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TECHNICAL REPORT #23

HABITAT RELATIONSHIPS  
OF BREEDING BIRDS IN  
NORTHERN ARIZONA  
PONDEROSA PINE  
AND PINE-OAK FORESTS  
*A Final Report*

STEVEN S. ROSENSTOCK  
August 1996

FEDERAL AID IN WILDLIFE  
RESTORATION PROJECT  
and  
ARIZONA GAME AND FISH  
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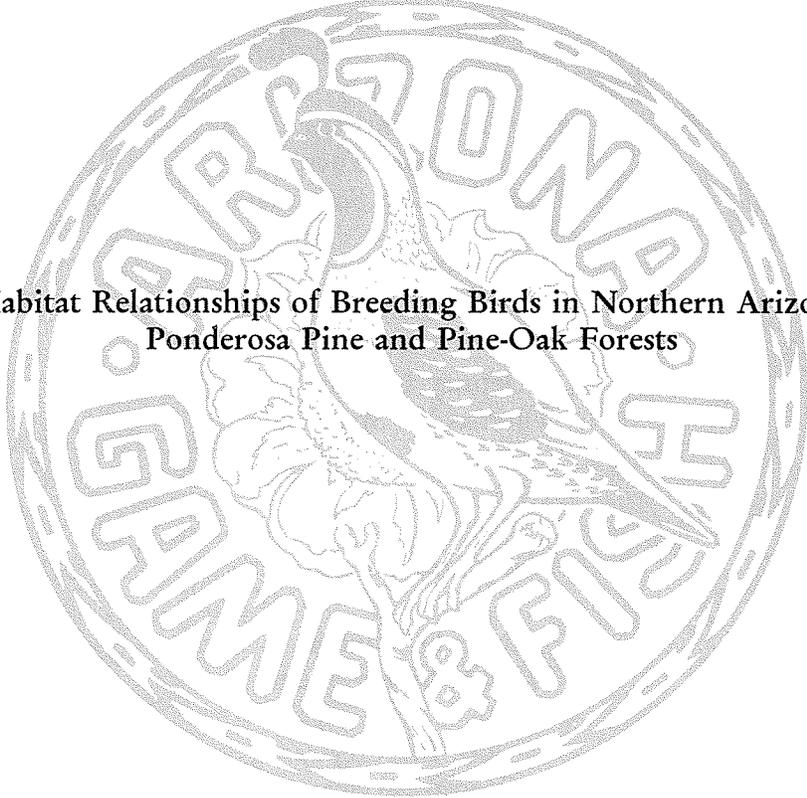


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Arizona Game and Fish Department  
Research Branch

Technical Report Number 23



Habitat Relationships of Breeding Birds in Northern Arizona  
Ponderosa Pine and Pine-Oak Forests

Steven S. Rosenstock

August 1996

Federal Aid in Wildlife Restoration  
Project W-78-R

and

Arizona Game and Fish Department  
Heritage Fund

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# Habitat Relationships of Breeding Birds in Northern Arizona Ponderosa Pine and Pine-Oak Forests

Steven S. Rosenstock

*Abstract:* I studied the habitat relationships of breeding passerine birds in ponderosa pine (*Pinus ponderosa*) and ponderosa pine-Gambel oak (*Quercus gambelii*) forests of northern Arizona from 1993-95. Birds and habitat characteristics were sampled in 23 stands representing a wide gradient of forest conditions resulting from management activities. The primary habitat variables defining this gradient were the size and density of ponderosa pine and Gambel oak trees, understory cover, and snag density. A total of 65 bird species occurred on the study areas, 46 of which were included in detailed analyses. Of these 46 species, 18 were neotropical migrants and 28 were year-round residents or short-distance migrants. The breeding avifauna was dominated by 16 species that occurred in >90% of the study stands. Stands with high bird abundance also had high bird species richness. Breeding bird communities in individual stands had considerable annual turnover in species composition, which ranged from 9-26%. Breeding bird communities differed between pine and pine-oak stands. Pine-oak stands had higher total species richness as well as greater species richness of neotropical migrants and cavity nesters. In both cover types, bird abundance and species richness were correlated with stand characteristics affected by management. However, individual species and species groups often were correlated with different habitat conditions. Breeding bird assemblages with the highest abundance and species richness were found in structurally diverse stands that usually had a well-developed mature pine component and numerous large snags. Breeding birds were most strongly associated with habitat variables that reflected tree size and density, canopy characteristics, shrub cover, and the density and condition of cavity-nesting substrates. Management practices that provide diverse habitat conditions will benefit breeding birds in northern Arizona forests.

*Key words:* Arizona, bird communities, breeding birds, forest management, Gambel oak, habitat relationships, neotropical migratory birds, *Pinus ponderosa*, ponderosa pine, *Quercus gambelii*, snags.

## INTRODUCTION

Conservation and management efforts directed at passerine birds have expanded tremendously in recent years, in response to increasing demand for non-consumptive wildlife uses and concerns over the status of many North American bird species. Beginning in the 1970s, significant declines were documented in populations of neotropical migratory birds, species that breed in North America and winter in the neotropics (Terborgh 1989, 1992). Declines were first observed in eastern U.S. forests; however, subsequent analyses of Breeding Bird Survey (BBS) data revealed similar trends elsewhere in North America (Peterjohn and Sauer 1994). Analyses of BBS data from the western U.S. suggested that local declines also had occurred in populations of year-round resident and short-distance migrant bird species (Paige 1990, Miller 1992). Potential factors responsible for declines in neotropical migrant populations include deforestation on wintering areas, fragmentation and alteration of breeding habitats in North America, exposure to pesticides and other toxins, and changes in climate (Finch

1991). Recent research has further indicated that neotropical migrants and other bird species can be limited by habitat conditions on breeding areas (Sherry and Holmes 1995).

Birds have evolved a high degree of habitat selectivity, favoring habitat features that increase survival and reproductive output (Cody 1985). An important consequence of this selectivity is the influence of habitat composition and physiognomy on avian populations and communities (Anderson 1980). Because most bird species are dependent on specific habitat attributes, habitat alterations have considerable potential to affect avian communities (Verner 1975, Martin 1992). This sensitivity to habitat changes also makes birds useful indicators of change in ecological systems (Morrison 1986).

Breeding birds in northern Arizona ponderosa pine and ponderosa pine-Gambel oak cover types were identified as a research priority, due to long-term anthropogenic impacts on forest habitats and impending changes in forest management. The effects of changes in forest structure on breeding birds in southwestern forests are not clearly

understood (Finch 1991, SWCA Inc. 1991). Several previous studies have examined responses of breeding birds to management practices in Arizona ponderosa pine forests. The most extensive research was associated with the Beaver Creek Watershed project, which examined effects of treatments designed to increase yields of water, wood fiber, and other resources from northern Arizona forests. Treatment effects on avian abundance and community structure were reported by Szaro and Balda (1979*a, b*; 1986), Gaud et al. (1986), and Brawn and Balda (1988*a*). Most of the forest treatments evaluated in these studies, such as clearcuts and strip cuts, were very different from current and emerging forest management practices. Some of these studies were conducted in pine-oak habitats; however, differences in avian communities between pine and pine-oak habitats were not quantified. Taken collectively, available information on breeding bird habitat requirements in northern Arizona forests was inadequate to assess the effects of ongoing and anticipated changes in forest conditions.

### Study Objectives

This study was initiated in 1992, to obtain information on the habitat relationships of breeding passerine birds in northern Arizona ponderosa pine and ponderosa pine-Gambel oak forests. My specific objectives were to:

- Describe and compare breeding bird communities in ponderosa pine and ponderosa pine-Gambel oak cover types;
- Quantify relationships between the abundance and species richness of breeding birds and forest habitat characteristics affected by management; and
- Develop forest management options beneficial to breeding birds.

### STUDY AREAS

Research was conducted from 1993-95 at 6 study areas in northern Arizona (Fig. 1). These areas were: the Coconino National Forest (Mormon Lake, Long Valley, and Peaks ranger

districts); Kaibab National Forest (North Kaibab Ranger District); Arizona Army National Guard Camp Navajo; and Grand Canyon National Park (North Rim). Five study areas had a history of commercial timber harvest. Logging on the 3 Coconino National Forest districts and nearby Camp Navajo began in the late 1800s, however, large-scale timber management on the North Kaibab did not occur until the 1950s (Cassady 1991). Managers of these forests have applied both even-aged and uneven-aged silvicultural systems. Common treatments included single-tree selection, shelterwood, group selection and patch cuts, and pre-commercial thinning (Schubert 1974). Wildfires on these study areas have been actively suppressed since the late 1800s. Prescribed fire was used in some areas, primarily for removal of woody debris following timber harvest or thinning. The study areas were grazed by domestic livestock, beginning in the 1800s and continuing to the present.

The study area on the Grand Canyon North Rim (Powell Plateau) was managed for natural values and dispersed recreation, and had not received silvicultural treatments. Powell Plateau received minimal use by livestock (primarily horses) before Park establishment. Over the last 100 years, this site had frequent low-intensity fires initiated by lightning strikes and limited fire suppression (Grand Canyon Natl. Park, Res. Manage. Off., unpubl. data).

Within the 6 study areas, I randomly selected 23 stands that reflected a wide range of forest conditions resulting from management activities. Stands were defined as contiguous areas of structurally-similar forest  $\geq 100$  ac (40.5 ha) in size. Eleven stands were in the ponderosa pine cover type, 12 stands were in the ponderosa pine-Gambel oak cover type. Study stands had no timber harvest or other treatment for  $\geq 5$  years prior to this study. Locations, characteristics and management histories of the 23 study stands are presented in Appendix 1.

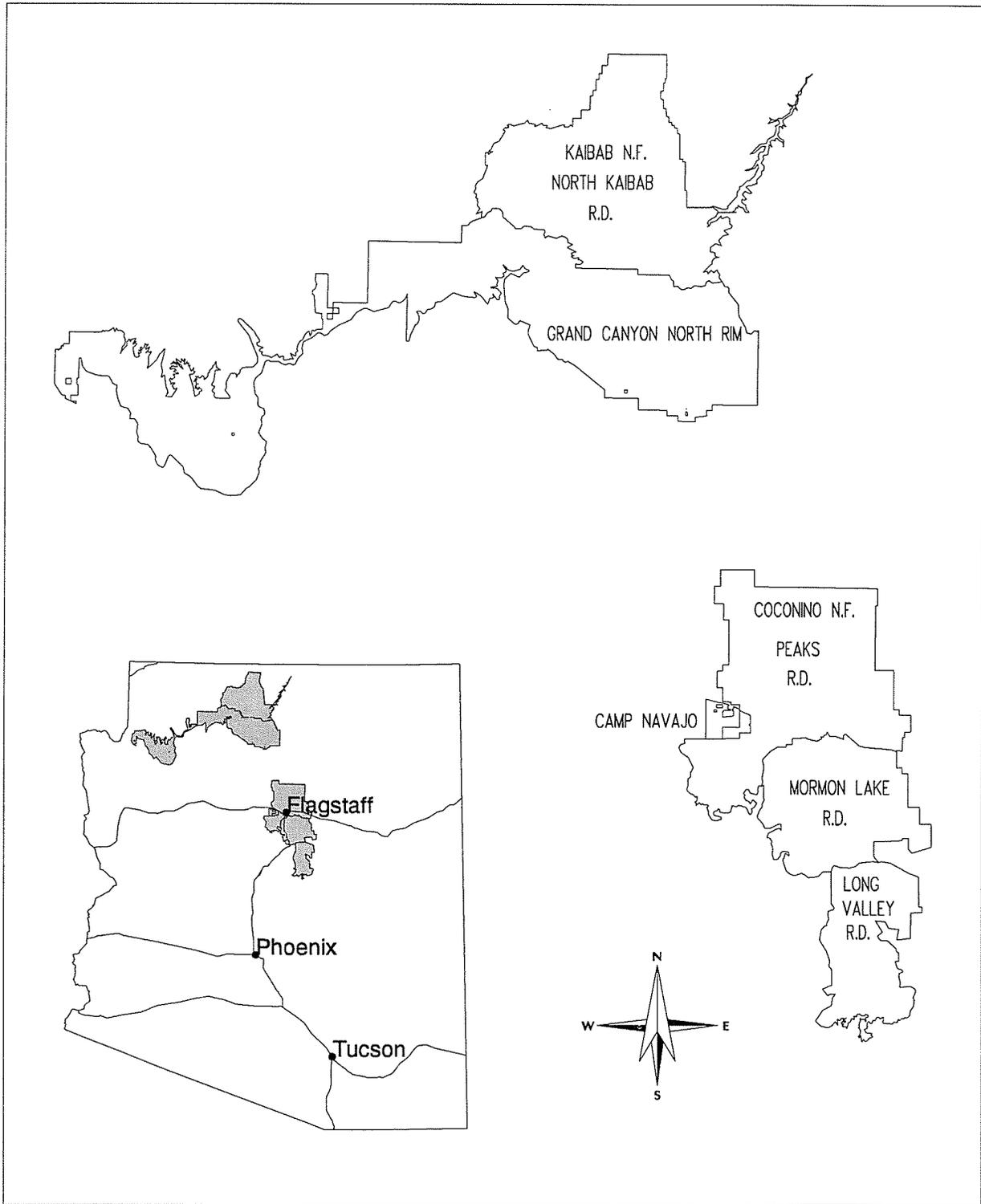


Figure 1. Locations of northern Arizona breeding bird study areas, 1993-95.

## METHODS

### Sampling Design

Within each stand, I laid out a rectangular grid of 7-8 sampling points for bird surveys and habitat measurements. The starting point for the grid was randomly located. The grid consisted of points spaced 656 ft (200 m) apart along 2 parallel transect lines, also spaced 656 ft (200 m) apart. In 2 stands with irregular shape, I used shorter transect lines perpendicular to the first transect instead of a second transect.

### Habitat Measurements

I measured habitat characteristics directly affected by management activities that are commonly used in studies of forest birds and other wildlife. Habitat measurements were taken once at each sampling point over the 3-yr duration of the study.

*Understory.* Understory cover was sampled at 100 intercepts, spaced 1.6 ft (0.5 m) apart on 2 perpendicular transects centered on the sampling point. At each intercept, observers recorded the presence of grasses, forbs, shrubs, and downed woody material.

*Live Trees.* Live trees were sampled in 3 non-overlapping 0.25-ac (0.1-ha) circular subplots associated with each sampling point. One subplot was centered on the point, the remaining 2 within a 328-ft (100-m) radius. Within each subplot, observers identified, counted, and measured the diameter at breast height (dbh) of all ponderosa pines, and diameter at root collar (drc) of Gambel oaks and junipers (*Juniperus* spp.).

I collected 2 measures of live tree canopy in each subplot: vertical projection canopy cover and canopy density. Vertical projection was measured with a custom-fabricated, gimbal-suspended sighting periscope (Fig. 2). Measurements were taken at 68 intercepts placed 3.3 ft (1 m) apart on 2 perpendicular transects. At each intercept, the observer sighted through the periscope and recorded the species for which live canopy foliage (>6.6 ft [2 m] above ground) was intercepted by the cross hairs. Canopy density was measured with a tripod-mounted concave spherical densiometer (Strickler 1959) (Fig. 3). Five densiometer readings were taken in each subplot; 1 at the center, and another 49.2 ft (15 m) out on each of the 4 transect radii. To reduce variability, all densiometer measurements were taken by 1 observer (Ganey and Block 1994). Total canopy

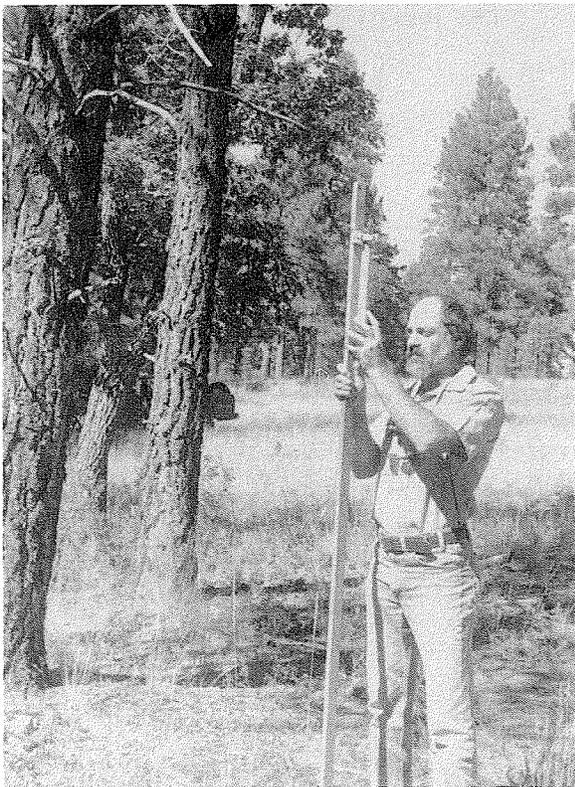


Figure 2. Measuring canopy cover with a vertical sighting periscope.

