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HABITAT COMPOSITION AND CONFIGURATION AROUND MEXICAN SPOTTED OWL NEST AND ROOST SITES IN THE TULAROSA MOUNTAINS, NEW MEXICO

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Abstract: The Mexican spotted owl (Strix occidentalis lucida) is a threatened subspecies whose recovery depends, in part, on both an understanding of its habitat requirements and the protection of its habitat. Therefore, we evaluated habitat composition and configuration around owl sites in the Tularosa Mountains, New Mexico, using a vegetation map derived from Landsat Thematic Mapper (TM) digital imagery and digital elevation models. Owls occupied sites with more mature mixed-conifer and mature pine and less pinyon-Juniper thinned by random sites. No difference existed in the amount of young forest between owl and random sites. After correcting for the area of the vegetation classes within owl territories, no difference existed in the mean patch size, edge distance, mean nearest neighbor distance, mean shape index, and habitat heterogeneity. We recommend retaining 235.8 ha of mature forest (124.2 ha mixed-conifer and 111.6 ha pine) around Mexican spotted owl sites, which is similar to the size of protected activity centers (243 ha) proposed by the U.S. Fish and Wildlife Service.

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Key words: habitat configuration, habitat selection, mature forest, Mexican spotted owl, New Mexico, Strix occidentalis lucida.

The Mexican spotted owl inhabits montane mixed-conifer forests, montane pine and pine-oak forests, and steep canyonlands in the southwestern United States and Mexico (Ganey and Balda 1989a, Gutiérrez et al. 1995). Conservation of the Mexican spotted owl is controversial, like that of the California spotted owl (S. o. occidentalis) and northern spotted owl (S. o. caurina), because of the owl’s association with commercially valuable late-successional forests.

Previous studies in the forested parts of its range indicate the Mexican spotted owl uses older forests for nesting and roosting (Seamans and Gutiérrez 1995) and foraging (Ganey and Balda 1994). In addition, home ranges of the Mexican spotted owl contain a high proportion of older forest (Ganey and Balda 1989b) and large areas of closed-canopy forest (Grubb et al. 1997). Habitat loss, mainly due to logging, fire, and projected changes in forest management led to the Mexican spotted owl’s listing as a threatened species in 1993 (Federal Register 1993).

Although the Mexican spotted owl has recently received increased attention from researchers, more information about its habitat use patterns is needed to implement recovery measures (Block et al. 1995:120). In addition, no data are available on the spatial configuration of habitat at Mexican spotted owl sites. In this paper, we measure Mexican spotted owl macrohabitat on the territory scale (Block and Brennan 1993) and estimate the owl’s selection for (1) specific habitat types, and (2) the spatial configuration of those habitat types.

STUDY AREA

Our study area encompassed 323 km² of the Tularosa Mountains, 8 km northeast of Reserve, New Mexico, and included approximately 70% of the mountain range. Topography was dominated by steep-sloped canyons and mountains, and elevation ranged from 1,990 to 2,900 m. Most of the study area (>99%) was managed by the U.S. Forest Service. Primary land uses were cattle grazing and timber harvesting, with shelterwood and selection the predominant timber harvesting methods.

Vegetation at higher elevations and on north-facing slopes was mixed-conifer forest dominated by Douglas-fir (Pseudotsuga menziesii) and white fir (Abies concolor). Southwestern white pine (Pinus strobus) and ponderosa pine (P. ponderosa), Gambel oak (Quercus gambelii),

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and quaking aspen (*Populus tremuloides*) were subdominant. Midelevations were dominated by ponderosa pine and Gambel oak. Lower elevations and south-facing slopes were composed of coniferous woodland dominated by pinyon pine (*P. edulis*) and alligator juniper (*Juniperus deppeana*). Open grassland was present at the lowest elevations and on mesa tops.

**METHODS**

**Vegetation Mapping**

We defined 7 possible vegetation classes based on community type (mixed-conifer, pine, aspen, pinyon–juniper, grassland) and seral stage (young vs. mature). Pine forests included both pure ponderosa pine stands and ponderosa pine–Gambel oak stands. Seral stages were separated by canopy closure and the basal area of trees >50 cm diameter at breast height (dbh; Table 1). In general, young forests were the result of timber harvesting. However, some unharvested stands met the criteria for the young forest classes because of fire or poor growing conditions (e.g., south-facing slopes). In addition, some lightly harvested stands met the criteria for the mature classes.

We used TM digital imagery and U.S. Geological Survey digital elevation models (DEMs) to map vegetation into the 7 classes. The imagery had a resolution of 30 x 30 m for each picture element (pixel) across 7 bands of the electromagnetic spectrum.

