EVALUATING WILD HOG PREFERENCES AND CONTROL STRATEGIES IN THE GREAT SMOKY MOUNTAINS NATIONAL PARK

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Abstract. Feral hogs (*Sus scrofa*) are an invasive species that have occupied Great Smoky Mountains National Park since the early 1900s. The population is in direct competition with native species, inflicts unprecedented damage to plant communities and is a reservoir for disease. The Park implemented a control program in place since the late 1950s and kept detailed geographic records on each removal since 1980. In an effort to inform the control efforts and better understand this population, we use data analyze the niche of the species in the Park and map it spatially.

INTRODUCTION

Invasive species are a pressing concern as their presence is costly and damaging to the environment [22]. Characterizing the suitable habitat areas for a species can facilitate management for invasive populations of plants and animals. Environmental Niche Factor Analyses have contributed to such characterizations [4,6,33]. We use such an approach to evaluate wild hog preferences and derive a habitat suitability map for the population in the Great Smoky Mountains National Park (GSMNP).

Wild boar, (*Sus scrofa*), were brought to the United States as a game animal by European settlers over a century ago. Since that time, the boars have mated with domestic swine and continue to spread throughout the southern U.S. at a steady pace [18]. Invasive species are significant environmental concerns, especially as they become more established in a new area [10,22]. Wild hogs are of particular concern as their behavior and spread are both monetarily and environmentally damaging. Economically, they cause damage to agriculture in excess of $800 million each year in crops alone and the potential spread of pseudorabies is a serious concern to the swine industry [5,24,34]. Ecologically, they compete with native species while destroying flora and fauna, reducing biodiversity, and cause soil erosion as well as water quality issues [3,16].

Wild boars were brought to the southern Appalachian Mountains in 1912 [30]. Since then, hogs have increased their range and can be found all across the region, including within the pristine and flourishing GSMNP. The Park was established in 1924 and contains $2,080$ km^2 of wilderness that spans the border between North Carolina and Tennessee. Elevation in the Park ranges from 270 m to 2,024 m with a high elevation ridgeline that runs diagonally through the center from the northeast to the southwest boundaries.

Since their initial invasion, wild hogs have spread throughout the entire Park. Acorns from oak trees are the most important part of their diet and locations of this food source play a role in their behavior [14,27]. Hogs are also known to scavenge for tubers, roots and other soft foods that can be found on the ground, especially in the absence of acorns. The population exhibits seasonal movement driven by food availability and temperature changes [27,29].

Wild hogs in GSMNP are in direct competition for food sources with native species. They are also known to eat salamanders, a valued ecological component of the Park [23,27]. Their rooting activity is also very destructive as it has been shown to disrupt vegetative communities, alter nutrient cycles, and aid the spread of invasive plant species [3,14,20]. Wild hogs are a known vessel for a number of diseases including porcine parvovirus, leptospirosis, toxoplasmosis and pseudorabies [5,26].

Due to the these concerns, GSMNP has had a hog control program in place since the late 1950s [32], including hunting hogs on foot, as well as setting traps in believed presence locations. The amount of effort the Park applies to the control program follows two seasons as dictated by seasonal conditions and available personnel. More time and manpower are usually applied from January through May with a

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limited effort put forth from June through December. Since 1980, detailed records have been recorded for each kill that include age, sex and geographic location producing over 11,000 records since 1980. Man power and specific locations chosen to hunt within the Park are decided according to reports of recent hog activity and past control history.

Two recent papers were written about wild hogs in GSMNP using removal data provided by the Park and vegetation data obtained via LIDAR [8, 17]. The first paper contains an agent based model in which individual hog behavior is modeled in order to examine population dynamics [25]. The second paper has a discrete metapopulation model that uses parameters that were carefully estimated using available data [15]. Historical effort levels of the control program were carefully estimated by comparing output of the metapopulation model with the removal data. Model simulations indicate that the control program is important in limiting the population [15]. One aim of this paper is to scientifically inform control efforts by illustrating locations where hogs can be effectively and efficiently removed from the Park.

The control data only conveys information related to the presence (not absence) of hogs in the Park. For this reason the harvset data lends itself to presence-only methods such as Environmental Niche Factor Analysis (ENFA) [11]. The theory aims to quantify a species niche by relating presence points to ecogeographic variables (EGVs). We can then scientifically and mathematically assess potential wild hog locations with the goal of limiting their population within Great Smoky Mountains National Park. Using this approach we are able to derive a detailed map of suitable locations for hog presence, as well as a map showing locations where one would be most likely to encounter hogs. Thus, results produced from this method have applications in illustrating wild hog habitat in the Park while also suggesting potentially bountiful places to hunt. This information can be used to increase our understanding of the population, evaluate historical hunt sites, and provide insight into other potentially fruitful locations. This methodology could also prove to be useful for other species found in GSMNP such as flying squirrels and Indiana bats. Since both of these species are threatened, understanding and protecting the geographic locations of their habitat could be invaluable to their recovery.