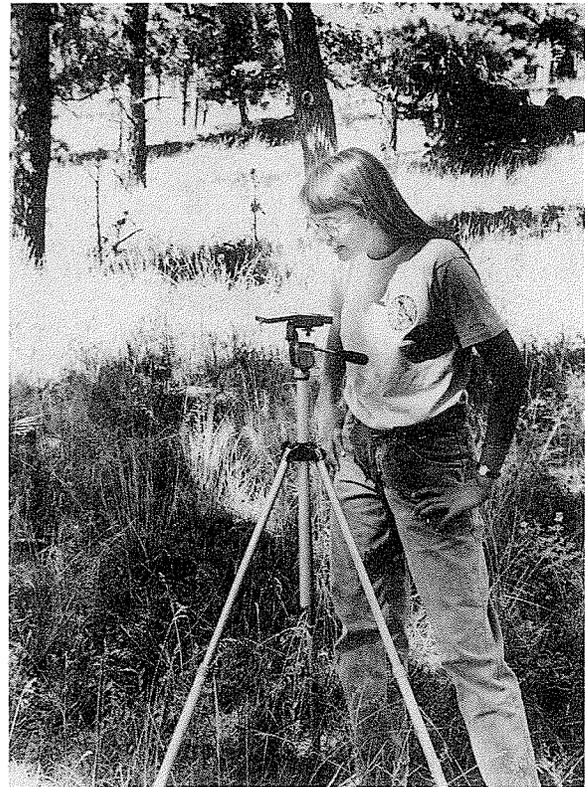


Figure 3. Measuring canopy density with a spherical densiometer.

cover and canopy density were calculated by summing intercepts for all species and subtracting the number of multiple interceptions.

*Snags and Other Cavity Substrates.* All snags within a 328-ft (100-m) radius of each sampling point were measured for dbh and classified by height and condition. Height was visually estimated and placed into 1 of 4 classes: <6.6 ft (2 m), 6.6-16.1 ft (2.0-4.9 m), 16.4-32.5 ft (5.0-9.9 m), and  $\geq$  32.8 ft (10 m). Condition was categorized into 1 of 5 classes following Thomas (1979) (Appendix 2). Snags <8 in (20 cm) dbh, snags displaced >45 degrees from a vertical position, and snags with extensive fire damage, were excluded. Observers also searched for and counted substrates other than snags that could contain nest cavities, including spike-topped live trees, lightning scars, and other dead portions of live tree boles and limbs.

*Dwarf Mistletoe.* Twenty live ponderosa pine trees within a 328-ft (100 m) radius of each sampling point were randomly selected and rated for dwarf mistletoe (*Arceuthobium vaginatum*) infection. Visible infection on each tree was quantified using the Hawksworth (1977) 6-class system. To reduce observer effects, all ratings were done by 1 person. Infection ratings for all trees were averaged to obtain an overall score for each stand.

*Derived Habitat Variables.* Six variables were calculated from measurements of live trees: stand density index (SDI), quadratic mean diameter (QMD), basal area, vegetative structural stage class (VSS), and 2 indices describing canopy heterogeneity and variability in ponderosa pine dbh. Raw SDI values were calculated for pine only, using formulas given by McTague and Patton (1989), and an exponent value of 1.605. Percentages of theoretical SDI limits were not used due to lack of consensus regarding maximum values. Separate QMD and basal area values were calculated for ponderosa pine and Gambel oak. Each study stand was assigned to 1 of 5 VSS classes, reflecting the dominant size class of ponderosa pine. Size classes were: VSS 2 = 1-4.9 in (2.5-12.4 cm) dbh, VSS 3 = 5-11.9 in (12.7-30.2 cm) dbh, VSS 4 = 12-17.9 in (30.5-45.5 cm) dbh, VSS 5 = 18-23.9 in (45.7-60.7 cm) dbh, and VSS 6 =  $\geq$  24 in (61.0 cm) dbh (Reynolds et al. 1992). I also calculated the proportion of total live ponderosa pine basal area by VSS class in each stand. Because densiometer measurements are strongly affected by canopy height (J. McTague, Northern Arizona University, Flagstaff, pers. commun.), I used the coefficient of variation of canopy density as a composite index of horizontal

and vertical canopy heterogeneity. The coefficient of variation of ponderosa pine dbh was used as a measure of variability in tree size. Habitat measurements were averaged across points to obtain stand values.

### Bird Surveys

*Survey Methods.* Breeding birds were surveyed using the variable circular-plot technique (Reynolds et al. 1980). Twenty of the 23 stands were sampled in 1993. All stands were sampled in 1994-95. Each stand was surveyed 3 times during the peak breeding season (June 1-July 10), once by each of 3 observers. All points within a stand were sampled during each visit. Visits were 10-14 days apart. Surveys were conducted during a 3-hr period beginning 30 min after sunrise, but not undertaken during periods of strong wind or rain, which could decrease avian activity and/or detectability. To reduce interobserver variability, field personnel were carefully selected and received extensive training in bird identification and survey methodology (Kepler and Scott 1981).

Upon arriving at a sampling point, the observer waited for 3 min and then conducted an 8-min count, during which all birds heard or seen within 328 ft (100 m) were recorded. Observers recorded as much of the following information as possible for each detection: species, sex, age (juvenile or adult), detection type (visual, song, call, or other auditory cue), and estimated distance from the observer. To minimize duplicate observations, birds flying overhead were not counted. Birds detected while walking between points and during waiting periods, also were not counted.

*Bird Response Variables.* Because data for many species violated assumptions of distance-based density estimators (Buckland et al. 1993), I used total counts as an index of avian abundance (Verner and Ritter 1985), an approach used in other studies of breeding birds across forest habitat gradients (Raphael 1987). To reduce repeat counts of species frequently detected at long distances, count data were truncated at 246 ft (75 m). Birds identified as juveniles were excluded from analysis. I also excluded species considered incidental to ponderosa pine and pine-oak cover types ( $n = 8$ ), as well as raptors and other species inadequately sampled by variable circular-plot surveys ( $n = 11$ ) (Appendix 3). Abundance values were calculated for each stand and year, and reflected the maximum number of individuals (by species) observed during the 3 survey visits. Abundance values for each stand were standardized by

dividing maximum counts by the total counting area of all sampling points. I also recorded the presence or absence of individual species at each sampling point.

I quantified the avian community in each stand with the following variables: (1) overall avian abundance (all species); (2) overall species richness (total number of species); (3) species richness and abundance within 3 groups of birds (neotropical migrants, year-round residents/short-distance migrants, cavity-nesters); and (4) annual turnover in species composition. There was overlap among the 3 bird groups, in that cavity-nesters also occurred in the other migration-based groups. However, all groups were biologically meaningful, representing birds with distinct life histories and potentially different management needs. I classified species that winter primarily or exclusively south of the U.S. as neotropical migrants (per Corman 1996). The cavity-nester group included both primary cavity excavators and secondary cavity users. Percent annual turnover in overall species composition was calculated following Diamond (1969).

### Statistical Analysis

*Data Screening.* Bird and habitat variables were tested for normality using Shapiro-Wilk's  $W$ -test. Nonparametric procedures were used when significant ( $P \leq 0.05$ ) departures from normality were present. Except as otherwise noted, statistical analyses were conducted using STATISTICA® (Statsoft, Inc. 1994). Results of all statistical tests were considered significant at ( $P \leq 0.05$ ).

*Habitat Gradient Analysis and Ordination.* I used principal components analysis (PCA) ordination (Ludwig and Reynolds 1988:223) to identify major habitat gradients across the 23 study stands. The ordination included principal component axes with eigenvalues  $\geq 1$  that captured significant variation in the raw data. Each axis reflected an orthogonal (independent) gradient, derived from correlations with original habitat variables. PCA scores on the first 3 axes were used to construct an ordination diagram, illustrating the relative positions of the 23 stands in multidimensional habitat space. I also plotted values (means and standard errors) of variables included in the PCA analysis, to illustrate habitat variation within and among the 23 stands.

*Relationships Among Bird Community Variables.* I assessed relationships between bird abundance and species richness across stands and years with Pearson product-moment correlations

( $r$ ). Similarity in bird species composition between stands in pine and pine-oak cover types was measured with Jaccard's Index ( $J$ ), using software provided by Ludwig and Reynolds (1988:131). This index ranges from 0-1, with 0 values representing pairs of stands with no species in common, and values of 1 representing complete overlap. Avian community variables in ponderosa pine and ponderosa pine-Gambel oak stands were compared with a  $t$ -test, using a Bonferroni adjustment for simultaneous multiple comparisons (Beal and Khamis 1990).

*Habitat Relationships.* I compared observed values of bird community variables among stands representing different VSS classes; however, differences were not tested statistically because of small sample sizes. Associations between bird response variables and habitat characteristics of stands were measured with Spearman rank correlations ( $r_s$ ), using a Bonferroni adjustment for simultaneous multiple comparisons (Beal and Khamis 1990). I further examined relationships between birds and significant habitat variables of potential concern to forest managers, by dividing each habitat variable into classes and calculating mean values of avian community variables within each class. This procedure identified ranges of habitat conditions where groups of birds or individual species were most abundant.

*Habitat Selection.* I developed models predicting occurrence of 5 bird species (brown creeper, brown-headed cowbird, chipping sparrow, Cordilleran flycatcher, western bluebird [scientific names are listed in Appendix 3]) at sampling points across all stands. These species were chosen to illustrate differing patterns of habitat selection at a smaller (sub-stand) scale. A species was considered present at a sampling point if detected within the 246-ft (75-m) count radius in  $\geq 2$  visits during any sampling year. Conversely, it was considered absent if these criteria were not met. Models were developed with classification tree analysis (CART), a stepwise, nonparametric procedure that builds binary (yes/no) decision trees from a set of independent variables (Steinberg and Colla 1995). CART differs from traditional approaches such as discriminant function analysis (DFA) or logistic regression (LR) because of its lack of assumptions, ability to detect nonlinear and/or complex relationships with independent variables, and robustness to outliers (Breiman et al. 1993). CART models also identify specific cut points for variables included in the decision tree, values that are more readily interpreted than DFA or LR variable coefficients.

Because sample sizes were insufficient to withhold data for independent testing, I used a jackknife cross-validation procedure to estimate CART model accuracy (Breiman et al. 1993). For each species, I generated separate models for pine and

pine-oak cover types. However, if the CART procedure did not yield significant models for both cover types, data were pooled to build a single model.



Old-growth ponderosa pine stand (NK3) on the Kaibab Plateau, Arizona.



## RESULTS

### Habitat Characteristics

The 23 stands represented a broad spectrum of habitat conditions. Most habitat variables had a wide range of observed values (Table 1). There also was considerable within-stand variability for many habitat variables. Between-stand variability was reflected in the PCA analysis, which identified 4 orthogonal habitat gradients. These gradients were described by 4 PC axes explaining 75% of total variance in the original data (Table 2). The ordination diagram illustrates relative positions of the 23 stands in multivariate habitat space, as described by the first 3 PC axes (Fig. 4). There were no strong groupings among the 23 stands and similar dispersion across the 3 habitat gradients illustrated in the diagram.

PC1 explained 27% of total variance and described ponderosa pine density and QMD. Twelve of the study stands had similar pine densities (<200 trees/ac [494 trees/ha]) and low within-stand variability (Figs. 5a, 6). The other 11 stands had more within-stand variability and densities of 200-970 trees/ac (494-2,396 trees/ha). Stands with very high pine densities also had a high proportion of total basal area in small (VSS class 2) trees (Figs. 7-8). The 23 stands represented a wide gradient of pine QMD, ranging from 6-17 in (15.2-43.2 cm) (Fig. 5b). Within-stand variability in QMD was relatively low in most stands.

PC2 explained 25% of total variance and described shrub cover, Gambel oak density, QMD, and basal area. Shrubs were rare or absent in most stands ( $n = 14$ ). The remaining 9 stands had shrub cover ranging from 3-14% and considerable within-stand variability (Fig. 5c). The most common shrubs and shrub-like plants were New Mexican locust (*Robinia neomexicana*) and immature Gambel oaks. A wide gradient of Gambel oak density was present in pine-oak stands, ranging from 3-190 trees/ac (7.4-469.3 trees/ha) (Fig. 5d). Pine-oak stands also represented wide gradients of oak QMD and basal area, which ranged from 3-9 in (7.7-22.9 cm) (Fig. 5e) and 2-27 ft<sup>2</sup>/ac (0.46- 6.2 m<sup>2</sup>/ha) (Fig. 5f), respectively. Most pine-oak stands had considerable within-stand variability of oak density, but variability of oak QMD and basal area were generally lower.

PC3 explained 12% of total variance and described herbaceous and downed woody material cover. A wide gradient of herbaceous vegetation cover was present across the 23 stands, which had

Table 1. Observed ranges of habitat variables across 23 northern Arizona ponderosa pine ( $n = 11$ ) and ponderosa pine-Gambel oak ( $n = 12$ ) study stands. Habitat characteristics were sampled once between 1993-95. Oak variables are from pine-oak stands only.

Variable	Range
Ponderosa pine density (trees/ac)	
VSS 2 (1-4.9 in dbh)	10.4 - 836.8
VSS 3 (5-11.9 in dbh)	18.9 - 201.2
VSS 4 (12-17.9 in dbh)	8.9 - 55.1
VSS 5 (18-23.9 in dbh)	1.5 - 18.7
VSS 6 (>24 in dbh)	0.2 - 12.3
Gambel oak density (trees/ac)	
< 8 in drc	0.3 - 118.1
8-15 in drc	1.7 - 72.6
> 15 in drc	0.2 - 6.5
Basal area (ft <sup>2</sup> /ac)	
Ponderosa pine	52.0 - 155.0
Gambel oak	2.4 - 27.3
Quadratic mean diameter (QMD) (in)	
Ponderosa pine	6.4 - 16.9
Gambel oak	2.6 - 9.3
Canopy cover (%)	
Ponderosa pine	19.7 - 63.7
Gambel oak	1.5 - 13.9
Canopy density (%)	
Ponderosa pine	28.3 - 63.9
Gambel oak	1.5 - 15.4
Stand density index (SDI)	107 - 454
Dwarf mistletoe rating	0.0 - 1.4
Snag density (snags/ac)	0.1 - 9.7
Understory cover (%)	
Herbs	10.0 - 71.0
Shrubs	0.0 - 13.8
Downed woody material	7.0 - 37.6

cover values ranging from 10-71% (Fig. 9a). There was less among-stand variability of downed woody material cover, which ranged from 7-38% (Fig. 9b). Within-stand variability of herbaceous plants and downed woody material was generally higher in stands with greater cover of these understory components.

Table 2. Principal component (PC) axes describing habitat characteristics of 23 northern Arizona ponderosa pine ( $n = 11$ ) and ponderosa pine-Gambel oak ( $n = 12$ ) study stands, 1993-95. Values are correlations between original variables and individual components. Asterisks indicate variables with greatest influence on each PC.

Variable	PC 1	PC 2	PC 3	PC 4
Pine density	0.87*	-0.11	0.22	0.20
Pine dbh	-0.91*	-0.18	0.06	0.02
Pine basal area	0.35	-0.29	0.49	0.54*
Shrub cover	-0.33	0.51*	0.06	0.23
Downed woody material cover	0.18	-0.01	0.77*	0.07
Herbaceous cover	-0.11	-0.22	-0.80*	-0.07
Snag density	0.06	0.04	0.08	0.90*
Gambel oak density	-0.03	0.87*	0.17	-0.14
Gambel oak drc	0.21	0.66*	-0.27	0.39
Gambel oak basal area	0.06	0.94*	0.04	0.01
Proportion of total variance explained	0.27	0.25	0.12	0.11

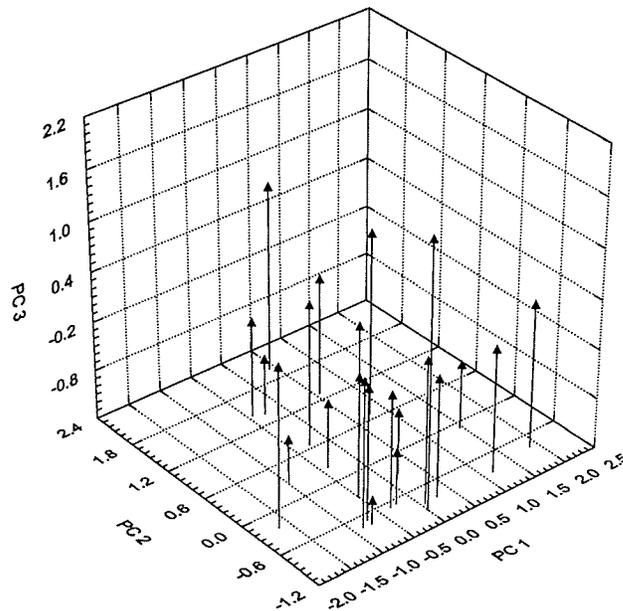


Figure 4. Principal components (PC) ordination of habitat characteristics at 23 northern Arizona ponderosa pine ( $n = 11$ ) and ponderosa pine-Gambel oak ( $n = 12$ ) study stands, 1993-95. Ordination diagram illustrates stand mean scores for first 3 components summarizing 64% of total variance. Components describe: pine density and diameter (PC1); shrub cover and oak density, size, and basal area (PC2); and downed woody material and herbaceous cover (PC3).

