Weights of Evidence Modeling in Archeology, Rocky Mountain National Park

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Abstract. Rocky Mountain National Park, USA is rich in Native American sites, many believed to have served religious purposes. Utilizing the ArcSDM (Spatial Data Modeller) extension, both site and individual feature data are incorporated into a Weights-of-Evidence model of the Park's sacred landscape. The model incorporates elevation, aspect, local relief, slope, a cost distance from historic and pre-historic trails surface, and the relative visibility of five sacred landmarks. An Agterber and Cheng conditional independence test, an approximate t-test, and the model's strength on a randomly chosen subset of sacred features are used to assess the model's validity. The model is shown to be moderately predictive of sacred sites. Using model results and other sources of information eight areas of further field survey work are recommended.

Introduction

In 1998, initiation of a major archeological inventory project in Rocky Mountain National Park (RMNP), Colorado, funded by the National Park Service's Systemwide Archeological Inventory Program (SAIP), opened the door for recovery of new knowledge on the Park's Native American history and cultural traditions. SAIP, operated by the University of Northern Colorado over a five year period (1998-2002), recorded more than 1,000 prehistoric and historic archeological sites within ~30,000 surveyed acres of the park's total 275,000 acres (Brunswig 2005b). By the second project year (1999), evidence emerged that many sites preserved evidence of past Native American religious as well as socio-economic activities. The Sacred Landscapes Project's primary goal has been to systemically collect data related to past Native American religious practices in RMNP in order to formulate and test models of cultural-religious belief and behavior within the park's cultural (archeological) and environmental-topographic landscapes.

The Sacred Landscapes Project research design (cf. Brunswig, Diggs, and Montgomery 2009; Brunswig, McBeth, and Elinoff 2009) emphasizes four main lines of inquiry: 1) "mining" of ethnographic and historic records related to the southern Rocky Mountains, and north central Colorado in particular, for information on Native American religious practices, belief systems, and physical manifestations of those practices and beliefs; 2) establishment of a long-term consultation program involving, in conjunction with Park visits, elders and members from the Ute and Arapaho tribes, tribes known to have historically occupied the Park and its region; 3) continued archeological field work designed to further identify sites with suspected or historically documented religious elements, including culturally built or modified features likely to have been associated with past ritual/ceremonial activities; and 4) the use of advanced scientific tools, including Geographic Information System software, to generate and test landscape models using ethnographic-historic, Native American consultation, and archeological data sources. This paper focuses on the fourth research program element, using GIS and the weights-of-evidence method to model the sacred landscape of RMNP.

Sacred Landscapes Data Sets and Modeling Approach

GIS site location predictive models had been previously developed for the earlier RMNP archeological inventory project (cf. Rohe 2003a, 2003b, 2004). However, those models did not specifically address sacred features and sites. The authors constructed a preliminary sacred landscape GIS model in 2006 using ESRI's ArcGIS 9.0 software. In the 2006 RMNP sacred sites model, the authors derived promising spatial correlations of sacred sites and sacred landmarks throughout the Park (Diggs and Brunswig 2006). GIS correlation analysis underpins an effort to determine site distribution patterns that, integrated with Native American ethnographic and ethno-historic evidence, may reveal elements of ancient cognitive landscapes created through a system (or multiple successive systems) of past Native American beliefs and practices, cognitively imbedded in natural landscapes.

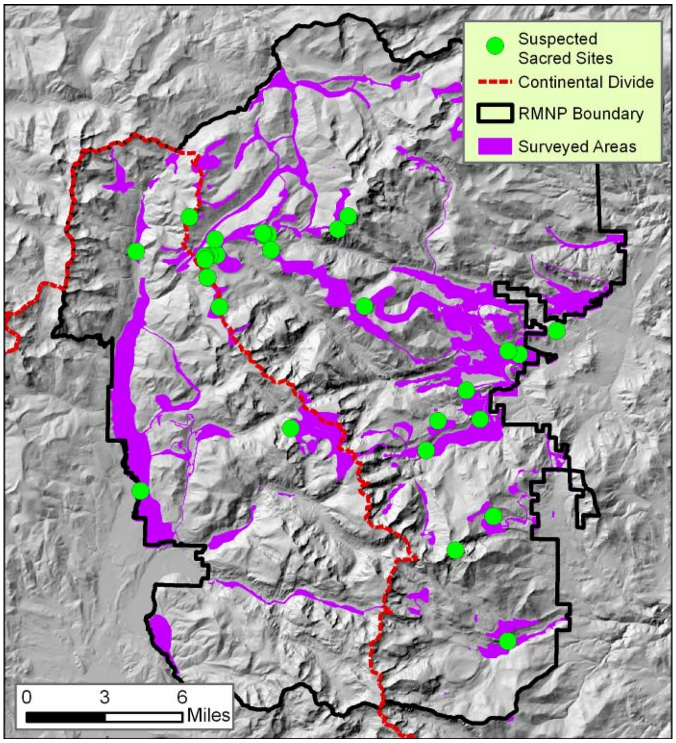


Figure 1. Archeological Survey Areas and Suspected Sacred Sites, Rocky Mountain National Park, USA.

