Evaluating Carrying Capacities for Protected Areas

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This paper discusses the concept of carrying capacity and proposes a new carrying capacity method for protected areas. What is considered the first documented concern about carrying capacity in national parks occurred in the mid-1930s when the National Park Service (NPS) posed the question: "How large a crowd can be turned loose in a wilderness area without destroying its essential qualities?" and the retort that recreation use be kept "within the carrying capacity" (Sumner 1936). The 1978 National Parks and Recreation Act (P.L. 95-625) requires carrying capacities to be determined for each park as part of the process of developing a general management plan. Specifically, amendments to Public Law 91-383 (84 Stat. 824, 1970) require general management plans developed for national park units to include "identification of and implementation commitments for visitor carrying capacities for all areas of the unit" and determination of whether park visitation patterns are consistent with social and ecological carrying capacities. Amendments to the National Trails System Act (Public Law 90-543, 1968) mandate "an identified carrying capacity of the trail and a plan for its implementation" be developed in comprehensive trail planning. Regulations implementing the National Forest Management Act of 1976 dictate that, in wilderness management planning, provision be made "for limiting and distributing visitor use of specific areas in accord with periodic estimates of the maximum levels of use that allow natural processes to operate freely and that do not impair the values for which wilderness areas were created." Similarly, the National Outdoor Recreation Plan requires "each federal recreation land managing agency [to] determine the carrying capacity of its recreation lands" (Bureau of Outdoor Recreation 1973).

Two forms of carrying capacity are relevant to protected areas: *human,* or social, and *biological,* or ecological (Seidl et al. 1999). Thomas Malthus gave, perhaps, the earliest analysis of human carrying capacity. He postulated that human population growth would outstrip the land's capacity to produce food resulting in food shortages (Malthus 1986 [1798]). In range and wildlife management, biological or ecological carrying capacity is defined as the maximum population of a particular species a habitat area can support in a given period of time without reducing the future ability of the area to support the species or damaging the area (Miller 1990; Hawden and Palmer 1994; Hanley et al. 1999). Leopold defined it as the maximum density a range is capable of supporting (Dhondt 1988). Exceeding a protected area's ecological carrying capacity increases the risk of irreversible ecosystem change, such as declines in plant community structure or species diversity (Caughley 1979; Wallace 1999). Other ecological effects include loss of soil and vegetation and damage to trees and wildlife disturbance (Manning 1998; Leung and Marion 2000). However, these definitions oversimplify the dynamic interactions between animal populations and landscapes, which are characterized by nonlinear dynamics and population thresholds (Seidl and Tisdell 1999).

In the mid-1960s the carrying capacity concept for protected areas was expanded beyond ecological effects to include human or experiential effects of visitation (Wagar 1964). Examples of such effects include crowding, use conflicts and excess resource degradation (Manning 1998; Leung and Marion 2000). Visitor carrying capacity for protected areas is defined as the maximum number and type of visitors an area can sustain without causing irreversible deterioration of the physical environment and appreciable loss of visitor satisfaction (Shelby and Heberlein 1986; Seidl and Tisdell 1999). Since the human, ecological, and economic components of visitor carrying capacity differ, carrying capacity is difficult to define. Biophysical characteristics of an area (e.g., vegetation type, topography and climate), human factors (e.g., location and mode of travel, season of use, group size, and behavior of other visitors), and management policies (use limitations) are more important determinants of ecological and social (visitor) carrying capacities than simply the size of the population or number of visitors. Accordingly, contemporary definitions of carrying capacity consider the acceptability of human, ecological, and economic impacts of visitation. In addition to these impacts, increased use of a protected area can alter management actions. Specifically, increased use is likely to result in more intensive management practices, such as periodic rest and rotation of degraded areas, construction of new roads and trails, and others (Manning et al. 1996b). In general, carrying capacity depends on value judgments, institutional arrangements, technologies, consumption patterns and human goals (Seidl and Tisdell 1999).

Carrying Capacity Methods

Several quantitative measures of carrying capacity have been developed and applied. The three most common ones are Limits of Acceptable Change (LAC), Visitor Impact Management (VIM), and Visitor Experience and Resource Protection (VERP). Rather than defining carrying capacity as the maximum number of visitors allowed in an area, the LAC method evaluates the acceptability of visitor impacts on key biophysical and social processes (Stankey et al. 1985; McCool and Cole 1997). Impact acceptability is judged by comparing a set of indicators of biophysical and social processes to standards of quality that "define the minimum acceptable condition of indicator variables" or limits of acceptable change (Newman et al. 2001). The latter define the desired future conditions for resource, social, and managerial settings (Merigliano 1990; Manning 1999; Newman et al. 2001). In essence, limits of acceptable change articulate the management objectives for an area (Frissell and Stankey 1972; Manning et al. 1996a; Manning 1999). If indicators exceed established standards, then a management action is taken to bring indicators into conformance.

