MODELING SMALL-SCALE VARIABILITY IN THE COMPOSITION OF GOSHAWK HABITAT ON THE KAIBAB NATIONAL FOREST

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ABSTRACT

We used field data, topographical information (elevation, slope, aspect, landform), and Landsat Thematic Mapper imagery to model forest vegetative types to a 10-m resolution on the Kaibab National Forest in northern Arizona. Forest types were identified by clustering the field data and then using a decision tree based on the spectral characteristics of a Landsat image and topographical information to predict the forest types. Significant variables in the models included raw basal area and proportion of basal area by species. Use of additional variables (canopy closure, understory vegetative height, seedling/sapling presence, and proportion of ground covered by vegetation) did not improve the model. Forest types described by the model included pinyon-juniper, ponderosa pine, ponderosa pine-fir mixes, spruce-dominated mixes, deciduous-dominated mixes, and clearings. Sample-based accuracy assessment accounted for 92.9% of the variability in the vegetation model. Error rates (post-stratified) were weighted by the proportion of area each forest type occupied. Independent validation using double sampling with post-stratification accounted for 74.5% of the estimated variability in the model. Ponderosa pine comprised the largest proportion (55.5%) of vegetative area and contributed the highest accuracy estimate (sample-based: 98.0%; cross-validation: 90.8%) to the overall forest model. Identified sources of error included (1) differentiating between pine-fir and spruce-dominated forest types (sample-based assessment) and (2) distinguishing openings in the forest from deciduous-dominated mixes (double sampling). This model has been used to describe forest structure (basal area, canopy cover, maximum understory vegetative height, presence of seedlings and saplings, and proportion of pine, aspen, spruce and fir basal areas) on the Kaibab National Forest to a 10-m resolution. Models of forest composition and structure will be linked with point-process models and a ranking of territories of northern goshawks with the purpose of identifying determinants of goshawk habitat quality.

Keywords: Classification, Landsat Thematic Mapper, double sampling, forest composition, northern goshawk habitat, *Accipiter gentilis,* Kaibab National Forest.

INTRODUCTION

Habitat changes due to forest management are thought to be responsible for declining populations of northern goshawks (*Accipiter gentilis atricapillus*) in the southwestern United States (Reynolds, 1983, 1989; Crocker-Bedford 1990, Reynolds et al. 1992). However, in a review of past studies, Kennedy (1997) found little evidence that goshawk populations have declined throughout North America. Either declines have not occurred or the spatial and temporal scales of field studies were insufficient to detect population declines. Alternatively, impacts of habitat change due to management may be measured more appropriately in terms of demographic performance on territories. Animals in populations are thought to fill landscapes by occupying high-quality habitats first, and then progressively settling into less suitable habitats as the population expands (Brown, 1969; Fretwell and Lucas, 1970). In poor or sink habitats, individuals often lack sufficient reproduction and survival to sustain the population in the absence of immigration from outside sources. Stable breeding populations therefore depend on the presence of adequate quantities of high quality or source habitats (Wiens, 1985). An accurate description of habitat is, therefore, paramount to understanding the relationship between demography and habitat. This is often a difficult endeavor when the study area is large and diverse and complete sampling is unrealistic. Traditional land classification techniques incorporate information derived from remotely sensed data, such as those provided by satellites [e.g., Landsat Thematic Mapper (TM) sensors] to develop models of land cover, and are limited to the resolution of those data (e.g., 30 m). In addition, land cover classifications are frequently driven by (supervised classification) or defined by (unsupervised classification) the interpretation of photography or by incidental knowledge of the study area. The former requires a high level of skill to reduce interpretation error, while the latter may not provide comprehensive coverage of the study area. In traditional classification methods, ground sampling at select points is used to validate the classification and/or compute an error rate. In this paper, we describe a method that uses field data to drive a classification of Landsat 5 TM imagery to a 10-m resolution in an attempt to characterize northern goshawk habitat on the Kaibab National Forest (KNF), in northern Arizona. The result of this study will be used to parameterize a comprehensive dynamic spatial simulation model (developed for grassland systems; Reich et al., 1997) that will take into account interactions among goshawk demographic performance, the spatial distribution and arrangement of goshawk territories, and habitat composition and structure.