Datasets Examined

Thirty-one site or feature cluster areas (out of 400 sites) were identified as having well-established or highly probable Native American religious or ritual components (see Figure 1 above). A total of 183 features were found in the sites. Individually, these sites included various permutations of possible vision quest features, older cairns suspected as possible offering sites, burials, crescent walls, cliff-side fissures with rock walls, various types of single to multiple course stone rings, rectangles, and ovals (see Brunswig 2003 and Brunswig, Diggs, and Montgomery 2009: 12-16 for feature assessment methods). Table 1 shows variables examined in our attempt to model the RMNP sacred landscape.

Table 1. Conceptual Model variables for Sacred Site Locations in RMNP

Variable(s)	Potential Importance
Elevation	High elevation areas have spiritual significance for many Native American cultures.
Local Relief (from Rohe 2003a)	Relief is related to terrain roughness. These could include an understanding of whether certain sites are in "dramatic" settings, with significant down-valley or up-slope views.
Aspect and related measures. (from Rohe 2003a)	Sites and individual features may have an orientation to view summer sunrise/sunset; or an orientation to north/south. Aspect and directional orientation may point to landmarks of great spiritual power or landmarks in line with the rising of sun or moon during times of seasonal change such as solstices and equinoxes, phases of the moon, constellation movements, etc.
Shelter (from Rohe 2003a)	Areas exposed or more sheltered to the elements may be desirable for ceremonial or ritual activities.
Vegetation and vegetation variety	Native American and prehistoric groups are known to have used certain plants for ritual purposes, many of which could be found or transplanted to, or near, ceremonial locations.
Historic Native American trails (from Lux 2005)	Access to known prehistoric and early historic trails in the park may be related to the location of sacred features. The Ute often located ritual/ceremonial sites on or near trails due to the belief the trails were conduits of spirit power, but situated their camps well away from those same trails.
Visibility of known sacred landmarks from sacred sites and features in the park	Ute elders have identified certain sacred landmarks in RMNP. Visibility of these features from various sacred sites and individual features may be important in predicting patterns in the sacred landscape.
Geology	Availability of basic building materials for construction of simple structures could be important. Iron rich rocks may attract more lightening, and thus have greater spiritual significance.
Slope	Steep slopes at some point will limit activities of spiritual significance.
Summer Light (from Rohe 2003a)	Since most features were located at higher elevation, there may be some association with solar insolation (especially during the summer months).

GIS data layers were created for the variables listed in Table 1. A digital elevation model (DEM) was used to create a life-zone layer which provided representation of montane, sub-alpine, and alpine areas within the park (10x10 meter cell resolution). Terrain roughness was examined using Rohe's (2003b) methodology of local relief, but within a 1 km radius (Rohe used a 3 km radius). Aspect was analyzed via the use of the following layers: aspect, and CosAspect (for N-S trending), and SinAspect (for E-W trending). Rohe's shelter layer (see Table 1) was replicated in an attempt to assess the hypothesis that many sacred sites are found in more exposed areas. Vegetation communities change over time and are not an infallible guide to vegetation as a site location indicator variable. The authors, however, still thought it important to see if vegetation or vegetation variety might aid in the modeling of sacred sites. Lux's (2005) study on ancient trails in RMNP was incorporated into our study. Many sacred sites appear to be close to these trails. Consultations with the RMNP archeologist resulted in the inclusion of additional trails as likely having historic and prehistoric importance (Dr. Bill Butler, pers. comm. 2007). Accordingly, a cost-distance from the trails variable was included in the model. Ute elders suggested that several sacred landmarks within the Park might be important for in our model: the Kawuneeche (Colorado) Valley, Longs Peak, Specimen Mountain, Grand Lake, and Lava Cliffs (as a physical feature in addition to possessing a major sacred site) (cf. Brunswig 2003: 66; Brunswig, Diggs, and Montgomery 2009: 17-24; Duncan and Goss 2000: 13-15). Another site just outside RMNP, Old Man Mountain, was later included in the analysis. Viewsheds from these locations were created and analyzed. Layers used were at a 10 x 10 meter cell resolution.