We used supervised classification procedures (Lillesand and Kiefer 1987) to assign each pixel on the map to 1 of the vegetation classes. We first delineated areas (>2 ha) with homogeneous spectral patterns on the satellite imagery (i.e., training fields) that corresponded to stands of homogeneous vegetation. We then took 1–5 vegetation samples within 74 such stands, depending on stand size. We placed plots nonrandomly to encompass as much of the variation in forest structure as possible. We estimated canopy closure with a spherical densiometer and the basal area of trees >50 cm dbh with a wedge prism (10 basal area factor). We calculated mean values for each stand and assigned stands to vegetation classes based on the criteria in Table 1.

Based on spectral response patterns within the training fields, the following provided the best separation among vegetation classes: TM Bands 4, 5; the ratio of Band 4 to Band 3; the ratio of Band 5 to Band 7; and the slope, elevation, and aspect data from the DEMs. Young mixed-conifer and young pine, however, were spectrally and structurally similar (low canopy closure and few trees >50 cm in dbh), and we therefore combined them into a single vegetation class (young forest). Finally, we assigned each pixel on the map to the vegetation class with the closest mean reflectance value.

To assess the accuracy of the habitat map, we collected a stratified random sample of 64 vegetation plots along logging roads throughout the study area. At 0.8-km intervals, we walked a random distance between 50 and 250 m from a road in a random direction (right or left) and estimated canopy closure and the basal area of large trees (see above). We cross-tabulated these plots

<table>
<thead>
<tr>
<th>Vegetation class</th>
<th>Dominant species</th>
<th>Basal area (m²/ha) of trees &gt;50 cm</th>
<th>% canopy</th>
<th>% study area</th>
<th>% accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mature mixed-conifer</td>
<td><em>Pseudotsuga menziesii</em></td>
<td>≥4.54</td>
<td>&gt;60</td>
<td>10.8</td>
<td>72.7</td>
</tr>
<tr>
<td></td>
<td><em>Abies concolor</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mature pine</td>
<td><em>Pinus ponderosa</em></td>
<td>≥4.54</td>
<td>&gt;35</td>
<td>9.8</td>
<td>81.8</td>
</tr>
<tr>
<td></td>
<td><em>Quercus gambelii</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Young mixed-conifer</td>
<td><em>P. menziesii</em></td>
<td>&lt;4.54</td>
<td>&lt;60</td>
<td>50.7</td>
<td>68.1</td>
</tr>
<tr>
<td></td>
<td><em>A. concolor</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Young pine</td>
<td><em>P. ponderosa</em></td>
<td>&lt;4.54</td>
<td>&lt;35</td>
<td>24.3</td>
<td>92.8</td>
</tr>
<tr>
<td></td>
<td><em>Q. gambelii</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pinyon–juniper</td>
<td><em>P. edulis</em></td>
<td></td>
<td></td>
<td>0.2</td>
<td></td>
</tr>
<tr>
<td>Quaking aspen</td>
<td><em>Juniperus deppeana</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grassland</td>
<td><em>Populus tremuloides</em></td>
<td></td>
<td></td>
<td>4.8</td>
<td>66.7</td>
</tr>
</tbody>
</table>

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J. Wildl. Manage. 63(1):1999  MEXICAN SPOTTED OWL HABitat • Peery et al. 37
with the final vegetation map to estimate its accuracy. We created a 9-pixel square (90 × 90 m) around the plot coordinate on the map and then compared the vegetation in the plot to the predominant vegetation class in the square.

We mapped all vegetation samples and locations of Mexican spotted owls (see below) with a GeoExplorer (Version 1.04) Global Positioning System receiver (Trimble Navigation Systems, Austin, Texas, USA). We corrected positions with Trimble’s GEO-PC program and base station files from the Gila National Forest Supervisor Office (approx 150 km south of the study area).

Owl Surveys

We used vocal imitations of Mexican spotted owl calls during nighttime surveys to elicit responses from territorial owls (Seamans and Gutiérrez 1995). We surveyed the entire study area 3–4 times during the breeding season (Apr–Aug), 1991–95. We then used daytime follow-up surveys to determine exact locations of nests and roosts.

