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LANDSCAPE-SCALE IDENTIFICATION OF MERRIAM'S WILD TURKEY ROOSTING HABITAT IN A MANAGED PONDEROSA PINE FOREST

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Abstract: The Merriam's wild turkey (*Meleagris gallopavo merriami*) most commonly occurs in the ponderosa pine (*Pinus ponderosa*) forests of the southwestern United States. Current management of ponderosa pine forests in portions of the Merriam's wild turkey range is focusing on restoring pre-settlement conditions through thinning of smaller trees and low-intensity, prescribed burning to reduce forest litter. These practices reduce basal area and canopy cover, 2 important components of Merriam's wild turkey roost-site selection. We used satellite technology to study wild turkey roost selection in a northern Arizona ponderosa pine forest planned for thinning. We derived a series of landscape-scale habitat variables using remotely sensed imagery to characterize habitat in our study area. We used logistic regression in an information-theoretic framework to evaluate roosting habitat selection by wild turkeys and identify potential roosting habitat to inform forest management. Wild turkeys most strongly selected rugged terrain at high elevations. Because of existing management constraints in these areas and the apparent widespread and abundant availability of roosts across our study area, we expect that the effect of planned treatments should be minimal.

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The Merriam's wild turkey (*Meleagris gallopavo merriami*) is found primarily in the ponderosa pine (*Pinus ponderosa*) forests of the western United States. Historically, these forests were characterized by stands of uneven aged, widely spaced, large-diameter trees (Covington and Moore 1994, Covington et al. 1997). Long-term artificial suppression of wildfire has altered historical structure, with many forests currently overstocked with dense thickets of smaller trees and high accumulations of forest litter (Moore et al. 2004). Increasingly, management of ponderosa pine

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forests in many portions of the Southwest is focusing on restoring historical conditions and reducing risk of catastrophic wildfire through thinning and low-intensity burning.

Roost sites are an important component of Merriam's wild turkey habitat, and availability and quality of roosts can affect habitat suitability (Boeker and Scott 1969, Scott and Boeker 1975). Thinning of ponderosa pine forests alters structural attributes that influence wild turkey selection of roost sites, including basal area, canopy cover, tree density, and canopy height (Rumble 1992, Wakeling and Rogers 1998). Martin et al. (2005) suggested a moderate forest restoration prescription in one study area did not cause roost-site abandonment by Merriam's wild turkey, although it did reduce some habitat features to, at, or near the minimum values used by the species. Another study suggested that more intensive timber management can cause complete abandonment of roost sites and surrounding habitat by Merriam's wild turkey (Scott and Boeker 1977). Considering the potential for forest thinning to disrupt Merriam's turkey roosts, identification of roosting habitat can help managers adapt forest prescriptions either to exclude roosts from treatment or to ensure that prescriptions maintain stand characteristics above minimums recommended for Merriam's wild turkey.

We used satellite technology to study Merriam's wild turkey selection of roosts in a northern Arizona ponderosa pine forest planned for thinning. We developed a suite of remotely sensed habitat variables to characterize topography and forest structure of our study area. We correlated roost selection with habitat variables to develop a predictive model of roosting habitat. We applied this model spatially across our study area to identify roosting habitat and inform mitigation of effects of timber management on wild turkey roost availability.

STUDY AREA

Our study area was located approximately 16 km west of Flagstaff, Arizona, on Camp Navajo, a 11,430-ha federal facility operated by the Arizona Army National Guard, as well as the surrounding Coconino National Forest. The dominant tree species was ponderosa pine, with localized stands of Gambel oak (*Quercus gambelli*), alligator juniper (*Juniperus deppeana*), and Utah juniper (*Juniperus osteosperma*). Common understory plants included Gambel oak seedlings and New Mexican locust (*Robinia neomexicana*). The topography was variable, consisting of mountains, ridges, and canyons interspersed with open meadows. Elevation in the study area reflected the topographical variability, with a maximum elevation of 2,453 m on mountaintops dropping to approximately 1,400 m in canyons. Higher elevations included pockets of Douglas fir (*Pseudotsuga menziesii*), white fir (*Abies concolor*), and quaking aspen (*Populus tremuloides*), and canyons contained patchy stands of Engelmann spruce (*Picea engelmannii*). Warm summers and cold winters characterized the local climate, with most annual precipitation (59.2 cm average) occurring during late summer monsoon storms and winter snows.