Statistical Significance of Variables Used in Modeling Sacred Features

Before attempting to model sacred sites in RMNP the authors examined and tested a number of variables (see Table 1) to see if the sacred sites/features had unique characteristics compared to a random sample of 4,000 points within RMNP. The values for “sites” could vary substantially within a specific site area. Some sites have dozens of features, others only one feature. A polygon feature class was created in ArcGIS that “encompassed” each site. Zonal statistics were then created for each polygon (which represented a site). For example, in the case of aspect all grid cells within the polygon that represented a specific site would be added and a mean determined. This would be the mean aspect for that site.

Similar to Rohe’s (2003a) work, ordered variables in Table 2 were subjected to a Kolmogorov-Smirnov (K-S) test. This test does not assume that data is normally distributed. The test can be used to assess if two data sets differ significantly (in our case the sacred sites and the random sites). P-values less than .1 were considered significant. Two variables: sinaspect (a measure of east-west orientation) and vegetation variety (# of vegetation communities within a specified area) did not pass the K-S test and were eliminated from further study. An important caveat regarding the relative location of the sites should be mentioned. It *is not* surprising that most variables were found to be of statistical significance when compared to a *random sample* of points within RMNP. Most of the sites and features are located at or above tree-line and it was natural to assume an inherent bias might be reflected in the sacred site/feature data. This bias could be potentially accounted for in future analysis by comparing an above tree-line random sample of points with a sample composed of sacred sites/features point data. However, the researchers decided that the method chosen for the current model was adequate for purposes of an exploratory modeling analysis.

Table 2. Two-Sample Kolmogorov-Smirnov Test of Significance Results*

Variable	**N**	**Mean**	**SD**	**z-score**	**p-value**	**K-S score**	**p-value**
Aspect							
Sacred Sites	31	204.39	86.26	**505.338**	**0.000**	**5.546**	**0.000**
Random Population	4000	6.53	2.18				
Cosaspect							
Sacred Sites	31	48.85	52.95	**3.744**	**0.000**	**2.010**	**0.001**
Random Population	4000	0.44	71.99				
CostDistance from Historic/Ancient Trails							
Sacred Sites	30	15361.97	27419.06	**-3.437**	**0.000**	**2.694**	**0.000**
Random Population	3995	38634.9	37089.51				
Elevation							
Sacred Sites	31	3342.93	508.21	**2.147**	**0.032**	**2.279**	**0.000**
Random Population		3208.51	348.56				
Relief							
Sacred Sites	31	839.74	228.6	**-3.857**	**0.000**	**2.538**	**0.000**
Random Population	4000	985.09	209.8				
Shelter							
Sacred Sites	31	60.58	4.38	1.123	0.262	**1.617**	**0.011**
Random Population	4000	59.39	5.9				
Sinaspect							
Sacred Sites	31	-0.09	58.64	-0.246	0.806	0.894	0.401
Random Population	4000	2.93	68.39				
Slope							
Sacred Sites	31	11.87	7.324	**-3.913**	**0.000**	**2.085**	**0.000**
Random Population	4000	19.93	11.47				
Summer Light							
Sacred Sites	31	215.97	26.7	**-2.094**	**0.036**	**1.298**	**0.069**
Random Population	4000	225.98	26.61				
Vegetation Variety							
Sacred Sites	31	4.85	1.24	0.401	0.690	0.665	0.768
Random Population	4000	4.74	1.53				
Viewshed (Mean)							
Sacred Sites	31	14.33	16.15	**3.991**	**0.000**	**2.182**	**0.000**
Random Population	4000	6.24	11.29				

* Variables in **Bold** are statistically significant at a p-value of .1 or less

Geology, soils, and vegetation were subjected to chi-square tests to assess whether those variables exhibited any statistical correlation with the 31 sites identified as having consultant or historic identified or trait-based sacred importance. Both geology and soils were found to be statistically different than the expected site numbers. Ultimately, in the modeling approach used by the authors, neither of these variables was incorporated in the final model. We were unable to derive a logical and explainable method of reclassifying soils and geology in to a smaller number of classes (2 to 5 which was needed in our modeling technique). Furthermore, when we tested different reclassification schemes for these layers, we were dissatisfied with the modeling results. However, we believe that future sacred site modeling should revisit the importance of soils, and, especially geology, in feature/site location. Vegetation type did not meet the critical alpha value of .1 and was excluded from the predictive model.

