Structural Characteristics of Forest Stands Within Home Ranges of Mexican Spotted Owls in Arizona and New Mexico

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ABSTRACT: *As part of a set of studies evaluating home-range size and habitat use of radio-markedMexican spotted owls* (Strix occidentalis lucida), *we sampled structural characteristics offorest stands within owl home ranges on two study areas in Arizona and New Mexico. Study areas were dominated by ponderosa pine* (Pinus ponderosa)–*Gambel oak* (Quercus gambelii) *forest (Arizona) or mixed-conifer forest (New Mexico). We describe structural characteristics offorest stands used by spotted owls for both foraging and roosting, in terms of central tendencies and variability in structural characteristics among stands. Our results indicated that stands used forforaging were more variable than stands used for roosting. Observed distributions of structural variables were consistent with recommendations in the recovery plan governing management of owl habitat with a few potentially important exceptions. We also provide additional recommendations for application in forest management, based both on observed data and on extensive collective experience with the owl and its habitat. West. J. Appl. For. 18(3):189–198.*

Key Words: Radio telemetry, stand basal area, ponderosa pine, Gambel oak.

The need to conserve habitat for the Mexican spotted owl *(Strixoccidentalis lucida)* has exerted considerable influence on management of forested lands in the southwestern United States. Although the Mexican spotted owl occurs in several habitat types, it is closely associated with well-structured, late-successional coniferous forests throughout much of its range (Ganey and Dick 1995, Gutiérrez et al. 1995). This owl was listed as a threatened species under the Endangered Species Act in 1993, primarily because of concerns over loss of late-successional coniferous forests to timber harvest and wildfire (USDI 1993). Following this listing, a recovery plan was produced for the Mexican spotted owl (USDI 1995), and this plan was formally adopted in an amendment to land-management plans for all national forests in the Southwestern Region of the USDA Forest Service (USFS; USDA 1996). This plan stressed the importance of (1) protecting existing forests suitable for spotted owls, and (2) developing future forests with similar characteristics. However, most available information on characteristics of forests used by spotted owls was based on studies conducted at finer spatial scales than those typically involved in land-management planning (Ganey and Dick 1995). Consequently, there was a fundamental incompatibility between our knowledge of owl habitat, which was based mainly on sampling of small (<0.2 ac) plots, and the scale at which forest planning occurs (forest stands 210 ac or larger landscapes; but see Grubb et al. 1997, Peery et al. 1999, May 2000). This situation was further complicated because most studies focused solely on nest sites or breeding-season roost sites (but see Ganey and Balda 1994, Zwank et al. 1994, Ganey et al. 1999).

Nest and breeding-season roost sites are important to the spotted owl. In fact, the recovery plan explicitly assumed that the availability of suitable nesting and roosting habitat served as an important factor limiting owl distribution (USDI 1995, p. 83). However, owls appear to use a wider variety of conditions for nocturnal foraging activities than they use for

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roosting and nesting (Ganey and Dick 1995). Further, owls frequently expand and/or shift their use area following the breeding season (Ganey and Balda 1989, Ganey et al. 1999). As a result, habitat conditions used during the nonbreeding season may differ from those used during the breeding season (Ganey et al. 1999). Therefore, an exclusive focus on microsite habitat conditions of areas used for roosting and nesting during the breeding season is likely to result in a narrow view of the range of forest conditions used by Mexican spotted owls. Information also is needed that describes forest structure at a variety of spatial scales in areas used for roosting outside of the breeding season and by foraging owls during both breeding and nonbreeding seasons.

As part of a set of studies evaluating home-range size and habitat use of radio-marked Mexican spotted owls, we sampled structural characteristics of forest stands within owl home ranges on two study areas in Arizona and New Mexico. These study areas were of interest with respect to stand structures used by spotted owls for several reasons. First, they encompassed the two main forest types occupied by Mexican spotted owls (mixed-conifer and pine-oak forest; Ganey and Dick 1995). Second, both areas had histories of timber harvest that varied in intensity across the landscape. Consequently, both study areas contained mosaics of stands that were highly variable in terms of extent and type of management that had occurred. These studies thus provided an opportunity to (1) describe structural characteristics in different forest types subjected to a wide variety of past management treatments, and (2) describe structure of stands used for both foraging and roosting during both the breeding and nonbreeding seasons.

Our primary objective here is to provide land managers with descriptions of structural characteristics of forest stands used by spotted owls. We hope that such descriptions will aid resource managers and planners in identifying forest conditions potentially useful to spotted owls and developing prescriptions to enhance the potential of developing stands for spotted owls. A secondary objective is to use this data to evaluate recommendations for forest management contained in the recovery plan for the Mexican spotted owl (USDI 1995).

Study Areas

The Sacramento Mountains study area was located in the Rio Peiiasco drainage, approximately 8 mi SE of Cloudcroft, south-central New Mexico. Moderate to steep montane canyons dominated topography in this area. Elevation in the study area ranged from approximately 7800–9200 ft. Many canyon bottoms consisted of meadows, whereas forests dominated canyon slopes and ridgetops. The predominant forest type was a relatively mesic mixed-conifer forest dominated by Douglas-fir (Pseudotsuga menziesii) and/or white fir (Abies concolor). Southwestern white pine (P. strobiformis) was prominent in most stands, and ponderosa pine (*P. ponderosa*) was frequently present. Large areas dominated by quaking aspen (Populus tremuloides) presumably indicated past wildfires (Moir 1993).