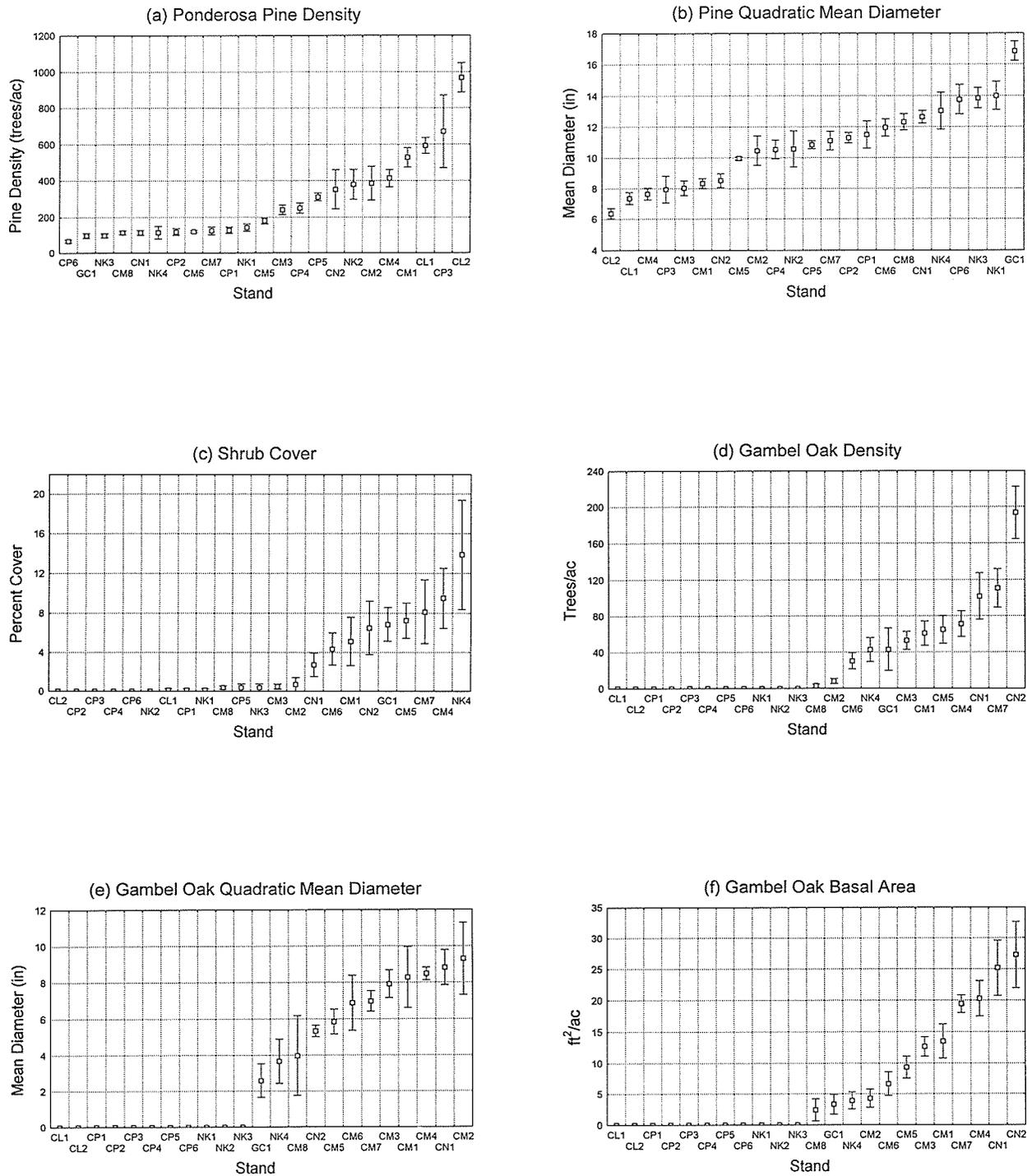


Figure 5. Habitat characteristics at 23 northern Arizona ponderosa pine ( $n = 11$ ) and ponderosa pine-Gambel oak ( $n = 12$ ) study stands, 1993-95: (a) ponderosa pine density, (b) ponderosa pine quadratic mean diameter, (c) shrub cover, (d) Gambel oak density, (e) Gambel oak quadratic mean diameter, and (f) Gambel oak basal area. Values are means  $\pm$  standard error.



Figure 6. Ponderosa pine stand (CP1) with low tree density and low within-stand variability.

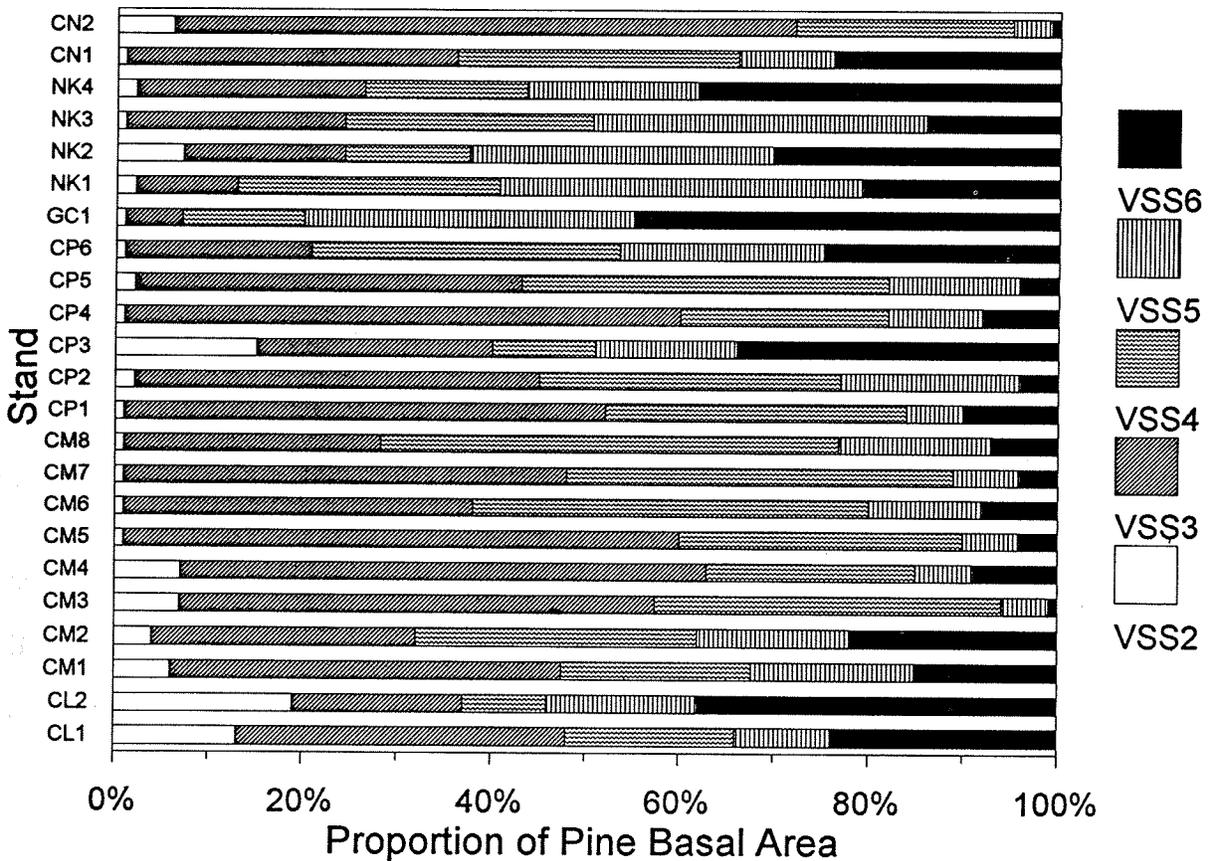


Figure 7. Proportional pine basal area by vegetative structural stage (VSS) class at 23 northern Arizona ponderosa pine ( $n = 11$ ) and ponderosa pine-Gambel oak ( $n = 12$ ) avian breeding bird study stands, 1993-95. Classes were: VSS 2 = 1-4.9 in (2.5-12.4 cm) dbh, VSS 3 = 5-11.9 in (12.7-30.2 cm) dbh, VSS 4 = 12-17.9 in (30.5-45.5 cm) dbh, VSS 5 = 18-23.9 in (45.7-60.7 cm) dbh, and VSS 6 =  $\geq 24$  in (61.0 cm) dbh.



*Figure 8.* Ponderosa pine stand (CM4) with very high basal area and a high proportion of small pines.

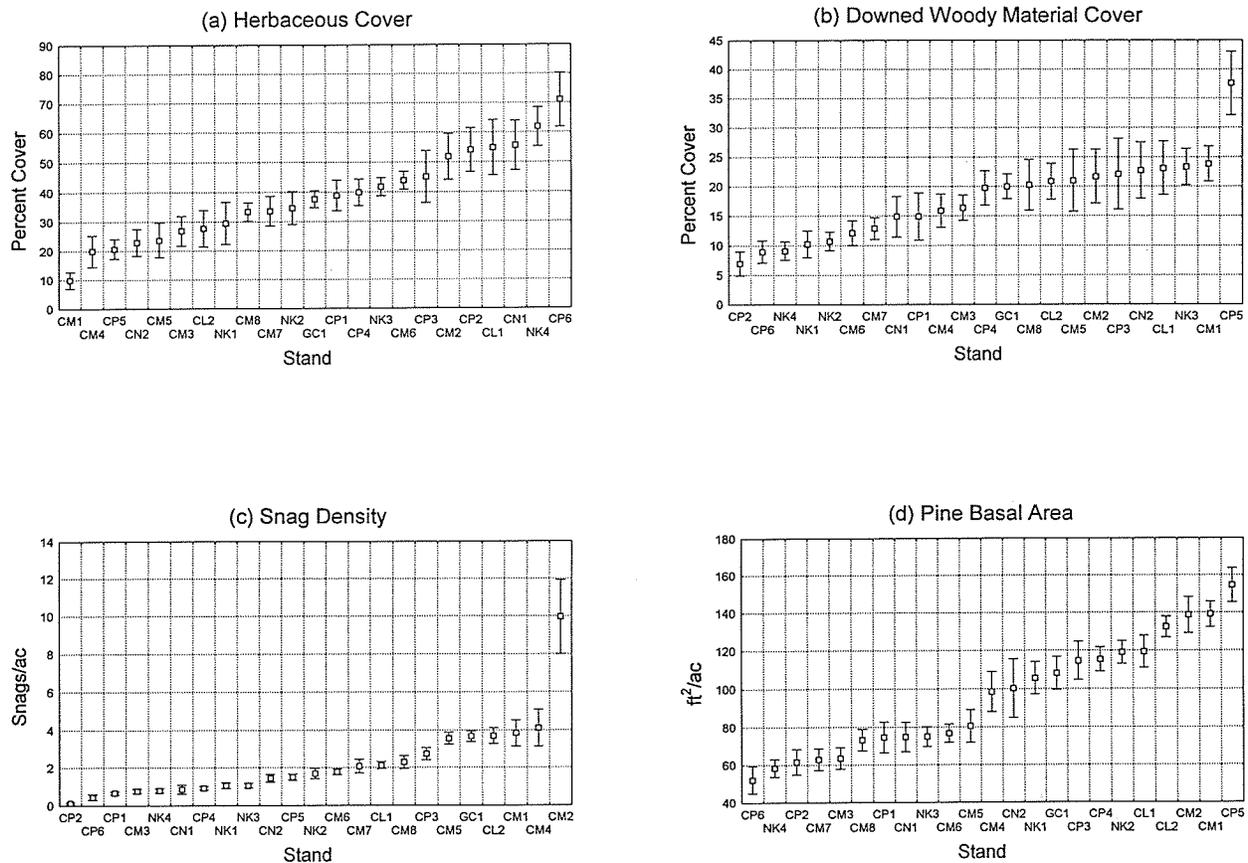


Figure 9. Habitat characteristics at 23 northern Arizona ponderosa pine ( $n = 11$ ) and ponderosa pine-Gambel oak ( $n = 12$ ) study stands, 1993-95: (a) herbaceous cover, (b) downed woody material cover, (c) snag density, and (d) ponderosa pine basal area. Values are means  $\pm$  standard error.

PC4 explained 11% of total variance and described snag density and pine basal area. The majority of the stands ( $n = 22$ ) represented a relatively narrow gradient of snag density, ranging from 0.1-4.1 snags/ac (0.2-10.1 snags/ha) (Fig. 9c). One stand (CM2) had very high snag density (10 snags/ac [24.7/snags ha]). Within-stand variability of snag density was low, except in the 3 stands with the highest snag density. A wide gradient of pine basal area was present across the 23 stands, ranging from 52-155 ft<sup>2</sup>/ac (11.9-35.5 m<sup>2</sup>/ha) (Fig. 9d). Within-stand variability of basal area was relatively low in most stands.

Four VSS classes were represented among the 23 stands. Most stands ( $n = 12$ ) were classified as VSS class 3. Four stands were classified as VSS class 4, 3 as VSS class 5, and 4 as VSS class 6

(Appendix 1). Contributions of individual VSS classes to total pine basal area varied considerably among stands (Fig. 7). Overall, the greatest amount of basal area was contributed by VSS class 3, the least by VSS class 2. Seven stands (CL2, CM1, CM2, CP3, GC1, NK1, NK2) were classified as or had attributes associated with old-growth ponderosa pine; primarily abundant large old pine trees and numerous large snags. Most of these old-growth stands also had patches of dense, small (2-4 in [5.1-10.2 cm] dbh) ponderosa pines that probably resulted from fire suppression and lack of silvicultural treatment (Fig. 10). One notable exception was stand GC1, which had been subjected to frequent fires, but no silvicultural treatments.



Figure 10. Old-growth ponderosa pine stand (CP3) with a dense understory of small pines.

### Avian Communities

Sixty-five bird species were detected in the 23 stands (Appendices 3-4). Nineteen species were considered incidental or inadequately sampled by the variable circular-plot technique. Of 46 species included in analyses of community variables and habitat relationships, 18 were neotropical migrants, 28 were year-round residents/short-distance migrants, and 14 were cavity-nesters (Appendix 3). The breeding avifauna was dominated by 16 abundant species that occurred in >90% of the study stands (broad-tailed hummingbird, solitary vireo, western tanager, dark-eyed junco, mountain chickadee, northern flicker, pygmy nuthatch, red crossbill, Stellar's jay, white-breasted nuthatch, western bluebird, Grace's warbler, yellow-rumped warbler, American robin, hairy woodpecker, and brown-headed cowbird).

Values of bird community variables varied among stands (Appendix 5). Overall breeding bird abundance ranged from 2.0-4.0 birds/ac (4.9-9.9 birds/ha), with a mean of 2.9 birds/ac (7.2 birds/ha) across all stands. Overall abundance was

highest in stand CM1 and lowest in stand CP5. Total species richness ranged from 17.0-26.3 species/stand ( $\bar{x} = 21.3$ ) and was highest in stand CM7 and lowest in stand CP2. Overall bird abundance and species richness were positively correlated ( $r = 0.64$ ,  $P \leq 0.05$ ). Significant positive correlations between abundance and species richness also were present within species groups (neotropical migrants  $r = 0.65$ , residents/short-distance migrants  $r = 0.54$ , cavity-nesters  $r = 0.47$ ).

Of the 3 species groups, residents/short-distance migrants had the highest abundance and species richness across the study stands. Abundance of residents/short-distance migrants ranged from 1.4-2.8 birds/ac (3.5-6.9 birds/ha), with a mean of 2.1 birds/ac (5.2 birds/ha) across all stands. Resident/short-distance migrant abundance was highest in stand CM1 and lowest in stand CP5. Resident/short-distance migrant species richness ranged from 11.3-16.0 species/stand ( $\bar{x} = 13.9$ ) and was highest in stands CM1 and CM2 and lowest in stand CP2. Nine resident/short-distance migrant species (dark-eyed

junco, mountain chickadee, northern flicker, pygmy nuthatch, red crossbill, Stellar's jay, white-breasted nuthatch, western bluebird, and yellow-rumped warbler) occurred in all 23 stands. Of these, the pygmy nuthatch and dark-eyed junco were most abundant (Table 3). Five resident/short-distance migrant species (lesser goldfinch, red-breasted nuthatch, ruby-crowned kinglet, rock wren, and spotted [rufous-sided] towhee) were found in only 1 stand.

Neotropical migrant abundance ranged from 0.4-1.3 birds/ac (1.0-3.2 birds/ha), with a mean of 0.8 birds/ac (2.0 birds/ha) across all stands. Neotropical migrant abundance was highest in stands CM1 and CP3 and lowest in stand CM4. Neotropical migrant species richness ranged from 4.5-11.0 species/stand ( $\bar{x} = 7.4$ ) and was highest in stand CM7 and lowest in stand CP4. The most common neotropical migrants were the broad-tailed hummingbird, solitary vireo, and western tanager, which occurred in all 23 stands. The most abundant neotropical migrant was the violet-green swallow (Table 4). The least common neotropical migrants were the dusky flycatcher and hepatic tanager, both of which were found in only 1 stand.

Cavity-nester abundance ranged from 0.8-2.2 birds/ac (1.0-5.4 birds/ha), with a mean of 1.3 birds/ac (3.2 birds/ha) across all stands. Cavity-nester abundance was highest in stand CP3 and lowest in stands CP5 and CP6. Species richness ranged from 5.0-9.7 species/stand ( $\bar{x} = 7.6$ ) and was highest in stand NK4 and lowest in stands CP4 and CP6. The most common cavity-nesters were the mountain chickadee, northern flicker, pygmy nuthatch, white-breasted nuthatch, and western bluebird, which occurred in all 23 stands. Of these, the pygmy nuthatch was most abundant. The least common cavity-nester was the red-breasted nuthatch, which was found in only 1 stand.