Camp Navajo's forest management plan calls for thinning of approximately 1,176 ha of ponderosa pine from forested lands. From 2004 to 2006, Camp Navajo conducted forest treatment activities on a portion (446 ha; 38% of planned) of these areas. Prescriptions of completed treatments have been variable, but most involved removal of smaller diameter (<45.7 cm diameter at breast height [dbh]) trees to reduce wildfire risk in areas surrounding critical infrastructure and equipment. Future treatments call for removal of no more than approximately 3 ponderosa pines/ha, retention of all trees ≥45 cm dbh, and maintenance of an overall basal area of 9.3–14.0 m^2/ha. Broadcast burning will be used in some areas to reduce fuel loads and encourage herbaceous growth.

METHODS

Trapping

We trapped wild turkeys during 3 periods: (1) 3 Jan 2006 through 30 Mar 2006, (2) 3 Jan 2007 through 15 Feb 2007, and (3) 1 Oct 2008 through 31 Oct 2008. Wild turkeys were trapped using rocket nets over baited trap stations (Bailey et al. 1980). All wild turkeys were fitted with a 60-g, solar-powered, global positioning system (GPS) satellite transmitter (GPS/Argos PTT, Microwave Telemetry, Inc., Columbia, Maryland, USA, and North Star Science and Technology LLC, King George, Virginia, USA), attached using a 5-mm, bungee-cord, backpack harness. Transmitters were programmed to upload ≥3 daily latitude–longitude locations of each monitored bird when ample sunlight was available.

We plotted all locations on a Geographic Information System (GIS). We identified roost locations by selecting those that were recorded between 30 min after sunset to 30 min before sunrise. We included only spring, summer, and fall locations in our analyses (15 Mar through 30 Nov) because most individuals are forced off our study area during the winter by heavy snows. We excluded locations for nesting females and females with broods <20 days old to avoid ground roosts (Dickson 1992). To ensure spatial independence between locations, we included a maximum of 1 roost location/individual/24 hr (White and Garrott 1990).

Habitat Measurements

Initially, we considered 9 habitat variables in our analyses that were represented as raster data sets in a GIS (Table 1). Terrain variables potentially associated with roosting habitat were derived from a 30-m digital elevation model (DEM). We generated the variables elevation (ELEV), ASPECT, SLOPE, and ruggedness (RUF) using the Spatial Analyst tool in ArcGIS v. 9.3 (ESRI, Redlands, California, USA). The RUF variable is an index of ruggedness or variability of surrounding terrain (Riley et al. 1999). For this, we used the square root of the elevation standard deviation calculated for each 30-m grid cell from a 3 × 3-pixel window. Using the equation, $1 - \cos\{[\pi/180(\text{aspect} - 30)]/2\}$, aspect was transformed from degrees to an index of solar radiation (TRASP). The index is on a scale of 0 to 1, where values close to 1 represent typically dry, south–southwesterly aspects with higher solar radiation, and values closer to 0 are cooler and relatively moist north–northeast aspects with low radiation (Moisen and

Table 1. Mean, range, and standard deviation of terrain and remote-sensing–derived variables included in logistic regression models of wild turkey use of roost sites in and around Camp Navajo, 2006–2009. Statistics were calculated for the minimum convex polygon that defined the extent of our logistic-regression analyses.

Variable	$\bar{x}$	Range	SD
Transformed aspect (TRASP)	0.51	0–1.00	0.38
Elevation (ELEV, m)	2,145	1,447–2,369	104
Slope (SLO, %)	11	0–187	16
Tree basal area (BA, m^2/ha)	22.55	0–50.74	12.20
Canopy cover (CAN, %)	39.59	0–60.02	14.75
Distance from nearest forest edge (EDGE, m)	485.15	0–3,671.54	435.25
Terrain ruggedness index (RUF)	2.32	0–6.41	2.32
Tree density (TPH, trees/ha)	211	0–1,181	146
Canopy height (HGT, m)	11.76	0–24.48	6.55

Frescino 2002). We extracted forest edges from the National Land Cover Dataset (United States Geological Survey Land Cover Institute, Reston, Virginia, USA; Homer et al. 2004) to create EDGE.