The Bar-M Canyon study area was located within the Bar-M and Woods Canyon watersheds, Coconino National Forest, approximately 16 mi S of Flagstaff, north-central Arizona. Elevation in this area ranged from 6000–8000 ft. Topography was relatively gentle with rolling terrain broken by scattered volcanic buttes and small canyons. Most of the study area consisted of ponderosa pine forest with scattered meadows or parks. Gambel oak (Q. gambelii) was a common associate in forested areas. Alligatorbark juniper (Juniperus deppeana) was present in many stands, particularly on warmer, drier sites. Small pockets of quaking aspen also occurred throughout the study area, and small numbers of narrowleaf cottonwood (P. angustifolia) and box-elder (Acer negundo) occurred in some canyons.

Methods

Radio Telemetry Methods

Methods for capturing and radio tracking owls and estimating home-range boundaries, discussed in Ganey et al. (1999), were similar in both study areas and will be summarized here only briefly. We captured owls, attached radio transmitters, and relocated the owls 4–5 days and nights per week throughout the year, at all hours of the day and night. All nocturnal locations were assumed to represent foraging activity, and all diurnal locations were classified as roosting locations. Nocturnal locations were based on triangulation of compass bearings to the radio-marked owl from 23 known locations, whereas roosting locations were based on visual observation of the owl. We assessed the accuracy of triangulated locations (see below) by double-sampling roost locations, collecting both triangulated and visual locations, in that order (Carey et al. 1990), and then comparing those locations.

Home-Range Estimation and Habitat Sampling

We used the accumulated owl locations to estimate 95% adaptive kernel home ranges (Worton 1989) and used these ranges to define a sampling universe for sampling stand characteristics. The adaptive kernel (AK) procedure converts the utilization distribution of a given owl into a probability density function. An AK home range then is the smallest area containing specified proportions of that probability density function (Worton 1989). We used this estimator rather than other estimators available because it requires no unrealistic assumptions about the utilization distribution (Worton 1989), and relative to many other estimators, it provides a fairly conservative estimate of available habitats (i.e., does not include large amounts of unused habitat).

We pooled locations among years for home-range estimates because the area used varied little among years (Ganey et al. 1999). Because small sample sizes (<50 locations; Seaman et al. 1999) or short tracking periods could result in biased estimates of home-range size and location, we estimated home ranges for individuals only where the number of radio locations was 280, and the owl was tracked for 25 months.

We sampled habitat characteristics within owl home ranges at the stand scale, using forest stands mapped by the USFS as our base habitat polygons. These stands were intended to represent homogeneous units of vegetation. We focused on this scale because it is important in land-management planning and because previous experience suggested that triangulated locations were not sufficiently precise to warrant finer scale analyses (Ganey and Balda 1994). We quantified use of forest stands by owls by overlaying owl locations on a geographical information system (GIS) coverage showing stand boundaries. We assigned each location to either the breeding (March 1–August 31) or nonbreeding season (September 1–February 28).

In both study areas, we based sampling intensity on the estimated number of plots required to accurately estimate snag density, the variable expected to show the greatest variation (sensu Bull et al. 1990). Sampling and analysis differed between study areas in other ways, however (see below).

Bar-M Canyon

In this study area, we sampled habitat characteristics in plots at 660 ft intervals on a grid laid out along a randomly selected bearing from a known starting point. Habitat characteristics were sampled using both fixed and variable-radius plots. Basal area of trees and snags was estimated from plot center using 20 and 5 basal area factor (BAF) prisms, respectively (Avery and Burkhart 1983, p. 185). All trees and snags sampled by the BAF prisms were identified to species, and diameter at breast height (dbh) was measured (nearest cm) using a dbh tape.

Logs (defined as down woody stems >6 in. in midpoint diameter and ≥6 ft in length) were sampled on 0.2 ac plots. For each log, we recorded midpoint diameter (nearest 0.5 in.) and total length within the plot boundary (nearest 0.3 ft).

We sampled canopy cover at point intercepts located at 3 ft intervals along a randomly oriented, 118 ft transect centered at plot center. At each intercept, we recorded the presence1 absence of overhead foliage using a sighting tube equipped with a crosshair (Ganey and Block 1994). Percent canopy cover was computed as [(number of intercepts with overhead cover/36) × 100]. All plots were sampled during the summer when deciduous trees had leaves. Consequently, our estimates likely overestimate canopy cover available during the nonbreeding season. The magnitude of this bias is unknown but could be considerable in stands where Gambel oak contributed much of the canopy cover.

Sampled habitat variables were aggregated across plots within stands to obtain estimates of mean stand characteristics and variability. We pooled stands across seasons to describe structure of foraging stands, because previous analyses indicated that characteristics of foraging stands did not differ between seasons in this study area (Ganey et al. 1999). In contrast, we described structure of roosting stands separately by season, because owls used many more stands for roosting during the nonbreeding season ($n = 138$) than during the breeding season ($n = 34$), and because previous analyses documented seasonal differences in roosting habitat (Ganey et al. 1999).

Because our objective was to describe stands, and because stand categories were not mutually exclusive (i.e., many stands were included in more than one category), we avoid statistical comparisons and simply summarize some stand characteristics of interest in forest management. These include: (1) tree and snag density, (2) tree and snag basal area, (3) log volume, and (4) canopy cover. We also summarized density and basal area of Gambel oak for pine-oak stands in this study area (pine-oak forest was defined following Dick et al. 1995). We were not able to provide summary information by size classes in this study area because we sampled with basal area factor prisms rather than on fixed-area plots. We used log volume (calculated assuming cylindrical shape) as our assay of coarse woody debris.