Model Selection and Using Weights of Evidence to Model Sacred Site Distribution

The technique chosen for modeling sacred sites and features was weights-of-evidence, a technique available in a free ArcGIS add on called ArcSDM 3.1 (Sawatzky et al. 2004). The software is now called “Spatial Data Modeler” which is available as a script for ArcGIS 9.2 (Raines 2009a). A version also exists for ArcGIS 9.3 (Raines 2009b). ArcSDM 3.1 includes weights of evidence, logistic regression, fuzzy logic and neural network modeling capabilities. The extension works best when a specific evidential theme is reduced to just two classes, although multi-class data can also be used (Raines, Bonham-Carter, and Kemp 2000, 46). Weights-of-evidence was first developed for mineral location analysis. However, it has also been applied to archeological site prediction in California and a number of other settings (see Hansen 2000, Hansen et al. 2002). Based on its inferred appropriateness to analyzing and predicting RMNP sacred sites, weights-of-evidence was chosen as a central exploratory technique for our GIS modeling analysis.

Weights-of-evidence combines data from different evidential themes to predict the occurrence of events (Raines, Bonham-Carter, Kemp 2000; Bonham-Carter 1994). Each evidential theme is analyzed and an output consists of the odds of occurrence or logits (Hansen 2000: 4). Logits are converted to natural logarithms and used to calculate a positive and negative weight for each characteristic (Hansen 2000: 4). Individual themes are usually (via reclassification and an assessment of weights) reduced to binary layers where one category represents areas where the features tend NOT to occur and the other category represents areas where the features tend to occur. Various binary themes are then combined to create a probability surface indicating the chances that one will find a feature within a stipulated area. Simplified themes do not have to be binary, they can also be ordered (i.e. low, medium, high). Calculation of theme weights for an evidential layer helps the user to set cut-off points for the generalized evidential layers (often binary) used to create a final response theme.

The weights-of-evidence method requires a training point dataset (samples or control points). Early on the authors struggled with the issue of whether the dataset should be represented by individual sacred features or the sacred sites. Thirty-one sacred sites, which included 183 sacred features, were identified through archeological surveys and Native American consultations. Most archeological GIS studies make use of site data, rather than individual features. We decided to use both techniques. Site data (as discussed above) were used to assess the statistical significance of individual variables. However, feature data (183 features) were used for the weights-of-evidence modeling and is presented here. We felt that assessing individual features provided a more robust model. A comparison was done with an earlier version of the model (using only the 31 site locations) and the resulting map patterns were quite similar (Brunswig, Diggs, and Montgomery 2009; Diggs and Brunswig 2006). Final posterior probabilities numbers did appear to be higher. There is likely an artificial inflation of the posterior probabilities with the use of all sites. However, since the model use is one of relative differences, we felt that the increased model robustness was worth the price of possibly inflated posterior probabilities.

ArcSDM was used to calculate category weights for the various layers. The W+ and W- fields indicate the positive and negative weights assigned to each elevation class given its area and the number of features found in each elevation class (Table 3). The Contrast is simply the difference between W+ and W-. Documentation for the method indicates that weights between .1 and .5 are mildly predictive, .5 to 1.0 moderately predictive, 1.0 to 2.0 strongly predictive, and above 2.0 extremely predictive. A detailed explanation of interpreting the weights-of-evidence resulting tables in archeological applications have been discussed elsewhere by the authors (Diggs and Brunswig 2006; Brunswig, Diggs, and Mongomery 2009). Hanson also discusses this technique (Hanson 2000).

Findings and Discussion of the RMNP Sacred Sites-Landscapes GIS Model

A series of “weights tables” were created for each layer and analyzed (see Brunswig, Diggs, and Montgomery 2009 for full results). Final analysis variables included: 1) Elevation, 2) CosAspect, 3) Local Relief, 4) Slope, 5) Cost Distance from Historic and Pre-Historic Trails, and 6) Relative Visibility of Four Sacred Landmarks. Examination of the weights in Table 3 show that the CosAspect and Elevation layers are moderately predictive of sacred features. The Relief, Cost Distance to Trails, and Slope layers are mildly predictive of sacred features. Rather than binary, the Viewshed of Sacred Landmarks layer was classed into three categories. Thus, the need for the *W+ (Viewshed)* column in Table 3. The viewshed layer is potentially extremely predictive of sacred features, which underscores the probable sacred nature of these features.

