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LARGE-AREA GOSHAWK HABITAT MODELING IN DIXIE NATIONAL FOREST USING VEGETATION AND ELEVATION DATA

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Abstract. To expedite the evaluation of potential Northern Goshawk (*Accipiter gentilis*) habitat in Dixie National Forest, Utah, four computer models were designed to delineate areas where there was high probability of finding goshawk nest sites. Digital elevation data and vegetation class information derived from satellite imagery was acquired from the USDA Forest Service. These data were used to determine diagnostic elevation and vegetation characteristics for 30 known nesting sites and their associated post fledgling family areas (PFA). The first model, using elevation class as the only discriminator, located 95% of the known goshawk nest sites within 50% of the Forest. Using vegetation class in lieu of elevation, the second model located the same number of nest sites within 37% of the Forest. The third model employed vegetation and elevation class concurrently. The amount of Forest delineated to account for 95% of the goshawk nest sites dropped to 19%. By adding PFA information to the vegetation and elevation data, the fourth model reduced the area of search to only 14% of the Forest.

Key Words: *Accipiter gentilis*; habitat modeling.

The Northern Goshawk's (*Accipiter gentilis*) breeding habitat consists of mature forest patches used for prey acquisition and nesting. The decline of some local goshawk populations (Crocker-Bedford 1990) has led to a Category 2 listing by the US Department of Interior (1991).

Searching for goshawk nests through large patches of mature forests is time consuming and laborious. Any model that could delimit potential goshawk nest sites within a study area based on readily available, accurate, and inexpensive data would be a valuable management tool. In this paper, we present four models for predicting potential goshawk nesting site habitat in Dixie National Forest, Utah. These models evaluate potential nesting territory habitat by manipulating digital elevation data and a digital vegetation map.

METHODS

STUDY AREA

The Dixie National Forest encompasses 801,000 hectares in south central Utah. Vegetation distribution in the Forest is complex, but is determined primarily by elevation, slope, and aspect. Pinyon pine (*Pinus edulis*) and Utah juniper (*Juniperus osteosperma*) are prevalent below 2400 m elevation, whereas ponderosa pine (*Pinus ponderosa*) is the most common tree between 2400 and 3050 m. A mixture of spruce (*Picea* ssp.) and fir (*Abies* ssp.) predominates above 3050 m. Patches of quaking aspen (*Populus tremuloides*) are scattered throughout the forest, but cover only about 1% of the total area.

DATA COLLECTION

We conducted field work within the study area 13 June–27 August, 1991 and 17 May–28 August, 1992. We verified previously located goshawk nests and searched for previously undiscovered nests within areas thought to be suitable goshawk habitat. We surveyed areas within the study region using at least one of three different methods. Some areas were surveyed following the call playback protocol of Kennedy and Stahlecker (1993). Where the forest patch was long and thin (<300 m wide) the playback protocol was adjusted by bending the transect line to permit us to remain on the hypothetical center-line of the strip. As a third alternative, we would walk slowly through suspected habitat, listening for goshawk vocalizations while looking for plucking perches, nests, or other indicators of goshawks.

Active goshawk nests were easily identified, whereas

TABLE 1. ELEVATION CLASSES WITHIN THE DIXIE NATIONAL FOREST STUDY AREA. ALL LOCATED GOSHAWK NEST SITES WERE FOUND BETWEEN 2350–3100 M

Elevation class	Number of known goshawk nest sites within elevation class	Study area within elevation class (%)
<1300	0	1.2
1300–1450	0	1.1
1450–1600	0	2.1
1600–1750	0	4.0
1750–1900	0	6.7
1900–2050	0	8.2
2050–2200	0	13.3
2200–2350	0	14.9
2350–2500	3	14.8
2500–2650	13	9.9
2650–2800	4	8.7
2800–2950	5	6.0
2950–3100	5	5.1
3100–3250	0	2.2
>3250	0	2.0
Total	30	

TABLE 2. VEGETATION CLASSES WITHIN THE DIXIE NATIONAL FOREST STUDY AREA. WITH EXCEPTION OF PONDEROSA PINE/JUNIPER TRANSITION, GOSHAWK NESTS WERE FOUND WITHIN ALL VEGETATION CLASSES

Vegetation class	Number of known goshawk nest sites within vegetation class	Study area composed of vegetation (%)
Aspen	1	1.1
Aspen/conifer	2	4.4
Pinyon pine/juniper	4	14.8
Ponderosa pine (high density)	6	4.7
Mixed conifer (low density)	1	3.4
Mixed conifer (high density)	8	7.9
Nonforested	3	55.3
Ponderosa pine (low density)	3	3.9
Ponderosa pine/mixed conifer transition	2	2.7
Ponderosa pine/juniper transition	0	1.8
Total	30	

inactive goshawk nests were distinguished from other species' nests by the estimated size of the nest, size of the nesting tree, height of the tree, local canopy cover within a 100-m radius of the tree, and size of the sticks used in the nest construction. Whereas heights and canopy cover were measured with a clinometer and densiometer respectively, we estimated the size of the nest and its sticks visually. When these criteria suggested a goshawk nest, we would examine the immediate area for definitive evidence of occupancy such as feathers, plucking perches, egg shell fragments, and prey remains. If a goshawk nest was found, its location was recorded using a Magellan Nav 5000 global positioning unit (GPU).