Believing that both central tendency and variability are important in describing and managing stand structure, we present estimates of both in stand descriptions. Because distributions often were nonnormal, we summarized information using box plots (Norušis 1993) These provide (1) an estimate of central tendency (the median), (2) information on the central 50% of the distribution of a particular variable [the interquartile range (IQR)], and (3) the total range for each variable. This information should provide managers with useful information both on central tendencies in stand conditions and the extent of variability in stands used by owls in two forest types. Note that we do not summarize fine-scale (i.e., within-stand) variability here because all variability estimates were computed among stands. We do not assume that within-stand variability is unimportant, but evaluating variability at that scale was beyond the scope of this article. In deference to working foresters, we use English units throughout this article.

Sacramento Mountains

Based on our earlier experience in the Bar-M Canyon area, we modified sampling methods in this study area. We allocated plots to stands based on stand area and desired sampling intensity. Plot locations then were mapped systematically within stands to obtain uniform coverage throughout the stand. To establish plots in the field, crews used topographic maps to locate the approximate mapped point, then paced a randomly selected distance (between 1 and 36 paces) and direction to locate the plot center.

Habitat characteristics were sampled on nested circular plots. Small live trees (4–11.9 in. dbh) and logs (midpoint diameter 24 in. and length >6 ft) were sampled on 0.07 ac plots. Plot size was expanded to 0.5 ac to sample trees with dbh 212 in. and all snags. All trees and snags sampled were identified to species, and dbh was measured using a diameter tape. Logs were sampled as described earlier.

We sampled canopy cover at 36 point intercepts along line transects as described earlier. However, in this study area we located intercepts along a pair of 59 ft line transects centered at plot center (the center point was sampled once), rather than along a single longer transect. The first transect was randomly oriented, and the second was placed perpendicular to the first. Percent canopy cover was computed as described above, and again all plots were sampled during the summer when deciduous trees had leaves. This was unlikely to result in much overestimation of canopy cover available in the nonbreeding season, however, because stands in this study area primarily consisted of coniferous trees.

As in the Bar-M Canyon area, we aggregated sampled habitat variables across plots within stands to obtain estimates of mean stand characteristics and variability. Unlike the Bar-M area, we pooled roosting stands across seasons in the

Sacramento Mountains because 40 of 43 stands used in the nonbreeding season also were used in the breeding season.

Because we sampled within fixed-area plots in the Sacramento Mountains area, we were able to provide information on diameter distributions for this study area. Consequently, variables summarized included: (1) tree and snag density, both overall and by size class, (2) tree and snag basal area, both overall and by size class, (3) log volume, and (4) canopy cover. We used 4 in. size classes in all summaries. As in the Bar-M Canyon area, we used log volume as our assay of coarse woody debris, used box plots to summarize stand characteristics, and note that fine-scale (i.e., within-stand) variability is underestimated here.

Results and Discussion

Bar-M Canyon

Home-range estimates were available for 13 individual owls representing seven owl territories in the Bar-M Canyon area. Median stand size within owl home ranges in this area was 96 ac (range = 27–1 085 ac). We sampled 2,460 plots in 328 stands in this area [$\bar{x}$ = 7.5 ± 0.4 (SE) plots/stand, or 1 plot/8.4 ac].

Stand assignment was identical for 71% of double-sampled triangulated and visual roost locations in this study area. We concluded from this that triangulated nocturnal foraging locations were accurate enough to allow for identification of specific stands used for foraging in the Bar-M Canyon area. Consequently, we summarized structural characteristics separately for stands used for foraging and roosting. These groups were not mutually exclusive; all roosting stands also were used for foraging (although the converse was not true).

Owls in the Bar-M Canyon area roosted and foraged primarily in pine-oak stands. Stands classified as pine-oak forest comprised approximately 60% of owl ranges by area, but 78, 91, and 85% of stands used for foraging, breeding-season roosts, and nonbreeding-season roosts, respectively, were classified as pine-oak forest.

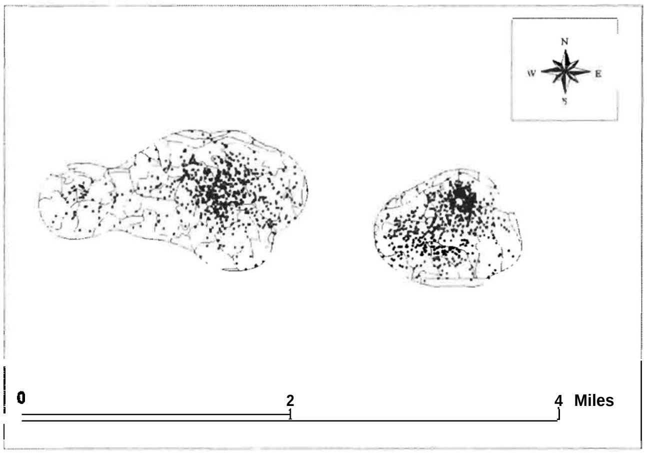


Figure 1. Distribution of foraging locations (black dots) among USFS-delineated stands within 95% adaptive kernel home ranges for two pairs of radio-marked Mexican spotted owls in the Sacramento Mountains, New Mexico. Outer lines denote the home-range boundary. Lines within the home range boundary denote stand boundaries. Note that in both cases, most stands within the home range show evidence of foraging use. Newman Canyon pair on the left, El Paso pair on the right.

Tree density was relatively similar among use categories (Figure 2A). Variability was reduced in stands used for roosting during the breeding season, because owls did not roost in the most open stands. Tree basal area tended to be greater in stands used for roosting during the breeding season than in other categories (Figure 2B). This, coupled with the similarity in density among use categories, suggested that breeding-season roost stands contained more large trees. Owls did not roost in stands with basal area <60 ft^2/ac during the breeding season, suggesting a potential threshold relative to roosting use.

Snag density and basal area were relatively similar among use categories (Figures 2C, D). Comparison of these figures suggested that most snags were small, contributing relatively little basal area. This was consistent with observed tree densities and likely indicated considerable mortality of smaller trees due to overtopping.