STUDY AREA

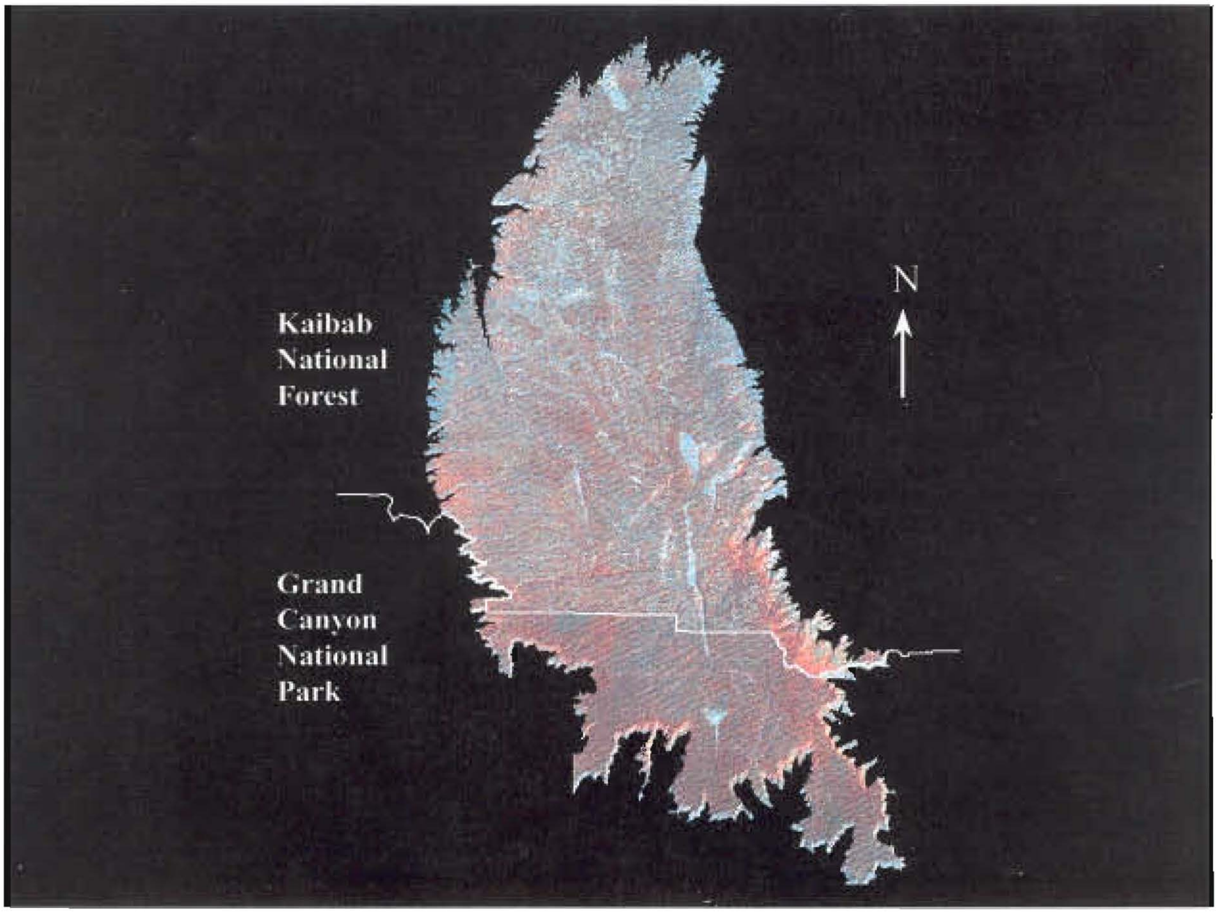
The Kaibab Plateau, in northern Arizona, is an oval-shaped (95 km x 55 km), limestone plateau that rises from a shrub-steppe plain at 1750 m above sea level (*asl*) to its highest point at 2800 m. Surface weathering has produced gentle drainages and moderately sloping valleys that appear across the Plateau. The Plateau is bounded by escarpments of the Grand Canyon of the Colorado River on its south side, by steep slopes on the east, and gentle slopes on the north and west sides that descend to the plain. The Kaibab National Forest (KNF), managed by the North Kaibab Ranger District (NKRD), occupies the northern two-thirds of the Plateau (Fig. 1).

The study area includes all of the KNF above 2,182 m *asl*, or about 1,285 km^2 [estimated from digital elevation models (DEM) using ARC/INFO® (ESRI, 1995)]. Pinyon (*Pinus edulis*)-juniper (*Juniperus* spp.) woodlands occur where elevations are below 2075 m *asl* on the study area. Ponderosa pine (*P. ponderosa*) forests occur between 2,075 and 2,450 m *asl*, mixed-conifer (*P. ponderosa, Pseudotsuga mensiesii, Abies concolor,* and *Picea pungens)* forests from 2,450 and 2,650 m *asl*, and spruce (*Picea engelmannii*)-fir (*A. lasiocarpa*) forests between 2,650 and 2,800 m asl (Rasmussen, 1941; White and Vankat, 1993). At transition zones of forest types, adjacent forest types typically intermix because of differences in slope and aspect. On south-facing slopes, pinyon-juniper forests extend into ponderosa pine, and on north-facing slopes, ponderosa pine extends into pinyon-juniper. The same relationships hold between ponderosa pine and mixed-conifer, and mixed-conifer and spruce-fir (White and Vankat, 1993). A series of narrow meadows occur on the Plateau that contains grasses and herbaceous vegetation. Each forest type has been altered by some form of management: livestock grazing, fire suppression, thinning, shelterwood, seed-tree and sanitation cuts, and clearcuts.

Prior to the introduction of livestock grazing (late-1800s), fire suppression (beginning in the early 1900s), and extensive logging (beginning in the 1980s), many ponderosa pine trees were in mature size classes, occurred in groups or were widely spaced on the Plateau. Understories were dominated by grasses (*Poa, Sitanion, and Muhlengergia* spp.) and were typically free from shrubs and smaller trees (Rasmussen, 1941; Merkle, 1962).