A description of Environmental Niche Factor Analysis (ENFA) will first be presented. Then our methods and the data used in the analysis will be discussed. A Niche Factor Analysis will the be applied to the data in order to assess wild hog preferences in GSMNP. Using the resulting information, two map products are produced and validated using a continuous Boyce index [2, 13]. Finally, we present conclusions from our map products and analysis.

Methods and Data

An Environmental Niche Factor Analysis uses the concepts of marginality and specialization to determine habitat preferences and model them spatially [11]. Marginality can be measured as the difference between the average conditions where the species is found and the average conditions of the study area. Specialization is the ratio of the variance of the conditions where the species can be found and the variance of the conditions of the study area. Together, marginality determines the types of conditions the species prefers and specialization measures how sensitive the species is to deviations from their preferences.

In order to measure these multiple variable dependent values, the powerful theory of principal component analysis is used in an innovative way to produce uncorrelated environmental predictors and conduct a factor analysis [11]. Ecogeographic preferences can then be determined and used to create two maps relevant to hog presence in the Park. Results of these maps are validated using a predicted-to-expected ratio and a continuous Boyce index, which will be explained later.

Since each data point represents a location where a hog was removed, the conditions are suitable for both hog presence as well as a successful hunt. For this reason even though the presence-only data is likely biased by the behavior of hunters, a distribution map derived from successful hunting locations using an ENFA conveys important information for the control program.

The study location is GSMNP, which is almost entirely undeveloped which limits the number of human-related ecogeographical variables to roads, trails and buildings. All of the data was initially processed into raster maps using ESRI ArcMap 10.1. All maps were re-projected to NAD 1983 UTM Zone 17N using a GSMNP boundary file to set the extent of each map and to clip the data to the study area. Given the size of the study area, available data and goals of the project, each raster map was constructed with a cell size of 30m by 30m. This resulted in 2899 columns and 1308 rows for a total of 3,791,892 cells.

Some data preparation and all analysis were then completed in BIOMAPPER 4.0, a software developed for ENFA [12].

All human related data was provided by GSMNP [9]. Roads and buildings are fairly uncommon within the Park and these variables were quantified in each cell with a closest Euclidean distance analysis performed in ArcMap 10.1. Trails, however, are more bountiful with certain areas of the Park containing larger densities of trails than others. Due to this fact, trails in the Park were quantified by the area covered by trails within a 2 km diameter centered on each cell using the frequency tool in BIOMAPPER [12]. Using a user supplied radius, the frequency tool measures the fraction of total area covered by the feature in a circle surrounding each cell. A 2 km radius was chosen after reviewing results using a number of different values.

Geographic data includes slope and elevation. Elevation was obtained from the National Elevation Dataset (NED) [7]. The digital elevation map was then used to derive the slope within the Park.

Not only is GSMNP almost entirely undeveloped, it is surrounded by national forests increasing the sheer magnitude of wilderness. As a result, it makes sense that hog preferences in the Park would be driven primarily by environmental factors related to vegetation, climate, food and water. A GIS vector map of locations of streams from GSMNP was quantified using the frequency tool in BIOMAPPER described previously [9].

Vegetative data includes understory vegetation and food preferences, as well as general growing conditions expressed by the normalized difference vegetation index. Detailed data related to the types of vegetation growth found throughout the Park was obtained via lidar and provided by [17]. This data includes overstory and understory values, both of which were used in the model. Since hogs root for part of their food source, ground vegetation is an important part of a hog habitat. Understory vegetation was extracted from this source into three major categories that collectively cover 85% of the park. These categories include Rhododendron, Kalmia and Herbaceous and Deciduous understory. A frequency map was derived from each understory category in ArcMap. Another indication of ground vegetation is given by the normalized difference vegetation index (NDVI), which was developed by Rouse et al. (1974) and is commonly used to assess the growing condition of green vegetation. The NDVI is numeric data and was obtained from the Global Land Cover Facility [21].

As previously discussed, food sources are believed to play a large role in the behavior and life cycle of hogs [27, 29]. As such, overstory vegetation information from [19] was used to create a food preference map based on the amount of kilocalories produced per acre in each cell during the fall months when food is most bountiful. Categorical values range from 1 to 5 the summary of which can be seen in Table 1. As each of these maps is categorical, they were quantified using the same frequency method.

Category	Kilocalories per Acre	Dominant Species
1	$< 5,000$	Spruce Fir
2	$5,000 - 7,000$	Oak, Pine and Northern Hardwoods
3	$7,000 - 9,000$	Oak and Pine
5	$> 11,000$	Cove Hardwoods

Table 1. Categorizing food sources based on the average amount of kilocalories produced per acre in the Fall. There is no category 4 as there are no locations in GSMNP produce between $9,000 - 11,000$ kilocalories per acre.

To consider the influence the climate found in GSMNP has on the hog habitat, 19 variables derived from temperature and rainfall data over the last 50 years were obtained from [1]. Since our study area is relatively small, temperature and rainfall values are similar across the Park which results in many of the maps being highly correlated. This results in most of the maps producing similar data in the factor analysis, requiring most maps to be discarded. Due to this fact, we only used average precipitation and average temperatures in the model. Even though most of the 19 variables could not be used, the two that were kept were the largest contributors to marginality and specialization. Furthermore, the high correlation between temperature and/or precipitation with the other variables mean they convey essentially the same information in the factor analysis.