Oak density also was relatively similar among use categories (Figure 2E), but again breeding-season roost stands had lower variability than other categories. In particular, roosting owls did not use stands with extremely high densities of oak during the breeding season (Figure 2E). Such stands typically contained multiple dense clones comprised of numerous small stems. Despite the fact that breeding-season roosting stands did not include those stands with highest oak densities, oak basal area was similar among use categories (Figure 2F). This suggested that breeding-season roosting stands contained more large oak trees than other use categories.

Log volume and canopy cover tended to be relatively similar across use categories (Figures 2G, H), although variability was reduced for both variables in breeding-season roost stands. This was particularly evident for canopy cover; owls did not roost in stands with canopy cover <25%, and 75% of owl use was in stands with canopy cover >40% (Figure 2H).

Sacramento Mountains

Home-range estimates were available for six owls representing four territories in the Sacramento Mountains study area. Median stand area within owl home ranges was 25 ac in this study area (range = 5–109 ac). We sampled 597 plots representing 94 stands in this area ($\bar{x}$ = 6.4± 0.5 plots/stand or 1 plot/5 ac).

Stand assignment was identical for only 52% of double-sampled roost locations in this study area. We suspect that this poor agreement in stand assignment between double-sampled roost locations was largely a result of small stands with irregular boundaries (Figure 1) in this area. Because of the poor agreement in stand assignment, we concluded that triangulated nocturnal foraging locations were not accurate enough to allow for identification of specific stands used for foraging in this study area. Instead, we used all stands within the home range as our assay of foraging habitat. We believe that this approach was justified in this area because: (1) home ranges were comparatively small [mean size = 541 ac (J.L. Ganey, unpublished data) versus 2,212 ac in the Bar-M Canyon area (Ganey et al. 1999)]; (2) most stands (83%, J.L. Ganey, unpublished data) were classified as mixed-conifer forest, a forest type commonly used by spotted owls; and most

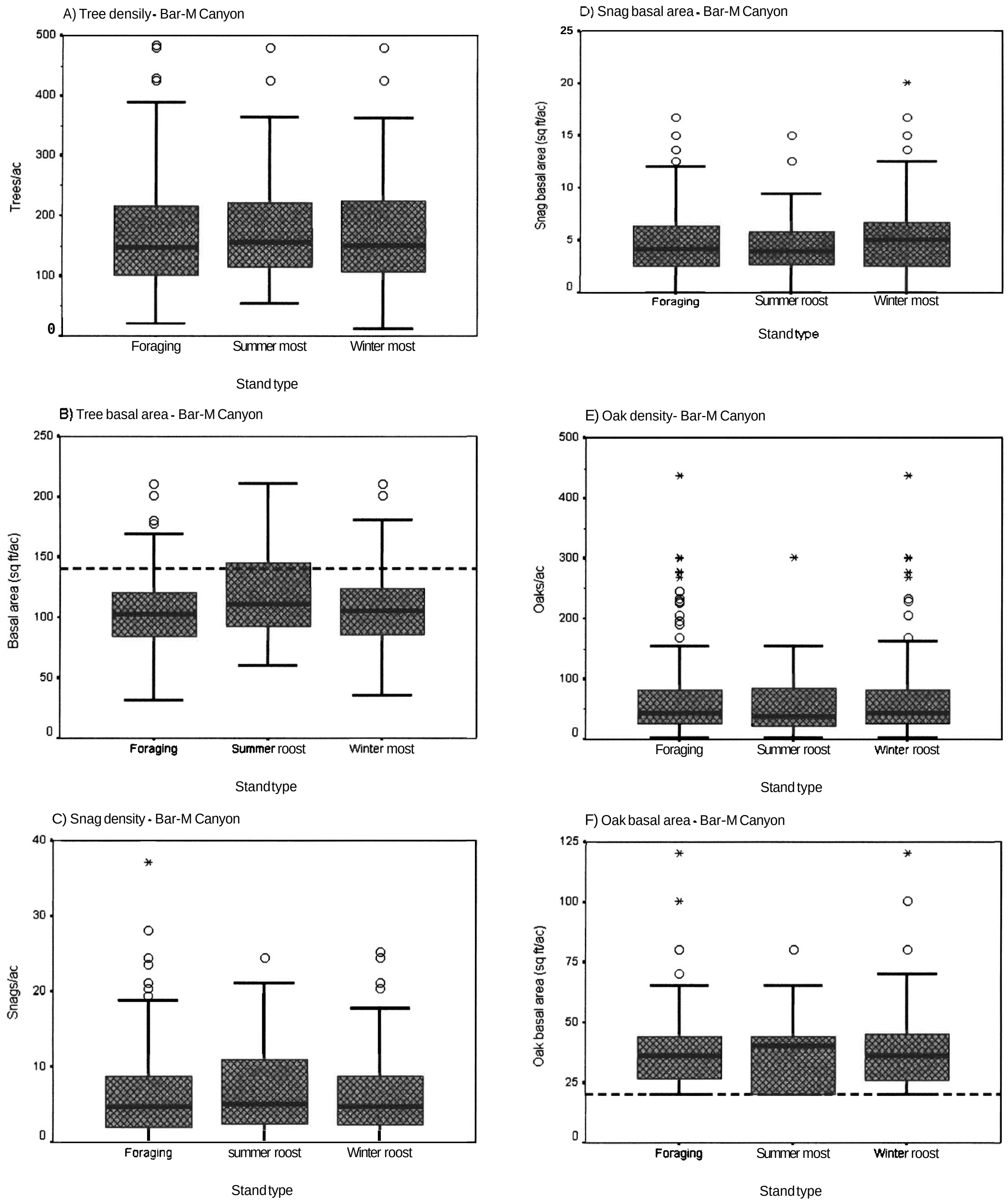
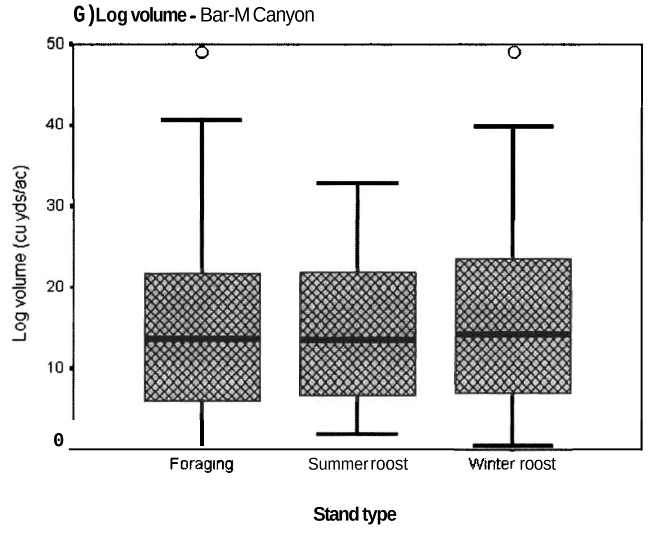