Currently much of the ponderosa pine type understory is dense with pine reproduction and, in upper elevations, with white fir reproduction.

Figure 1. 1997 Landsat TM image (bands 4, 3, and 2) of the Kaibab Plateau, Arizona, above 2,182 m in elevation, denoting the Kaibab National Forest and Grand Canyon National Park.



METHODS

Classification of Forest Cover Type

To generate a classification of forest types we sampled 272 plots consisting of nine 10-m x 10-m subplots on the KNF. Each plot corresponded to a 30-m x 30-m pixel of Landsat TM imagery, the location of which was verified using a Trimble Navigation Pathfinder™ Asset Surveyor Global Positioning System with an estimated accuracy of 1-3 m. Plots were located on the ground using enlarged digital maps, USDI Geological Survey (USGS) 7.5 min quadrangles (1:24,000), and knowledge of the area. Enlarged digital maps of the sample plots were made by merging (ARC/INFO®; ESRI, 1995) 22 DEMs (provided by USGS; 1:24000; 30-m resolution) overlaid with digital line graphs of KNF roads (provided by R. Crawford, NKRD, Arizona). Each enlarged digital map contained 4-12 plots.

Three sets of field data were collected.

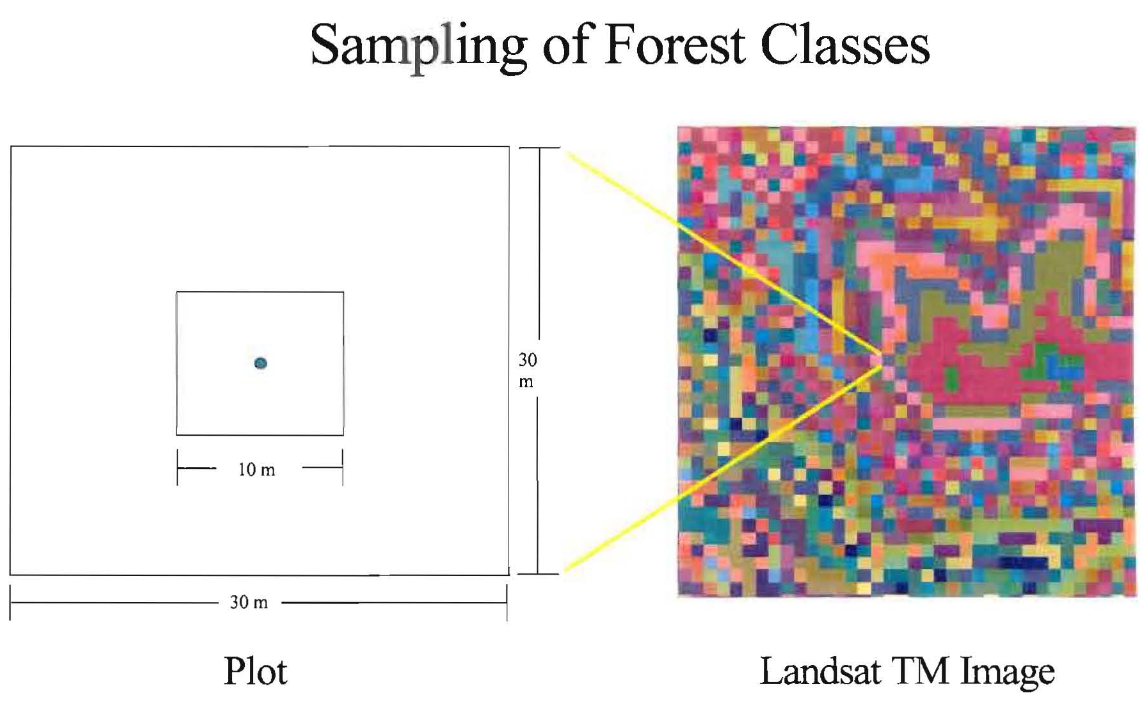
Spectral-derived Plots: To capture the spectral possibilities on the KNF, we performed an unsupervised classification (IMAGINE® version 8.3, Classification function; ERDAS, 1997) on a 1994 Landsat TM scene [16 July; centered on Path 37and Rows 34 and 35; obtained from the Earth Observation Satellite Company] of the study area using an ISODATA (Iterative Self-Organizing Data Analysis Techniques A) algorithm (Tou and Gonzalez, 1974). The algorithm computes the minimum distance between spectral signatures to identify clusters of pixels with similar spectral characteristics. Fifty spectral classes were generated. To sample the vegetative characteristics in the field, we generated two random coordinates per spectral class (IMAGINE®, Evaluate Classification function; ERDAS, 1997). Each coordinate represented the center of a 3 x 3 pixel "window" of like spectral class. Due to difficult terrain, we sampled 98 of the 100 plots.

Goshawk Nest Plots: Among breeding years, a northern goshawk pair may use more than one "alternate" nest within its territory. To measure the range of vegetative characteristics found at goshawk nest areas, one plot (centered on the nest tree) was established at one randomly-selected, alternate nest within 95 goshawk territories (i.e., all known territories on the KNF in 1997). Due to errors in field sampling, 92 of the 95 plots were used in analyses.