Hog location data was provided by Great Smoky Mountains National Park and consists of the age, sex and geographic location of nearly all hogs removed in the Park since 1980 [8]. The data can be categorized by hogs that were trapped or hunted. Traps draw hogs into certain locations and thus may not accurately represent the species niche. However, hunted hog locations result from park employees

EGV	Minimum	Maximum	Mean	S.D.
Elevation	270	2,026	1,005	460
Slope	0	61	15	283
Distance to Roads	0	13,114	3,210	2,748
Distance to Buildings	0	24,306	7,191	4,863
Frequency of Trails	0	99	17	18
Frequency of Rhododendron	0	98	30	23
Frequency of Herbaceous Veg. & Deciduous Shrubs Understory	0	100	46	24
Frequency of Kalmia Understory	0	100	48	33
Calorie Level #1 Freq.	0	100	28	33
Calorie Level #2 Freq.	0	91	22	19
Calorie Level #3 Freq.	0	92	29	20
Calorie Level #5 Freq.	0	96	21	17
NDVI	20	250	162	23
Frequency of Streams	0	19	7	2
Average Temperature	6	14	11	1.5
Average Precipitation	100	148	129	9

TABLE 2. List of the 16 ecogeographical variables used in the analysis. Precipitation values are measured in mm, distances in m and frequency values in percent covered.

hiking through the backcountry throughout the park in search of hogs and thus better represent the species niche. With this in mind we chose to use locations of hunted hogs as our presence points, which results in 1,553 unique entries. See Figure 1 for a map of the locations. Note that even if this data is biased due to hunter preferences and behavior, it is suitable for this analysis since we wish to determine hunting locations that best limit the population. Also, hunting takes place at all locations where a trap is placed. Thus, although we are not considering trap locations explicitly, our results can be used to determine appropriate locations to place traps as well.

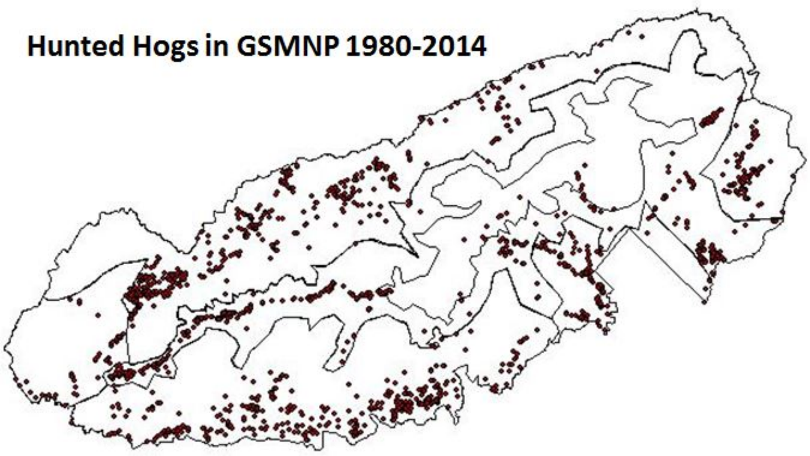


FIGURE 1. Locations of hunted hogs from 1980-2014 used as presence points in the analysis equals 1,553 in total.

Although all the data was obtained in ESRI format, BIOMAPPER requires Idrisi format. Converting into Idrisi format was carried out using Global Mapper and final preparation as well as analysis was conducted in BIOMAPPER 4.0. A summary of all EGVs used in our analysis can be found in Table 2. The mean and standard deviation values are useful when considering the results of the factor analysis in Table 3. In order to ensure the data took a Gaussian shape, the Box-Cox transformation was applied to all EGVs as recommended by [11]. This assists in ensuring the data take a Gaussian shape, though the method is robust to deviations from normality [11].

ENFA Results

After performing the niche factor analysis relating our EGVs to presence locations, we wanted to retain enough factors to explain at least 80% of the total information in the data. The values of the EGVs on each of the 8 factors is shown below in Table 3. The first factor explains 100% of the marginality and factors 1-8 account for 70% of specialization for a combined 85% of total information explained by the model. Thus, eight factors were used to compute the habitat suitability map. For the marginality factor values, positive values indicate the data points are found in locations that contain higher than average values with respect to the given variable, values near zero indicate a preference for average conditions and negative values indicate presence in locations with lower than average values. Only the magnitude of the specialization factor values is important, not their sign. Larger magnitude indicate restricted ecological tolerance compared with the overall range of conditions in the study area, and magnitude closer to zero indicates that the population deviates from their preference.

