RESEARCH REPORT

Creating exploratory maps for wilderness impact surveys: Applications in campsite searches

By E. Tyson Cross, Paul Evangelista, Melinda Laituri, and Peter Newman

Abstract

Camping activities are known to damage vegetation, impede ecological processes, and negatively affect visitor experiences in wilderness areas. Understanding the spatial distribution of wilderness campsites prior to inventory, monitoring, and impact assessments can help direct land managers to minimize costs and use of limited resources. Spatial modeling can be used to create maps to predict the locations of recreational activities and their impacts. Models can be developed based either on a priori knowledge of campsite preferences or on field observations. In both cases the information can be related to environmental attributes (e.g., distance from trails) to predict where campsites are likely to occur. For this study campsite likeliness was predicted with two models: a Recreation Habitat Suitability Index (expert-based) and a Maximum Entropy model (statistics-based). Models tested in this study were selected because of their relative ease of use and potential contribution as a practical management instrument. Evaluations of model results using campsite occurrence coordinates suggested that the models performed equally well and therefore offer resource managers two options to prioritize and conduct impact inventories in wilderness areas. The model results reduced the area needed for campsite searches by at least one-third and highlighted areas of high probability. The resulting maps serve as a planning tool, helping to deploy inventory crews in an organized and efficient manner. These modeling techniques are promising instruments for a broad range of other recreation and wilderness character monitoring activities.

Key words

campsite monitoring, predictive models, recreation ecology, wilderness management

CONGRESSIONALLY DESIGNATED WILDERNESS AREAS benefit from the highest level of protection of lands in the United States. As wilderness, land remains in its “natural” condition and is administered for the use and enjoyment of society in such a way that leaves it unimpaired for future generations (Wilderness Act 1964, section 2a). Though wilderness is protected from substantial development by humans, it is used for the primary purpose of “unconfined recreation” (Wilderness Act 1964). Unconfined recreation has led to a proliferation of ecological and social impacts from camping that have necessitated inventory, monitoring, and analysis efforts to understand and manage camping-related impacts (Cole 1993, 2004). Managing campsite impacts has both an ecological and a social significance. A review by Cole (2004) suggests that trampling associated with camping activities can affect soils and vegetation, damage or kill plants, compact mineral soils, and effectively displace organic soil horizons. Social impact studies have indicated that the presence of campsites in areas considered pristine (wilderness areas) can result in a “soiled” or “used” feel to an area (Leung and Marion 1999). Even camping-related impacts that are ecologically inconsequential, such as small pieces of litter, campfire rings, and small tree scars, can invoke negative symbolic meaning in the minds of wilderness visitors (Farrell et al. 2001).

Recognition of the ecological and social consequences related to campsite impacts has resulted in intensified inventory and monitoring efforts throughout the National Wilderness Preservation System (Cole 1993, 2004). While past inventories focused primarily on highly used areas, 21st-century management practices have trended toward inventory of entire wilderness areas (Cole 2004). The expansive area of potential wilderness camping makes it a challenge to travel efficiently to and locate campsites during the inventory process. Efficiency is increased when managers know beforehand where to target resources. Spatial models are a useful tool for resource managers, as they provide a cost-effective means to determine probability across large landscapes. Models are increasingly being used for early detection and to assess risk, develop management strategies, set priorities, and formulate policy (Lawson and Manning 2002; Van Wagtendonk 2003; Manning 2007). By integrating data and expertise with geographic information systems (GIS), models are used to map and predict probable campsite distributions.

This study examines two modeling approaches: (1) the Recreation Habitat Suitability Index (RHSI), an expert-based approach that uses a priori knowledge about campsite preferences, and (2) the Maximum Entropy model (Maxent), a statistics-based model that uses occurrence locations to predict conducive environmental conditions. Both models are relatively easy to employ and offer managers an applied planning tool to estimate the location of camping-related wilderness impacts. The tools presented in this study can be adapted to address a range of issues under a manager’s purview, including invasive species management, solitude studies, and sensitive species monitoring efforts.

MAP BY TYSON CROSS. DATA FOR INDEX COLLECTED FROM USFS REGION 2 OFFICE.
BACKGROUND TOPOGRAPHIC MAP DATA COLLECTED FROM HTTP://SVINETFC4.FS.FED.US/CLEARINGHOUSE/INDEX.HTML.