Breeding bird assemblages differed between pine and pine-oak stands. Thirty-eight species occurred in pine stands, 43 in pine-oak stands. Mean similarity in species composition between stands representing these cover types was  $J = 0.67 \pm 0.01SE$ . One infrequently detected species, Clark's nutcracker, was found only in pine stands, whereas 7 species were detected only in pine-oak stands (dusky flycatcher, downy woodpecker, lesser goldfinch, rock wren, spotted towhee, Virginia's warbler, and warbling vireo). Four species that frequently occurred in pine-oak stands (acorn woodpecker, black-headed grosbeak, house wren, and red-faced warbler) were rarely detected in the pine cover type. Three bird community

variables were different ( $P \leq 0.05$ ) in pine compared to pine-oak stands. Pine-oak stands had higher overall species richness as well as greater numbers of neotropical migrant and cavity-nesting species (Table 5).

Breeding bird assemblages in individual stands changed from year to year. Annual species turnover ranged from 8.7-26.3% ( $\bar{x} = 17.3\%$ ). Turnover was lower in pine-oak stands; however, this difference was not significant after Bonferroni adjustment. Turnover rate varied among species groups, and was lowest among resident species (1.8%), followed by neotropical migrants (2.2%) and short-distance migrants (2.6%). Much of the species turnover in stands was driven by 4 species (mourning dove, pine siskin, red crossbill, and Townsend's solitaire).

### Habitat Relationships

*Bird Community Variables.* Breeding bird community variables differed among VSS classes in both pine (Table 6) and pine-oak stands (Table 7); however, the magnitude of most differences was relatively small. In both cover types, overall bird abundance and species richness were slightly higher in VSS class 6 stands than in stands representing other VSS classes. Neotropical migrant abundance and species richness were similar across VSS classes in pine-oak stands, but highest at VSS class 4 and 6 stands in the pine cover type. Residents/short-distance migrants had similar abundance in all VSS classes in both cover types, but species richness was higher in VSS class 6 stands in the pine type. Cavity-nesters had similar abundance and species richness in all 3 VSS classes represented in pine-oak stands. In the pine cover type, cavity-nester abundance and species richness were similar in stands representing VSS classes 3-5, but higher in VSS class 6 stands. Annual turnover in species composition was highest in VSS class 4 stands in both cover types. In the pine type, species turnover was considerably lower in VSS class 6 stands than in the other classes.

Most avian community variables were correlated ( $P \leq 0.05$ ) with  $\geq 1$  stand habitat variable. Significant habitat characteristics included the density and proportional basal area of pines in several VSS classes, pine canopy cover, SDI, variability of pine dbh, shrub cover, snag density, snag size, snag condition, and the density of non-snag cavity-nesting substrates. Overall bird abundance and species richness were positively correlated with the density and proportional basal area of VSS class 6 ponderosa pines, and cover of

Table 3. Occurrence (number of stands) and abundance (birds/ac) of 28 resident/short-distance migrant breeding bird species at 23 northern Arizona ponderosa pine ( $n = 11$ ) and ponderosa pine-Gambel oak ( $n = 12$ ) study stands, 1993-95. NA = not applicable.

Species	Occurrence	Abundance	
		Mean	Range
Dark-eyed junco	23	0.26	0.09 - 0.57
Mountain chickadee	23	0.13	0.03 - 0.21
Northern flicker	23	0.08	0.03 - 0.23
Pygmy nuthatch	23	0.60	0.20 - 1.35
Red crossbill	23	0.28	0.03 - 1.89
Stellar's jay	23	0.10	0.03 - 0.26
White-breasted nuthatch	23	0.11	0.03 - 0.34
Western bluebird	23	0.15	0.03 - 0.46
Yellow-rumped warbler	23	0.13	0.03 - 0.34
American robin	22	0.06	0.03 - 0.14
Hairy woodpecker	22	0.07	0.03 - 0.16
Brown-headed cowbird	21	0.08	0.03 - 0.20
Pine siskin	19	0.07	0.03 - 0.40
Brown creeper	18	0.07	0.03 - 0.29
Mourning dove	18	0.06	0.03 - 0.17
Hermit thrush	16	0.07	0.03 - 0.16
Townsend's solitaire	15	0.05	0.03 - 0.14
Acorn woodpecker	11	0.06	0.03 - 0.14
Williamson's sapsucker	7	0.04	0.03 - 0.06
Cassin's finch	5	0.04	0.03 - 0.06
Clark's nutcracker	4	0.05	0.03 - 0.09
Downy woodpecker	4	0.05	0.03 - 0.09
Three-toed woodpecker	2	0.04	0.03 - 0.06
Lesser goldfinch	1	0.03	NA
Red-breasted nuthatch	1	0.06	NA
Ruby-crowned kinglet	1	0.03	NA
Rock wren	1	0.03	NA
Spotted (rufous-sided) towhee	1	0.11	NA

Table 4. Occurrence (number of stands) and abundance (birds/ac) of 18 neotropical migrant breeding bird species at 23 northern Arizona ponderosa pine ( $n = 11$ ) and ponderosa pine-Gambel oak ( $n = 12$ ) study stands, 1993-95. NA = not applicable.

Species	Occurrence	Abundance	
		Mean	Range
Broad-tailed hummingbird	23	0.08	0.03 - 0.20
Solitary vireo	23	0.13	0.03 - 0.33
Western tanager	23	0.11	0.03 - 0.26
Grace's warbler	22	0.15	0.03 - 0.37
Violet-green swallow	19	0.19	0.03 - 0.80
Western wood-pewee	19	0.08	0.03 - 0.20
Cordilleran flycatcher	17	0.07	0.03 - 0.23
Chipping sparrow	14	0.09	0.03 - 0.34
Black-headed grosbeak	13	0.07	0.03 - 0.20
House wren	7	0.07	0.03 - 0.20
Olive warbler	7	0.04	0.03 - 0.07
Red-faced warbler	7	0.08	0.03 - 0.23
Virginia's warbler	6	0.05	0.03 - 0.11
Band-tailed pigeon	4	0.06	0.03 - 0.11
Olive-sided flycatcher	4	0.05	0.03 - 0.09
Warbling vireo	3	0.05	0.03 - 0.06
Dusky flycatcher	1	0.03	NA
Hepatic tanager	1	0.03	NA

Table 5. Bird community variables at northern Arizona ponderosa pine ( $n = 11$ ) and ponderosa pine-Gambel oak ( $n = 12$ ) forest study stands, 1993-95. Values are means across sites and years  $\pm$  standard error. Asterisked variables are significantly different between cover types ( $t$ -test,  $P \leq 0.05$ ).

Variable	Pine	Pine-oak
Total avian abundance (birds/ac)	2.7 $\pm$ 0.1	3.0 $\pm$ 0.1
Total species richness*	19.5 $\pm$ 0.5	23.1 $\pm$ 0.4
Neotropical migrant abundance (birds/ac)	0.7 $\pm$ 0.1	0.9 $\pm$ 0.1
Neotropical migrant species richness*	6.0 $\pm$ 0.3	8.7 $\pm$ 0.3
Resident/short-distance migrant abundance (birds/ac)	2.0 $\pm$ 0.1	2.2 $\pm$ 0.1
Resident/short-distance migrant species richness	13.5 $\pm$ 0.4	14.4 $\pm$ 0.3
Cavity-nester abundance (birds/ac)	1.3 $\pm$ 0.1	1.4 $\pm$ 0.1
Cavity-nester species richness*	6.8 $\pm$ 0.3	8.4 $\pm$ 0.2
Annual species turnover (%)	18.7 $\pm$ 0.9	16.2 $\pm$ 0.7

Table 6. Bird community variables at 11 northern Arizona ponderosa pine forest study stands representing 4 vegetative structural stage (VSS) classes, 1993-95. Classes were: VSS 3 = 5-11.9 in (12.7-30.2 cm) dbh, VSS 4 = 12-17.9 in (30.5-45.5 cm) dbh, VSS 5 = 18-23.9 in (45.7-60.7 cm) dbh, and VSS 6 =  $\geq 24$  in (61.0 cm dbh). Values are means across sites and years  $\pm$  standard error.

Variable	VSS 3	VSS 4	VSS 5	VSS 6
Overall abundance (birds/ac)	2.4 $\pm$ 0.2	3.1 $\pm$ 0.6	2.7 $\pm$ 0.2	3.5 $\pm$ 0.1
Overall species richness	18.5 $\pm$ 0.8	19.5 $\pm$ 2.5	11.4 $\pm$ 0.8	22.5 $\pm$ 0.4
Neotropical migrant abundance (birds/ac)	0.6 $\pm$ 0.0	1.0 $\pm$ 0.1	0.5 $\pm$ 0.1	1.2 $\pm$ 0.1
Neotropical migrant species richness	5.7 $\pm$ 0.3	7.5 $\pm$ 0.5	5.4 $\pm$ 0.5	7.2 $\pm$ 0.6
Resident/short-distance migrant abundance (birds/ac)	1.8 $\pm$ 0.1	2.1 $\pm$ 0.7	2.2 $\pm$ 0.2	2.3 $\pm$ 0.1
Resident/short-distance migrant species richness	12.8 $\pm$ 0.6	12.0 $\pm$ 3.0	13.4 $\pm$ 0.4	15.3 $\pm$ 0.6
Cavity nester abundance (birds/ac)	1.1 $\pm$ 0.1	0.8 $\pm$ 0.0	1.1 $\pm$ 0.1	2.1 $\pm$ 0.1
Cavity-nester species richness	6.2 $\pm$ 0.4	5.0 $\pm$ 1.0	6.8 $\pm$ 0.4	8.7 $\pm$ 0.3
Annual species turnover (%)	19.1 $\pm$ 0.8	23.1	21.6 $\pm$ 1.2	12.2 $\pm$ 1.6

Table 7. Bird community variables at 12 northern Arizona ponderosa pine-Gambel oak study stands representing 3 vegetative structural stage (VSS) classes, 1993-95. Classes were: VSS 3 = 5-11.9 in (12.7-30.2 cm) dbh, VSS 4 = 12-17.9 in (30.5-45.5 cm) dbh, and VSS 6 =  $\geq 24$  in (61.0 cm dbh). Values are means across sites and years  $\pm$  standard error.

Variable	VSS 3	VSS 4	VSS 6
Overall abundance (birds/ac)	2.9 $\pm$ 0.2	3.1 $\pm$ 0.1	3.3 $\pm$ 0.2
Overall species richness	23.1 $\pm$ 0.6	22.3 $\pm$ 0.6	24.2 $\pm$ 0.8
Neotropical migrant abundance (birds/ac)	0.8 $\pm$ 0.1	0.9 $\pm$ 0.1	0.9 $\pm$ 0.1
Neotropical migrant species richness	8.5 $\pm$ 0.4	8.5 $\pm$ 0.4	9.3 $\pm$ 0.6
Resident/short-distance migrant abundance (birds/ac)	2.1 $\pm$ 0.1	2.2 $\pm$ 0.1	2.4 $\pm$ 0.2
Resident/short-distance migrant species richness	14.6 $\pm$ 0.4	13.8 $\pm$ 0.6	14.8 $\pm$ 0.7
Cavity nester abundance (birds/ac)	1.3 $\pm$ 0.1	1.4 $\pm$ 0.1	1.4 $\pm$ 0.2
Cavity-nester species richness	8.3 $\pm$ 0.2	8.4 $\pm$ 0.4	8.5 $\pm$ 0.7
Annual species turnover (%)	16.0 $\pm$ 1.0	17.2 $\pm$ 1.4	15.3 $\pm$ 1.1

shrubs, respectively (Table 8). More neotropical migrant species occurred in stands with lower canopy cover and SDI, lower proportional basal area of VSS class 2 pines, fewer VSS class 5 pines, and greater shrub cover (Table 8).

Residents/short-distance migrants were more abundant in stands with more VSS class 6 pines, and had higher species richness in stands with more VSS class 2 pine basal area, greater variability of pine dbh, and less pine basal area in VSS class 4 (Table 8). Abundance and/or species richness of cavity-nesting birds increased in stands with higher canopy cover, higher SDI, higher density and proportional basal area of VSS class 2 and 6 pines, lower proportional basal area of VSS class 4 pines, greater variability of pine dbh, lower proportions of small snags (<18 in [45.7 cm] dbh), higher proportions of large snags (>18 in [45.7 cm] dbh), higher proportions of tall snags (>32.8 ft [10 m] in height), fewer snags in class 1, and greater abundance of non-s snag cavity substrates (Table 9).

Two management-influenced habitat components, VSS class 6 pines and snags, had strong positive relationships with bird abundance within species groups. Abundance of residents/short-distance migrants and cavity-nesters

both increased with the density and proportional basal area of VSS class 6 pines. Residents/short-distance migrants were most abundant in stands with VSS class 6 pines comprising 40-50% of pine basal area and in stands with >4 VSS class 6 trees/ac (>9.9 trees/ha). Cavity-nesters were most abundant in stands with VSS class 6 pines comprising >40% of pine basal area and in stands with 10-12 VSS class 6 trees/ac (24.7-29.6 trees/ha). Abundance of cavity-nesting birds also increased with greater snag density, greater proportions of tall snags, and greater proportions of large dbh snags. Cavity-nesters were most abundant in stands with >4 snags/ac (>9.9 snags/ha), >50% of snags >32.8 ft (10 m) tall, and >40% of snags >18 in (45.7 cm) dbh.

*Bird Species.* I found significant relationships between the abundance of individual bird species and 5 stand habitat characteristics: (1) canopy cover and heterogeneity, (2) basal area within different pine VSS classes, (3) variability of ponderosa pine dbh, (4) Gambel oak canopy cover and size, and (5) the density and physical characteristics of cavity-nesting substrates. In general, individual species showed stronger correlations with stand habitat variables than did species groups.

Table 8. Spearman rank correlations ( $P \leq 0.05$ ) between abundance and species richness of all bird species, neotropical migrants, year-round residents/short-distance migrants, and habitat characteristics at 23 northern Arizona ponderosa pine ( $n = 11$ ) and ponderosa pine-Gambel oak ( $n = 12$ ) study stands, 1993-95. NS = not significant.

Habitat variable	All birds		Neotropical migrants	Residents/short-distance migrants	
	Abund.	Spp. rich.	Spp. rich.	Abund.	Spp. rich.
Pine canopy cover	NS	NS	-0.39	NS	NS
Stand density index <sup>1</sup>	NS	NS	-0.34	NS	NS
Density VSS <sup>2</sup> 2 pines (1-4.9 in dbh)	NS	NS	NS	NS	0.36
Density VSS 5 pines (18-23.9 in dbh)	NS	NS	-0.33	NS	NS
Density VSS 6 pines (>24 in dbh)	0.35	NS	NS	0.40	NS
Proportion basal area VSS 2 pines	NS	NS	-0.36	NS	NS
Proportion basal area VSS 4 pines (12-17.9 in dbh)	NS	NS	NS	NS	-0.37
Proportion basal area VSS 6 pines	0.36	NS	NS	0.36	NS
Variability pine dbh	NS	NS	NS	NS	0.38
Shrub cover	NS	0.53	0.58	NS	NS

<sup>1</sup> Raw value calculated per McTague and Patton (1989).

<sup>2</sup> Vegetative structural stage classification per Reynolds et al. (1992).

Table 9. Spearman rank correlations ( $P \leq 0.05$ ) between abundance and species richness of cavity-nesting birds, and habitat characteristics at 23 northern Arizona ponderosa pine ( $n = 11$ ) and ponderosa pine-Gambel oak ( $n = 12$ ) study stands, 1993-95. NS = not significant.

Habitat variable	Abundance	Species richness
Pine canopy cover	0.36	NS
Stand density index <sup>1</sup>	0.46	NS
Density VSS <sup>2</sup> 2 pines (1-4.9 in dbh)	0.43	NS
Density VSS 6 pines (>24 in dbh)	0.51	NS
Proportion basal area VSS 2 pines	0.32	NS
Proportion basal area VSS 4 pines (12-17.9 in dbh)	-0.37	NS
Proportion basal area VSS 6 pines	0.42	NS
Variability pine dbh	0.47	NS
Snag density	0.60	0.33
Density other cavity substrates	0.48	0.49
Proportion snags (<12 in dbh)	-0.52	NS
Proportion snags (12-17.9 in dbh)	NS	-0.34
Proportion snags (>18 in dbh)	0.54	0.35
Proportion snags (<16 ft tall)	-0.35	NS
Proportion snags (>32 ft tall)	0.47	NS
Proportion class 1 snags	-0.49	-0.39

<sup>1</sup> Raw value calculated per McTague and Patton (1989).

<sup>2</sup> Vegetative structural stage classification per Reynolds et al. (1992).