Random Plots: One hundred random plots were generated to capture the remaining variability in the study area. Randomly located plots were established irrespective of territories and nests. Due to time constraints 85 of these plots were measured. The majority of unmeasured plots were located at the edge of the study area where access was difficult.

Measurements of field plots occurred between August and September 1997. Each plot was established in a north-south, east-west fashion with the coordinate systematically assigned to either the center (spectral-derived plots and nest plots) or lower left corner (random plots) of the plot. Vegetative characteristics and measurements were recorded on each of the nine 10-m x 10-m subplots and included: 1) canopy closure (measured with a concave, spherical densiometer [Lemmon, 1956; 1957]), 2) overstory species and basal area (measured with an angle gauge), 3) understory species, height, and overall percent cover, and 4) presence of seedlings and/or saplings. Each plot was also photographed. In developing our model of forest composition, we used only the central subplot (Fig. 2).

Figure 2. Plot layout for sampling of forest types to a 10-m resolution.



Following vegetative sampling, a new (1997), cloud-free, TM image (22 June; Path 37, Row 35) of the study area was obtained that corresponded in time as closely as possible to the field work. These data included Landsat bands 1-5 and 7 in band sequential format (W. Krausman, USDA Forest Service). Band layers were exported (Export tool; IMAGINE®; ERDAS, 1997) as ARC/INFO® (ESRI, 1995) grid coverages and resampled (resample, nearest neighbor; ARC/INFO®; ESRI, 1995) to 10 m corresponding to the resolution of the field data. The value of each pixel was averaged (Focalmean function, ARC/INFO®; ESRI, 1995) by passing a 3 x 3 moving window over the resampled grids. This resulted in a grid with a continuous surface where every 10-m x 10-m pixel represented the average of the surrounding 30-m x 30-m pixel.

Elevation, slope, aspect, and landform (McNab, 1989) were also determined for each plot. Landform (McNab, 1989) is an index that expresses surface shape as a measure of surface concavity or convexity (computed as the mean slope gradient from the original cell to adjacent cells in 4 directions) creating a continuous variable. Prior to extracting the cell values, each grid was resampled to 10 m as described above, but not averaged.

To identify forest types, vegetative measurements were grouped into like classes using a hierarchical clustering algorithm in S-PLUS© (1995; hclust function, "average" method) (Reich and Davis, 1998). The resulting clusters were assigned modified Anderson Level II or III (Anderson et al., 1976) land cover classes (Table 1). S-PLUS© (1995) was then used to generate a stepwise decision tree (Breiman et al., 1984; Friedl and Brodley, 1997) that determined which independent variables (Landsat bands, elevation, slope, aspect, or landform) were important in discriminating among forest types. The decision tree initiates with one variable at the root node and then recursively partitions the data according to a decision framework that maximizes the distance between attributes assigned to each subsequent node. Subdivisions of spectral characteristics that were too refined were "pruned." These data were then used as "training" statistics (i.e., they train the computer to recognize mathematical patterns) to aid in classifying the 1997 image.

Table 1. Modified land cover classification system (Anderson et al., 1976) for forest types on the Kaibab National Forest. Characteristics at higher levels are nested within the lower level.

Land Cover		
Level I	Level II	Level III
Forest	Coniferous	Ponderosa pine
		Ponderosa pine-fir
	Deciduous	Deciduous-dominated mix
	Mixed	Pinyon-Juniper
		Spruce-dominated Mix
Non-Forested	Opening	

Accuracy Assessment

A sample-based assessment of accuracy (i.e., that based on the same data used to generate the classification) for the decision tree was calculated by weighting the classification error associated with a given forest type proportional to its area (i.e., post-stratification) (Cochran, 1977a). To independently estimate the accuracy of the final cover types, we used Arc Macro Language (ARC/INFO®, ESRI, 1995) to generate 498 random plots using simple random sampling. We identified forest type at the 498 independent plots and at 269 of the 272 field plots (ancillary data were not available for 3 plots) through the interpretation of ancillary photographic data (see below). At each sample location, forest class was estimated for an area corresponding to a 10-m x 10-m plot. Double sampling (Czaplewski, 1992; Kalkhan et al., 1996; Kalkhan et al., 1998; Czaplewski, 1999) with post-stratification (Cochran, 1977b) was used to correct for classification errors associated with the photographic interpretation. An error matrix of the overall classification accuracy and Kappa statistic for a stratified random sample (Stehman, 1996) was calculated to measure the difference between classified and ground-verified themes and the agreement contributed by chance.

Ancillary data used to assess the classification accuracy included: color aerial photography (1:12000, 1991; NKRD), infrared National High Altitude Photography (NHAP) (1:58,000, 1980, USGS), and Digital Orthophoto Quadrangles (DOQs) (1:12,000, 1992, USDA Forest Service Geometric Service Center, USGS), and photographs taken during field sampling. Information on forest management activities [Resource Information System (RIS) data] aided in identifying management treatments that occurred subsequent to the acquisition of the photography and was provided by the NKRD (K. Fuelling, D. Steffensen, pers. comm.).