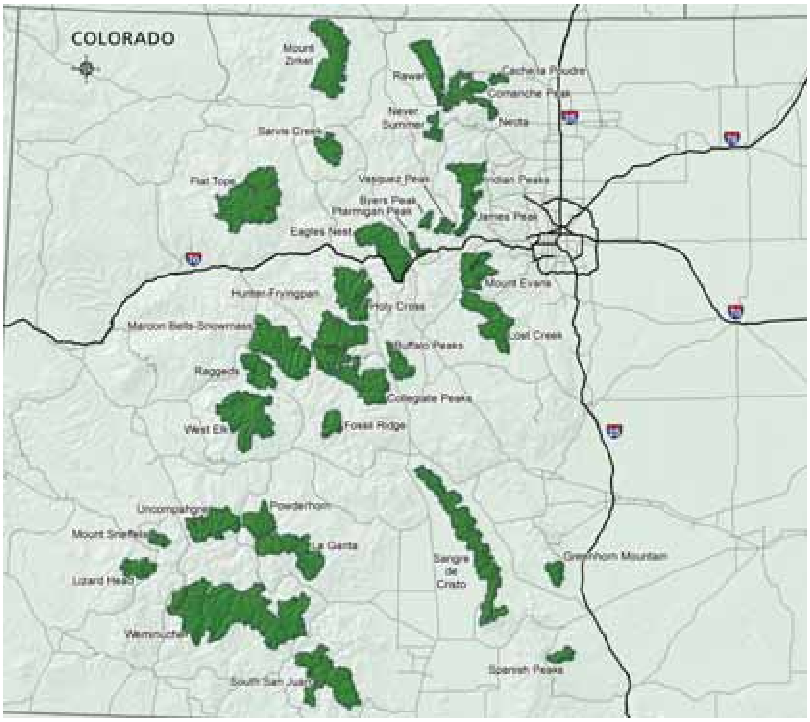

Figure 1. The study area includes 36 wilderness areas in Colorado. Scale: 1:3,000,000.

This method allows managers to visualize the areas requiring surveys, plan logistics for the search teams, and track inventory progress.

Methods

Study area and field data

The study was conducted in 36 federally designated wilderness areas in Colorado, generally located in the central and western parts of the state (fig. 1). These wilderness areas range in size from the 8,800-acre (3,564 ha) Byers Peak Wilderness to the 497,228-acre (201,377 ha) Weminuche Wilderness. In total the wilderness areas cover approximately 3.2 million acres (1.3 million ha). Study site ecosystem types vary from arid piñon-juniper woodlands of the Southwest to high alpine meadows in the central Rocky Mountains. Though the wilderness areas of Colorado are diverse, recreation in all of these areas is limited to primitive, nonmechanized activities with minimal facilities.

As part of an ongoing survey across Colorado, campsite location points were collected by independent field teams in the study area from 2004 to 2010. These points were used to develop the statistical model and to independently test both models. Location coordinates were acquired using Global Positioning Systems (GPS). A total of 2,607 campsites were recorded across the study area. A random selection of 30% (n = 782) of sites were set aside to test the two models; the remaining 70% (n = 1,825) were used to construct the Maxent model.

Recreation Habitat Suitability Index

Habitat Suitability Indexes (HSIs) are spatial models used by ecologists and wildlife biologists to map areas that organisms could potentially inhabit (Clark 1987; Larson et al. 2004). Originally, HSIs were developed to assist biologists with environmental impact assessments and in making daily decisions about managing wildlife, their distributions, and habitats. Clark (1987) adapted several wildlife habitat concepts to create a Recreation Habitat Suitability Index (RHSI). Similar to Habitat Suitability Indexes, RHSIs use a suite of predictor variables that are represented spatially, such as elevation, slope exposure, proximity to trail corridors, and proximity to water (Brunson and Shelby 1990). By integrating predictor variables with known recreational preferences, the RHSIs can predict probable areas of a given activity (e.g., wilderness camping).

In this study the RHSI is derived from expert knowledge, which determines the appropriate variables and how they should be weighted. A focus group consisting of wilderness program managers, lead wilderness rangers, and recreation ecologists examined the literature (Clark 1987; Brunson and Shelby 1990) and participated in development of the model (U.S. Forest Service, focus group discussions, personal communication, 18 September 2008). The RHSI was developed using the following algorithm:

$$RHSI = [0.2V_1 + 0.2V_2 + 0.35V_3 + 0.05V_4] + 0.2V_5$$

For this equation, distance to trails (V_1), streams (V_2), lakes (V_3), roads (V_4), and areas of low slope (V_5) was calculated using standard GIS methodology (ESRI ArcGIS v9.2). The variable V is a continuous score between 0 and 1, where 0 represents areas more than 800 m (875 yd) away from the variable and 1 represents areas directly adjacent to the variable. Variables are weighted based on the expected importance of the variable to camping. For example, because the focus group believes lakes are a more important predictor of campsite location than roads, this equation gives a higher weight to areas closer to lakes ($0.35V_3$) than to roads ($0.05V_4$). The modeled results are spatially displayed as a map using GIS, which shows the range of likeliness of a campsite between 0 and 1 (fig. 2).