Forest structure also was considered important to wild turkey roosting habitat. Digital data layers (30 m) depicting common forest structural parameters were derived for the entire study area using U.S. Forest Service Forest Inventory and Analysis (FIA) plots (http://www.fia.fs.fed.us/) and 2006 Landsat Thematic Mapper (TM; National Aerospace and Space Administration, Washington, D.C., USA) satellite imagery. We used 721 FIA plots and associated tree measurements as a source of ground-reference data for calculating basal area (BA), stem density (TPH), canopy height (HGT), and canopy cover (CAN) on each individual plot. We estimated CAN as the amount of horizontal overstory tree canopy corrected for crown overlap (Crookston and Stage 1999). To derive digital grids of forest structural variables, spectral bands from leaf-on (August–September) and leaf-off (October) TM images and spectral vegetation indices, such as the Normalized Difference Vegetation Index, were used as a set of predictor variables. Therefore, FIA ground-reference data were used to predict forest structure response variables from sampled to unsampled grid cells at a 30-m spatial resolution.

To develop spatial predictive models, the geographic location reference FIA plots were intersected with predictor variable grid cells to create a matrix of predictor and associated forest structure response variables. Robust Random Forest classification and regression tree models (Brieman 2001) were used to estimate forest structure parameters, which have been used increasingly in ecology to generate spatial data and habitat covariates across extensive study area landscapes (Cutler et al. 2007, Evans and Cushman 2009). A total of 2000 Random Forest regression trees were used to develop a final predictive model. At each model iteration, we used bootstrapped error estimation, which was generated by separating approximately one-third of the reference data set, with replacement, to test model prediction accuracy (Brieman 2001). The average amount of variance explained by the model was reported from these iterations. A second set of comparisons was made using a subset of validation data separated from the original ground-reference data ($n = 271$), without replacement, to determine prediction accuracy. For these comparisons, forest structure models were assessed using Pearson's correlation coefficients. We estimated variance explained by the model, and residual error derived by comparing observed and predicted response variables from the validation data set. The R statistics package v. 2.8 (R Foundation for Statistical Computing 2008) was used to model and derive forest structure layers.

We examined a Pearson's Correlation Matrix to identify collinearity between variables, considering 2 variables with $r \geq 0.7$ correlated. Because SLOPE was correlated with RUF ($r = 0.86$) and because we considered RUF a more informative measure of the overall variability of terrain across the study area and terrain heterogeneity surrounding roost locations, we removed SLOPE from our variable set.

Data Analysis

Our analyses followed Design I described by Thomas and Taylor (2006). Under this design, all roost locations collected from all individuals were pooled, and we measured roost selection of all individuals collectively across habitat variables. We calculated a minimum convex polygon (Mohr 1947) for all roost locations to define the extent of our analyses. Within our polygon we created an equal number of random locations as we had actual roost locations to simulate "unused" locations. We calculated values of each habitat variable at all locations. We used logistic regression (Hosmer and Lemeshow 2000) to measure relationships between habitat variables at roost and random locations. All calculations were performed in SPSS statistical software (SPSS, Chicago, Illinois).

We tested a suite of 14 models developed a priori that included single habitat variables or combinations of variables against a null model that included only an intercept term. A priori models reflected our specific hypotheses regarding factors influencing wild turkey roost selection in our study area. We also tested a global model, which included all habitat variables. We calculated the Akaike's Information Criterion (AIC; Akaike 1973) corrected for small sample size (AICc; Burnham and Anderson 2002) for all models. We considered the model

Table 2. Forest structure model validation statistics generated from bootstrapped error estimates (% variance explained) using 1,000 Random Forest trees (model iterations). Person correlation coefficients and mean and median residual error were estimated from validation data separate from modeling ($n = 271$ FIA plots).[a]

	Validation statistics			
Structural variable	r	Mean residual error	Median residual error	Variance explained by model (%)
BA (m^2/ha)	0.68	6.0	3.7	64.0
TPH (no. trees/ha)	0.82	53	11	51.7
CAN (% cover)	0.82	7	4.4	73.4
HGT (m)	0.83	2.26	1.1	77.8

[a] Abbreviations: BA, basal area; TPH, tree density; CAN, canopy cover; HGT, canopy height.