Figure 2. Structural characteristics of stands used by radio-marked Mexican spotted owls in the Bar-M Canyon study area, Arizona. Stands used for year-round foraging or roosting during the breeding and nonbreeding seasons are shown separately. The box denotes the interquartile range (**25th** to **75th** percentile), while the black line within the box denotes the median (**50th** percentile). The whiskers indicate the range, excluding outliers and extremes. Outliers, defined as observations more than 1.5 box lengths from the box, are denoted by circles. Extremes, defined as observations more than 3 box lengths from the box, are indicated by asterisks. (A) tree density **(B)** tree basal area (dotted reference line indicates recovery plan recommendation for maintenance of tree basal area) (**C**) snag density (D) snag basal area **(E)** oak density (**F**) oak basal area (dotted reference line indicates recovery plan recommendation for maintenance of oak basal area).



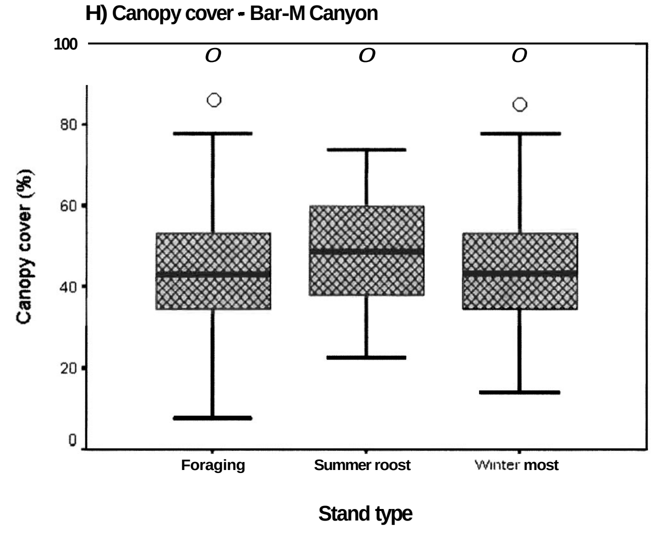


Figure 2. (continued) (G) log volume (H) canopy cover. Except for figures involving oak density and basal area, figures are based on 194 stands used by foraging owls, 34 stands used for roosting during the breeding season, and 138 stands used for roosting during the nonbreeding season. Figures summarizing oak density and basal area include only pine-oak stands (defined after Dick et al. 1995), and are based on 150 stands used by foraging owls, 31 stands used for roosting during the breeding season, and 116 stands used for roosting during the nonbreeding season, respectively.

importantly, (3) owls appeared to forage throughout most or all of the home range (Figure 1). As in the Bar-M Canyon area, all roosting stands were used for foraging in this study area, but the converse was not true.

Median tree densities were similar between foraging and roosting stands in the Sacramento Mountains, but variability was greatly reduced in roosting stands (Figure 3A). Roosting owls showed little use of either the densest or the most open stands. Median basal area also was similar between use categories, but again roosting stands showed much lower variability (Figure 3B). Owls did not roost in stands at the lower end of the basal area spectrum; basal area was <75 ft^2/ac in only one of 43 roost stands.

Snag density and basal area were similar among use categories (Figures 3C, D). As in the Bar-M area, a comparison of these figures suggests that most snags were small, contributing little basal area. Again, this was consistent with dense stands, in which overtopping of smaller trees results in considerable mortality.

Log volume and canopy cover also were similar between use categories, but canopy cover tended to be less variable among roosting stands than among foraging stands (Figures 3E, F). All but two roosting stands had canopy cover >40%, and 75% of stands used for roosting had canopy cover >60%

Examination of tree size-class distributions (Figures 4A, B) indicated few differences between use categories. The primary difference was a trend for roosting stands to have more trees, and consequently greater basal area, in mid-size trees (12–20 in. dbh, Figures 4A, B).

Comparisons Between Study Areas

Direct comparisons between study areas were complicated by differences in methodology, but some generalizations can be made. First, differences in densities and basal areas of trees and snags were consistent with differences in dominant forest types between areas, with all values being greater in the area dominated by mixed-conifer forest. Differences between areas were particularly striking in terms of tree densities, with median densities in the Sacramento Mountains more than double those in the Bar-M Canyon area (Figures 2A, 3B). In contrast, median basal areas typically differed by only 30–35% between study areas. This greater consistency between areas suggested that basal area was more important than tree density in stand selection by owls. In support of this hypothesis, used and unused stands in both study areas differed significantly in comparisons based on basal area but not in comparisons based on tree density (Ganey et al. 1999, unpublished data).