Seven species showed correlations ( $P \leq 0.05$ ) with canopy cover and/or heterogeneity (Table 10). Two species (chipping sparrow, western bluebird) were inversely related to canopy cover. Chipping sparrows were most abundant in stands with <30% canopy cover, western bluebirds were most abundant in stands with <20% canopy cover. Four species (pygmy nuthatch, violet-green swallow, Cordilleran flycatcher, brown creeper) increased with increasing canopy cover. Pygmy nuthatches and violet-green swallows were most abundant in stands with >40% canopy cover, brown creepers and Cordilleran flycatchers were most abundant in stands with >50% canopy cover. Five species were correlated with canopy heterogeneity. Chipping sparrows and Stellar's jays were more abundant in stands with greater canopy heterogeneity, whereas pygmy nuthatches,

violet-green swallows, and Cordilleran flycatchers were more abundant in stands with more homogenous canopy (Table 10).

Ten species were correlated ( $P \leq 0.05$ ) with the proportion of pine basal area in  $\geq 1$  VSS class (Table 11). Pine siskins were most abundant in stands with 15-20% of basal area in VSS class 2. Cordilleran flycatchers were most abundant in stands with 5-20% of basal area in VSS class 2. Brown creepers and violet-green swallows were most abundant in stands with 15-20% of basal area in VSS class 2 and in stands with 30-40% of basal area in VSS class 6. Black-headed grosbeaks were most abundant in stands with 30-50% of basal area in VSS class 4. Red crossbills were most abundant in stands with 30-40% of basal area in VSS class 5. House wrens were most abundant in stands with 30-40% of basal area in VSS class 5 and in stands

Table 10. Spearman rank correlations ( $P \leq 0.05$ ) between abundance of 7 bird species and canopy characteristics at 23 northern Arizona ponderosa pine ( $n = 11$ ) and ponderosa pine-Gambel oak ( $n = 12$ ) study stands, 1993-95. Species are grouped by correlation patterns. NS = not significant.

Group Species	Canopy cover	Canopy heterogeneity
A - Low canopy cover		
Chipping sparrow	-0.54	0.42
Western bluebird	-0.42	NS
Stellar's jay	NS	0.31
B - High canopy cover		
Pygmy nuthatch	0.53	-0.59
Violet-green swallow	0.54	-0.47
Cordilleran flycatcher	0.57	-0.54
Brown creeper	0.62	NS

Table 11. Spearman rank correlations ( $P \leq 0.05$ ) between abundance of 10 bird species and proportion of ponderosa pine basal area in vegetative structural stage (VSS) classes at 23 northern Arizona ponderosa pine ( $n = 11$ ) and ponderosa pine-Gambel oak ( $n = 12$ ) study stands, 1993-95. Classes were: VSS 2 = 1-4.9 in (2.5-12.4 cm) dbh, VSS 3 = 5-11.9 in (12.7-30.2 cm) dbh, VSS 4 = 12-17.9 in (30.5-45.5 cm) dbh, VSS 5 = 18-23.9 in (45.7-60.7 cm) dbh, and VSS 6 =  $\geq 24$  in (61.0 cm dbh). Species are grouped by correlation patterns. NS = not significant.

Group Species	Proportion of total basal area				
	VSS 2	VSS 3	VSS 4	VSS 5	VSS 6
VSS 2					
Pine siskin	0.56	NS	NS	NS	NS
Cordilleran flycatcher	0.54	NS	-0.42	NS	NS
VSS 2 + 6					
Violet-green swallow	0.53	-0.34	-0.45	NS	0.40
Brown creeper	0.59	NS	-0.43	NS	0.35
VSS 4					
Black-headed grosbeak	-0.52	NS	0.65	NS	NS
VSS 5					
Red crossbill	NS	NS	NS	0.33	NS
VSS 5 + 6					
House wren	NS	-0.73	-0.80	0.78	0.75
Chipping sparrow	NS	-0.51	NS	0.49	0.42
VSS 6					
Pygmy nuthatch	NS	NS	NS	-0.36	0.36
Northern flicker	NS	NS	-0.38	NS	0.39

with 30-50% of basal area in VSS class 6. Chipping sparrows were most abundant in stands with 10-20% of basal area in VSS class 5 and in stands with 30-50% of basal area in VSS class 6. Pygmy nuthatches were most abundant in stands with 40-50% of basal area in VSS class 6. Northern flickers were most abundant in stands with 20-50% of basal area in VSS class 6.

Six species were correlated ( $P \leq 0.05$ ) with within-stand variability of pine dbh. Abundances of brown creepers ( $r_s = 0.64$ ), Cordilleran flycatchers ( $r_s = 0.67$ ); hairy woodpeckers ( $r_s = 0.31$ ), house wrens ( $r_s = 0.55$ ), pygmy nuthatches ( $r_s = 0.45$ ), and violet-green swallows ( $r_s = 0.67$ ) were higher in stands with greater coefficients of variation for pine dbh.

Abundances of 4 species were correlated ( $P \leq 0.05$ ) with characteristics of the Gambel oak component in pine-oak stands. Black-headed grosbeaks were most abundant in stands with >10% Gambel oak canopy cover ( $r_s = 0.56$ ). House wrens and red-faced warblers were most abundant in stands with 50-60% of oak basal area in small (<8 in [20.3 cm] drc) trees ( $r_s = 0.85$  and 0.61, respectively). The western wood-pewee was most abundant in stands with 30-50% of oak basal area in large (>15 in [50.8 cm] drc) trees ( $r_s = 0.58$ ).

Abundances of 5 cavity-nesting species were correlated ( $P \leq 0.05$ ) with variables describing the

density and physical characteristics of cavity-nesting substrates (Table 12). Cordilleran flycatchers, pygmy nuthatches, and violet-green swallows increased along with snag density. Cordilleran flycatchers were most abundant in stands with >3 snags/ac. Pygmy nuthatches were most abundant in stands with >1 snag/ac. Violet-green swallows were most abundant in stands with >2 snags/ac. Northern flickers, pygmy nuthatches, and violet-green swallows increased with the proportion of tall snags (>32.8 ft [10 m] in height). Northern flickers and pygmy nuthatches were most abundant in stands with >30% of snags in the tall height class. Violet-green swallows were most abundant in stands with >40% of snags in the tall height class. Northern flickers and pygmy nuthatches increased in stands with a greater proportion of large diameter snags (>18 in [45.7 cm] dbh). Northern flickers were most abundant in stands with >60% large diameter snags. Pygmy nuthatches were most abundant in stands with >40% large diameter snags. Cordilleran flycatchers and pygmy nuthatches were more abundant in stands with >20% of snags in class 2. Two species (pygmy nuthatch and white-breasted nuthatch) increased with the density of non-snag cavity substrates. Both species were more abundant in stands with >0.1 non-snag cavity substrates/ac.

Table 12. Spearman rank correlations ( $P \leq 0.05$ ) between abundance of 5 cavity-nesting bird species and snag characteristics at 23 northern Arizona ponderosa pine ( $n = 11$ ) and ponderosa pine-Gambel oak ( $n = 12$ ) study stands, 1993-95. NS = not significant.

Species	Snags	Density of other cavity substrates	Proportion of total snags		
			>32 ft tall	>18 in dbh	Class 2
Cordilleran flycatcher	0.64	NS	NS	NS	0.55
Northern flicker	NS	NS	0.32	0.42	NS
Pygmy nuthatch	0.56	0.34	0.41	0.32	0.39
Violet-green swallow	0.57	NS	0.52	NS	NS
White-breasted nuthatch	NS	0.42	NS	NS	NS

### Habitat Selection

Cover type specific CART models were developed for 4 species (brown creeper, brown-headed cowbird, chipping sparrow, and Cordilleran flycatcher). A combined cover type model was developed for the western bluebird. Occurrence of each species was best predicted by a different set of 1-3 habitat variables. However, cover type-specific models for a species usually shared 1 variable. Overall classification accuracy of the CART models ranged from 61-86%.

Models for brown creepers in pine and pine-oak cover types had classification accuracies of 85% and 70%, respectively. In pine stands, brown creepers were associated with points that had SDI values  $>215$  and pine density  $>458$  trees/ac (1,131 pines/ha) or  $>47\%$  pine canopy cover (Appendix 6a). In pine-oak stands, brown creepers occurred at points with SDI  $>267$  or points with  $>19$  ft<sup>2</sup>/ac (4.4 m<sup>2</sup>/ha) of Gambel oak basal area (Appendix 6b).

Models for brown-headed cowbirds in pine and pine-oak cover types had classification accuracies of 61% and 63%, respectively. In pine stands, brown-headed cowbirds were absent from points with  $>63\%$  pine canopy cover or  $>17$  VSS class 5 and 6 pines/ac (42 pines/ha)

(Appendix 7a). In pine-oak stands, brown-headed cowbirds were absent from points having Gambel oak QMD  $\leq 5$  in (12.7 cm) or points with  $>308$  pines/ac (761 pines/ha) (Appendix 7b).

Models for chipping sparrows in pine and pine-oak cover types had classification accuracies of 86% and 71%, respectively. In the pine cover type, chipping sparrows occurred at points with  $\leq 146$  pines/ac (361 pines/ha) (Appendix 8a). In pine-oak stands, occupied points had  $\leq 149$  pines/ac (368 pines/ha) and  $\leq 6$  ft<sup>2</sup>/ac (1.4 m<sup>2</sup>/ha) of Gambel oak basal area or pine QMD  $>12$  in (30.5 cm) (Appendix 8b).

Models for Cordilleran flycatchers in pine and pine-oak cover types had classification accuracies of 80% and 75%, respectively. In the pine cover type, Cordilleran flycatchers occurred at points with  $>2$  snags/ac (4.9 snags/ha) or  $>383$  pines/ac (946 pines/ha) (Appendix 9a). In pine-oak stands, occupied points had  $>199$  pines/ac (492 pines/ha) (Appendix 9b).

The combined cover type model for western bluebirds had a classification accuracy of 76%. In both cover types, western bluebirds were absent from points with  $>139$  ft<sup>2</sup>/ac (31.8 m<sup>2</sup>/ha) of pine basal area (Appendix 10).



Structurally diverse stands with numerous mature ponderosa pines and large snags had high breeding bird abundance and diversity. Location is stand NK4, Kaibab Plateau, Arizona.



## DISCUSSION

### Scope of Inference

The 23 study stands represented a broad habitat gradient, from intensively managed stands with large openings, to unmanaged stands with dense thickets of young trees under a well-developed mature pine overstory. Habitat components such as snags and oak trees also varied in their abundance and physical characteristics. Considerable within-stand variability also was present, primarily consisting of small openings and patches of trees of different size classes, stem densities, and canopy structure. Previous studies in northern Arizona ponderosa pine forests (Szaro and Balda 1979a, b; Siegel 1989) have focused on relatively few structural types along this gradient. Because I examined a greater number of stands and a wider diversity of habitat conditions, results of this study should be more widely applicable to management of breeding bird habitat in these forests.

The habitat relationships described in this study used bird density as 1 indicator of habitat quality. As noted by Van Horne (1983), there are situations in which this assumption does not hold. In a study concurrent with mine, Stearns (1995) tested relationships between density and habitat quality for 5 species (solitary vireo, pygmy nuthatch, western bluebird, American robin, and white-breasted nuthatch). She compared bird abundance estimates (derived from my avian surveys), nesting densities (determined by spot-mapping), and reproductive success (using the index of Vickery et al. 1992) in 10 of my stands. Three species (solitary vireo, pygmy nuthatch, western bluebird) showed significant positive correlations between abundance and nesting density. For these 3 species, point count surveys and spot mapping yielded similar rankings of stands, i.e., stands with the highest abundance index values also had the greatest number of nesting pairs. The relationship between abundance and reproductive success varied among species. When stands were grouped into categories of low, medium, and high bird abundance, solitary vireo reproductive success did not vary among abundance classes. Pygmy nuthatches showed increased reproductive success as abundance increased. Reproductive success of western bluebirds was highest at high abundance, but lowest at medium abundance. These results further support the notion that direct measures of population performance (reproduction and survival) are better measures of habitat quality for

breeding birds (Martin 1992). Unfortunately, such data are extremely time and labor-intensive to obtain, and usually beyond the scope of extensive habitat studies.

### Avian Communities

The ponderosa pine and pine-oak forests I studied supported diverse breeding bird communities. All 3 species groups, neotropical migrants, year-round residents/short-distance migrants, and cavity-nesters were well represented. The majority of breeding birds were widely-distributed species that are year-round residents or short-distance migrants. Species composition in my stands was similar to that reported in previous studies conducted in nearby areas on the Coconino National Forest (Szaro and Balda 1979b), Kaibab National Forest, and Grand Canyon North Rim (Burgoyne 1980, Siegel 1989). Bird abundance in my stands was similar to that found by other researchers, though specific comparisons could not be made because of differences in methodology among studies.

Breeding bird communities in pine and pine-oak forests are dynamic, exhibiting considerable turnover in breeding species composition from year to year. In this study, much of this fluctuation was driven by "irruptive" species (pine siskin, red crossbill) that respond to flushes of conifer seed production. Other studies in these habitats also have found substantial year to year turnover. Balda (1975a) reported even higher annual turnover rates than I observed (9-40% vs. 9-26%). Brawn and Balda (1988a) also found the lowest turnover rates among resident species, and frequent local appearance/disappearance by pine siskins and Townsend's solitaires. Annual species turnover in my study stands was negatively correlated with species richness and abundance, a pattern documented in many North American breeding bird habitats (Noon et al. 1985). Climatic factors can influence breeding bird communities in ponderosa pine forests, and may also have contributed to species turnover. Szaro and Balda (1986) found that bird density was lower in breeding seasons preceded by harsh winter and spring weather, perhaps due to effects on prey insect emergence and abundance. However, they also indicated that weather effects were typically short-term and had less influence on avian communities than habitat conditions.

Breeding bird species richness was higher in pine-oak than in ponderosa pine stands. Several species also were more abundant in pine-oak stands. Previous studies in southwestern forests

have reported increased abundance of secondary cavity nesters and other species in stands containing Gambel oak (Balda 1975*b*, Brawn and Balda 1988*a*, O'Brien 1990). Similar patterns also have been found in other North American pine forests with a hardwood component (Morrison and Meslow 1984, Morrison 1992, Dickson et al. 1995).

The role of Gambel oak in forest bird communities is not well understood. Oak may be an important cavity-nesting substrate, particularly when snags are limiting. Unlike live ponderosa pines, relatively small oaks (8-10 in [20.3-25.4 cm] drc) frequently have dead portions of the bole or limbs that can be used by cavity-nesters. Cunningham et al. (1980) found that western bluebirds and white-breasted nuthatches frequently nested in live oaks, and that pygmy nuthatches and mountain chickadees also nested in oaks when snags were rare. Brawn and Balda (1988*a*) speculated that Gambel oak provides a preferred foraging substrate and may support higher densities of insect prey than ponderosa pine.

### Habitat Relationships

Breeding birds in the ponderosa pine and pine-oak habitats I studied showed strong responses to habitat characteristics within and across stands. The 5 species for which I developed habitat models appeared to select distinct habitat conditions within stands. Abundances of individual species, including widely-distributed generalists and less common species, were correlated with  $\geq 1$  stand habitat characteristic. Community variables describing species richness and abundance within groups of birds also were correlated with stand habitat characteristics. These results fit the model of Urban and Smith (1989), in which overall avian community structure is driven by microhabitat selection of individual species. Stand-level patterns are then determined by the availability and distribution of microhabitats within a stand.

In this study, breeding bird assemblages with the highest abundance and species richness were found in structurally diverse stands that usually had a well-developed mature pine component, abundant shrubs, and numerous large snags. Breeding birds were most strongly associated with habitat variables that reflected tree size and density, canopy characteristics, shrub cover, and cavity-nesting substrates.

*Tree Size and Density.* Tree size and density were key habitat characteristics in my study stands. Breeding bird abundance and community

variables were associated with the density and/or proportional basal area of ponderosa pines in different dbh classes, particularly VSS class 6. Breeding bird abundance and species richness also were positively correlated with within-stand variability of tree dbh. However, avian community characteristics were not strongly associated with overall stand VSS classifications, which were too coarse to effectively describe habitat characteristics important to breeding birds. In the pine-oak cover type, several species were more abundant in stands with higher proportional basal area of small (<8 in [20.3 cm] drc) or large (>15 in [38.1 cm] drc) oaks.

Studies in other western forests have found that individual bird species were more abundant in particular successional stages dominated by different size/age class trees (Verner 1980, Schwab and Sinclair 1994). However, previous studies in southwestern ponderosa pine forests contain limited information on the influence of tree size and density on breeding birds. Balda et al. (1983) and Brawn and Balda (1988*a*) indicated that secondary cavity nesters preferred stands with well-spaced mature pines interspersed by trees of intermediate age. Siegel (1989) found similar species richness in 3 types of ponderosa pine old-growth stands in northern Arizona, all of which had more bird species than a managed area. He found the highest overall bird abundance in dense old growth stands with >50% of trees <14 in (35.6 cm) dbh. I also found high avian abundance and species richness under similar conditions, typified by stands CM1, CL2, and CP3. However, the unmanaged stand in Grand Canyon National Park (GC1) also had high bird abundance and species richness. This stand had the greatest proportion (80%) of basal area in mature pines (VSS classes 5-6), but lacked a dense understory of smaller trees.