Table 3. AICc rankings of a null, global, and 14 *a priori* logistic regression models of Merriam's wild turkey roost site selection in and around Camp Navajo, 2006–2009. Our global model was the best model, with no models competing.[a]

Variables	AICc	ΔAICc	No. parameters	Model likelihood	Model weight
All (GLOBAL)	2,352.67	0.00	9	1	1
ELEV, TRASP, RUF	2,500.51	147.84	4	0	0
BA, RUF, TRASP	2,873.56	520.89	4	0	0
BA, RUF, CAN, EDGE	2,877.41	524.74	5	0	0
BA, RUF, CAN	2,882.26	529.59	4	0	0
BA, RUF	2,900.77	548.10	3	0	0
RUF, TRASP	3,314.67	962.00	3	0	0
RUF	3,327.32	974.65	2	0	0
ELEV	3,399.13	1,046.46	2	0	0
TPH, HGT, CAN	3,470.56	1,117.89	4	0	0
EDGE, BA, CAN	3,484.58	1,131.91	4	0	0
BA, CAN	3,489.82	1,137.15	3	0	0
BA, HGT, CAN	3,491.70	1,139.03	4	0	0
BA	3,520.87	1,168.20	2	0	0
BA, HGT	3,522.22	1,169.55	3	0	0
None (NULL)	4,147.02	1,794.35	1	0	0

[a] Abbreviations: AIC_c, Akaike's Information Criterion adjusted for sample size; ELEV, elevations, TRASP, transformed aspect; RUF, terrain ruggedness index; BA, basal area; CAN, canopy cover; EDGE, distance from nearest forest edge; TPH, tree density; HGT, canopy height.

with the lowest AICc value our best model. We considered any models that fell within 3 AICc values of our best model to be competing, and we averaged all parameters from competing models (Burnham and Anderson 2002). We used standardized parameter estimates to compare the relative ability of habitat variables to predict roost site selection by wild turkeys. We calculated odds ratios for all parameter estimates, which can be interpreted as the relative increase in the probability of roost site occurrence with each unit increase of the parameter (Hosmer and Lemeshow 2000). We assessed model goodness-of-fit for our global model using a Hosmer and Lemeshow (2000) test and evaluated the model's classification performance of the response variable (roost presence/absence). We used unstandardized parameter estimates to calculate the probability of roosting habitat occurrence across Camp Navajo (Manly et al. 2002, equation 5.11). These results were reflected in a raster data set with 30 × 30-m cell size to match our input data representing habitat covariates.

RESULTS

Trapping

We trapped 6 wild turkeys (1 male, 5 female) in 2006, 4 males in 2007, and 3 females in 2008 for a total of 13 individuals. We collected 1,495 spring, summer, and fall roost locations ($\bar{x}$ = 115/individual) from March 2006 through May 2009. Mean survival for monitored individuals was 281 days. Our minimum convex polygon covered an area of 465 km^2.

Data Analysis

Variance explained by the Random Forest regression trees model generally was high (>60%) with low residual error (Table 2). An exception was modeled tree densities; which showed the lowest variance explained (51.7%); it typically is difficult to predict for areas of high tree density given some limitations of medium resolution TM satellite data. Nevertheless, model results generally were favorable for characterizing differences in roost site forest structural conditions with relatively low residual error and $r \geq 0.68$ (Table 2).

All a priori models ranked higher than the null model (Table 3). The best model was the global model, which included all habitat variables. No other models were competing (Table 3). Our global model adequately fit our data ($\chi^2 = 20.29$, df = 8, $P = .009$) and classified 85% of roost presence/absence correctly.

Model variables RUF and ELEV were the strongest predictors of wild turkey roost sites, indicating the importance of topographical factors (Table 4). Of the forest structural candidates, BA and CAN showed the strongest, positive relationships with roost sites. Other habitat variables were found to be relatively weak

Table 4. Standardized estimates, standard error, and odds-ratio of parameters included in our highest-ranked logistic regression model of Merriam's wild turkey roost site selection in northern Arizona, 2006–2009.[a]

Variable	Parameter estimate	SE	Odds ratio
TRASP	0.29	0.05	1.33
BA	0.82	0.26	2.28
CAN	0.71	0.27	2.03
ELEV	1.37	0.08	3.94
HGT	−0.50	0.18	0.61
RUF	1.54	0.08	4.68
TPH	−0.21	0.09	0.81
EDGE	−0.054	0.05	0.95
Constant	−0.26	0.06	0.77

[a] Abbreviations: TRASP, transformed aspect, BA, basal area; CAN, canopy cover; ELEV, elevation; HGT, canopy height; RUF, terrain ruggedness index; TPH, tree density; EDGE, distance from nearest forest edge.