Basal area also was more tightly linked to canopy cover in both areas [Bar-M Canyon, Spearman's correlation coefficient (r_s) = 0.59; Sacramento Mountains, r_s = 0.771 than was tree density (Bar-M Canyon, r_s = 0.30; Sacramento Mountains, r_s = 0.42). Because canopy cover was identified as a potentially important habitat element in most studies of Mexican spotted owl habitat (reviewed in Ganey and Dick 1995), this greater correlation between canopy cover and basal area also suggested that basal area was a better predictor of owl habitat than tree density.

Stands in the Sacramento Mountains were dominated by trees in the smaller size classes (Figure 4A). This also appeared to be true in the Bar-M Canyon area. Although our sampling methods did not allow us to characterize diameter distributions for the Bar-M area, the observed basal areas appear possible, given the observed densities, only if most trees were small (compare Figures 2A, 2B). Snags showed a similar pattern in both areas (compare Figures 2C and 2D, and Figures 3C and 3D). The large number of small snags in both areas, coupled with observed tree densities, strongly suggests that many of these stands were self-thinning, with considerable mortality of small trees occumng due to overtopping (Avery and Burkhart 1983, p. 253, Spies 1997).

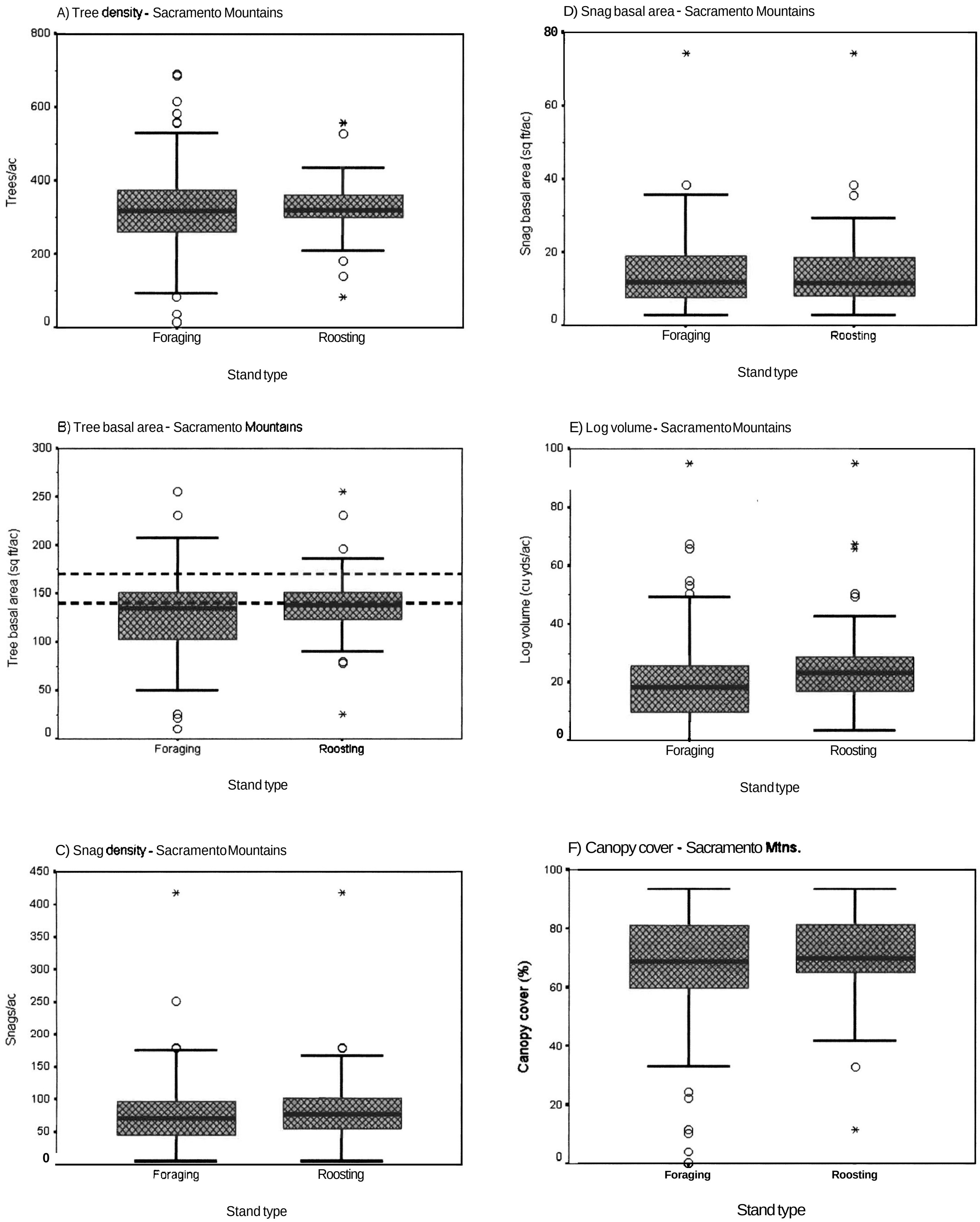


Figure 3 Structural characteristics of stands used by radio-marked Mexican spotted owls in the Sacramento Mountains, New Mexico. Stands used for foraging or roosting are shown separately. (See Figure 2 for an explanation of figure features.) (A) tree density (B) tree basal area (Dotted reference lines indicate recovery plan recommendations for maintenance of basal area. Lower value is to be maintained on 20% of the landscape; upper value on 10% of the landscape.) (C) snag density (D) snag basal area (E) log volume (F) canopy cover. Based on 94 stands used by foraging owls and 43 stands used for roosting.