The VIM method is very similar to the LAC method. It evaluates visitor impacts by comparing standards for key indicators of natural resources, cultural resources, and visitor experiences with values of those indicators measured under existing field conditions, and identifies and implements appropriate management action when standards are violated (Graefe et al. 1990). LAC and VIM have been applied to backcountry management planning in Shenandoah National Park (Marion et al. 1985).

In 1992, NPS established the VERP method to evaluate carrying capacity in developing general management plans for park units (U.S. Department of the Interior 1997). The VERP method was first implemented in Arches National Park (Hof et al. 1994; Manning 2001) and a number of other national parks in the United States (Vande Camp et al. 2001). Like the LAC and VIM methods, the VERP method determines the amounts and kinds of visitor use a management zone can sustain without causing unacceptable resource and social impacts (Shelby and Heberlein 1986, Manning et al. 1996a). Resource impacts include loss in vegetation, tree damage, soil erosion and compaction and wildlife disturbance, and social impacts encompass crowding, use conflicts (e.g., snowmobiling vs. cross-country skiing), reduced quality of visitor experiences due to excessive resource degradation and other factors that diminish visitor satisfaction (Leung et al. 2002). Other carrying capacity methods include Visitor Activity Management Planning (Nilsen and Grant 1998) and the Tourism Optimization Management Model (Manidis Roberts Consultants 1997).

Implementation of the VERP method requires managers to (1) select appropriate management objectives for different zones within a protected area; (2) translate the objectives for each zone into indicators and standards of quality for resource and social impacts; (3) implement a monitoring program to measure indicators; (4) design and implement a new management action when the standards are violated; and (5) monitor the new management action for compliance with the standards (Manning 2001; Leung et al.

2002). The LAC, VIM, and VERP methods have several elements in common, namely (1) determining the types of recreation opportunities to be provided in different zones; (2) defining opportunities in terms of specific indicators and standards of quality; (3) monitoring indicators for compliance with standards; and (4) implementing appropriate management actions when standards are violated (Manning 1999).

Proposed Method

The proposed method for evaluating carrying capacity is called the Multiple Attribute Scoring Test for Capacity, or MASTEC (Prato 2001). MASTEC integrates elements of the LAC, VIM, and VERP methods. It allows managers to quantitatively determine whether the current state of a protected area ecosystem is in compliance with established standards for ecological and social carrying capacities when there is uncertainty regarding the state of the ecosystem (phase 1) and, if the standards are violated, uses a multiple-attribute evaluation method to identify the best management action for achieving compliance with the standards (phase 2). Consider a unit of the National Park System that encompasses an ecosystem that can be in one of four mutually exclusive states of compliance with biophysical and social carrying capacities: M_1 (highly non-compliant), M_2 (moderately non-compliant), M_3 (moderately compliant), and M_4 (highly compliant). Prior probabilities of states are $p(M_1)$, $p(M_2)$, $p(M_3)$ and $p(M_4)$, which sum to 1 and represent expert judgment about the current probabilities of different states of compliance. Suppose the park manager believes states M_1 and M_2 indicate non-compliance and states M_3 and M_4 indicate compliance with carrying capacities.

Let the ecosystem's current state of compliance be evaluated in terms of two ecological attributes (percent of native species present and habitat suitability for an endangered species), and two social attributes (level of congestion on backcountry hiking trails and the length of time visitors have to wait for in-park transportation). In addition, let the state of the ecosystem be assessed in terms of four measured ecosystem conditions as follows. R_1 represents significant losses in native species, highly degraded habitat for endangered species, high congestion on trails, and very long waiting times. R_2 represents moderate losses in native species, moderately degraded habitat for endangered species, moderate congestion on trails, and long waiting times. R_3 represents most native species present, good habitat for endangered species, low congestion on trails, and short waiting times. R_4 represents widespread abundance of native species, excellent habitat for endangered species, no trail congestion, and very short waiting times. Ecosystem conditions improve from R_1 to R_4. Bayes' theorem, which comes from Bayesian statistics (Peterman and Peters 1988), is used to minimize the occurrence of two kinds of decision errors that the park manager can make in determining the current state of the ecosystem. The first error is that manager decides the ecosystem is M_3 or M_4 (compliant states) when it is really M_1 or M_2 (non-compliant states). When this error is committed, the manager takes no corrective action when such action is warranted. The second error is that manager decides the ecosystem is M_1 or M_2 (non-compliant states) when it is really M_3 or M_4 (compliant states). When this error is committed, the manager takes corrective action when no such action is warranted, which implies unnecessary expenditures.