Analysis

We compared habitat composition and configuration between areas Mexican spotted owls used and areas available to them (Johnson 1980, Thomas and Taylor 1990). We considered owls to select habitat features if they used them more than expected based on availability. To measure used habitat, we used program IDRISI (Eastman 1992) to generate concentric circular plots with the following radii: 500 m (78.9 ha), 1,000 m (315.5 ha), 1,500 m (707.5 ha), 2,000 m (1,256.9 ha), 2,500 m (1,965.3 ha), 3,000 m (2,830.4 ha), 3,500 m (3,848.5 ha), and 4,000 m (5,030.4 ha) around 1 owl location from each territory (owl plots). Because owl locations within territories were not independent, we randomly selected 1 location from each territory to use as a plot center in the following order of priority: a nest site, a roost site, and an activity center (i.e., multiple observations in an area during daytime surveys; see Peery [1996] for details).

We generated identical circular plots around an equal number of randomly placed locations (random plots) to estimate available habitat. The designation of available habitat has an important influence on inferences in use versus availability studies such as ours (Johnson 1980). We felt justified in placing centers of “available” plots completely randomly throughout the study area because (1) virtually the entire study area was managed by the U.S. Forest Service (i.e., public land), (2) Mexican spotted owl nest and roost sites encompassed the entire extent of the study area (i.e., north to south, east to west), (3) Mexican spotted owl nest and roost sites encompassed almost the entire elevation gradient within the study area, and (4) Mexican spotted owls at 2 territories consistently nested and roosted in rock faces surrounded by pinyon–juniper woodland.

Composition implies both the area of each vegetation class (Li and Reynolds 1994) and the relative proportions of the vegetation classes. Hence, we calculated the area of each vegetation class and Simpson’s diversity index (Simpson 1949) within owl and random plots. The diversity index provided a measure of habitat heterogeneity within owl and random plots. Configuration implies (1) the spatial arrangement of patches, (2) patch-shape, and (3) contrast between neighboring patches (Li and Reynolds 1994). We attempted to select indices of configuration that would adequately describe variation in these 3 aspects. We used program FRAGSTATS (McGarigal and Marks 1995) to calculate the mean patch size, the mean nearest-neighbor distance among patches, the mean patch-shape index, and the contrast-weighted edge density for each vegetation class in each owl and random plot.

Patches with relatively simple shapes (e.g., circular) had low shape index values, while patches with relatively complicated shapes had high values. The contrast-weighted edge density for a vegetation class measured the amount of edge between that vegetation class and other vegetation classes. Edges between vegetation classes that were used more than expected based on availability (see below) were given a weighting of zero. The mean nearest-neighbor distance for a particular vegetation class was only meaningful if at least 2 patches of that class existed. Similarly, the contrast-weighted edge density and the mean shape index were only meaningful when at least 1 patch was present. Hence, only plots containing at least 2 patches were considered in statistical analyses of the mean nearest neighbor distance, and only plots with at least 1 patch were considered in statistical analyses of edge density and the mean patch-shape index.

Simulations show that most indices of configuration are highly dependent on the area of the
vegetation class in the landscape that the indices are intended to measure (Gustafson and Parker 1992, Li and Reynolds 1994). In addition, landscape-scale studies of northern spotted owl habitat use have found strong correlations between the area of old-growth forest and associated indices (Carey et al. 1992, Lemkuhl and Raphael 1993, Ripple et al. 1997). As a result, although owl sites often have larger areas of old-growth forest than random sites, no conclusions can be drawn about the importance of old-growth configuration in terms of spotted owl habitat use. For these reasons, when comparing indices between owl and random plots, we statistically controlled for the effect of the area of the associated vegetation class (see below). This control allowed us to ask whether owl and random plots with the same area of a certain vegetation class have different configurations of that vegetation class.

For initial analyses, we selected owl and random plots with radii most similar to half the mean nearest-neighbor distance between adjacent territory centers. For this plot size, we used F-tests to test the null hypothesis that the area of each vegetation class did not differ between owl and random plots. For significant vegetation classes, we compared indices of habitat configuration between owl and random plots. Comparison of indices was done via analysis of covariance where each index was treated as a dependent variable, plot type (owl or random) as a grouping variable, and area of vegetation class as a covariate. We used the same approach when comparing Simpson’s diversity index between owl and random plots, except all vegetation classes were used as covariates. Variables used significantly more than expected based on availability were further tested for all plot sizes. All variables except the mean shape index were log_{10} transformed for analysis. All statistical analyses were conducted with PROC GLM in program SAS (SAS Institute 1991).

RESULTS

Map accuracy was 76.7% (Table 1). Grassland and quaking aspen were uncommon (Table 1) and therefore were not included in statistical analyses.