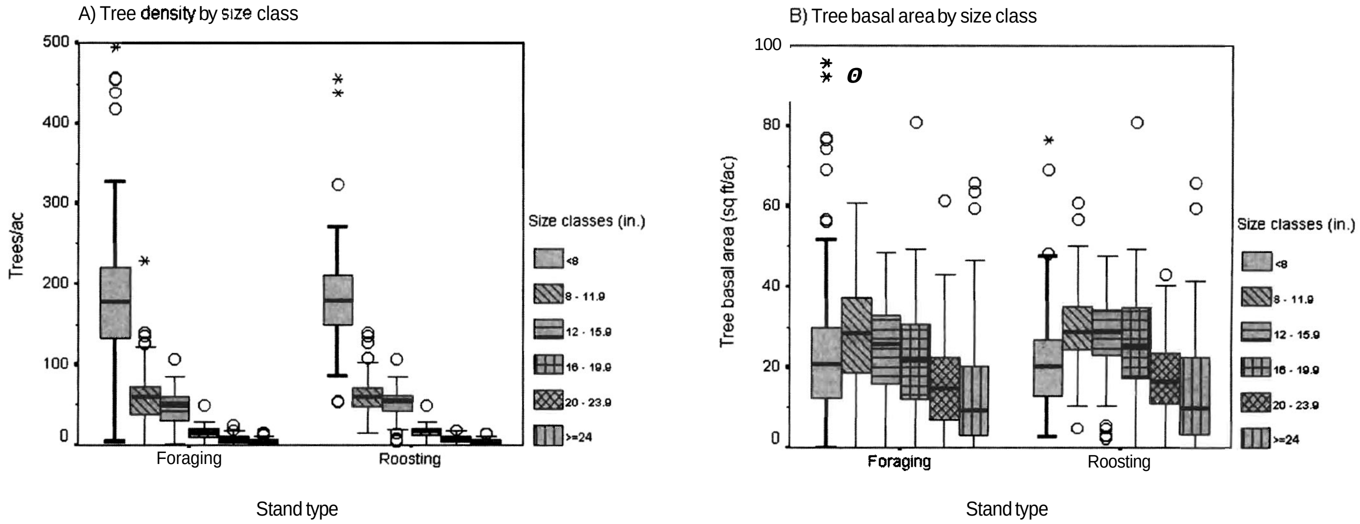


Figure 4. Distribution of tree density and basal area by size class in stands used by radiomarked Mexican spotted owls in the Sacramento Mountains, New Mexico. (See Figure 2 for an explanation of figure features.) (A) tree density (B) tree basal area. Based on 94 stands used by foraging owls and 43 stands used for roosting.

Comparisons with the Mexican Spotted Owl Recovery Plan

The recovery plan for the Mexican spotted owl (USDI 1995:83) explicitly assumed that (1) providing stands with conditions typical of roosting/nesting habitat would provide foraging habitat as well, and (2) some stands, useful as foraging habitat, would fall outside the range of typical roosting/nesting habitat in terms of structural conditions. Our data supported these assumptions. All stands used for roosting also were used for foraging. The converse was not true, however, and the range of structural conditions observed in foraging stands typically exceeded that observed in roosting stands (Figures 2, 3, and 4).

The recovery plan also contained specific recommendations aimed at managing stands to retain or provide owl habitat. These recommendations were specific to both geographic area and forest type. For pine-oak forests in the Bar-M study area, the recommendations called for managing 10% of the target landscape to provide stands with 2139 ft^2/ac of tree basal area (USDI 1995: Table III.B.I). This value fell above the median and towards the upper end of the interquartile range of roost stands used during the breeding season in this study (Figure 2B). Thus, although our data provided limited support for this recommendation, they also suggested that managing for lower basal areas may be appropriate in some cases.

The recovery plan also calls for maintaining 220 ft^2/ac of basal area of oak in pine-oak stands (USDI 1995:Table III.B.I). All pine-oak stands used for foraging and/or breeding-season roosts in this study area contained at least 20 ft^2/ac of basal area of oak, and half contained 236 ft^2/ac of basal area of oak (Figure 2F). This suggested that the recommended threshold (USDI 1995) is appropriate, but that managing for greater oak basal area also should be encouraged. We recognize that historically it has been difficult for forest managers to manage for oak directly, but our data suggest that steps should be taken to minimize loss and encourage recruitment of large oaks. Minimizing loss may require prohibiting harvest of oaks, especially large oaks, for fuelwood (Ganey et al. 1992, Seamans et al. 1999). In some cases, it also may be necessary to manage for lower basal areas (see above) and provide openings in the canopy to provide adequate sunlight to maintain oaks in well-developed stands. Finally, encouraging recruitment of larger oaks may require reducing grazing pressure by wild and domestic ungulates, which currently browse on oak regeneration and maintain oak sprouts in a sapling stage in many areas (USDI 1995).

For mixed-conifer forests in the Sacramento Mountains, the recommendations called for managing 20% of the target landscape to provide stands with 2139 ft^2/ac of tree basal area and 220 trees/ac 218 in. dbh. with another 10% of the target landscape managed for basal area 2170 ft^2/ac (USDI 1995:Table III.B.I). Our data generally support these recommendations. Median basal area of roost stands was approximately 139 ft^2/ac; 170 ft^2/ac fell within the observed range for roost stands, although well outside of the IQR (Figure 3B), and median numbers of large trees observed were roughly similar to the recommended values (Figure 4A).