Maxent model

The Maxent model uses location points to create a statistical model that can then be transferred to areas without data to predict where new location points are likely to be found. This tool was designed as a general-purpose predictive model that can be applied to incomplete data sets (Phillips et al. 2004; Phillips et al. 2006). Freely distributed on the Web (www.cs.princeton.edu/~schapire/maxent/) and fairly easy to use, Maxent operates on the principle of maximum entropy, making inferences from available data while avoiding unfounded constraints from the unknown (Phillips et al. 2006). Entropy can be described as a measure of uncertainty associated with a random variable; the greater the entropy, the greater the uncertainty. Adhering to these concepts, Maxent uses occurrence points (e.g., geographic coordinates of wilderness campsites) with multiple predictor variables (e.g., distance from trails) to model probability of occurrence. Predictions are presented as probability values from 0 to 1, with 1 being the highest likelihood. New applications of the Maxent model have demonstrated its wide utility in many subjects related to natural resource management (Evangelista et al. 2009; Evangelista et al. 2011).

To develop the Maxent model, a random selection of 70% of the campsite location data was used to train the model and the remaining 30% was retained for model evaluation. For comparison purposes with the RHSI model, the same environmental variables are used for both models. As with the RHSI, the modeled results are spatially displayed as a map using GIS.

Model evaluation

Evaluation of the model results was conducted by two statistical methods: the Area Under the receiver operating characteristic Curve (AUC) (Fielding and Bell 1997) and Cohen's Kappa (Cohen 1960). The AUC and Kappa values were calculated using Schroeder's ROC_AUC software (Schroeder 2006), developed specifically to assess modeling validity. The AUC measures the probability that a random positive point would fall outside the predictive range and the probability that a random negative would fall inside the predictive range. This measurement varies between 0 and 1. An AUC score of 0.5 indicates no better than random, while 1 is perfect discrimination. The Kappa statistic accounts for the probability of chance agreement between the model and the data, ranging from −1 to +1. The closer the Kappa statistic is to +1, the greater the agreement of the model.

Results

Both models were found to perform well when tested with the independent data. The AUC values for the RHSI and Maxent models were 0.92 and 0.93, respectively (table 1). Based on the definitions for AUC models by Hosmer and Lemeshow (2000), both models offered "outstanding" performance (>0.9). The Kappa values for RHSI and Maxent models were 0.66 and 0.72, respectively, both offering "good" performance based on Hosmer and Lemeshow (2000) (table 1). The RHSI predicted that the probable area for wilderness campsites was 979,661 acres (396,763 ha), while Maxent predicted that the probable area was 982,196 acres (397,789 ha) out of a total of 3,510,000 acres (1,421,550 ha).

Table 1. Performance of two models for campsite suitability

Model	AUC	Kappa
RHSI	0.92	0.66
Maxent	0.93	0.72

Note: The models were evaluated by Area Under Curve (AUC) and Cohen's maximized Kappa. All values are significant at $p<0.001$.

Discussion

The results of this study indicate that both RHSI and Maxent models are effective tools for wilderness management. When exploratory maps are displayed with topography (fig. 2), the resulting image provides managers with a planning tool for implementing efficient impact inventory efforts in wilderness. Using the methods presented by this study, search teams will focus on highly likely areas first and then move to surrounding areas of lower priority when sites are discovered in a given area, as opposed to gridding the wilderness or simply checking areas that appear to be good camping spots. When the maps are plotted, survey teams can track their progress by hashing out areas they have visited. In summary, this method allows managers to visualize the areas requiring surveys, plan logistics for the search teams, and track inventory progress.