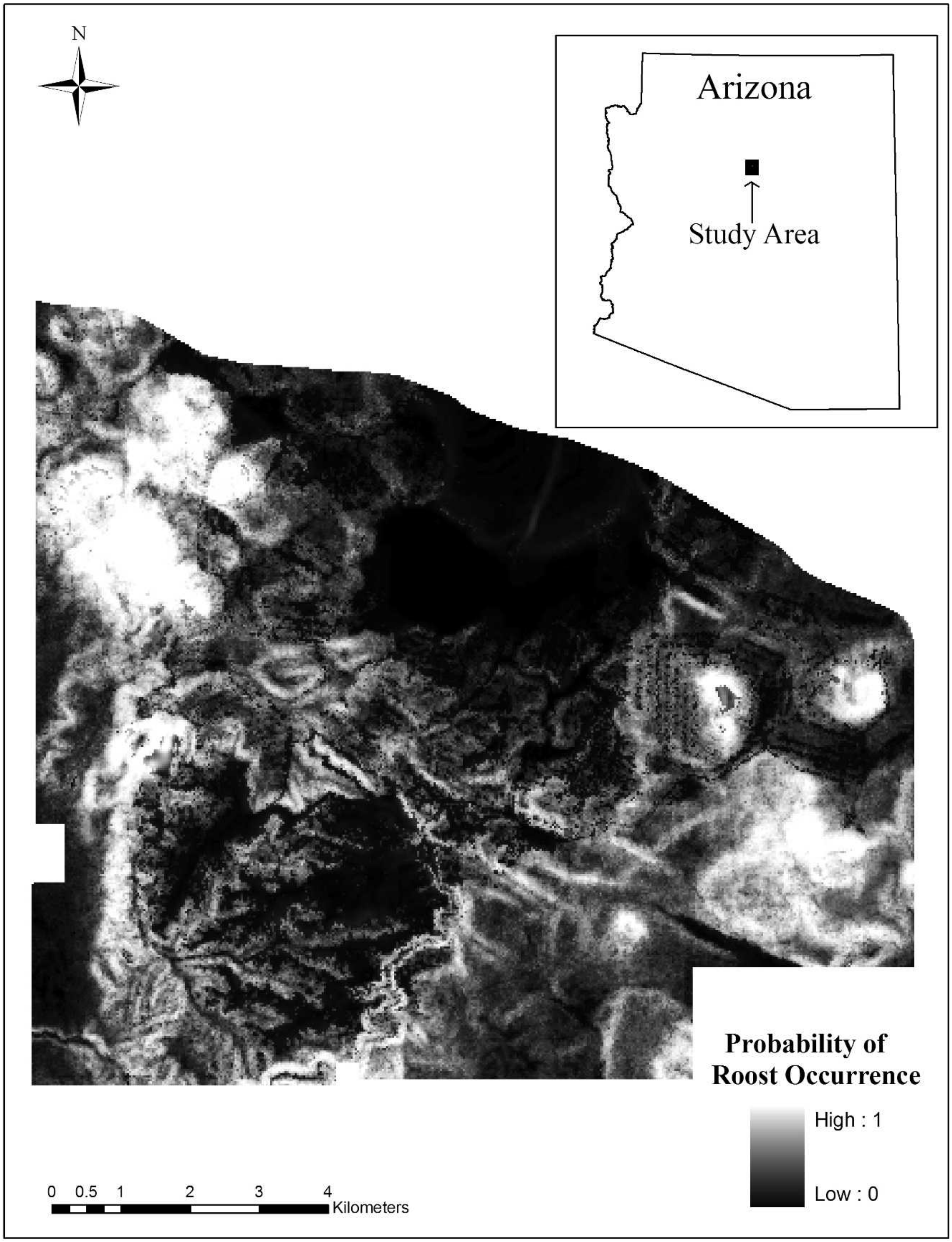

Figure 1. Probability of roost site occurrence on Camp Navajo, Arizona.

predictors of wild turkey roost-site selection (Table 4). High-probability roosting locations around our study area were widespread (Fig. 1).