Conclusions and Recommendations

The stand descriptions presented here can serve as a starting point for use in assessing and managing habitat for Mexican spotted owls. Using this information will not be entirely straightforward, however, for several reasons. First, our study evaluated only habitat use and did not address habitat quality. Therefore, although we identified a range of stand conditions used, we cannot unequivocally identify conditions that confer high habitat quality for owls. Future studies should address this uncertainty by attempting to link specific habitat conditions to owl survival and fecundity. This may allow us to determine which habitat conditions and/or features influence habitat quality for owls (e.g., Franklin et al. 2000).

Second, our knowledge of habitat use by spotted owls is based on current conditions. Because of the extensive history of fire suppression in the forests occupied by Mexican spotted owls, vegetation conditions may be outside the natural range of variation in some cases. For example, tree densities and log volumes likely are greater than levels observed under natural fire regimes (see Covington and Moore 1994 and Kaufmann et al. 1998 for discussion of historical conditions in and around these study areas). Therefore, it also would be desirable to study habitat use by owls in areas subject to a natural or nearly natural fire regime to see if structural characteristics of stands used in such areas differ from those of stands used in areas subject to fire suppression. We are unaware of any areas occupied by Mexican spotted owls which meet this criterion in the United States, however. Opportunities may exist to study owls in areas subject to natural or nearly natural fire regimes in Mexico, but we are uncertain if such forests exist in areas occupied by owls. As noted above, it would be helpful to study fitness parameters as well as habitat use to evaluate the influence of habitat features on fitness parameters.

Third, we also know little about how to arrange stands spatially to provide owls with appropriate landscape configurations or about how owls respond to variability and/or spatial arrangement of habitat elements within stands. For example, it may matter whether or not habitat elements such as large trees are clumped or dispersed within a stand. Similarly, relative juxtaposition of different habitat elements (e.g., large trees and logs) may influence how owls perceive a stand. Resolving these questions is beyond the scope of this article.

Finally, this information is based on a small number of owls in only two study areas. It would be desirable to develop similar information from both additional owl ranges and a wider range of geographic areas. Until we can do that, uncertainty will remain over how representative the areas sampled are and over the extent of natural variation in stand characteristics among geographic areas.

Given these caveats, we offer the following guidelines:

1. Focus management more on retaining (or enhancing) appropriate basal area and canopy cover than on managing for tree or snag density or log volume. Basal area and canopy typically were highly correlated with owl use (Ganey and Dick 1995, Seamans and Gutierrez 1995, Grubb et al. 1997, Ganey et al. 1999), and maintaining stands with high basal area and canopy cover likely will result in stands containing appropriate numbers of trees, snags, and logs (see also USDI 1995). Because owl use is often correlated with the medium-to-large tree component, and because large trees and snags are habitat elements that are difficult to replace if they are lost, managers also should emphasize retaining existing or recruiting large trees, with the goal of having trees 216 in. dbh contributing 250% of the stand basal area.

2. In terms of appropriate values for basal area and canopy cover, we recommend managing for values in the upper 75% (i.e., above the 25th percentile) of the observed distributions (Figures 2B. 2H, 3B, 3F) where the goal is to provide nesting or roosting habitat. If the goal is to provide foraging habitat, values from the entire distribution likely are appropriate. Our reasoning here is that nesting and roosting habitat is where owls show the most specificity for closed-canopy stands with high basal area (Ganey and Dick 1995). Closed-canopy stands with high basal area may provide a more moderate microclimate during the day, as well as greater concealment from avian predators for both roosting adults and young near the nest. In contrast, foraging habitat is more variable, perhaps because most foraging occurs at night when microclimatic considerations may be less important, and the suite of potential avian predators is reduced.

3. Retain or recruit a diverse mix of tree sizes. Diversity in tree-size distributions is typical of stands used by owls and should provide for the vertical structure thought to be important to owls (Ganey and Dick 1995, Seamans and Gutiérrez 1995). We assume that the large numbers of trees observed in the smaller size classes in this study are largely an artifact of fire suppression, however, and are not necessary to facilitate use by owls. Further, such numbers are undesirable from a fire risk perspective. Thus, we recommend striving for a more balanced age/size distribution with considerable basal area in large trees.

4. Avoid attempting to develop a single management target in applying the above recommendations. Given the range of values observed in used stands, the extent of ecological variability inherent to southwestern landscapes, and our uncertainty over the relationships between particular habitat elements and habitat quality, we suggest managing for a range of stand conditions rather than trying to identify a single, assumed optimal condition.

The above recommendations represent our best assessment of how to translate observed data on stand structure into appropriate management actions. Although they are based both on data for stand structures used by owls and on extensive experience with the owl and its habitat, we admit that there is as much art as science in these recommendations. It would be desirable to test them experimentally by (1) applying them to areas occupied by owls and monitoring habitat use and demographic performance of owls in those areas, and/or (2) applying them to areas not occupied by spotted owls and evaluating results. Colonization by owls would be the best indicator of success here, but this might not occur quickly even if the resulting stand structure was favorable for spotted owls. Consequently, the short-term measure of success here might be determined by whether or not the manipulation resulted in the predicted stand structure. Until we are able to undertake such studies, considerable uncertainty will remain over the effects of management actions on spotted owls and their habitat.

We also recognize that these recommendations may conflict with recommendations in the recovery plan (USDI 1995) at times. This essentially makes it impossible to implement these recommendations in the Southwestern Region of USDA Forest Service, which formally adopted the recovery plan through an amendment to land-management plans (USDA 1996). We therefore urge the recovery team to consider the new information and recommendations presented here, with the possible goal of reconciling conflicting recommendations to improve habitat management guidelines for Mexican spotted owls.

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