RESULTS

Sample-based Accuracy

Using total basal area, we were able to distinguish stands of pure ponderosa pine from all other forest types with an accuracy of 98.0% (Table 2). To improve the accuracy estimates of non-ponderosa pine forest types, we separated the non-pine types and repeated the cluster analysis using the proportion of basal area by species (Table 3). Proportions among species were transformed by taking the arcsin of the square root of the proportion to ensure that the data fell within the bounds 0-1. We also consolidated one forest type (fir-dominated mix; Table 2) into other forest types (ponderosa pine-fir and spruce-dominated mixes; Table 3). The estimated overall sample-based classification accuracy (post-stratified) for the model was 92.9% (Table 4). The use of auxiliary variables (canopy cover, understory vegetation height, seedling/sapling presence and proportion of ground covered) did not improve the model.

Table 2. Classification error rate of the decision tree for forest types using total basal area by species.

Forest Cover Type	Misclassified Plots	Total Plots	Classification Error Rate
Pinyon-Juniper	5	15	0.33
Ponderosa Pine	3	151	0.02
Ponderosa Pine-Fir Mix	12	23	0.52
Fir-dominated Mix	4	10	0.40
Spruce-dominated mix	8	22	0.36
Deciduous-dominated Mix	17	28	0.61
Opening	7	23	0.30
Column Totals	**56**	**272**	
Overall Post-stratified Error			**0.21**

Table 3. Classification error rate of the decision tree for non-pine forest types using proportion of basal area by species.

Forest Cover Type	Misclassified Plots	Total Plots	Classification Error Rate
Pinyon-Juniper	2	16	0.12
Ponderosa Pine-Fir Mix	4	33	0.12
Spruce-dominated mix	4	31	0.13
Deciduous-dominated Mix	2	20	0.10
Opening	5	22	0.23
Column Totals	**17**	**122**	
Overall Post-stratified Error			**0.14**

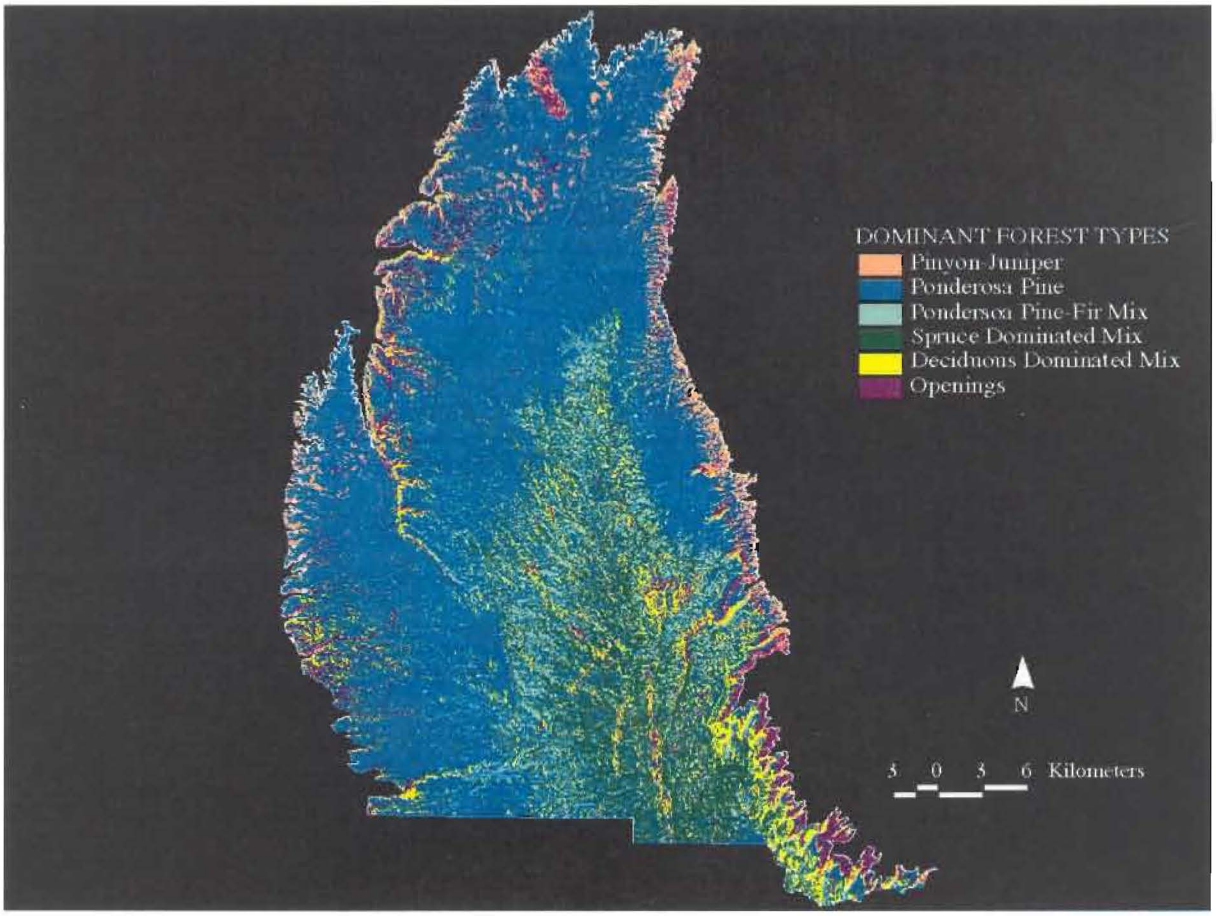
Table 4. Weighted classification error rates for the model of forest types (ordered by proportion of area).

