# DEVELOPMENT OF A PREDICTIVE MODEL FOR HABITAT OF THE MEXICAN SPOTTED OWL IN NORTHERN NEW MEXICO

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ABSTRACT—The Mexican spotted owl (*Strix occidentalis lucida*) was listed as a threatened species under the Endangered Species Act in 1993. We developed a predictive, vegetation-based model for habitat of the species in the Jemez Mountains, New Mexico, using logistic-regression modeling techniques and analyzed seven habitat variables with six of the variables included in the final model. A plot analysis using Receiver Operating Characteristics indicated a high performance of the model, and validation of the model confirmed proper function. Compared with random unoccupied sites, the model indicates that owls in the Jemez Mountains prefer habitat with greater diversity, density, and height of trees, canopy cover, and shrub density, which is in agreement with much of the literature on biology of the Mexican spotted owl. This model can be used with fine-scale assessments of habitat for land-management agencies that have a priority to accurately delineate habitat of the Mexican spotted owl. Los Alamos National Laboratory will use this model to re-delineate habitat of owls to reduce assessment costs and to better protect appropriate habitat.

RESUMEN—El búho manchado mexicano (*Strix occidentalis lucida*) fue puesto en la lista de especies amenazadas en 1993 bajo el Acto de Especies Amenazadas. Desarrollamos un modelo de predicción de hábitat basado en la vegetación para la especie en las Jemez Mountains en Nuevo México utilizando técnicas de modelación de regresión logística. Analizamos siete variables de hábitat con seis de las variables incluidas en el modelo final. Un análisis de parcelas usando Características de Operación para el Recibidor indicó un alto rendimiento del modelo, y la validación del modelo confirmó la función apropiada. Comparado con sitios aleatorios no ocupados, el modelo indica que los búhos de las Jemez Mountains prefieren el hábitat con una mayor diversidad, densidad, altura y cubierta de dosel de árboles, y densidad de arbustos, lo cual está de acuerdo con mucha de la literatura sobre la biología del búho manchado mexicano. Este modelo se puede utilizar para llevar a cabo evaluaciones muy finas del hábitat para las agencias de manejo de terreno que tienen la prioridad de delinear exactamente el hábitat del búho manchado mexicano. El Laboratorio Nacional de Los Alamos utilizará este modelo para delinear de nuevo el hábitat del búho para así reducir los costos de evaluación y para proteger mejor el hábitat apropiado.

Under the Endangered Species Act, the United States Fish and Wildlife Service listed the Mexican spotted owl (*Strix occidentalis lucida*) as a threatened species in 1993 (United States Fish and Wildlife Service, 1993) and developed a recovery plan in 1995 (United States Department of the Interior, 1995). The eventual goal of any recovery plan is the removal of the species from the list of threatened and endangered species (White et al., 1999).

The Mexican spotted owl is a species resident to the Jemez Mountains, New Mexico, and is found throughout other mountains and canyons of New Mexico, Arizona, southern Colorado, southern Utah, and northern and central Mexico. Most of these owls reside in a band of mixed-coniferous and ponderosa pine-Gambel oak (*Pinus ponderosa-Quercus gambelii*) forest. Mexican spotted owls generally nest in trees, although in the northern part of their range (southern Utah and Colorado) they often nest in caves or cliff ledges in canyons and seem to prefer shady habitat with steep cliffs and rocky terrain (Rinkevich et al., 1995; Rinkevich and Gutierrez, 1996). Spotted owls in the Jemez Mountains generally nest on or near cliffs in mid-elevation canyons (J. A. Johnson and T. H. Johnson, in litt.). Occupancy of nesting territories in the Jemez Mountains has declined markedly since the mid-1980s, and productivity has varied greatly from year to year (T. H. Johnson, in litt.).

The present study aimed to facilitate conservation of the species in northern New Mexico by developing a predictive, vegetation-based, fine-scale, habitat model that can be used to assess breeding territories of individual Mexican spotted owls for habitat quality. Most studies that model habitat are developed for predicting habitat on a large, landscape scale, many using a geographic information system (GIS). The advantage of this study is that it uses logistic regression to predict quality of habitat on a finer scale for better management of territories of individual owls, a need of various land-management entities.