EGV	**Marg.**	**Spec. 1**	**Spec. 2**	**Spec. 3**	**Spec. 4**	**Spec. 5**	**Spec. 6**	**Spec. 7**
Slope	-0.510	-0.019	0.064	0.012	0.016	0.059	-0.247	-0.128
Frequency of Rhododendron Understory	-0.399	0.061	-0.175	-0.015	0.303	-0.216	0.078	0.175
Frequency of Herbaceous Veg. & Deciduous Shrubs Understory	0.365	-0.035	-0.082	-0.010	0.076	0.002	0.107	-0.092
Distance to Roads	-0.260	0.010	0.044	0.014	-0.054	0.021	0.184	0.093
Frequency of Trails	0.239	-0.002	0.010	-0.048	-0.054	-0.040	-0.221	-0.015
Elevation	-0.238	-0.641	-0.486	-0.588	0.472	-0.704	-0.311	-0.734
Average Precipitation	0.236	0.153	0.215	0.013	0.066	-0.237	-0.361	-0.041
Average Temperature	0.232	-0.727	-0.680	-0.757	0.138	-0.600	-0.226	-0.542
NDVI	-0.181	-0.017	-0.030	-0.001	0.251	0.063	-0.064	-0.127
Calorie Level #3 Freq.	0.169	-0.066	-0.030	0.202	0.434	-0.077	-0.323	0.096
Frequency of Streams	0.158	0.010	-0.012	0.041	-0.002	-0.027	0.474	-0.233
Calorie Level #5 Freq.	-0.143	-0.011	-0.169	0.125	-0.356	-0.021	-0.030	-0.094
Calorie Level #1 Freq.	0.141	0.123	-0.332	0.079	0.035	0.080	-0.225	-0.018
Frequency of Kalmia Understory	-0.116	-0.057	-0.181	-0.095	-0.227	0.086	-0.074	-0.005
Calorie Level #2 Freq.	0.097	-0.092	-0.147	0.066	0.446	0.104	0.356	0.112
Distance to Buildings	-0.083	-0.006	-0.128	0.000	-0.147	-0.004	0.209	-0.025

Table 3. Coefficients of the variables generated by the principal component analysis in ENFA arranged in decreasing order by their value on the marginality factor.

The largest contributors to marginality are slope, frequency of rhododendron and frequency of herbaceous vegetation and deciduous shrubs. As Table 3 indicates, hogs prefer areas with slope and frequency of rhododendron values far less than average (-0.510 and -0.399). Furthermore, they prefer locations with a higher than average frequency of herbaceous vegetation and deciduous shrubs (0.365). Factors 2-8 each accounted for between 9-12% of the specialization in the model. Since one factor did not dominate, in order to interpret the information the average magnitude of each EGV was calculated weighted by the amount of specialization explained by each factor. The weighted average indicated that wild hogs in GSMNP are most sensitive to changes in elevation and average temperature. The weighted average of all other specialization values were fairly low relative to temperature and elevation, indicating that hogs are not highly specialized animals. These findings are consistent with the widespread and resilient nature of the species and agree with past research [27, 29].

Map Creation and Validation

Two map products were produced from the niche factor analysis. The first is a habitat suitability map that ranks each cell in the study area from unsuitable to most suitable (Figure 3). This map was derived based on hog preferences evident from the factor analysis and categorizes the areas in GSMNP in terms of conditions needed to support wild hogs. The second map product was constructed using validation results and labels each cell in the Park with the likelihood of encountering a hog at the given location

(Figure 6). This is accomplished by emphasizing the regions within the suitable classes that contain the most predicted presence points by the model. Both maps convey information related to hog presence in the Park, but each with a different purpose. While the habitat suitability map ranks locations in terms of environmental conditions, the likelihood map may be more appropriate for finding hogs to remove for the control program.

The first map product was derived using the results of the factor analysis paired with the geometric mean algorithm in BIOMAPPER (see Figure 3) [12]. In order to estimate a habitat suitability value at each cell in the study area the geometric mean algorithm measures the cumulative distance, in the factor space, of the environmental conditions at each cell from the conditions at all presence locations. The performance of the model was evaluated using a k-fold cross-validation procedure that produces k estimates of the number of predicted points (P) and expected points(E) for increasing habitat suitability levels. The value of E is proportional to the area of the map covered by the given habitat suitability range. The value of P is derived from the number of presence points predicted by the model to fall within the given habitat suitability range. The ratio of these values can be represented as a continuous plot for increasing habitat suitability levels and is known as the P/E curve. We took $k = 10$ partitions along with a random seed following the method described in [13]. The method produces 10 estimates of the P/E curve, which allows us to determine the accuracy and consistency of the model. A model is deemed accurate if the P/E ratio is less than 1 for low habitat suitability values and increases monotonically past 1 as the habitat suitability range is expanded. The Boyce index ranges from -1 to 1 and measures this trend [2, 13]. Positive values indicate the model predictions are consistent with the distribution of presence points with values near 1 indicating the most accurate models [13]. Values near zero indicate the model's predictions are no better than chance. Negative Boyce index values indicates the model predicts too many presence points fall within poor suitability areas. As a measurement of the consistency of the model, a variance can be calculated using all 10 trials and appended to the Boyce index value. See Figure 2 to view the general trend of the P/E curve surrounded by the variance derived from all 10 trials. The curve is generally monotonic with any decrease reasonably within the displayed variance. A Boyce index value of 0.936 ± 0.049 measures this trend and indicates that the habitat suitability map is both accurate and consistent.