DISCUSSION

The focus of this study was identification of wild turkey roosts to inform management on a particular forest planned for treatment. However, considering the general similarity in ponderosa pine forest physiognomy across the Southwest, our results likely will be useful in identifying roosting habitat throughout much of the range of the Merriam's wild turkey.

The most important predictors of wild turkey roost sites according to our models were topographical. Specifically, our results suggest that areas of rugged terrain at higher elevations represent the best roosting habitat in our study area. This coincides well with a previous study of landscape-scale roost site selection of wild turkeys in north-central Arizona that indicated the importance of wild turkey roosts in ponderosa pine forests (Wakeling 2005). Other studies that focused on micro-site characteristics of roost selection have reported Merriam's wild turkey roosts at the tops of steep slopes and in rugged topography, although these areas typically have only ancillary importance compared with other characteristics, such as basal area and canopy cover (Goerndt 1983, Mollohan et al. 1995, Wakeling and Rogers 1998). In our study, basal area and canopy cover appeared to have only a moderate influence on wild turkey roost selection. This discrepancy could indicate that, when considering roost selection on the landscape scale in pine forests similar to those that comprised our study area, structural characteristics, such as high basal area and high canopy cover, generally are abundant and thus are not the strongest limiting factors of wild turkey roost selection.

Several factors bode well for the continued availability of wild turkey roosts on Camp Navajo. First, because of existing management restrictions, forest treatments will be limited to removal of only small ($<$22.9 cm dbh) trees in the rugged terrain and high elevations that we found to be most critical to wild turkey roost availability. Thus, there will be only a minor reduction of basal area and canopy cover, and these areas will retain the larger trees typically selected for roosts (Boeker and Scott 1969, Mollohan et al. 1995). Although some studies have suggested that roosts should be excluded from any forest treatment (Hoffman et al. 1993, Mollohan et al. 1995), more recent research found that wild turkeys will not abandon roosts that occur in areas where treatments have focused on removal of only small trees (Martin et al. 2005). Furthermore, according to our model, likely roosts are abundant and widespread across our study area. Thus, treatments planned for only a portion (10%) of our study area will allow roost density to adequately exceed the recommended 0.8 roosts/km^2 (Wakeling and Rogers 1998).

We note that, because our goal was to identify roosting habitat on the landscape scale and not to identify specific roost sites, our approach did not assess the importance of microsite characteristics. For example, we could not determine dbh, height, or layering and spacing of branching of individual trees, all factors which have been shown to influence selection of roosts by wild turkeys (Rumble 1992, Mollohan et al. 1995, Wakeling and Rogers 1998). Additionally, some studies have suggested that wild turkeys select roosts near small openings (Hoffman 1968), and openings smaller than 30 m $\times$ 30 m could not be detected with our methods. Therefore, although we predicted approximately 13% of Camp Navajo to have a $>$0.75 probability of constituting roosting habitat for wild turkeys, we suggest further study to determine whether roost-site availability is being limited by microsite scale characteristics (Mollohan et al. 1995).

MANAGEMENT IMPLICATIONS

The most important factors affecting roost selection in our study were topographical, and will not be affected by forest treatment. Management constraints in rugged areas, as well as the widespread occurrence of wild turkey roosts across our study area, likely will limit the overall effect of planned treatments on roost sites in the our study area. However, if forest treatment is expanded in the future, we recommend that our models be used to identify areas where likely roosts overlap treatment areas to ensure maintenance of overall basal area of $\geq$20 m^2/ha and retention of large ($>$50 cm dbh) roost trees. If these measures prove so restrictive and widespread that they hinder forest management goals, we recommend that ground searches be conducted in areas where high-probability roosting areas overlap planned forest-treatment areas be conducted to identify actual roosts.

We conclude by noting that maintenance of roosting habitat plays only a partial role in ensuring viability of wild turkey populations. Other aspects of wild turkey habitat need to be considered in forest management plans, including effects of forest restoration on landscape permeability, loafing sites, food availability and abundance, and nesting ecology.

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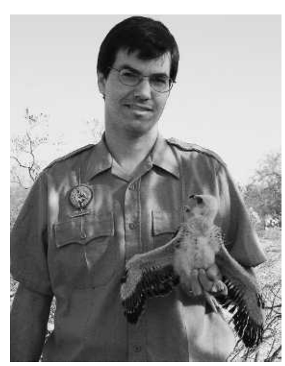

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