*Canopy Characteristics.* Two community variables showed significant, but differing responses to changes in pine canopy cover. Open stands had higher neotropical migrant species richness, but lower overall abundance of cavity-nesters. These patterns reflected responses of individual species, which were not necessarily similar among all members of a group. For example, more open conditions were suitable for neotropical migrants such as the chipping sparrow, whereas the Cordilleran flycatcher and violet-green swallow were more abundant in stands with greater canopy closure. The most common cavity-nester, the pygmy nuthatch, was most abundant in stands with high canopy closure, whereas another common cavity-nester, the western bluebird, was

negatively correlated with this canopy characteristic. In the pine-oak cover type, 1 species (black-headed grosbeak) was more abundant in stands with higher oak canopy closure. Species associations with changes in canopy cover generally paralleled those reported in other studies in western forests (Szaró and Balda 1979a, 1982, 1986; Szaró 1986; Hejl et al. 1995).

Bird abundance and species richness within species groups were not correlated with canopy heterogeneity. However, several individual bird species increased with greater canopy heterogeneity, whereas others decreased. Studies in deciduous forests have found positive correlations between avian species richness and vertical (foliage height) diversity (MacArthur and MacArthur 1961, Karr 1971, Willson 1974); however, studies in southwestern ponderosa pine forests have failed to corroborate this pattern (Szaró and Balda 1979b). Szaró and Balda (1979b) also found no correlation between bird species richness and a heterogeneity measure reflecting variation in tree spacing. However, a later paper (Brawn and Balda 1988a) linked canopy patchiness with avian diversity, indicating that the highest avian diversity was found in a moderately thinned stand with a mixture of closed-canopy patches of pole timber, interspersed with openings containing dispersed mature pines and a productive understory.

*Shrub Cover.* Two breeding bird community variables were significantly associated with understory shrubs. Overall species richness and species richness of neotropical migrants were higher in stands with greater shrub cover. I was unable to find any specific information in published literature concerning the importance of shrubs to breeding birds in ponderosa pine and

pine-oak forests. However, the presence of a well-developed shrub component would certainly benefit breeding birds such as red-faced warblers, house wrens, and chipping sparrows that nest and/or forage in this vegetation layer.

*Cavity-Nesting Substrates.* Snags are a critical habitat requirement for cavity-nesting birds in ponderosa pine forests. The observed increases in cavity-nester abundance and species richness with greater snag density strongly suggest that snags were limiting in some stands. Similar correlations between cavity-nesters and snag density were found on the Beaver Creek watershed study areas (Balda 1975b, Cunningham et al. 1980, Balda et al. 1983) and in other western forests (Scott 1979, Raphael and White 1984, Zarnowitz and Manuwal 1985, Horton and Mannan 1988). Brawn and Balda (1988b) provided experimental evidence that a lack of cavities can limit abundance of secondary cavity-nesters in ponderosa pine and pine-oak habitats.

Cavity-nester abundance and species richness also were associated with snag characteristics. Large snags and snags beyond class 1 appeared particularly important to cavity-nesters in my study areas. Studies of snag use by cavity-nesters in southwestern forests have found a consistent preference for large snags (Scott 1978, Cunningham et al. 1980, Horton and Mannan 1988).

Cavity-nesting birds also were positively correlated with the abundance of other cavity substrates, such as spike-topped trees, lightning scars, and dead portions of live oaks. Use of these non-snag substrates has been documented in other studies of montane forest cavity-nesters (Scott 1978, Cunningham et al. 1980, Raphael and White 1984).



## CONCLUSIONS AND MANAGEMENT OPTIONS

### Forest Management

Management practices in southwestern forests are changing. Current forest conditions have been linked to a number of forest health problems and are considered by many to be unsustainable over the long-term. Perceived problems include: outbreaks of tree-damaging insects, pathogens, and parasites; increased incidence and size of high-intensity wildfires; reduced nutrient cycling; and loss of herbaceous vegetation (Johnson 1994, Sackett et al. 1994). Concerns also have been raised about the population status of 2 forest raptors, the northern goshawk and Mexican spotted owl.

To address these issues, forest managers are considering new ecologically-based management approaches, commonly referred to as "ecosystem management." Among these new approaches are habitat management guidelines developed for the goshawk (Reynolds et al. 1992) and spotted owl (USDI Fish and Wildlife Service 1995), which will be widely applied on National Forests in northern Arizona (USDA Forest Service 1995). Another emerging paradigm for management of southwestern ponderosa pine forests is restoration of conditions that existed prior to European settlement. To achieve this goal, managers would use intensive thinning and prescribed fire to remove post-settlement trees, reduce fuel loads, and create more open, park-like conditions (Covington and Moore 1992, Covington et al. 1995).

The development of ecosystem management strategies for southwestern forests represents an opportunity to address habitat requirements of neotropical migrants and other passerine birds (Block et al. 1995). For example, management guidelines for both goshawks and spotted owls specify desired habitat conditions, but offer flexibility in on-the-ground implementation. Using information obtained from this study, forest managers may develop treatment prescriptions that also are beneficial to breeding birds.

### Management Options

Breeding bird communities in northern Arizona ponderosa pine and pine-oak forests are composed of many species with distinct habitat requirements. Although overall bird diversity and abundance were correlated with particular stand characteristics, no single forest condition or

structural type will benefit all species simultaneously. Providing a mosaic of habitat conditions containing various habitat components will maximize habitat values for nongame birds. I encourage forest managers to consider the following guidelines when planning and evaluating forest management activities:

1. Breeding birds in ponderosa pine and pine-oak forests respond to habitat diversity at multiple scales. Consequently, diversity is important both within and among stands. Desirable landscape-scale habitat characteristics include:
  - a. Stands containing the full range of VSS classes, including uneven-aged patches with a mix of different size classes along with a mature tree component.
  - b. Stands representing a range of canopy conditions, from open and savannah-like to dense and closed.
  - c. Retaining old-growth forest attributes, including abundant large old trees and large snags.
  - d. Critical patch sizes are unknown; however, larger ( $\geq 5$  ac [12.4 ha]), relatively homogeneous patches may be important to species associated with both very open habitats and mature/closed-canopy forest conditions.
2. Large, old ponderosa pines (VSS class 6) appear particularly important to breeding birds. Smaller "mature" trees (VSS class 5) do not offer the same habitat values.
  - a. A desirable condition would be to have VSS class 6 trees comprising  $>40\%$  of total basal area at a density of  $>8$  trees/ac (19.8 trees/ha).
  - b. Retention and recruitment of large trees should be a priority in stands dominated by younger age-classes.
  - c. VSS classes 5 and 6 should be treated separately when evaluating existing stand conditions and defining management targets for breeding bird habitat.
3. Gambel oaks are a key habitat component in the pine-oak type. Management of this hardwood component should emphasize production and retention of oaks in all size classes. Oaks are particularly valuable as alternate cavity-nesting sites where pine snags are limiting.

4. Snags are a critical habitat component and may be limiting in many areas. Cavity-nesting species will benefit from:
- Snag densities of  $\geq 4$  snags/ac (9.9 snags/ha).
  - Having a large proportion ( $>50\%$ ) of standing pine snags  $>18$  in (45.7 cm) dbh and  $>32.8$  ft (10 m) tall. Producing and retaining snags with these characteristics will require recruiting sufficient numbers of large trees and reducing losses from poaching, windthrow, etc.
  - Retaining spike-topped and lightning-scarred trees that provide alternate nesting substrates.
5. A number of birds responded positively to the presence of a well-developed shrub component. Prescribed fire and other management practices that increase shrub cover will benefit these species.
6. Whole-stand VSS classifications convey limited information about breeding bird habitat. However, bird abundance and species richness were associated with the density and species; however, specific habitat values of oaks and patterns of avian exploitation are poorly understood.
3. Functions and values of large ponderosa pines. Large (VSS class 6) trees are an important habitat component for breeding birds. However, specific habitat values of large pines and patterns of avian exploitation are poorly understood. In addition, it is unclear whether the habitat value of large trees is related to size, age, or other characteristics.

proportional basal area of trees representing individual VSS classes. The latter measures should be used when assessing the costs/benefits of management activities to breeding birds.

#### Research Needs

This project raised additional questions with respect to the ecology and management of bird communities in ponderosa pine and pine-oak forests. The following topics are recommended for future research:

- Effects of patch size, configuration, and arrangement on breeding bird species and communities. Landscape-scale habitat characteristics will become increasingly important in southwestern forests managed under the northern goshawk guidelines (Reynolds et al. 1992) or other strategies that promote creation of small forest patches and distinct landscape mosaics.
- Functions and values of Gambel oak. The presence of Gambel oak changes the breeding bird community. Physical characteristics of oak trees also appear important to some bird
- Effects of new management prescriptions. Management practices designed to restore pre-settlement conditions or benefit northern goshawks and Mexican spotted owls will bring about significant habitat changes in southwestern ponderosa pine forests. Long-term studies are needed to evaluate the effects of these changes on breeding bird distribution, abundance, diversity, and productivity.

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Appendix 1. Locations, characteristics, and management histories of 23 northern Arizona ponderosa pine ( $n = 11$ ) and ponderosa pine-Gambel oak ( $n = 12$ ) study stands, 1993-95.

Note: Locations are Universal Transverse Mercator (UTM) coordinates of sampling grid centers. Vegetative Structural Stage (VSS) classifications represent dominant size class of ponderosa pine trees. Size classes were: VSS 3 = 5-11.9 in (12.7-30.2 cm) dbh, VSS 4 = 12-17.9 in (30.5-45.5 cm) dbh, VSS 5 = 18-23.9 in (45.7-60.7 cm) dbh, and VSS 6 =  $\geq 24$  in (61.0 cm) dbh. Management histories were compiled from stand databases, timber sale records, maps, and other data maintained by the respective management agencies. Available information varied considerably with respect to the time period covered and level of detail. Dates of commercial logging activities reflect time of sale, however, actual treatment usually occurred 1-5 years later. In many cases, precise locations of particular activities/events were not recorded, and may have only affected a portion of the study plot. Most of the recorded wildfires were small, and affected only small areas within the study plots. For ease of interpretation, records are organized by management agency and administrative unit.

### COCONINO NATIONAL FOREST, LONG VALLEY RANGER DISTRICT

#### **Stand CL1:**

*UTM* - 3824212 N, 469997 E  
*Cover Type* - Ponderosa pine  
*VSS Class* - 3  
*Silviculture* - Located within designated research area (Long Valley Experimental Forest), no records of commercial logging. Several mature ponderosa pines selectively removed for research purposes in 1993.  
*Fire* - Rotational fall burning treatments applied annually, beginning in 1976. Two recorded wildfires, a 50-ac burn in July 1991, and a small lightning strike in October 1994.

#### **Stand CL2:**

*UTM* - 3826229 N, 470491 E  
*Cover Type* - Ponderosa pine  
*VSS Class* - 6  
*Silviculture* - Located in virgin stand, with no records of commercial logging. Some evidence of minor (illegal) cutting.  
*Fire* - One wildfire in July 1984. No records of prescribed burning.

### COCONINO NATIONAL FOREST, MORMON LAKE RANGER DISTRICT

#### **Stand CM1:**

*UTM* - 3861255 N, 448062 E  
*Cover Type* - Ponderosa pine-Gambel oak  
*VSS Class* - 3  
*Silviculture* - Selection cut 1954, intermediate shelterwood cut in 1987.  
*Fire* - Two recorded wildfires, September 1985 and August 1986. No records of prescribed burning.

#### **Stand CM2:**

*UTM* - 3855421 N, 457812 E  
*Cover Type* - Ponderosa pine-Gambel oak  
*VSS Class* - 4  
*Silviculture* - Multiproduct sale in 1992.  
*Fire* - One wildfire in August 1989. No records of prescribed burning.

## Appendix 1. (continued)

**Stand CM3:**

*UTM* - 3879110 N, 441027 E  
*Cover Type* - Ponderosa pine-Gambel oak  
*VSS Class* - 3  
*Silviculture* - Pulpwood sale in 1976, overstory removal in 1987, commercial thinning in 1988.  
*Fire* - No records of wildfires. Slash piled and burned in fall 1992, 1993.

**Stand CM4:**

*UTM* - 3862607 N, 444690 E  
*Cover Type* - Ponderosa pine-Gambel oak  
*VSS Class* - 3  
*Silviculture* - Selection and salvage cut in 1947, untreated control area for Beaver Creek Watershed Project (1960s through 1982).  
*Fire* - One wildfire in July 1988.

**Stand CM5:**

*UTM* - 3862691 N, 446376 E  
*Cover Type* - Ponderosa pine-Gambel oak  
*VSS Class* - 3  
*Silviculture* - Selection cut in 1953, sawtimber sale in 1979.  
*Fire* - Two small wildfires, June 1984 and September 1991. Slash piled and burned in 1984.

**Stand CM6:**

*UTM* - 3855050 N, 448921 E  
*Cover Type* - Ponderosa pine-Gambel oak  
*VSS Class* - 4  
*Silviculture* - Sawtimber and pulpwood sales in 1978.  
*Fire* - Two small wildfires, August 1986 and October 1991. Slash piled and burned in 1985.

**Stand CM7:**

*UTM* - 3856893 N, 450059 E  
*Cover Type* - Ponderosa pine-Gambel oak  
*VSS Class* - 3  
*Silviculture* - Sawtimber and pulpwood sales in 1978 and 1988.  
*Fire* - No records of wildfires. Slash piled and burned in 1987.

**Stand CM8:**

*UTM* - 3854743 N, 453291 E  
*Cover Type* - Ponderosa pine-Gambel oak  
*VSS Class* - 4  
*Silviculture* - Sawtimber sale in 1979, pulpwood sale in 1980.  
*Fire* - No records of wildfires. Slash piled and burned in 1983, some fire spread to adjacent areas.

COCONINO NATIONAL FOREST, PEAKS RANGER DISTRICT**Stand CP1:**

*UTM* - 3913273 N, 445909 E  
*Cover Type* - Ponderosa pine  
*VSS Class* - 3  
*Silviculture* - Sawtimber cut in 1960s, seedcut in 1968, shelterwood removal cut in 1990, precommercial thinnings in 1964, 1971, and 1973.  
*Fire* - No records of wildfires or prescribed burning.

## Appendix 1. (continued)

**Stand CP2:**

*UTM* - 3914185 N, 446720 E  
*Cover Type* - Ponderosa pine  
*VSS Class* - 3  
*Silviculture* - Selection cut in 1960s, reforestation planting in 1986.  
*Fire* - No records of wildfires or prescribed burning.

**Stand CP3:**

*UTM* - 3903262 N, 432060 E  
*Cover Type* - Ponderosa pine  
*VSS Class* - 6  
*Silviculture* - Located within Gus Pearson Natural Area of the Fort Valley Experimental Forest. Some railroad logging in early 1900s, no commercial harvest since. Some evidence of illegal cutting (snag removal).  
*Fire* - No records of prescribed burns. Wildfires in January 1981, August 1983, and June 1985.

**Stand CP4:**

*UTM* - 3923874 N, 433479 E  
*Cover Type* - Ponderosa pine  
*VSS Class* - 3  
*Silviculture* - Sawtimber cut in 1975, precommercial thinning in 1976.  
*Fire* - No records of wildfires or prescribed burning.

**Stand CP5:**

*UTM* - 3918260 N, 436044 E  
*Cover Type* - Ponderosa pine  
*VSS Class* - 4  
*Silviculture* - Sawtimber cut in early 1970s, precommercial thinning in 1975.  
*Fire* - No records of wildfires or prescribed burning.

**Stand CP6:**

*UTM* - 3922328 N, 436951 E  
*Cover Type* - Ponderosa pine  
*VSS Class* - 4  
*Silviculture* - Selection cut in 1960s.  
*Fire* - No records of prescribed burning. One wildfire in August 1986.

KAIBAB NATIONAL FOREST, NORTH KAIBAB RANGER DISTRICT**Stand NK1:**

*UTM* - 4069675 N, 391745 E  
*Cover Type* - Ponderosa pine  
*VSS Class* - 5  
*Silviculture* - Sawtimber cuts in 1947 and 1948.  
*Fire* - No records of wildfires or prescribed burns.

**Stand NK2:**

*UTM* - 4067775 N, 387625 E  
*Cover Type* - Ponderosa pine  
*VSS Class* - 5  
*Silviculture* - Sawtimber cut in 1947.  
*Fire* - No records of wildfires or prescribed burns.

Appendix 1. (continued)

**Stand NK3:**

*UTM* - 4064360 N, 394450 E  
*Cover Type* - Ponderosa pine  
*VSS Class* - 5  
*Silviculture* - Sawtimber cuts in 1946 and 1983, precommercial thinning in 1975.  
*Fire* - No records of prescribed burning. One wildfire in October 1976.

**Stand NK4:**

*UTM* - 4045500 N, 377600 E  
*Cover Type* - Ponderosa pine-Gambel oak  
*VSS Class* - 6  
*Silviculture* - Sawtimber sales in 1968 and 1984, thinning in 1972.  
*Fire* - No records of wildfires. Slash piled and burned in 1984.

ARMY NATIONAL GUARD, CAMP NAVAJO

**Stand CN1:**

*UTM* - 3893428 N, 417178 E  
*Cover Type* - Ponderosa pine-Gambel oak  
*VSS Class* - 3  
*Silviculture* - Railroad logged in 1926, thinned in 1933.  
*Fire* - No records of wildfires or prescribed burns.