Forest Type	Pixels/Class (10 m x 10 m)	Proportion of Total Area	Classification Error Rate	Post-stratified Error Rate
Ponderosa Pine	7137947	0.555	0.020	0.011
Ponderosa Pine-Fir Mix	1454207	0.113	0.121	0.014
Spruce-dominated Mix	1300085	0.101	0.129	0.013
Deciduous-dominated Mix	1124891	0.088	0.100	0.009
Pinyon-Juniper	1055726	0.082	0.125	0.010
Opening	778865	0.061	0.227	0.014
Column Totals	**112851721**	**1.000**		**0.071***

* Overall Classification Error

Ponderosa pine occupied the majority (55.5%) of the study area at lower elevations, with ponderosa pine-fir (11.3%) and spruce-dominated mixes (10.1%) at higher elevations (Fig. 3). Pinyon-juniper (8.2%) was found predominantly along lower elevational edges of the study area and where crown-destroying fire and intensive management (e.g., shelterwood and seed-tree cuts) had occurred at lower elevations. Deciduous-dominated mixes (8.8%) and openings (6.1%) occurred throughout the study area.

Figure 3. Dominant Forest types on the Kaibab National Forest, Arizona, modeled to a 10-m resolution.



Model Validation

The accuracy of the model when compared to the photo interpreted data was 62.8%, with a Kappa of 32.9% (Table 5). The low value associated with the Kappa statistic suggests that there is a poor relationship between the classification derived from the decision tree and the photo interpreted classification. Low accuracy estimates associated with some forest types (Table 5) contributed largely to the low overall accuracy and were due to the difficulty in distinguishing among pine, fir, spruce, and aspen where they were mixed, packed densely, or occurred in small patches. Photo interpretation of these forest types was difficult using mid-summer, true color aerial photography and black and white DOQs. Openings were also misclassified at a relatively high rate and may have resulted from post-harvest regeneration or management activities and fire creating openings subsequent to collection of the ancillary photographic data. In addition, spectral similarities between deciduous and open forest vegetation may have contributed to the error estimate. A series of narrow (< 800 m) meadows comprised of grasses and forbs were classified predominantly as deciduous-dominated vegetation, rather than as clearings.

Table 5. Joint probability error matrix for forest types derived from remote sensing (Landsat bands 1-5 and 7, elevation, slope, aspect, and landform) (columns) and photographic interpretation (rows) using a simple random sample of 498 points and 269 field plots with post-stratification.

	Forest Types							
Forest Type	PJ	PP	PFM	SDM	DDM	OPN	**Row Totals**	Accuracy
Pinyon-Juniper (PJ)	0.0313	0.0222	0.0000	0.0000	0.0000	0.0078	**0.0613**	0.5106
Ponderosa Pine (PP)	0.0222	0.4003	0.0117	0.0104	0.0261	0.0078	**0.4785**	0.8365
Ponderosa Pine-Fir Mix (PFM)	0.0026	0.0561	0.0469	0.0130	0.0143	0.0039	**0.1368**	0.3429
Spruce-dominated Mix (SDM)	0.0000	0.0209	0.0326	0.0717	0.0169	0.0026	**0.1447**	0.2687
Deciduous-dominated Mix (DDM)	0.0013	0.0378	0.0104	0.0052	0.0235	0.0091	**0.0873**	0.4955
Opening (OPN)	0.0052	0.0430	0.0091	0.0078	0.0117	0.0143	**0.0911**	0.1571
Column Totals	**0.0626**	**0.5803**	**0.1107**	**0.1081**	**0.0925**	**0.0455**	**0.9997**	

Overall Accuracy = 62.82% (Overall Standard Error = 0.99%)
Kappa = 32.90%

When double sampling was used to adjust the error matrix associated with the model to reflect differences in the photo interpretation at the 498 independent plots and 269 field plots used to develop the model, the estimated accuracy for the overall model increased to 74.5% (Table 6). All classes except openings had an estimated accuracy of greater than 50%. The Kappa for the overall model was approximately 50%, which indicated good agreement between the model and what is actually on the ground.

Table 6. Joint probability error matrix relating the forest types derived from remote sensing (Landsat bands 1-5 and 7, elevation, slope, aspect, and landform) (columns) to the field data (rows) using double sampling with post-stratification to correct for errors in the photographic interpreted classes.