GIS DATA BASE

Maps of elevation and vegetation were provided by the USDA Forest Service (USFS) for potential goshawk nesting habitat elevation. Already in digitized grid-cell (i.e., raster) format, these maps were imported into an Intergraph geographic information system (GIS). Both data sets of 796,770 grid cells covered the entire Dixie National Forest and adjacent areas with a grid cell resolution of 120 m. The elevation map divided the study area into 15 equal elevation classes of 150 vertical meters. Table 1 presents the 15 elevation classes, the proportion of study area belonging to each, and number of located nest sites found within each class. The second digitized map contained ten broad vegetation community classes derived from USFS analysis of Landsat satellite imagery (Table 2).

CONSTRUCTING THE PFA VEGETATION FREQUENCY MAPS

The models we created were designed to discriminate between known goshawk nest sites and surrounding areas. Given the data sets provided, we decided to base this discrimination on three factors: (1) the dominant vegetation class of the nest site itself, (2) the elevation class of the nest site, and (3) the vegetation community composition within the post-fledgling family area (PFA). Where unconstrained by lakes or other landscape features, this PFA was originally defined as the 242.8 hectare (600 acre) circular zone centered on a nesting site (Reynolds et al. 1992). However, because of software limitations and the finite 120 meter grid cell size, a square PFA was assumed in this analysis.

Determining the PFA vegetation community composition for a cell was a multiple step process. As shown

TABLE 3. AVERAGE VEGETATION COMMUNITY CHARACTERISTICS OF POST FLEDGLING FAMILY AREAS (PFA) FOR 30 NEST SITES

Vegetation class	Number of cells within PFA possessing vegetation class (N = 30 nest site PFAs) $\bar{X}$ (cells)	SD
Aspen	4.21	6.57
Aspen/conifer	24.12	22.35
Pinyon pine/juniper	10.70	12.79
Ponderosa pine (high density)	28.67	25.21
Mixed conifer (low density)	6.24	12.88
Mixed conifer (high density)	36.30	32.26
Nonforested	29.48	25.82
Ponderosa pine (low density)	7.30	8.81
Ponderosa pine/mixed conifer transition	15.21	11.95
Ponderosa pine/juniper transition	3.64	8.70