We detected 40 independent Mexican spotted owl territories within or immediately adjacent to the study area. Twenty-nine of these territories were represented by nests, 8 by roosts, and 3 by activity centers. Half the mean nearest-neighbor distance between Mexican spotted owl territories in 1993 was 1,060 m (SE = 89, n = 31). Hence, we used 1,000-m-radius plots for initial analyses. We used owl territories in 1993 to calculate the mean nearest-neighbor distance between territories because density in this year was greatest, which allowed for a conservative estimate of territory size and minimal plot overlap.

Mexican spotted owls occupied sites with more mature mixed-conifer and mature pine than would be expected based upon the availability of these classes (Table 2). The area of both types of mature forest was greater in owl plots for all plot sizes (P < 0.05; Figs. 1, 2). No difference existed in the area of young forest between 1,000-m-radius owl and random plots (Table 2). However, 1,000-m-radius owl plots contained less pinyon–juniper than equal-sized random plots (Table 2).

Habitat heterogeneity within 1,000-m-radius owl and random plots was dependent on the area of mature mixed-conifer (F_{1,74} = 9.46, P < 0.01) and mature pine (F_{1,74} = 4.47, P = 0.04), but not the area of young forest (F_{1,74} = 0.59, P = 0.44) and pinyon–juniper (F_{1,74} = 3.49, P = 0.07). Habitat heterogeneity did not differ between 1,000-m-radius owl and random plots (F_{1,74} < 0.01, P = 0.95), after we removed the variation due to the area of each of the vegetation classes.

Indices of habitat configuration were also de-

Table 2. Area (ha) of 4 vegetation classes within a radius of 1,000 m around Mexican spotted owl and random plots in the Tularosa Mountains, New Mexico, 1991–95. All variables were log_{10} transformed for analysis.
Fig. 1. The difference in the area of mature mixed-conifer between Mexican spotted owl habitat plots and random plots for several plot sizes in the Tularosa Mountains, New Mexico, 1991–95.

Fig. 2. The difference in the area of mature pine between Mexican spotted owl habitat plots and random plots for several plot sizes in the Tularosa Mountains, New Mexico, 1991–95.
Table 3. Results of analyses of covariances comparing indices of spatial configuration between Mexican spotted owl habitat plots and random plots in the Tularosa Mountains, New Mexico, 1991–95. All 2-way interactions between plot and area were nonsignificant (P > 0.05) and not displayed. All variables except mean patch shape index were log10 transformed for analysis.

<table>
<thead>
<tr>
<th>Comparison</th>
<th>Mature mixed-conifer</th>
<th>Mature pine</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>F</td>
<td>P</td>
</tr>
<tr>
<td>Mean patch size</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plot</td>
<td>1.22</td>
<td>0.27</td>
</tr>
<tr>
<td>Area</td>
<td>255.27</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Mean patch shape index</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plot</td>
<td>0.20</td>
<td>0.65</td>
</tr>
<tr>
<td>Area</td>
<td>61.25</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Edge density</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plot</td>
<td>2.25</td>
<td>0.14</td>
</tr>
<tr>
<td>Area</td>
<td>0.77</td>
<td>0.38</td>
</tr>
<tr>
<td>Nearest-neighbor distance</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plot</td>
<td>0.08</td>
<td>0.77</td>
</tr>
<tr>
<td>Area</td>
<td>22.77</td>
<td>&lt;0.01</td>
</tr>
</tbody>
</table>

Dependent on the area of the vegetation class they measured in 7 of 8 comparisons (Table 3). After we removed the effect of area of mature forest, none of the indices were significantly different between owl and random plots (Table 3). In other words, given owl and random plots with similar areas of mature forest, no difference existed in the mean patch size, edge distance, mean nearest-neighbor distance, and mean shape index.

**DISCUSSION**

Unlike the coastal subspecies of the spotted owl, the Mexican spotted owl inhabits a diverse array of habitats from semiarid canyons to high elevation, mixed-conifer forests. Our study showed that Mexican spotted owls in the Tularosa Mountains used sites with more mature mixed-conifer and mature pine forest than expected based on availability. This selection pattern suggests Mexican spotted owls select territories, in part, based on the area of mature forest present. Differences between owl and random sites decreased with increasing plot size because owl plots encompassed more unused habitat as plots became larger. That areas of both mature mixed-conifer and mature pine were significantly greater in owl plots up to 4,000 m in radius further suggests large areas of mature forest are important for territory selection. Finally, because we found significant differences for all plot sizes, we believe our results were not simply an artifact of plot size.