MATERIALS AND METHODS—*Study Area*—The study area was located in the Jemez Mountains, New Mexico, in parts of Sandoval, Rio Arriba, Santa Fe, and Los Alamos counties. This relatively small, isolated mountain range covers 3,366 km$^2$. The forest-cover types in higher elevations are characterized as a mix of Rocky Mountain Subalpine Conifer and Rocky Mountain Montane Conifer forests (Brown, 1994). Common species in Rocky Mountain Subalpine Conifer Forest are Engelmann spruce (*Picea engelmannii*), subalpine fir (*Abies lasiocarpa*), blue spruce (*Picea pungens*), and quaking aspen (*Populus tremuloides*). Common species in Rocky Mountain Montane Conifer Forests are Douglas fir (*Pseudotsuga menziesii*), white fir (*Abies concolor*), limber pine (*Pinus flexilis*), and blue spruce, with ponderosa pine at lower elevations.

*Study Site*—This study compared habitat variables at occupied nesting territories and randomly selected unoccupied areas in the Jemez Mountains. Occupied study sites were based on occupancy data from Protected Activity Centers collected in the 1990s by the Mexican Spotted Owl Recovery Team, as well as surveys conducted by biologists of the Santa Fe National Forest, contractors, or both. A Protected Activity Center is about 240 ha and, in the Jemez Mountains, they include canyon bottoms and sides and mesa tops, encompassing the core of the suspected breeding range of this owl. An occupied study site was omitted from the study if it was in an area having fire damage during the past 10 years because the target habitat to be analyzed by this model was in unburned areas at Los Alamos National Laboratory.

Unoccupied study sites were located in canyons with topographical features similar to occupied areas. Holding topographical features constant would force the model to only examine the vegetative component between occupied and unoccupied habitat. Using a GIS with paired *t*-tests and $\chi^2$ analyses, areas were identified that were statistically similar to nearby Protected Activity Centers in size, elevation, aspect, and slope. Sites were omitted from the study if they were in canyons already having a Protected Activity Center, in areas having fire damage during the past 10 years, or on private land. We then randomly chose 10 unoccupied study sites selected by the GIS for development of the model.

*Vegetation Plots*—Field crews randomly placed eight 10 by 10-m plots throughout each study site in forested, canyon-bottom locations. Randomization of locations of study plots was achieved by using a random-point generator within ArcView© Version 3.2a (ESRI, Inc., Redlands, California). We used a global positioning system to identify random locations in the field, which were required to be in homogeneous forested habitat. If location of the random point did not fall within forested habitat, such as in a stream bed or in an open meadow, we moved it to forested habitat closest to the random point.

Habitat variables selected to be modeled were empirically known to affect presence of the Mexican spotted owl. Because this was to be a fine-scale predictive model, we selected habitat characteristics on a local scale rather than landscape. We recorded seven habitat variables at each plot; diameter of tree at breast height (cm) for all trees, height of all trees (m), percent canopy cover, density of trees using number/plot, density of shrubs using number/plot, density of snags using number/plot, diversity of trees using number of species of trees/plot.

*Statistical Methods*—We used a General Linear Model to predict occupancy of habitat. Because the response variable was binary (presence or absence of Mexican spotted owls), the appropriate form of the General Linear Model was logistic regression (Carroll et al., 1999). Logistic regression has been used previously to predict habitat for owl species (Mills et al., 1993; Christie and van Woudenberg, 1997; Hershey et al., 1998; Buchanan et al., 1999; Swindle et al., 1999; Loyn et al., 2001; McComb et al., 2002). Additionally, logistic regression is preferable to linear discriminate analysis of binary data when the explanatory variables are nonnormal (Press and Wilson, 1978), which is true of the continuous habitat variables in this study.