	Forest Types							
Forest Type	PJ	PP	PFM	SDM	DDM	OPN	**Row Totals**	Accuracy
Pinyon-Juniper (PJ)	0.0374	0.0133	0.0000	0.0000	0.0000	0.0115	**0.0622**	0.6014
Ponderosa Pine (PP)	0.0149	0.4956	0.0100	0.0035	0.0118	0.0102	**0.5460**	0.9076
Ponderosa Pine-Fir Mix (PFM)	0.0000	0.0308	0.0667	0.0192	0.0046	0.0000	**0.1213**	0.5499
Spruce-dominated Mix (SDM)	0.0000	0.0179	0.0197	0.0736	0.0139	0.0010	**0.1261**	0.5017
Deciduous-dominated Mix (DDM)	0.0000	0.0261	0.0100	0.0038	0.0402	0.0000	**0.0801**	0.5838
Opening (OPN)	0.0000	0.0163	0.0055	0.0089	0.0057	0.0279	**0.0643**	0.4333
Column Totals	**0.0523**	**0.6000**	**0.1119**	**0.109**	**0.0762**	**0.0506**	**1.0000**	

Overall Accuracy = 74.47% (Overall Standard Error = 1.56%)
Kappa = 49.87%

DISCUSSION

The objective of this study was to model the composition of goshawk habitat on the Kaibab National Forest to a 10-m resolution using a non-parametric, supervised approach based on field data, physiographic information, and Landsat TM imagery. Forest types were identified by clustering the field data and then using a decision tree based on the spectral characteristics of a Landsat image, elevation, slope, aspect, and landform to predict the forest types. Dominant forest types included pinyon-juniper, ponderosa pine, ponderosa pine-fir mixes, spruce-dominated mixes, deciduous-dominated mixes, and openings. Significant variables in our models were per species raw basal area and proportion of basal area. Stands of pure ponderosa pine were identified with high (98.6%, Table 4; 90.8%, Table 6) accuracy. Differentiating between pine-fir and spruce-dominated forest types was difficult due to their spectral and physical similarities. Auxiliary variables (canopy closure, understory vegetative species and height, proportion of ground covered by vegetation, and seedling/sapling presence) did not improve the model perhaps because they were strongly correlated with basal area. The sample-based estimated classification accuracy of the model was 92.9%. However, the overall estimated accuracy decreased to 74.5% when validated using an independent sample of plots. In the latter estimate, the error matrix associated with the model was used to correct for differences in the photo interpretation of random plots and the field plots used to develop the model. Sample-based accuracies tell us how well a decision tree classifies the field data; while, independent assessment of accuracy better reflects the accuracy estimate associated with a model (i.e., it provides a less-biased estimate of the error rate). This is especially relevant when dealing with classification trees where splitting minimizes the classification error.

Northern goshawks occur in a wide range of forest types and structures that vary considerably in quality. Qualitative differences among habitat characteristics may be measured in terms of the fitness of the individuals who occupy the habitat (Fretwell and Lucas, 1970; Van Horne, 1983). To understand how goshawks are affected by their environment, we are linking their demographic performance on territories and their spatial arrangement in the landscape to an accurate description of their habitat. The model of forest composition generated here is one component of an overall effort to characterize goshawk habitat on the KNF. The model has been used successfully (Suzanne M. Joy, Dept. of For. Sci., CSU, unpublished data) as an auxiliary variable in (1) describing forest structure (basal area, canopy cover, maximum understory vegetative height, presence of seedlings and saplings, and proportion of pine, aspen, spruce and fir basal areas) to a 10-m resolution and (2) predicting the probability of goshawk nest tree locations on the KNF.

ACKNOWLEDGMENTS

We are grateful to the following persons for their assistance in the field: Carrie M. Erickson, Matthew A. Gavin, Luke J. H. Hunt, Amy M. Iniguez, Jose M. Iniguez, Mohammed A. Kalkhan, Donna C. Laing, Jeffrey S. Lambert, Joanna L. Nelson, Susan S. Salafsky, John C. Seyfried, Geroge S. Stamatellos, Rebecca A. Steffensen, Vernon L. Thomas, J. David Wiens, Laura E. Williams. Vernon L. Thomas provided Avenue code and guidance on GIS manipulations. We thank Donna C. Laing for the interpretation of photographic images. Raymond L. Czaplewski, Curits H. Flather, Mohammed A. Kalkhan, and Rudy M. King provided helpful reviews of the manuscript. The North Kaibab Ranger District (NKRD, Fredonia, AZ) kindly provided housing and logistical support. Special thanks to Rick Crawford, Karl Fuelling, and Dave Steffensen of the NKRD for support in acquiring RIS data, DOQs, and road coverages of the KNF, and to William (Bill) Krausman for providing the 1997 raw Landsat TM image. This study was funded by Region 3 (Albuquerque, NM) and the Rocky Mountain Research Station (Fort Collins, CO), USDA Forest Service.

REFERENCES

Anderson, J. R., E. Hardy; J. Roach, and R. Witmer. (1976). A land use and land cover classification system for use with remote sensor data. Geological Survey Professional Paper 964. U. S. Government Printing Office, Washington, D.C., pp. 1-28.

Breiman, L., J. H. Friedman, R. A. Olshen, and C. J. Stone. (1984). *Classification and regression trees.* Wadsworth Ind. Group, Belmont, CA, pp. 1-58.

Brown, J. L. (1969). Territorial behavior and population regulation in birds. A review and re-evaluation. *Wilson Bulletin,* 81:293-329.

Cochran, W. G. (1977a). *Sampling techniques.* John Wiley & Sons, New York, pp. 134-135.

Cochran, W. G. (1977b). *Sampling techniques.* John Wiley & Sons, New York, pp. 327-335.