An outcome is defined as a combination of an ecosystem state and condition. For example, the outcome (M_1R_2) represents ecosystem state M_1 and ecosystem condition R_2. Since outcomes are mutually exclusive, the prior probability of an ecosystem condition, say R_2, is the sum of the joint probabilities:

$$p(R_2) = p(M_1R_2) + \ldots + p(M_4R_2) = \Sigma_i p(M_i)p(R_2|M_i),$$

where $p(M_i)$ is the prior probability of M_i and $p(R_2|M_i)$ is the likelihood function or the likelihood of observing R_2 given the ecosystem state is M_i. The posterior probability is the probability that the ecosystem is in state M_1 given the condition is R_2. It is determined from Bayes' theorem as follows:

$$p(M_1|R_2) = p(M_1R_2)/p(R_2) = [p(M_1)\,p(R_2|M_1)]/[\Sigma_i p(M_i)p(R_2|M_i)].$$

The posterior probability combines the prior probabilities and the likelihood functions. The importance of the prior probability relative to the likelihood function in determining the posterior probability decreases (increases) as the amount of new data provided by management actions increases (decreases).

An example of how Bayes' theorem is used to calculate posterior probabilities is given in Table 1. The example shows posterior probabilities for four hypothetical ecosystem states with ecosystem conditions R_1 and R_3. The fourth column of the table shows that ecosystem state M_1 has the highest posterior probability (0.63) when the ecosystem condition is R_1. Since M_1 is not compliant with carrying capacities, then the second stage is needed to determine the best management action for achieving compliance with carrying capacities.

The second-stage decision is modeled as the following mathematical programming problem, which for simplicity contains only one ecological and one social attribute:

$$\text{Max } U(A) = w_j\, e_j^* + w_k\, s_k^*$$
subject to:
$$p(e_j^* \geq e_j^{**}) \geq 1 - \alpha_j \text{ and } p(s_k^* \geq s_k^{**}) \geq 1 - \beta_k$$
$$0 \leq w_j \leq 1,\ 0 \leq w_k \leq 1 \text{ and } w_j + w_k = 1$$
$$0 \leq \alpha_j \leq 1 \text{ and } 0 \leq \beta_k \leq 1.$$

where A stands for management action for complying with carrying capacities, U(A) is the utility provided by A, e_j^*, and s_k^* are normalized mean values of the ecological and social attributes of management actions, respectively, w_j is the weight for the j^{th} eco-

Table 1. Posterior probabilities for four hypothetical ecosystem states with ecosystem conditions R_1 and R_3

		R_1		R_3	
Ecosystem state	$p(M_i)$[a]	$p(R_1\|M_i)$[b]	$p(M_j\|R_1)$[c]	$p(R_3\|M_i)$	$p(M_i\|R_3)$[d]
M_1[e]	0.4	0.5	0.63[g]	0.1	0.19
M_2[e]	0.3	0.3	0.28	0.2	0.29
M_3[f]	0.2	0.1	0.13	0.4	0.38[h]
M_4[f]	0.1	0.1	0.06	0.3	0.14

a. Prior probabilities of ecosystem states
b. Likelihood functions
c. $[p(R_1 \mid M_i)\, p(M_i)]/[\Sigma_i p(R_1 \mid M_i)\, p(M_i)]$

d. $[p(R_3 \mid M_i)\, p(M_i)]/[\Sigma_i p(R_3 \mid M_i)\, p(M_i)]$

e. States not in compliance with carrying capacities
f. States in compliance with carrying capacities
g. Maximum posterior probability for condition R_1
h. Maximum posterior probability for condition R_3

logical attribute, w_k is the weight for the k^{th} social attribute, and e_j^{**} and s_k^{**} are the normalized standards for ecological and social attributes, respectively. Chance (probabilistic) constraints require the best management action to provide biophysical attributes that are at least as great as the biophysical standards for carrying capacity with reliability $1 - a_j$ and social attributes that are at least as great as the social standards for carrying capacity with a reliability $1 - b_k$. Suppose the management action determined by solving the above mathematical programming problem is implemented and leads to ecosystem condition R_3. As Table 1 illustrates, the highest posterior probability given R_3 is for ecosystem state M_3. Since M_3 complies with carrying capacities, there is no need to alter the management action until ecosystem conditions change.

Mathematical optimization models, like the one given above, have been used to address a variety of natural management problems. Prato and Wu (1995) used a chance-constrained linear programming problem to determine the economically efficient farming systems for improving water quality in an agricultural watershed in north-central Missouri. Peterson et al. (1994) used mixed-integer programming to implement a multiple-objective planning process for inventory and monitoring programs in Olympic National Park in the state of Washington.

Conclusion

Units of the National Park System are managed to conserve their natural and cultural resources for the benefit of future generations, and allow public enjoyment by the current and future generations. This dual mandate and the legal requirement to identify and implement visitor carrying capacities for park units pose a major challenge for park managers. Meeting this challenge requires defensible, quantitative procedures for assessing and complying with ecological and social carrying capacities. The carrying capacity method proposed here (MASTEC) incorporates Bayesian statistics, multiple-attribute decision-making, and mathematical programming. Implementation of MASTEC requires considerable information. This feature alone is likely to discourage its use by park managers. Implementing MASTEC using a spatial decision-support tool would significantly increase user accessibility. In addition, the tool would facilitate public understanding and hopefully acceptance of the procedures used by protected areas to comply with carrying capacities.

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