Johnson (1980) advances a 4-level hierarchical ordering of selection processes where first-order selection reflects selection of a geographic range, second-order selection determines the location of the home range, third-order selection pertains to the usage of habitat components within the home range, and fourth-order selection refers to procurement of food resources. Hence, habitat selection can be scale-dependent because animals may select different habitats at different scales to meet different life-history requirements (Orians and Wittenberger 1981). However, Mexican spotted owls appear to select forest with late seral stage characteristics at both the second- (Seamans and Gutiérrez 1995, Grubb et al. 1997, this study) and third-order (Ganey and Balda 1994) scales.

Our results are consistent with similar studies of northern spotted owl habitat (Ripple et al. 1991, Lemkuhl and Raphael 1993, Hunter et al. 1995, Ripple et al. 1997), despite markedly different land management histories between the Southwest and the Pacific Northwest. Early seral stage forests in the Pacific Northwest are generally the product of clearcutting, while young forests on our study area are due to both shelterwood and selection harvest. Young forests on our study area are therefore probably more structurally diverse than managed forests in studies of the northern spotted owl (except see Flliard et al. 1993). In spite of these structural differences, however, Mexican spotted owls did not use large areas of younger forest in this study.

After we controlled for variation due to the area of the vegetation classes, indices of habitat configuration were not different between owl and random plots. However, because indices used in this study were highly dependent on
area of the vegetation class they measured, we cannot discount the possibility that habitat configuration might be important for Mexican spotted owls (see Block and Brennan 1993). In fact, Franklin (1997) showed that northern spotted owl fitness is, in part, related to the spatial arrangement of owl habitat.

Gutiérrez (1985) suggested 5 nonexclusive hypotheses to explain the owl's association with late seral stage forests. These were (1) the nesting hypothesis, (2) the microclimate hypothesis, (3) the prey hypothesis, (4) the predator hypothesis, and (5) the adaptation hypothesis. An increasing number of studies have examined which of these factors determine the northern spotted owl's association with mature forests. Carey et al. (1992), Zabel et al. (1995), and Ward et al. (1998) provided strong evidence that northern spotted owls select habitats according to the distribution of their prey. We do not know any of these relations for our study population and therefore cannot propose mechanisms for the pattern of selection we observed.

MANAGEMENT IMPLICATIONS

One principle behind habitat selection theory is that habitat preferences should evolve to increase individual fitness (i.e., survival and reproduction; Levins 1968). We believe that managing for large areas of mature mixed-conifer and mature pine should increase the chance of maintaining viable Mexican spotted owl populations. Northern spotted owl reproduction (Bart and Forsman 1992, Ripple et al. 1997) and fitness (Franklin 1997) appear related to the amount and distribution of mature forests. Because managing for the mean area of mature forest within northern spotted owl sites may not provide enough habitat for many owl pairs to reproduce, Ripple et al. (1997) recommended maintaining 1 standard deviation above the mean. Using our results and Ripple's recommendation, we found this would result in 235.8 ha of mature forest (124.2 ha mixed-conifer, 111.6 ha pine) around Mexican spotted owl sites. Our estimate is similar to the size of protected activity centers (243 ha) proposed by the U.S. Fish and Wildlife Service (Block et al. 1995). Within Mexican spotted owl sites, we recommend uneven-aged harvesting (e.g., selection harvest) because it retains more large trees than even-age harvesting (Smith 1962), and thus is less likely to reduce mature forest characteristics. At owl sites where 235.8 ha of mature forest is not available (due to past disturbances or a paucity of the mixed-conifer and pine community types), we recommend minimal disturbance.

For several reasons, we urge caution when interpreting results from our study. First, because of the natural variation in Mexican spotted owl habitat use across its geographic range, inferences should be limited to regions within the Upper Gila Mountain Recovery Unit (west-central New Mexico and central Arizona; Block et al. 1995) that are dominated by canyons and mountains that contain coniferous forests. Second, the Mexican spotted owl population we studied experienced a significant decline from 1991 through 1997 (R. J. Gutiérrez and M. E. Seamans, unpublished data). Hence, if poor habitat quality in the Tularosa Mountains caused the decline, the above recommendations may be inadequate. Third, habitat quality is not a categorical (e.g., young vs. mature forest) but a continuous variable dependent upon several factors including forest structure and prey availability. Fourth, quantifying the relation between Mexican spotted owl habitat quality and demographic parameters such as survival and reproduction is essential for understanding how much mature forest is required to support viable populations. However, obtaining habitat composition and configuration data from each territory as we have done here is an essential component in modeling the effect of variation in habitat on spotted owl populations (see Franklin 1997).

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