Table 3. Final Weights for Sacred Features Models

Layer	**W+**	**W+ (Viewshed)**	**W-**	**Contrast**	**Confidence**
CosAspect	0.68		-0.30	0.98	6.18
Cost Distance Trails	0.34		-2.90	3.24	5.55
Elevation Class	0.93		-2.44	3.37	10.27
Relief Class	0.31		-1.50	1.80	6.19
Slope Class	0.20		-2.90	2.43	4.77
Viewshed (sacred landmarks)	-0.48*	3.64	-2.49	6.13	17.05

** Represents low visibility category*

Figures 2 and 3 (below) show the final models used in our exploration of RMNP sacred site location prediction. Because of the large unit area (.5 sq. km.) used in the analysis and the clustering of features into a small number of sites at high elevation, probability numbers are likely inflated. It is probably more appropriate for the reader to look at the probability numbers as a poorer-to-better scale. Mihalasky (2001: C3) has suggested that the posterior probability maps should be viewed more as “favorability” maps rather than “probabilistic” maps. Research has suggested that weights-of-evidence modeling results will often mirror those done with weighted logistic regression. Comparison of patterns between the two methods will be similar, but probability numbers will tend to be inflated with weights-of-evidence (Mihalasky 2001).

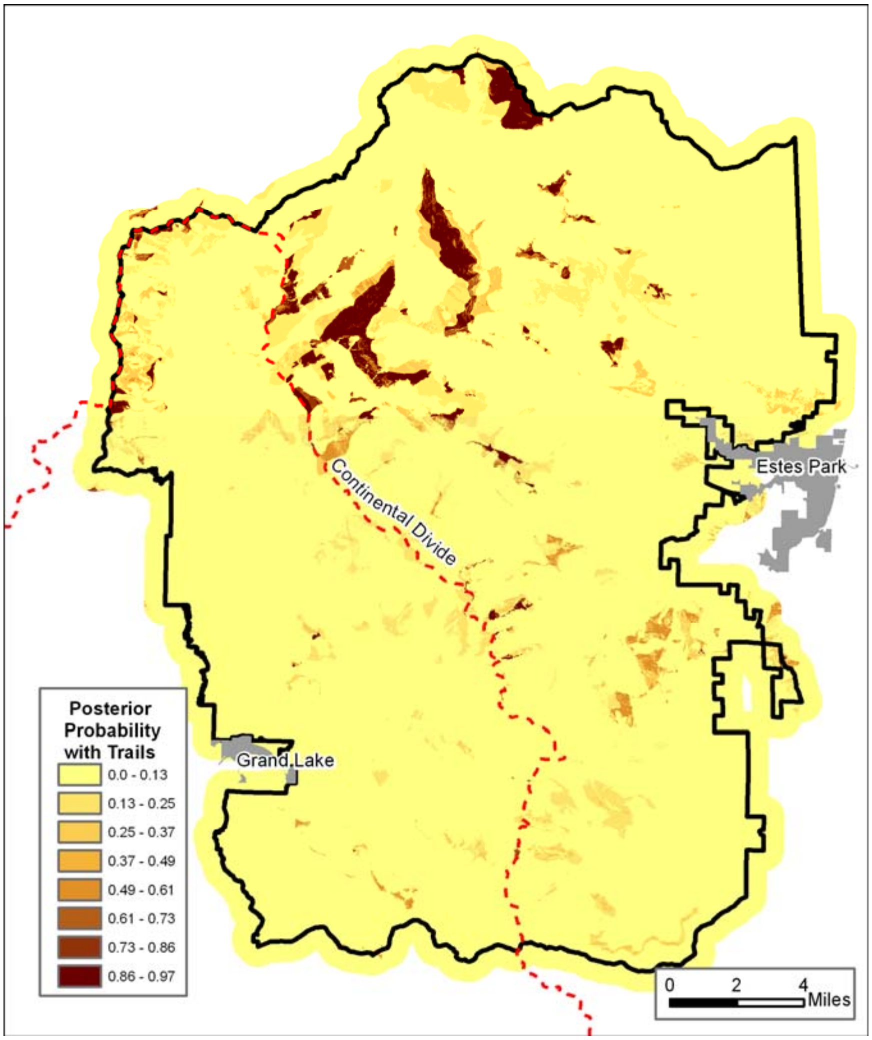


Figure 2. Posterior Probability of finding sacred Features (with trails) within .5 sq. km.