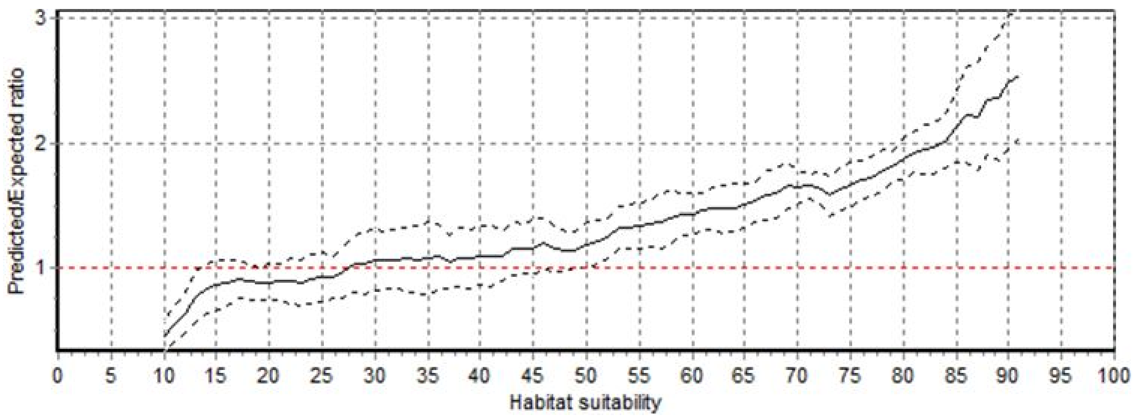


FIGURE 2. Ratio of predicted presence points to expected presence points for increasing habitat suitability values.

The P/E curve was then used to re-classify the suitability map into the 5 classes seen in Figure 3. Since the confidence interval surrounding the curve was fairly uniform, distinctions between classes were solely based on the shape and values of the curve. How each class was partitioned is shown in Table 4. Figure 7 allows one to visually verify the trend of the P/E curve and Boyce index values.

In addition to a reaffirming continuous Boyce index value indicating an accurate and precise model, the suitability map is also consistent with past research and qualitative information received by Park rangers [27–29, 31]. The unsuitable class is predominately located in areas of the Park that exhibit high elevation. High elevation is related to lower average temperatures as well as the types of vegetation and food sources hogs do not prefer [27, 29]. Although hogs are believed to range into the higher elevations during the summer months, it is out of necessity, not preference. In contrast, the top three suitable classes are at low elevations where the slope is relatively flat and oak trees, their favorite food source, are dominant. These locations are also where herbaceous vegetation and deciduous shrubs understory

Classification	Habitat Suitability Range	Reasoning
Unsuitable	$0 - 10$	No presence points
Mildly Suitable	$10 - 25$	$P < E$ in this range
Moderately Suitable	$25 - 50$	P slightly larger than E in this range
Suitable	$50 - 70$	P significantly larger than E in this range
Most Suitable	> 70	Steepest part of the P/E curve

TABLE 4. Explanation of how each class in Figure 3 was partitioned using the information in Figure 2.

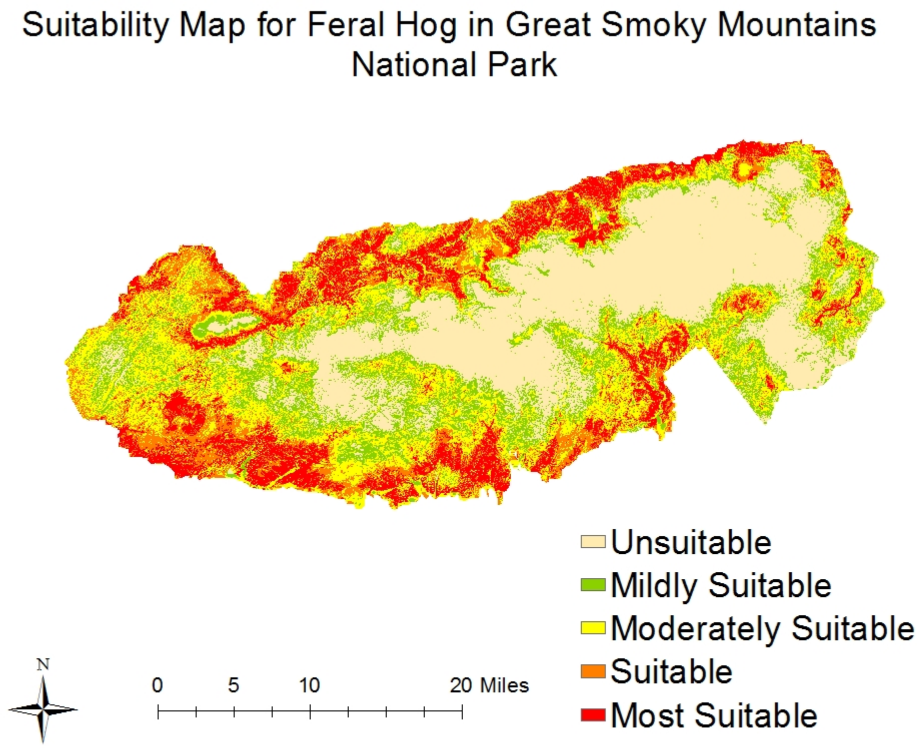


FIGURE 3. The 5 classes were partitioned using trends and standard deviation of the P/E validation curve shown in Figure 2.

are most prevalent. Due to their lower elevation, these areas have a higher average temperature and precipitation as well, for which hogs evidently have a preference based on their values in the marginality factor.

