative visitor use management practices. This approach represents a potential improvement over visitor surveys that include only hypothetical management scenarios that may not be possible to achieve.

While the findings presented in this paper are encouraging, current applications of computer simulation to nature-based tourism planning and management, including the examples presented in this paper, have not been guided by a standardised set of procedures and methods. In order to ensure that computer simulation is a reliable and valid tool for sustainable tourism management and planning in protected natural areas, more work is needed to standardise procedures and methods related to selecting a software package for a given application, verifying and validating models, and input and output modelling. The following paragraphs provide specific recommendations for each of these elements of computer simulation design and implementation.

In recent years, computer simulation models of visitor use have been developed almost exclusively using one of the two software packages mentioned earlier in this paper – Extend and RBSim2. Preliminary research has been conducted to examine the relative strengths and weaknesses of these two software platforms and initial insights have been made, although this work is currently unpublished. Future research should focus on developing a set of guidelines to assist potential users of computer simulation in the selection of the most appropriate software for a given application.

Extensive research has been conducted in the field of computer simulation to develop standard verification and validation procedures (Law & Kelton, 2000). While a number of these methods have been implemented in previous applications of computer simulation to nature-based tourism, including the examples presented in this paper, the number, type and rigour with which these methods have been applied has varied across studies. In order to proceed with confidence in the use of computer simulation as a tool to assist and inform nature-based recreation planning and management, efforts should be made to develop, document and incorporate a standard set of verification and validation procedures into all recreation simulation projects.

An additional set of procedures and methods related to input and output modelling need to be developed and documented for computer simulation of visitor use in protected natural areas. For example, development of the computer simulation models presented in this paper required the selection of theoretical and empirical distributions to represent the rate at which simulated visitor groups arrive at trailheads and park entrance stations. Distributions also had to be selected to specify hiking speeds along specific trail sections, and to specify the travel routes of simulated recreation groups. These and other input modelling decisions are common across many nature-based tourism applications of computer simulation, yet standard procedures and guidelines are not documented or published. Additional research, including collaboration with computer simulation scientists from other fields should be conducted to address these matters.

Conclusion

Visitor use constitutes one of the primary 'agents of change' in protected natural areas. Thus, sustainable tourism management and planning in protected natural areas requires information about visitor use of these areas. As the examples from the Inyo National Forest and Isle Royale National Park presented in this paper illustrate, computer simulation can provide managers and planners of protected natural areas with a tool to describe, monitor, and manage visitor use. These findings suggest that computer simulation has significant potential to assist and inform planning and management of visitor use in protected natural areas.

To ensure that computer simulation models provide valid and reliable information in a cost-effective manner, it is important that state-of-knowledge procedures and methods be adopted for simulation of nature-based tourism. A primary product of future research should be a set of technical standards and procedures that guide future applications of computer simulation to visitor use of protected natural areas. These goals can be achieved, in part, though collaboration with computer simulation scientists from other disciplines, and by drawing upon existing literature that addresses computer simulation modelling and analysis.

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