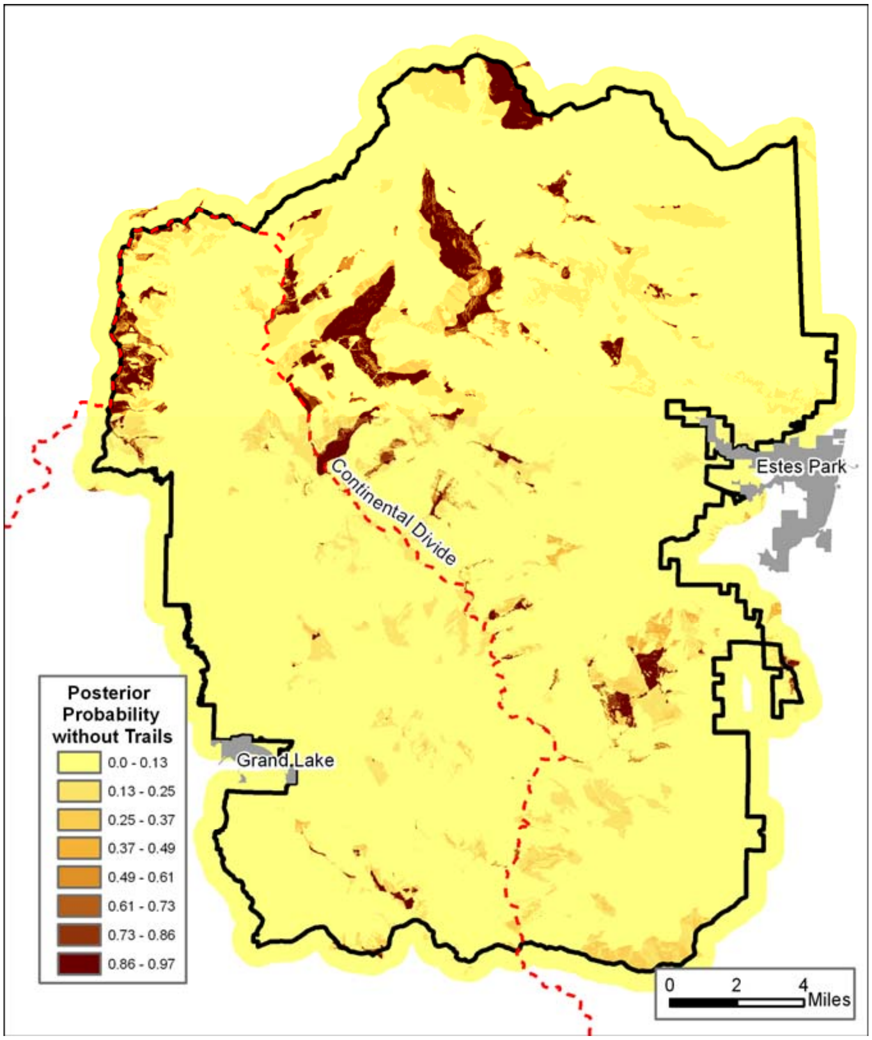


Figure 3. Posterior Probability of finding sacred Features (without trails) within .5 sq. km.

The relative lack of ethno-historically or archeologically documented trails in certain parts of the Park (such as the southern portion of RMNP) appreciably affects the resulting cost distance grid that was created. Therefore, two models were created: one which included the cost distance to documented historic/prehistoric trails (Figure 2), and one which did not (Figure 3). Comparison of the models indicates substantial differences in sacred site/feature prediction for the southern portion of RMNP, and to a lesser degree for the western part of RMNP in the Never Summer Range. On the one hand we believe that nearness to historic/prehistoric trails was an important factor, but we cannot rule out the possibility that important historic/prehistoric trails once existed in the southern portion of RMNP but have not yet been, or cannot be, documented at present due to erosion, soil build-up, and/or plant growth after falling into disuse for more than a century.

The question should be asked whether our final prediction maps (Figures 2 and 3) are truly predictive of sacred features. Three tests were conducted to help answer that question. The weights-of-evidence method requires layers be conditionally independent from one another. ArcSDM conducts a Agterber and Cheng Conditional Independence Test which generates a conditional independence ratio by dividing the actual number of training points by the expected number of training points. Values below 1.00 may indicate conditional dependence between two or more variables (Bonham-Carter 1994). Both of the models presented here (Figures 2 and 3) had conditional independence ratios well above 1.00 (figure 2 CI= 1.52, figure 3 CI=1.24).

Another measure of model reliability advocates a much more cautioned view of the final maps. Mihalasky (2001: C25) shows that an approximate t-test can be conducted on the posterior probability maps by dividing each cell's posterior probability by its standard deviation. Grey areas in the Figure 4 maps have less than a 70% of being accurate; the pink and red areas have a 90% or better chance of being "real" and are not an artifact of chance. Clearly, for large swaths of RMNP we are unable to determine sacred site predictability with a strong degree of certainty. Given this concern, we recommend models developed in this study should be used as only one part of a broader, more holistic approach to predicting sacred feature and site locations.