We averaged data from the eight study plots/site for use in development of the model. Using a backward stepwise analysis, we included variables in each step using as criteria the level of $P = 0.05$ for entry and $P = 0.10$ for removal. We transformed the value of Logit($P$) into a probability-of-occurrence value using the following equation:

$$\text{Probability of occurrence} = \frac{e^{[\text{logit(P)}]}}{1 + e^{[\text{logit(P)}]}}$$

where $e$ is the base of the natural logarithm (Luck, 2002). We assessed power of the logistic-regression model using the plot of Receiver Operating Characteristics, a threshold-independent measure. Area under the curve of Receiver Operating Characteristics, varying from 0.5 to 1, provides a measure of overall accuracy based on several different probability thresholds, and can be translated as the probability that the model will correctly distinguish between two cases (Fielding and Bell, 1997). We performed all statistical procedures with the SPSS statistical package Version 13.0 (SPSS, Inc., Chicago, Illinois).

*Validation of Model*—Validation is an important part of development of a model, which we performed using data from 10 independent study sites not used in development of the model and or in deriving scores from those locations. We collected data at validation

TABLE 1—Mean and standard deviation for habitat variables used in the development of a model of habitats occupied by the Mexican spotted owl in the Jemez Mountains, New Mexico. Diversity of trees, density of trees, density of shrubs, and density of snags are an average number per plot. Canopy cover is an average percent cover per plot, height of tree is average height in meters per plot, and DBH is diameter in centimeters at breast height of all trees per plot. Size of plots was 10 by 10 m.

| Status | Diversity of trees | Density of trees | Density of shrubs | Density of snags | Canopy cover (%) | Height of tree (m) | DBH (cm) |
|---|---|---|---|---|---|---|---|
| Occupied | 4.04 (±1.08) | 20.21 (±7.53) | 30.35 (±21.65) | 4.2 (±4.44) | 88.71 (±5.59) | 9.9 (±2.49) | 379.77 (±127.50) |
| Unoccupied | 2.55 (±0.93) | 11.16 (±3.94) | 16.76 (±12.75) | 1.87 (±2.45) | 79.18 (±8.89) | 8.61 (±2.09) | 209.56 (±72.92) |

sites using the same methods described earlier and then used averages to run the logistic-regression model. Calculation by the model determined the score, which was between 0 and 1. The logistic function has the shape of an ''S'' when graphed. Values of predictor variables are on the horizontal axis and probabilities are on the vertical axis.

A scoring system was developed to describe quality of habitat on a scale from 0 to 1 based on empirical results from study sites used to develop the model and on expectations of how high-quality habitat for Mexican spotted owls as identified in the literature would perform in the model. A score of 0–0.30 indicated that habitat was predicted to have a low probability of sustaining Mexican spotted owls. A score of 0.70–1.0 indicated that the habitat was predicted to have a high probability of sustaining Mexican spotted owls. A score of 0.30–0.70 indicated the habitat had a moderate probability of sustaining Mexican spotted owls. For management purposes, sites scoring in this range would be evaluated on a case-by-case basis by an expert.

RESULTS—We built the model with 10 occupied and 10 unoccupied study sites, averaged data for individual plots to the level of occupancy, and used these averages for development of the model. Table 1 summarizes data by status of occupancy. The backward stepwise function analyzed the seven habitat variables and identified diversity of trees, density of trees, density of shrubs, canopy cover, height of trees, and density of snags as significant variables (Table 2). Respective odds ratios were 3.081, 1.263, 1.070, 1.189, 1.147, and 0.784. Total diameter at breast height was not significant and not selected in the backward stepwise analysis for the model. The respective plot of Receiver Operating Characteristics indicated a high power of the model with an area under the curve of the Receiver Operating Characteristics of 0.964 ± 0.014 ($P < 0.001$). The model had a Cox and Snell r-square value of 0.597 and a Nagelkerke r-square value of 0.796. The final equation for the model is as follows:

$$\begin{aligned}\text{Logit(P)} = & -26.847 + 1.125\,(\text{Diversity of trees}) \\ & + 0.234\,(\text{Density of trees}) \\ & + 0.068\,(\text{Density of shrubs}) \\ & + 0.173\,(\text{Canopy cover}) \\ & + 0.137\,(\text{Height of trees}) \\ & - 0.243\,(\text{Density of snags})\end{aligned}$$