One can see the ENFA results playing out when examining the output from our model. For example, the highest contributions to marginality were shown to be preferences for slope and two understory categories. When carefully examining the habitat suitability map it is clear that slope has a significant hand in determining suitable locations (see Figure 5a compared to Figure 5b). Further distinctions between appropriately flat mild/moderate suitability locations and appropriately flat suitable/high suitability locations are being made in part due to understory values (see Figure 5a compared to Figure 5b and Figure 5c). Though some results can be deciphered using the naked eye, some cannot. For example, it is not obvious how the red areas in the likelihood map are determined and is likely a result of the model picking up on important and complex relationships that exist between the population and the environment. For this reason, in order to learn more about the wild hog population, these locations in the habitat likelihood map should be investigated in person in order to further validate the model.

Another useful result from this analysis is the creation of a map depicting where one is most likely to encounter hogs based on the model findings. Again using the P/E curve, we partition the results into locations where one is less likely to encounter a hog compared with random chance ($P/E \leq 1$), cells

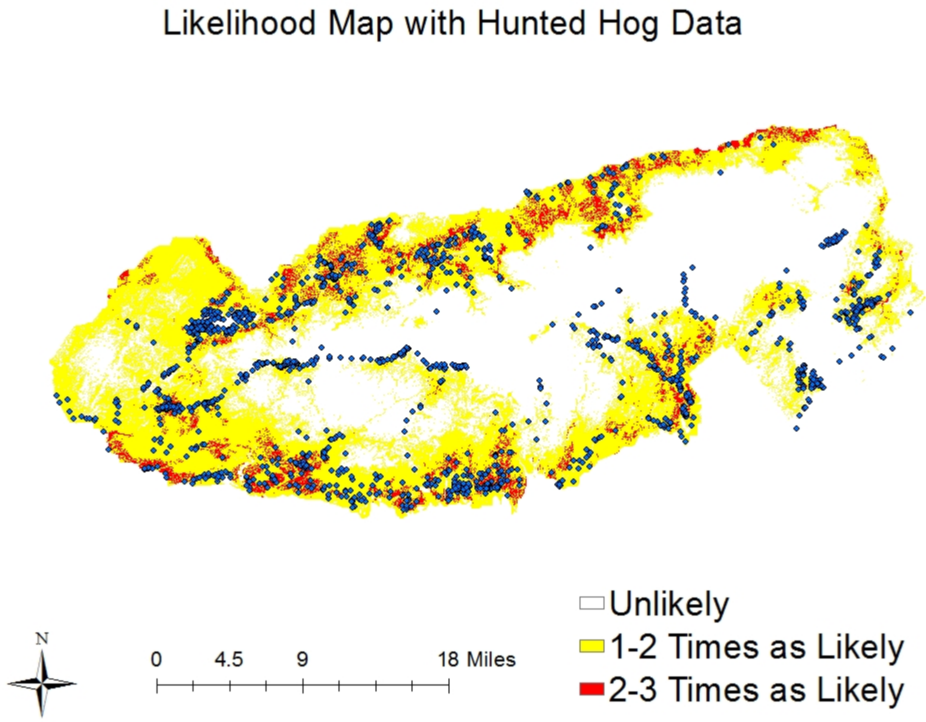


FIGURE 4. The likelihood of encountering a hog map superimposed with hunted hog data.

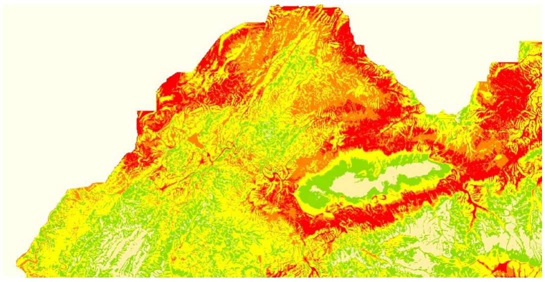
where one is 1-2 times as likely to encounter a hog compared with random chance ($1 < P/E < 2$) and locations where one is 2-3 times as likely to encounter a hog ($2 \leq P/E \leq 3$). This map in Figure 6 illustrates subsections within the suitable areas in Figure 3 that one is most likely to encounter a wild hog. These areas may have the highest hog densities in the Park, which sheds light on hog preferences while also being invaluable to park officials in terms of informing management strategies.