**Stand CN2:**

*UTM* - 3895705 N, 417417 E  
*Cover Type* - Ponderosa pine-Gambel oak  
*VSS Class* - 3  
*Silviculture* - Railroad logged in 1926, thinned in 1933.  
*Fire* - No records of wildfires or prescribed burns.

NATIONAL PARK SERVICE, GRAND CANYON NATIONAL PARK

**Stand GC1:**

*UTM* - 4021375 N, 376680 E  
*Cover Type* - Ponderosa pine-Gambel oak  
*VSS Class* - 6  
*Silviculture* - None.  
*Fire* - No prescribed burning. Wildfires in 1983, 1985, and 1987.

Appendix 2. Classification system (Thomas 1979) used to describe condition of individual snags at 23 northern Arizona ponderosa pine ( $n = 11$ ) and ponderosa pine-Gambel oak ( $n = 12$ ) study stands, 1993-95.

- Class 1: Recently dead tree, limbs and branches present, top usually pointed, tight bark, sapwood intact.
- Class 2: Large limbs and stubs present, upper 10% of bole may be broken off, bark starting to slough, base solid.
- Class 3: Without limbs, stubs present, up to 50% of top broken off, bark generally sloughed, base beginning to decay.
- Class 4: Without limbs, few stubs, little/no bark left, sapwood decayed, generally 50-80% of top broken.
- Class 5: Without limbs, few/no stubs, sapwood decay, advanced base decay, <20% of tree remains standing.

Appendix 3. Avian species observed at 23 northern Arizona forest study stands, 1993-95. Species marked with an asterisk were included in analyses of avian community variables and habitat relationships. Species group assignments are: NT = neotropical migrant, RS = resident/short-distance migrant, CV = cavity nester. Other species were considered incidental (IN) or not sampled effectively by variable circular-plot censuses (NO).

Common name	Acronym	Species	Group
turkey vulture		<i>Cathartes aura</i>	NO
sharp-shinned hawk		<i>Accipiter striatus</i>	NO
Cooper's hawk		<i>Accipiter cooperi</i>	NO
northern goshawk		<i>Accipiter gentilis</i>	NO
red-tailed hawk		<i>Buteo jamaicensis</i>	NO
American kestrel		<i>Falco sparverius</i>	NO
blue grouse		<i>Dendragapus obscurus</i>	IN
Merriam's turkey		<i>Meleagris gallopavo</i>	NO
band-tailed pigeon*	BTPI	<i>Columba fasciata</i>	NT
mourning dove*	MODO	<i>Zenaida macroura</i>	RS
great horned owl		<i>Bubo virginianus</i>	NO
Mexican spotted owl		<i>Strix occidentalis</i>	NO
common nighthawk		<i>Chordeiles minor</i>	NO
black-chinned hummingbird		<i>Archilochus alexandri</i>	IN
broad-tailed hummingbird*	BTHU	<i>Selasphorus platycercus</i>	NT
northern flicker*	NOFL	<i>Colaptes auratus</i>	RS, CV
acorn woodpecker*	ACWO	<i>Melanerpes formicivorus</i>	RS, CV
Williamson's sapsucker*	WISA	<i>Sphyrapicus thyroideus</i>	RS, CV
downy woodpecker*	DOWO	<i>Picoides pubescens</i>	RS, CV
hairy woodpecker*	HAWO	<i>Picoides villosus</i>	RS, CV
three-toed woodpecker*	TTWO	<i>Picoides tridactylus</i>	RS, CV
Cassin's kingbird		<i>Tyrannus vociferans</i>	IN
olive-sided flycatcher*	OSFL	<i>Contopus borealis</i>	NT
western wood-pewee*	WWPE	<i>Contopus sordidulus</i>	NT
dusky flycatcher*	DUFL	<i>Empidonax oberholseri</i>	NT
Cordilleran flycatcher*	COFL	<i>Empidonax occidentalis</i>	NT, CV
violet-green swallow*	VGSW	<i>Tachycineta thalassina</i>	NT, CV
pinyon jay		<i>Gymnorhinus cyanocephalus</i>	IN
Stellar's jay*	STJA	<i>Cyanocitta stelleri</i>	RS
Clark's nutcracker*	CLNU	<i>Nucifraga columbiana</i>	RS
American crow		<i>Corvus brachyrhynchos</i>	IN
common raven		<i>Corvus corax</i>	NO
mountain chickadee*	MOCH	<i>Parus gambeli</i>	RS, CV
bushtit		<i>Psaltriparus minimus</i>	IN
brown creeper*	BRCR	<i>Certhia americana</i>	RS
white-breasted nuthatch*	WBNU	<i>Sitta carolinensis</i>	RS, CV
red-breasted nuthatch*	RBNU	<i>Sitta canadensis</i>	RS, CV
pygmy nuthatch*	PYNU	<i>Sitta pygmaea</i>	RS, CV
house wren*	HOWR	<i>Troglodytes aedon</i>	NT, CV

## Appendix 3. (continued)

Common name	Acronym	Species	Group
rock wren*	ROWR	<i>Salpinctes obsoletus</i>	RS
ruby-crowned kinglet*	RCKI	<i>Regulus calendula</i>	RS
western bluebird*	WEBL	<i>Sialia mexicana</i>	RS, CV
Townsend's solitaire*	TOSO	<i>Myadestes townsendi</i>	RS
hermit thrush*	HETH	<i>Catharus guttatus</i>	RS
American robin*	AMRO	<i>Turdus migratorius</i>	RS
solitary vireo*	SOVI	<i>Vireo solitarius</i>	NT
warbling vireo*	WAVI	<i>Vireo gilvus</i>	NT
Virginia's warbler*	VIWA	<i>Vermivora virginiae</i>	NT
yellow-rumped warbler*	YRWA	<i>Dendroica coronata</i>	RS
Grace's warbler*	GRWA	<i>Dendroica graciae</i>	NT
red-faced warbler*	RFWA	<i>Cardellina rubrifrons</i>	NT
olive warbler*	OLWA	<i>Peucedramus taeniatus</i>	NT
black-headed grosbeak*	BHGR	<i>Pheucticus melanocephalus</i>	NT
spotted (rufous-sided) towhee*	RSTO	<i>Pipilo maculatus</i>	RS
chipping sparrow*	CHSP	<i>Spizella passerina</i>	NT
dark-eyed junco*	DEJU	<i>Junco hyemalis</i>	RS
western meadowlark		<i>Sturnella neglecta</i>	IN
Brewer's blackbird		<i>Euphagus cyanocephalus</i>	IN
brown-headed cowbird*	BHCO	<i>Molothrus ater</i>	RS
western tanager*	WETA	<i>Piranga ludoviciana</i>	NT
hepatic tanager*	HETA	<i>Piranga flava</i>	NT
pine siskin*	PISI	<i>Carduelis pinus</i>	RS
lesser goldfinch*	LEGO	<i>Carduelis psaltria</i>	RS
red crossbill*	RECR	<i>Loxia curvirostra</i>	RS
Cassin's finch*	CAFI	<i>Carpodacus cassinii</i>	RS

Appendix 4. Avian species found at 23 northern Arizona ponderosa pine ( $n = 11$ ) and ponderosa pine-Gambel oak ( $n = 12$ ) study stands, 1993-95. Species considered incidental or not sampled effectively by variable circular-plot surveys are excluded. See Appendix 3 for full species names.

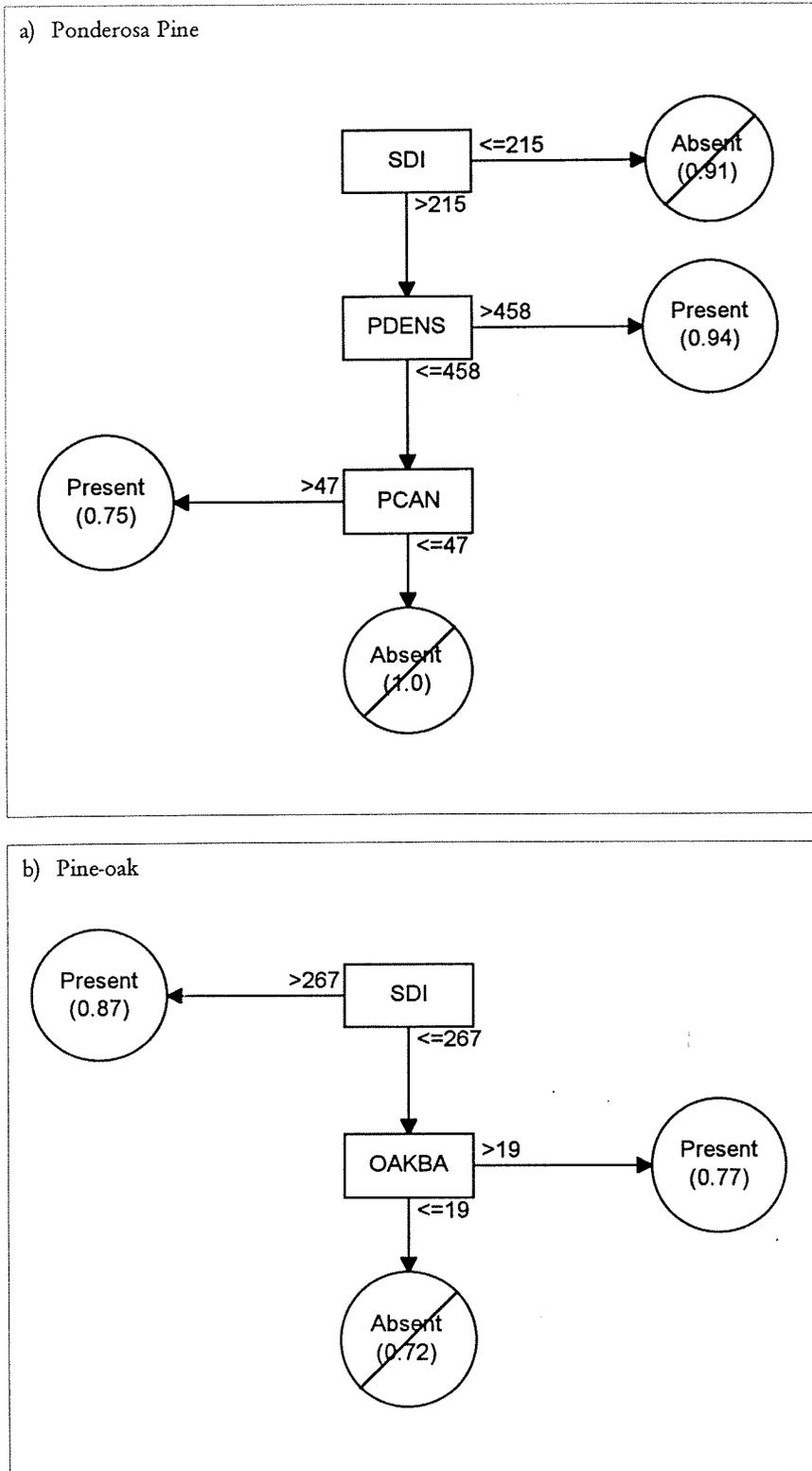
Species	Stand																							
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ACWO	√	√	√			√	√	√	√	√							√					√	√	
AMRO	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√			√	√	√	√	√
BHCO	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√			√		√	√	√	√
BHGR	√		√	√		√	√	√	√								√	√	√			√	√	√
BRCR	√	√	√	√	√	√	√	√	√				√	√	√		√	√	√	√			√	√
BTHU	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
BTPI						√			√				√			√								
CAFI		√											√				√			√	√			
CHSP					√		√	√		√	√	√					√	√	√	√	√	√	√	√
CLNU											√				√	√	√							
COFL	√	√	√	√	√	√	√	√	√	√			√		√				√		√	√	√	√
DEJU	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
DOWO			√	√	√				√															
DUFL																							√	
GRWA	√	√	√	√	√		√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
HAWO	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
HETA																	√							
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HOWR							√	√	√	√							√					√	√	
LEGO																		√						
MOCH	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
MODO	√		√	√	√	√	√	√	√	√	√	√					√		√	√		√	√	√
NOFL	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
OLWA		√		√	√			√	√	√	√													
OSFL	√	√							√				√											
PISI	√	√	√	√	√	√	√	√	√	√	√	√	√			√	√		√	√				√
PYNU	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
RBNU													√											
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RECR	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
RFWA		√	√	√		√	√	√	√															
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Appendix 4. (continued)

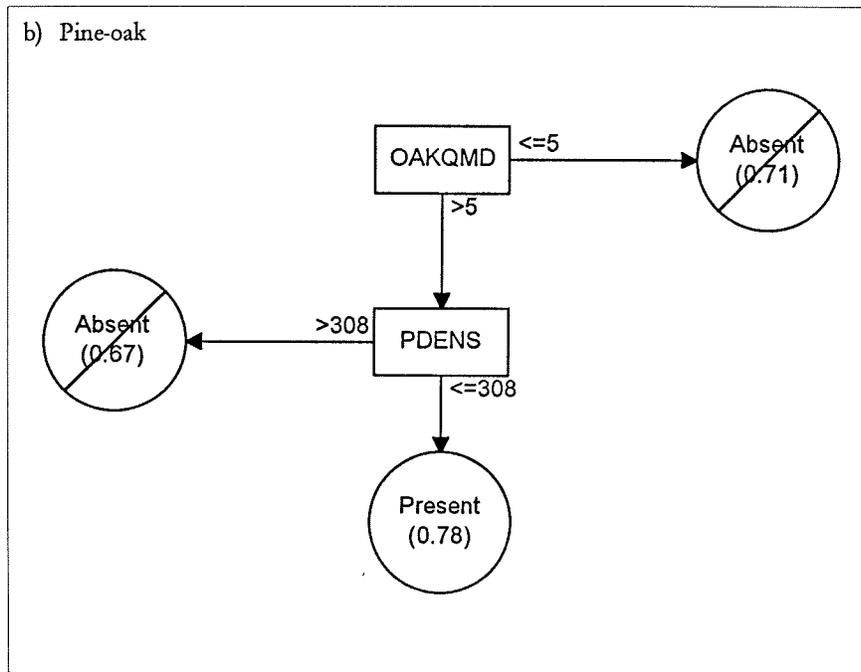
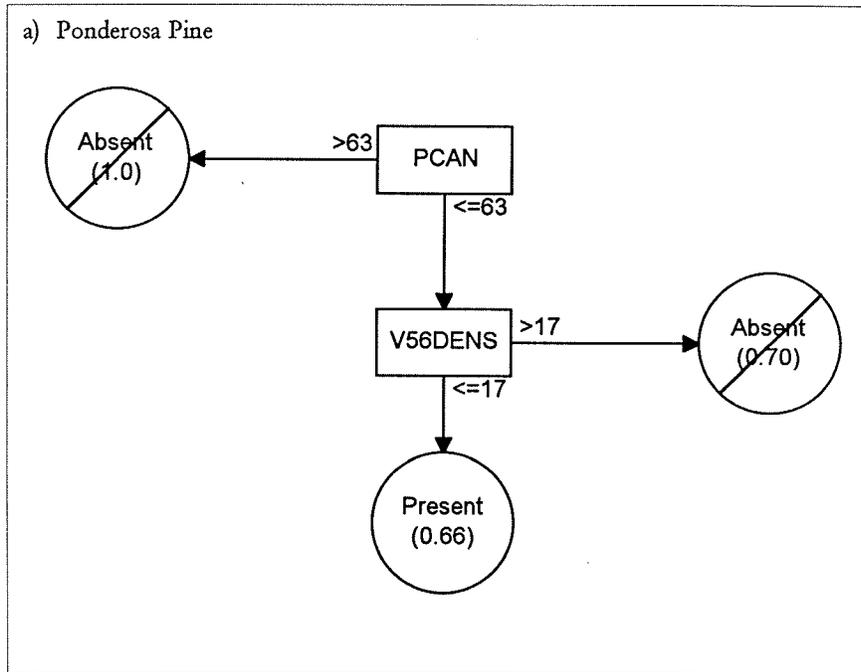
Species	Stand																							
	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C	G	N	N	N	N	C	C	
	L	L	M	M	M	M	M	M	M	M	P	P	P	P	P	P	C	K	K	K	K	N	N	
	1	2	1	2	3	4	5	6	7	8	1	2	3	4	5	6	1	1	2	3	4	1	2	
WAVI							√										√					√		
WBNU	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
WEBL	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
WETA	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
WISA	√	√		√															√	√	√	√		
WWPE		√	√		√		√	√	√	√	√	√	√	√		√	√	√	√	√	√	√	√	√
YRWA	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√

Appendix 5. Abundance (birds/ac) and species richness of all birds, neotropical migrants, resident/short-distance migrants, and cavity-nesters at 23 northern Arizona ponderosa pine ( $n = 11$ ) and ponderosa pine-Gambel oak ( $n = 12$ ) study stands, 1993-95. Values are means  $\pm$  standard error.