Crocker-Bedford, C. (1990). Goshawk reproduction and forest management. *Wildlife Society Bulletin,* 18:262-269.

Czaplewski, R. L. (1992). Accuracy assessment of remotely sensed classifications with multi-phase sampling and the multivariate composite estimator. In: Proceedings of the 14th International Biometric Conference, Hamilton, New Zealand, December 7-11, Volume 2. International Biometrics Society, Hamilton Ruakura Agricultural Centre, p. 22.

Czaplewski, R. L. (1999). Accuracy assessment and areal estimates using two-phase stratified random sampling, cluster plots, and the multivariate composite estimator. In: *Quantifying spatial uncertainty in natural resources: theory and applications for GIS and remote sensing,* H. T. Mowrer and R. G. Congalton, eds., Ann Arbor press, Chelsea, Michigan, pp. 79-100.

ERDAS. (1997). *IMAGINE® 8.3 Software and on-line help manual.* ERDAS, Inc. Atlanta, GA.

ESRI. (1995). *ARC/INFO® Software and on-line help manual.* Environmental Research Institute, Inc., Redlands, CA.

ESRI. (1998). *ArcView® 3.1 on-line help manual* Environmental Research Institute, Inc., Redlands, CA.

Fretwell, S. D., and H. L. Lucas. 1970. On territorial behavior and other factors influencing habitat distribution in birds. I. Theoretical development. *Acta Biotheoretica,* 19:16-36.

Friedl, M. A., and C. E. Brodley. (1997). Decision tree classification of land cover from remotely sensed data. *Remote Sensing and the Environment,* 61:399-409.

Kalkhan, M. A., R. M. Reich, and R. L. Czaplewski. (1996). Statistical properties of measures of association and the Kappa statistic for assessing the accuracy of remotely sensed data using double sampling. In: 2nd International Symposium of Spatial Accuracy Assessment in Natural Resources and Environmental Sciences. General Technical Report RM-GTR-277. U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO, pp. 467-476.

Kalkhan, M. A., R. M. Reich, and T. J. Stohlgren. (1998). Assessing the accuracy of Landsat Thematic Mapper classification using double sampling. *International Journal of Remote Sensing,* 19:2049-2060.

Kennedy, P. L. (1997). The northern goshawk (*Accipiter gentilis atricapillus*): is there evidence of a population decline? *Journal of Raptor Research,* 31:95-106.

Lemmon, P. E. (1956). A spherical densiometer for estimating forest overstory density. *Forest Science*, 2(4):314-320.

Lemmon, P. E. (1957). A new instrument for measuring forest overstory density. *Journal of Forestry*, 55(9):667-668.

McNab, W. H. (1989). Terrain shape index: quantifying effect of minor landforms on tree height. *Forest Science*, 35:91-104.

Merkle, J. (1962). Plant communities of the Grand Canyon area, Arizona. *Ecology*, 43:698-711.

Rasmussen, D. I. (1941). Biotic communities of the Kaibab Plateau, Arizona. *Ecological Monographs*, 11: 230-274.

Reich, R. M., C. D. Bonham, and K. L. Metzger. 1997. Modeling small-scale spatial interactions of shortgrass prairie species. *Ecological Modeling*, 101:163-174.

Reich, R. M., and R. A. Davis. (1998). *On-line spatial library for the S-PLUS© statistical software package*. Colo. State Univ., Fort Collins.

Reynolds, R.T. (1983). Management of western coniferous forest habitat for nesting *Accipiter* hawks. General Technical Report RM-102. U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO, 7 pp.

Reynolds, R.T. (1989). Accipiters. In: Proceedings of the Western Raptor Management Symposium and Workshop. National Wildlife Federation Scientific and Technical Series No. 12, Washington, DC., pp. 92-102.

Reynolds, R.T., R. T. Graham, M. H. Reiser, R. L. Bassett, P. L. Kennedy, D. A. Boyce, Jr., G. Goodwin, R. Smith, and E. L. Fisher. (1992). Management recommendations for the northern goshawk in the southwestern United States. General Technical Report RM-217, U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO, 90 pp.

S-Plus. 1995. *S-PLUS© 3.3Statistical software package for personal computers*. StatSci Division, MathSoft, Inc., Seattle, WA.

Stehman, S. U. (1996). Estimating the kappa coefficient and its variance under stratified random sampling. *American Society of Photogrammetry and Remote Sensing*, 62:401-402.

Tou, J. T., and R. C. Gonzalez. (1974). Isodata algorithm. In: in *Pattern Recognition Principles*. Addison-Wesley Publ. Co., Reading MA, pp. 97-104

Van Horne, B. (1983). Density as a misleading indicator of habitat quality. *Journal of Wildlife Management*, 43:893-901.

White, M. A., and J. T. Vankat. (1993). Middle and high elevation coniferous forest communities of the North Rim region of the Grand Canyon National Park, Arizona, USA. *Vegetation* 109:161-174.

Wiens, J. A. (1985). Habitat selection in variable environments: shrub-steppe birds. Pages 227-251 in Cody, M. L. (ed.), *Habitat Selection in Birds*. Academic Press, New York.