Conclusions

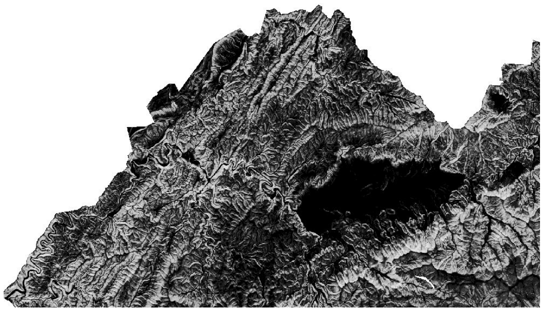
The presence of wild hogs (*Sus scrofa*) has been a concern to officials of Great Smoky Mountain National Park since the late 1940s. Their destructive nature and status as disease carriers prompted the creation of a control program over 50 years ago with records that have aided this research. However, since little is known about the population, locations of focused control efforts have been based solely on historical success and recent reports of hog presence. We have used control data from hunted hogs over the past 34 years and relevant ecogeographical variables to create two maps to assist the understanding of wild hog preferences and help determine good locations to hunt. We are able to make use of the two map products when assessing each objective.

Both maps increase our understanding of the preferences and whereabouts of this invasive exotic species. Since successful hunt locations convey adequate conditions for wild hog presence, we are able to create a general habitat suitability map for the population in the Park. The model examines the presence location across all EGVs and illustrates other locations throughout the park whose environmental conditions are also deemed to be suitable for hog presence, shown in Figure 3. This can be explored further by looking at Figure 6, as this second map displays areas throughout GSMNP that may harbor a high density of hogs. These apparent hot spots of hog activity may convey unknown information related to the behaviors and preferences of this population.

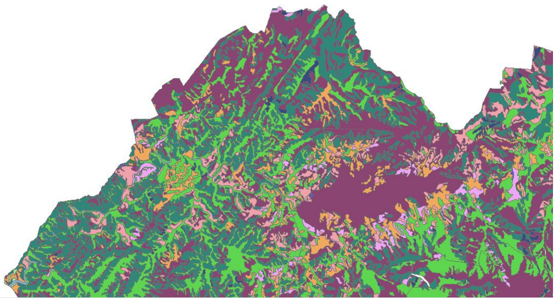
The map products can also directly relate to the control program as they allow us to evaluate past hunting locations while also highlighting other potentially fruitful areas to explore for hog presence. As you can see in Figure 7, while there are a number of additional habitats for hunters to explore, the vast majority of removals lie within the cells deemed most suitable by the habitat suitability model. The second map we created (Figure 6) is also highly relevant to hunting efforts. Notice that all cells are a subset of the locations from the general habitat suitability map with the red areas illustrating possibly



(A) Habitat Suitability



(B) Slope



(C) Understory

FIGURE 5. A zoomed view of the northwest corner of Great Smoky Mountains National Park for three different maps. The oval region is a high-elevation cove known as Cades Cove.

the best places to hunt as the model has deemed them most likely to contain hogs. Similar to the previous map, the red areas contain many of the historic removals with plenty of additional untapped locations being clearly displayed as well (see Figure 4). Thus, historic hunting sites can be appreciated while also examining alternative locations for future hunts in the orange/red areas throughout the park that have yet to result in a hog kill.

One might argue that the results presented here are skewed because of bias that may exist in the data points as a result of hunter preferences. However, even if this were true, the bias introduced by the hunters will still produce results relevant to the control program. That is, whatever bias that exists is a result of the preferences intrinsic to hunters and each location lies in the intersection of locations that are both accessible to hunters as well as suitable for hog presence. For example, though the model indicates that presence locations occur in cells with below average frequency of rhododendron, it is not clear whether this is due to hog preferences or hunter behavior. Nevertheless what *is apparent* is how kills are more likely to occur in locations that lack rhododendron, which is a useful piece of information regardless of its driving cause. In this light, the hunting data may even better lend itself to evaluating hunting choices compared with unbiased presence data.

We can view both maps and make recommendations for future control activities. For example, Figure 4 shows that the total area where the likelihood of encountering a hog is $1-3$ times as likely compared with random chance dwarfs the area where control efforts have historical taken place illustrating additional potential hunting sites. It is also clear that a number of areas near the edge of the Park generally contain more suitable conditions and should to be exploited. Furthermore, since many of the suitable locations are on the edge of the Park, it begs the question of the hog-related activities taking place directly adjacent