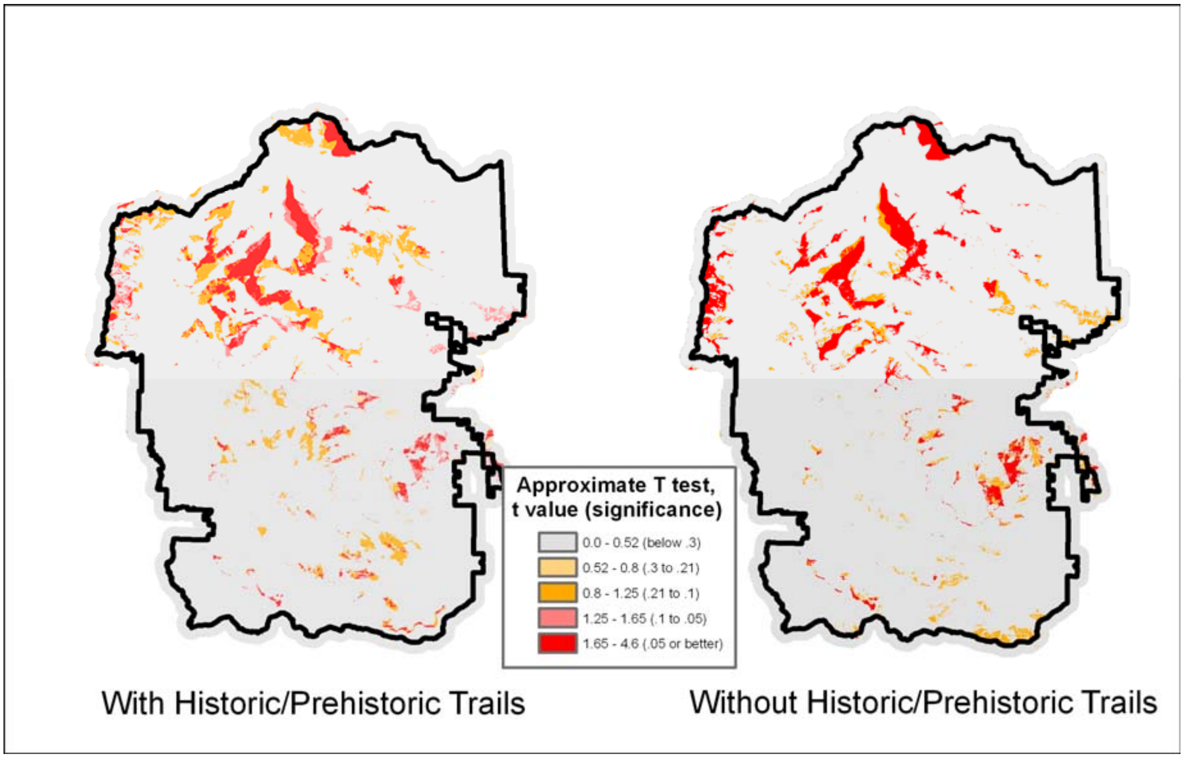
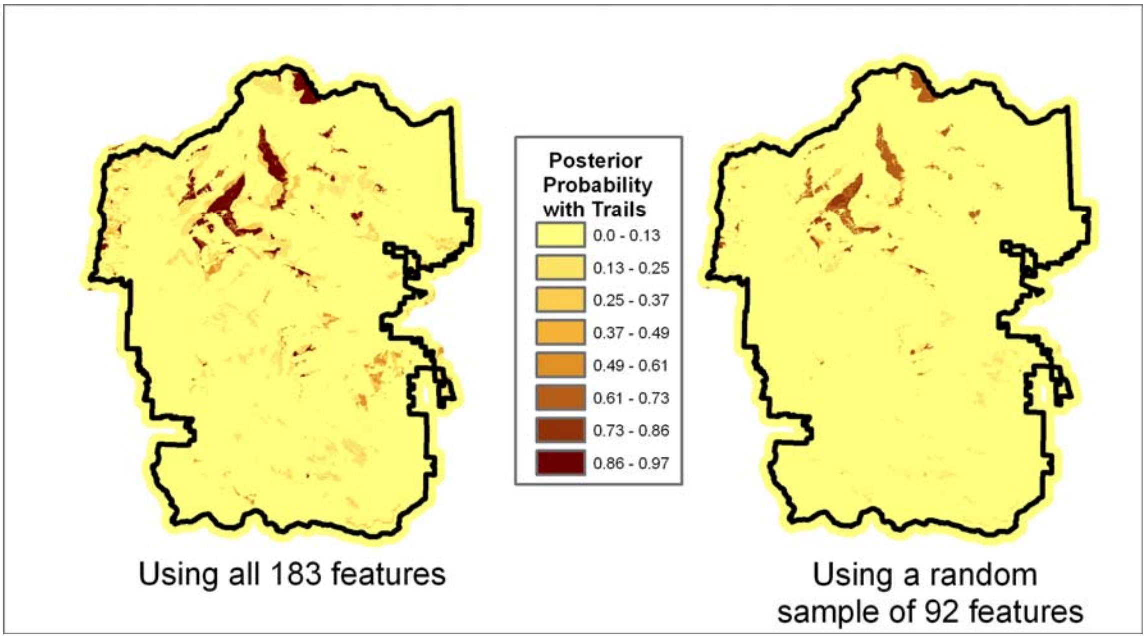


Figure 4. Relative certainty of the Posterior Probability.