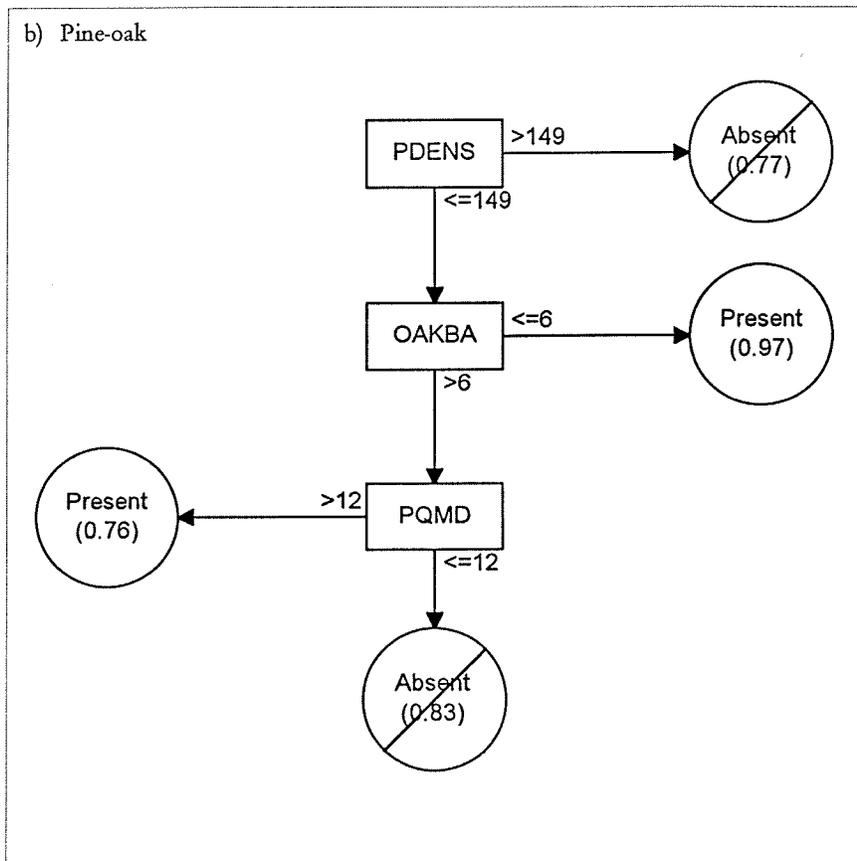
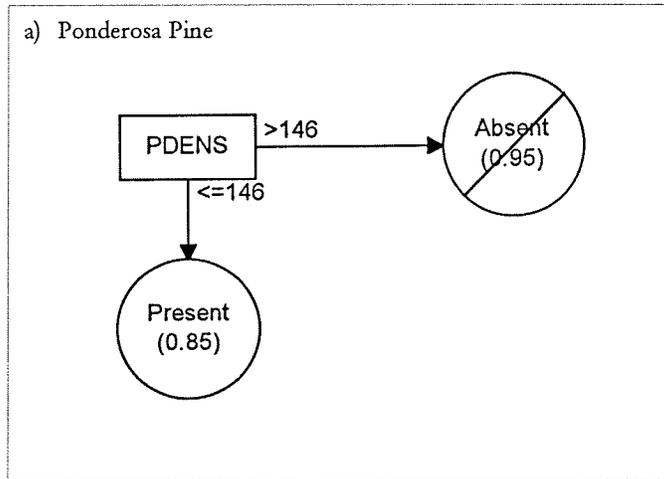
Stand	All birds		Neotropical migrants		Resident/short-distance		Cavity-nesters	
	Abund.	Spp. rich.	Abund.	Spp. rich.	Abund.	Spp. rich.	Abund.	Spp. rich.
CL1	2.8 $\pm$ 0.6	19.7 $\pm$ 1.8	0.6 $\pm$ 0.1	5.3 $\pm$ 0.7	2.2 $\pm$ 0.5	14.3 $\pm$ 1.3	1.8 $\pm$ 0.3	8.0 $\pm$ 0.6
CL2	3.4 $\pm$ 0.1	22.3 $\pm$ 0.7	1.2 $\pm$ 0.3	7.3 $\pm$ 0.9	2.3 $\pm$ 0.3	15.0 $\pm$ 1.0	2.0 $\pm$ 0.1	9.3 $\pm$ 0.3
CM1	4.0 $\pm$ 0.6	24.3 $\pm$ 1.9	1.3 $\pm$ 0.1	8.3 $\pm$ 0.7	2.8 $\pm$ 0.5	16.0 $\pm$ 1.5	1.8 $\pm$ 0.2	8.7 $\pm$ 0.7
CM2	3.2 $\pm$ 0.1	23.7 $\pm$ 1.2	0.7 $\pm$ 0.1	7.7 $\pm$ 0.7	2.5 $\pm$ 0.1	16.0 $\pm$ 0.6	1.4 $\pm$ 0.2	8.7 $\pm$ 0.3
CM3	2.5 $\pm$ 0.3	21.7 $\pm$ 0.9	0.6 $\pm$ 0.1	7.0 $\pm$ 0.0	1.9 $\pm$ 0.2	14.7 $\pm$ 0.9	1.1 $\pm$ 0.1	8.0 $\pm$ 0.6
CM4	2.2 $\pm$ 0.1	20.0 $\pm$ 1.0	0.4 $\pm$ 0.1	6.3 $\pm$ 0.3	1.9 $\pm$ 0.1	13.7 $\pm$ 1.3	1.3 $\pm$ 0.1	8.0 $\pm$ 0.0
CM5	3.2 $\pm$ 0.3	24.0 $\pm$ 0.6	1.1 $\pm$ 0.2	10.0 $\pm$ 0.6	2.1 $\pm$ 0.5	14.0 $\pm$ 0.6	1.3 $\pm$ 0.2	9.0 $\pm$ 0.0
CM6	3.1 $\pm$ 0.4	22.3 $\pm$ 0.9	0.9 $\pm$ 0.1	9.3 $\pm$ 0.9	2.2 $\pm$ 0.3	13.0 $\pm$ 0.6	1.6 $\pm$ 0.2	8.3 $\pm$ 0.7
CM7	3.5 $\pm$ 0.2	26.3 $\pm$ 1.5	1.2 $\pm$ 0.1	11.0 $\pm$ 1.2	2.3 $\pm$ 0.2	15.3 $\pm$ 2.3	1.2 $\pm$ 0.2	9.3 $\pm$ 0.7
CM8	2.9 $\pm$ 0.3	21.0 $\pm$ 1.0	1.0 $\pm$ 0.1	8.7 $\pm$ 0.7	1.9 $\pm$ 0.2	12.3 $\pm$ 0.3	1.3 $\pm$ 0.2	8.3 $\pm$ 1.3
CP1	2.3 $\pm$ 0.2	19.7 $\pm$ 0.9	0.6 $\pm$ 0.1	7.0 $\pm$ 0.6	1.8 $\pm$ 0.2	12.7 $\pm$ 0.3	0.9 $\pm$ 0.1	6.3 $\pm$ 0.3
CP2	2.1 $\pm$ 0.4	17.0 $\pm$ 3.1	0.5 $\pm$ 0.1	5.7 $\pm$ 0.9	1.6 $\pm$ 0.3	11.3 $\pm$ 2.2	0.9 $\pm$ 0.2	5.7 $\pm$ 1.5
CP3	3.6 $\pm$ 0.1	22.7 $\pm$ 0.7	1.3 $\pm$ 0.1	7.0 $\pm$ 1.0	2.4 $\pm$ 0.2	15.7 $\pm$ 0.9	2.2 $\pm$ 0.1	8.0 $\pm$ 0.0
CP4	2.4 $\pm$ 0.1	18.5 $\pm$ 0.5	0.5 $\pm$ 0.1	4.5 $\pm$ 0.5	1.8 $\pm$ 0.1	14.0 $\pm$ 1.0	0.9 $\pm$ 0.1	5.0 $\pm$ 0.0
CP5	2.0 $\pm$ 0.1	17.5 $\pm$ 0.5	0.6 $\pm$ 0.1	5.5 $\pm$ 0.5	1.4 $\pm$ 0.1	12.0 $\pm$ 1.0	0.8 $\pm$ 0.1	5.5 $\pm$ 0.5
CP6	3.1 $\pm$ 0.6	19.5 $\pm$ 2.5	1.0 $\pm$ 0.1	7.5 $\pm$ 0.5	2.1 $\pm$ 0.7	12.0 $\pm$ 3.0	0.8 $\pm$ 0.1	5.0 $\pm$ 1.0
GC1	3.4 $\pm$ 0.3	23.3 $\pm$ 1.2	0.8 $\pm$ 0.1	8.7 $\pm$ 0.9	2.6 $\pm$ 0.4	14.7 $\pm$ 1.4	1.7 $\pm$ 0.4	8.0 $\pm$ 0.6
NK1	2.8 $\pm$ 0.8	18.3 $\pm$ 1.5	0.5 $\pm$ 0.1	5.6 $\pm$ 1.2	2.4 $\pm$ 0.7	12.7 $\pm$ 0.3	1.1 $\pm$ 0.1	7.0 $\pm$ 1.2
NK2	2.6 $\pm$ 0.2	18.3 $\pm$ 1.5	0.4 $\pm$ 0.1	4.6 $\pm$ 0.9	2.2 $\pm$ 0.2	13.7 $\pm$ 0.7	1.2 $\pm$ 0.2	6.3 $\pm$ 0.3
NK3	2.6 $\pm$ 0.2	20.0 $\pm$ 0.6	0.6 $\pm$ 0.1	6.0 $\pm$ 0.6	2.0 $\pm$ 0.1	14.0 $\pm$ 1.0	1.0 $\pm$ 0.1	7.0 $\pm$ 0.0
NK4	3.2 $\pm$ 0.4	25.0 $\pm$ 1.0	1.0 $\pm$ 0.1	10.0 $\pm$ 0.6	2.2 $\pm$ 0.4	15.0 $\pm$ 0.6	1.1 $\pm$ 0.1	9.7 $\pm$ 0.7
CN1	2.9 $\pm$ 0.2	24.7 $\pm$ 1.3	0.7 $\pm$ 0.1	9.0 $\pm$ 0.6	2.1 $\pm$ 0.2	14.7 $\pm$ 0.9	1.5 $\pm$ 0.1	8.7 $\pm$ 0.9
CN2	2.2 $\pm$ 0.2	21.7 $\pm$ 0.9	0.5 $\pm$ 0.1	7.7 $\pm$ 1.3	1.7 $\pm$ 0.2	14.0 $\pm$ 0.6	1.0 $\pm$ 0.1	7.0 $\pm$ 0.6



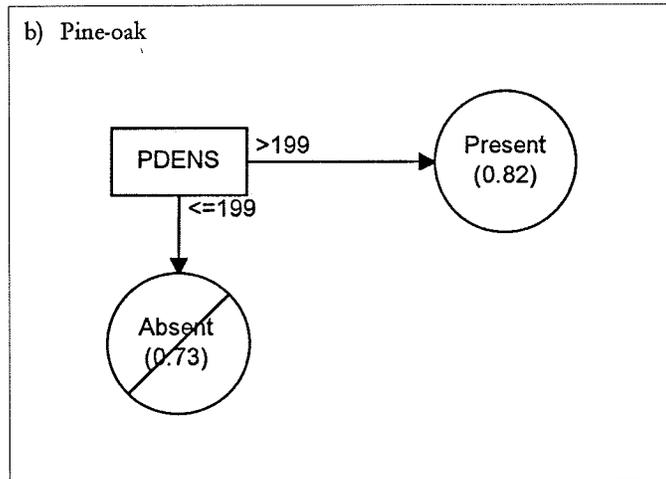
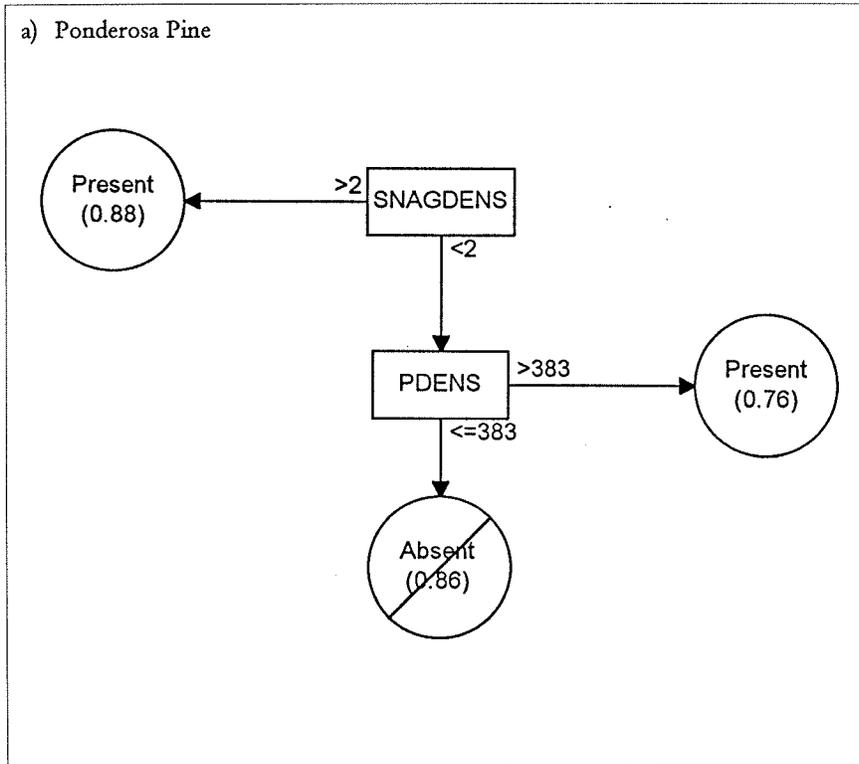
Appendix 6. Classification tree models of habitat selection by brown creepers in northern Arizona (a) ponderosa pine ( $n = 11$ ) and (b) ponderosa pine-Gambel oak ( $n = 12$ ) stands, 1993-95. Overall classification accuracies were 85% and 70%, respectively, as determined by jackknife cross-validation. Habitat variables (in boxes) are: SDI = stand density index, PDENS = pine density (trees/ac), PCAN = pine canopy cover (%), and OAKBA = oak basal area (ft<sup>2</sup>/ac). Circles represent model predictions. Values in parentheses represent proportion of observations correctly assigned to each outcome.



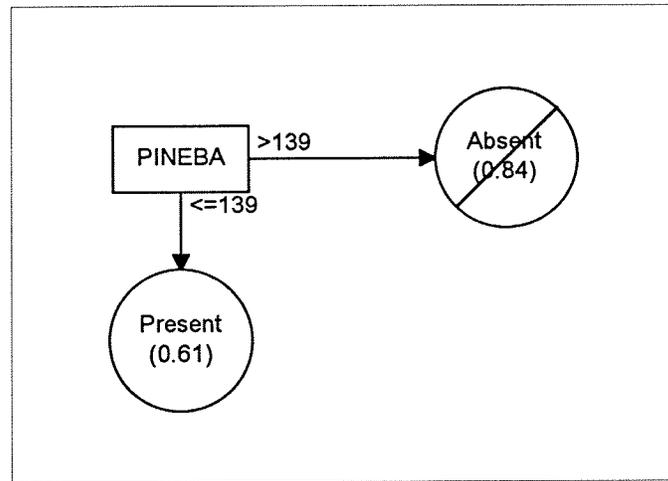
Appendix 7. Classification tree models of habitat selection by brown-headed cowbirds in northern Arizona (a) ponderosa pine ( $n = 11$ ) and (b) ponderosa pine-Gambel oak ( $n = 12$ ) stands, 1993-95. Overall classification accuracies were 61% and 63%, respectively, as determined by jackknife cross-validation. Habitat variables (in boxes) are: PCAN = pine canopy cover (%), V56DENS = density VSS 5-6 pines (trees/ac), OAKQMD = oak quadratic mean diameter (in), and PDENS = pine density (trees/ac). Circles represent model predictions. Values in parentheses represent proportion of observations correctly assigned to each outcome.



Appendix 8. Classification tree models of habitat selection by chipping sparrows in northern Arizona (a) ponderosa pine ( $n = 11$ ) and (b) ponderosa pine-Gambel oak ( $n = 12$ ) study stands, 1993-95. Overall classification accuracies were 86% and 71%, respectively, as determined by jackknife cross-validation. Habitat variables (in boxes) are PDENS = pine density (trees/ac), OAKBA = oak basal area (ft<sup>2</sup>/ac), and PQMD = pine quadratic mean diameter (in). Circles represent model predictions. Values in parentheses represent proportion of observations correctly assigned to each outcome.



Appendix 9. Classification tree models of habitat selection by Cordilleran flycatchers in northern Arizona (a) ponderosa pine ( $n = 11$ ) and (b) ponderosa pine-Gambel oak ( $n = 12$ ) study stands, 1993-95. Overall classification accuracies were 80% and 75%, respectively, as determined by jackknife cross-validation. Habitat variables (in boxes) are SNAGDENS = snag density (snags/ac), and PDENS = pine density (trees/ac). Circles represent model predictions. Values in parentheses represent proportion of observations correctly assigned to each outcome.



Appendix 10. Classification tree model of habitat selection by western bluebirds in northern Arizona ponderosa pine ( $n = 11$ ) and ponderosa pine-Gambel oak ( $n = 12$ ) study stands, 1993-95. Overall classification accuracy was 76%, as determined by jackknife cross-validation. Habitat variable (in box) is PINEBA = pine basal area ( $\text{ft}^2/\text{ac}$ ). Circles represent model predictions. Values in parentheses represent proportion of observations correctly assigned to each outcome.

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