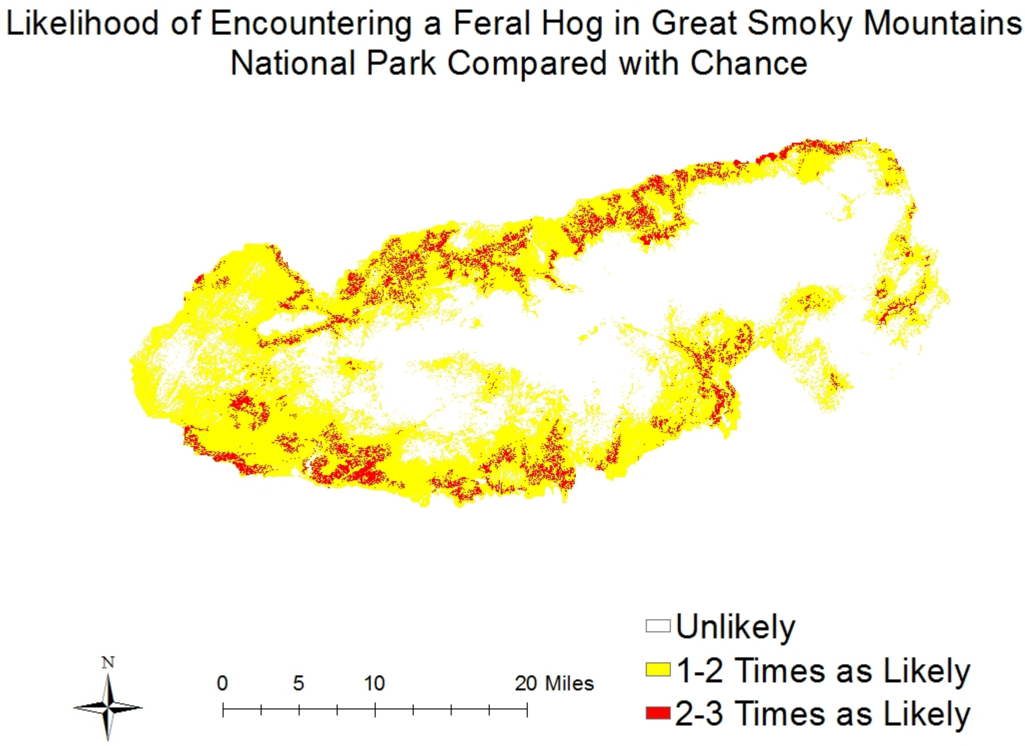


FIGURE 6. Map showing the likelihood of encountering a hog throughout Great Smoky Mountains National Park partitioned using the P/E curve shown in Figure 2.

to these locations but on the outside of the Park. Areas of particular interest include Nantahala National Forest, Cherokee Reservation and the Cosby/Gatlinburg area. Although few historic removals have taken place in the northwest corner and far eastern border of the Park, Figure 6 suggests a high likelihood of encountering a hog in these areas indicating that they may be effective and efficient places to hunt. Finally, although many kills occur in open fields in areas such as Cades Cove and Cataloochee, the model indicates the wooded areas surrounding these fields are the suitable habitat for wild hogs (see Figure 5). For this reason, efforts should continue in the woods surrounding these fields.

It is easy to understand why some of locations that the model predicts to be highly suitable for hog presence have yet to produce kills, while other locations need to be studied further. For example, it is easy to understand that although the region in the northwest corner of GSMNP has good conditions for hog presence, not a single control kill has been produced in this area of the Park as it very remote with few trails and only a single dirt road. On the other hand, locations such as the far eastern border that are in fact accessible but are yet to produce hog kills are particularly interesting and may be worth exploring for signs of wild hogs. Such inaccessible or unexploited locations where the model indicates quality conditions for wild hog presence are concerning as they may serve as reservoirs for the population that work against the control efforts of the Park. The only way to determine this for sure is to carefully examine such locations for hog presence.

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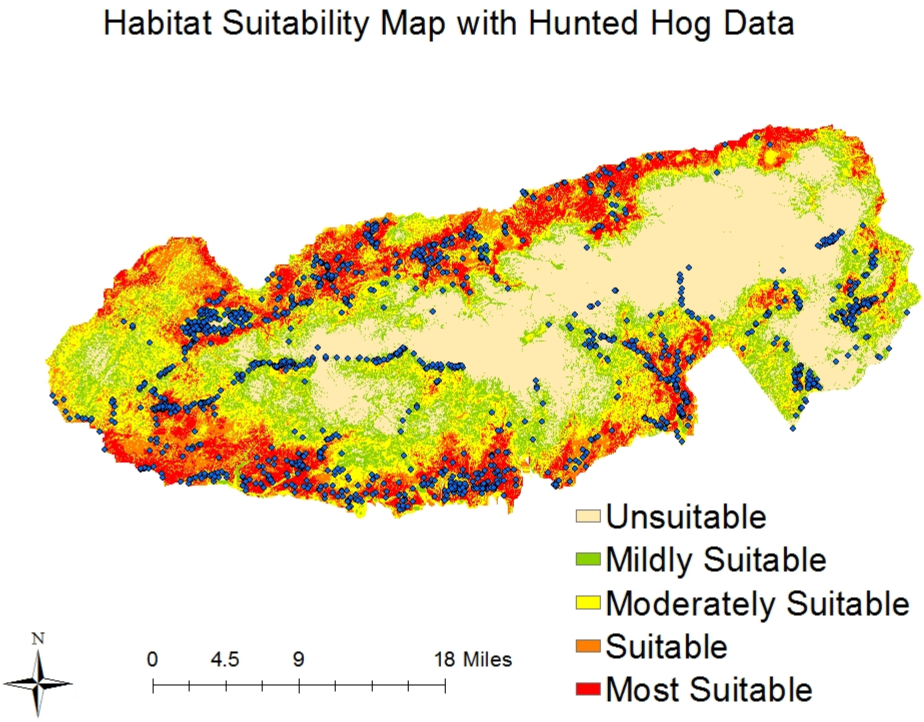

FIGURE 7. The habitat suitability map superimposed with hunted hog data.

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