Finally, a comparison was made between the model (with trails) and a subset of the sacred feature data set. Ninety-two randomly selected sacred features were selected from the original data set of 183. Using the same six variables (elevation, coaspect, slope, cost distance to trails, relief, and viewed) the weights-of-evidence method was used to model predicted sacred site locations. A comparison between the two models is shown in figure 5. Patterns between maps of the two models are quite similar. Overall, however, posterior probabilities were lower, likely a result of the smaller training point sample size. Again, it is necessary to reiterate that the posterior probabilities are best thought of a occurring along a poor to good scale with the realization that actual posterior probability numbers may be inflated. Given that assumption, we were satisfied the model accurately predicted the randomly chosen subset of sacred features.



Using all 183 features

Using a random sample of 92 features

Figure 5. Comparison of model with all features and model with random sample of 92 features from original data set.

Recommendations for Future Field Investigations Based on GIS Modeling

Using the model results (Figures and 2 and 3) and other sources of information eight areas of further field survey work were recommended (see Figure 6). Due to concerns about the protection of archeologically sensitive areas, we are unable to provide the reader with the precise locations of these areas. The GIS models were an important factor in the selection of the eight recommended areas for further survey. Equal weight, however, was given to the authors' familiarity with RMNP, discussions with RMNP personnel, and knowledge gained from Native American consultations.

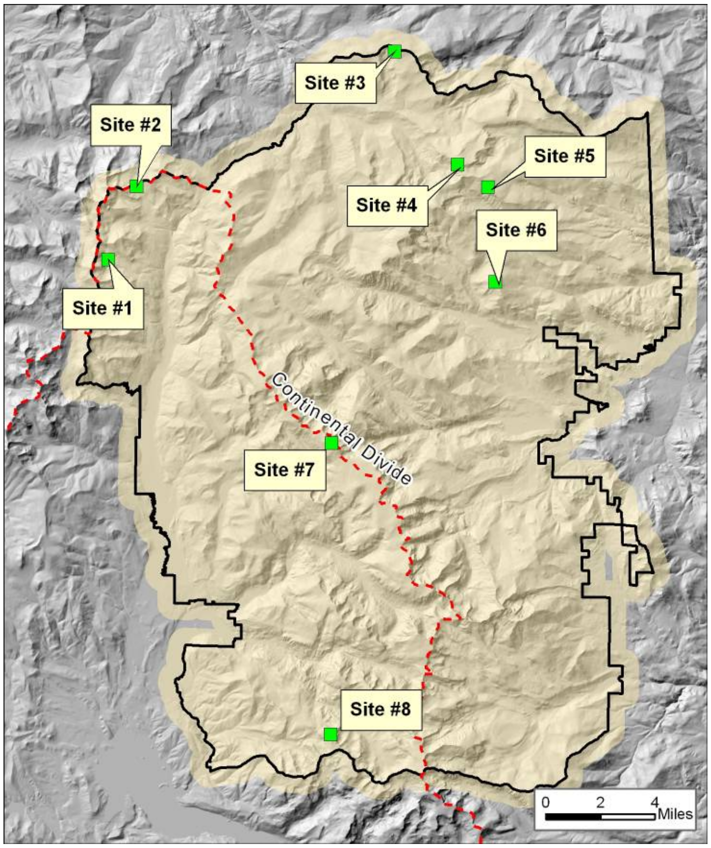


Figure 6. Areas recommended for future archeological survey.

Conclusions

The above study describes results of a continuing series of investigations on the nature of past Native American cultural landscapes, specifically related to ritual-ceremonial practices, in Rocky Mountain National Park. By combining diverse sources of archeological, ethnographic, and historic knowledge with Geographic Information System software and multi-layered data sets and applying the weights-of-evidence technique to our GIS model, we were able to advance efforts in predictive modeling of sacred site spatial distribution patterns. Representations of elevation, viewsheds of known and inferred sacred landmarks, local relief, slope steepness, north facing slopes, and nearness to known prehistoric and early historic trails constituted important predictor variables for modeling sacred site locations with the current site data set. The study also shows the weights-of-evidence method is a valuable heuristic device for exploring data associations and testing hypotheses. Testing and reification of this model (or future ones), however promising, will still require further field surveys and archeological data collection as well as follow-up Native American consultation studies.

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