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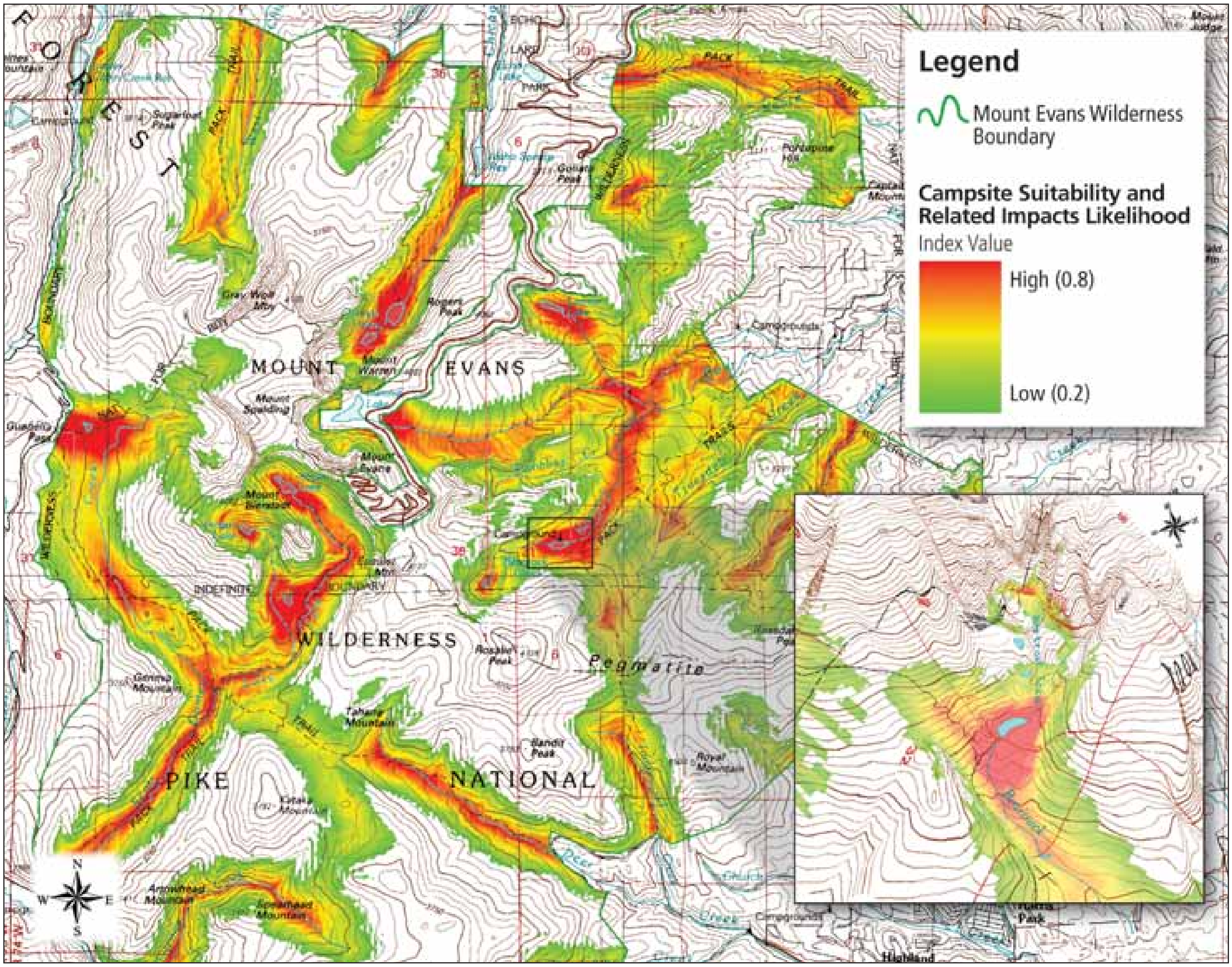

Figure 2. The map shows campsite suitability and the likelihood of camping impacts in the Mount Evans Wilderness, Colorado. Suitability ranges from 0 to 1, with 0 (green) being least likely and 1 (red) being most likely areas to find camping and related impacts. The inset map is a three-dimensional simulation that has been intentionally distorted to emphasize the way that the model interacts with environmental variables, such as slope, in Beartrack Creek drainage.

In addition to informing impact surveys, the models presented in this study can help management to create and standardize impact search protocols across districts and agencies, resulting in more cooperative and standardized data collection across management units. Furthermore, the modeling methods may be adapted for other priority wilderness management projects, such as solitude monitoring that highlights areas of the wilderness where one is least likely to have visitor encounters. Using these modeling techniques to create an exploratory encounters map, statistical surveys can be developed that prioritize areas least likely to encounter visitors while still monitoring areas with high likelihood of encounters. With these methods a wilderness manager may be able to create a better picture of the true Wilderness Recreation Opportunity Spectrum within the management unit, demonstrating the continuum of an area from low to high use (Cross 2010). Additionally, exploratory mapping techniques are frequently applied to invasive species inventories and may be useful to wilderness managers interested in mapping the potential distribution of invasive species prior to surveys (Evangelista et al. 2009).

This article introduces and validates two different methods for spatially modeling the same problem. The research concludes that the Recreation Habitat Suitability Index offers a simple approach to guide campsite searches for resource managers who do not have access to field data of wilderness campsites, while Maxent offers a statistical modeling approach for managers who do have access to current and historical survey data. This is a key distinction, and the appropriate tool will depend on the extent of the data or local knowledge available.

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