We validated the model using data from 10 independent study sites not used in development of the model. Five were occupied and five were unoccupied. The five validation study sites that were occupied scored 0.83, 0.78, 0.62, 0.96, and 0.78, and the five that were unoccupied scored 0.04, 0.12, 0.01, 0.11, and 0.01. The occupied site that scored a 0.62 was, by our model's standards, of moderate quality. Although vegetation in this habitat was not high quality according to the model, it contained several other topographical features necessary for high-quality habitat (i.e., >40% slope and presence of cliff structure). These results of validation indicated that the model functioned appropriately in identifying habitat of the Mexican spotted owl.

DISCUSSION—We used the odds ratios to determine the substantive effect of each variable on the model. For quantitative variables, it is useful to subtract 1 from the odds ratio and multiply by 100. This identifies the percentage change in the odds for each 1-unit increase in the independent variable (Allison, 1999).

A review of the odds ratios, Exp(B) in Table 2, indicates that the height of trees, density of trees, diversity of trees, canopy cover, and density of

TABLE 2—Logistic-regression model coefficients, standard error, *P*-value, and odds ratio [Exp (B)], by variable, for habitat of the Mexican spotted owl in the Jemez Mountains, New Mexico.

| Variable | Coefficient | Standard Error | *P*-value | Exp (B) |
|---|---|---|---|---|
| Constant | −26.847 | 5.386 | 0.0 | 0.0 |
| Diversity of trees | 1.125 | 0.371 | 0.002 | 3.081 |
| Density of trees | 0.234 | 0.078 | 0.003 | 1.263 |
| Density of shrubs | 0.068 | 0.022 | 0.002 | 1.070 |
| Canopy cover | 0.173 | 0.051 | 0.001 | 1.189 |
| Height of trees | 0.137 | 0.048 | 0.004 | 1.147 |
| Density of snags | −0.243 | 0.131 | 0.063 | 0.784 |

shrubs had positive relationships with occupancy. Diversity of trees had the largest odds ratio (3.081), indicating that, for every 1-unit increase in the diversity of trees, the change in odds increases by 207%. The odds ratio for diversity of trees was more than double that of all other variables. This suggests that the most important vegetative component of habitat for Mexican spotted owls in the Jemez Mountains is the diversity of trees, which is in agreement with other literature on biology of this species (United States Department of the Interior, 1995). Generally, forests used for nesting and roosting contain mature old-growth stands with complex structure; these forests typically are uneven-aged, multistoried, and have a high canopy closure (Rinkevich et al., 1995). Density of trees (1.263), height of trees (1.147), canopy cover (1.189), and density of shrubs (1.070) followed as influential positive variables. Density of snags had negative relationships with occupancy having odds ratios of 0.784. Snag trees are an integral component of mixed-conifer forests. Data suggest that, as density of snags increases, the quality of nesting and roosting habitat decreases. Possibly, greater densities of snags would equate to larger openings in the canopy cover.

*Management Implications*—Most habitat-modeling capabilities are designed to delineate habitat on a large scale. The model developed in this study was used on a smaller scale to look at individual territories of Mexican spotted owls to assess for quality of habitat. Many government agencies have the need to examine their inventories of habitat of the Mexican spotted owl to ensure that boundaries are correctly delineated. As an example, at Los Alamos National Laboratory the large-scale habitat modeling that took place in the past delineated protected areas that were conservative in size. Due to recent changes in quality of habitat from landscape-scale phenomena, such as drought, fire, and insect-vectored tree mortality, coupled with high demand for land for continuing the Laboratory's mission, revisions to the habitat boundaries of this species needed to be addressed. This type of model allows smaller sections of a larger protected area to be examined to determine if they are suitable or not. It also allows for assessing areas that may have been overlooked in large landscape-scale, habitat-modeling efforts. We believe these methods could be used elsewhere to develop similar localized models, and the model could be recalibrated for localized conditions.

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