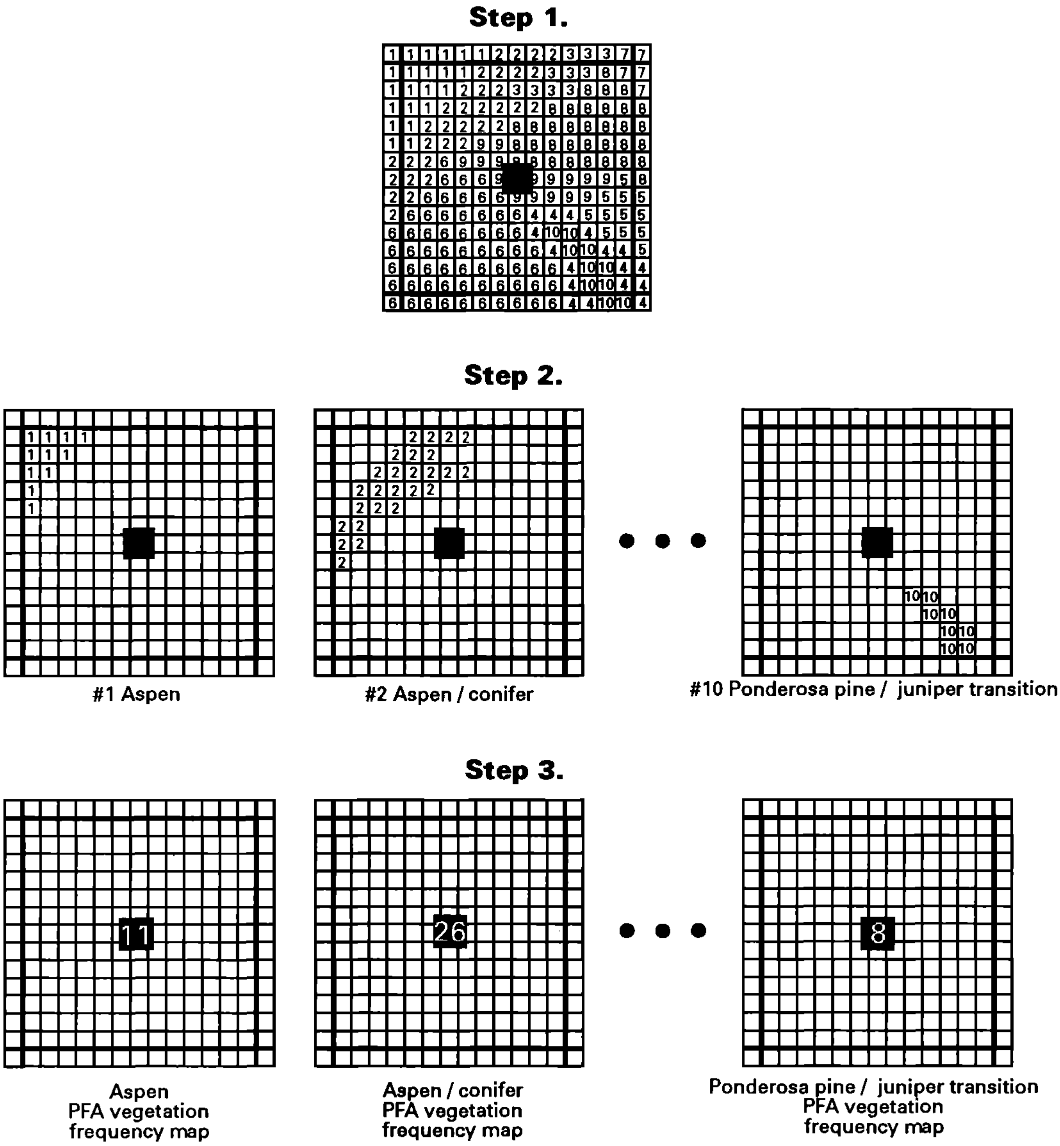

FIGURE 1. PFA value calculation for a single cell in the vegetation map is a three step process. In performing this calculation for every cell in the study area, the "sliding window" is placed over each cell successively, and the three step process is repeated. Step 1: A sliding window defining the PFA is centered over a cell in the original map. Step 2: The cells for each vegetation class are isolated within the sliding window and counted. Step 3: The counts are placed in the PFA frequency map cells which correspond to the center of the sliding window.

in Figure 1, a "sliding window" defining the 242.8 hectare PFA was centered over the cell's location on the digital vegetation map. The cells for each of the ten vegetation classes within the sliding window were then counted. The resulting counts for each of the ten vegetation classes were next placed into new PFA frequency maps at the cell location corresponding to the center of the window (Fig. 1, Step 3). To map the PFA vegetation community composition for the entire study area, this process was repeated for each of the 796,770 cells defining the Forest. The result of this process was ten PFA frequency maps, one corresponding to each vegetation class. Once completed, we located the 30 nest sites on the PFA vegetation frequency maps. The PFA composition of the 30 nest sites is summarized in Table 3.

TABLE 4. ORDER OF SEARCH ACCORDING TO MODEL I. ORDER IS DETERMINED BY RANKING OBSERVED − EXPECTED DIFFERENCES FROM HIGH TO LOW

		Known goshawk nest sites (N = 30)	
Order of search	Elevation class	Observed	Observed minus expected
1	2500–2650	13	10.05
2	2950–3100	5	3.49
3	2800–2950	5	3.21
4	2650–2800	4	1.38
5	1300–1450	0	−0.33
6	<1300	0	−0.36
7	>3250	0	−0.59
8	1450–1600	0	−0.64
9	3100–3250	0	−0.65
10	1600–1750	0	−1.21
11	2350–2500	3	−1.45
12	1750–1900	0	−2.00
13	1900–2050	0	−2.46
14	2050–2200	0	−3.98
15	2200–2350	0	−4.46

BUILDING THE MODELS

We built four models of goshawk nesting site location based on differences between observed and expected distributions of nest sites within different categories of elevation and vegetation (e.g., Fienberg 1980). Model I was based on elevation, Model II on vegetation classes, and Model III on both. Model IV used the PFA vegetation community composition in addition to elevation and vegetation. This model used a heuristic approach that combined the observed–expected differences with similarity measures used in cluster analysis. The interested reader should consult Spath (1980, 1985) for a discussion of these measures.

Based on the null hypothesis that no relationship existed between goshawk nest site location and elevation class, Model I predicts the percentage of the 30 goshawk nest sites located within an elevation class to be equal to the percentage of the study area covered by the class. Subtracting the number of goshawk nesting sites expected in an elevation class from the number observed and ranking the differences from high to low, the elevation classes are ordered in a sequence that, when used for field work, would maximize the number of goshawk nest sites found while minimizing the area searched (Table 4). This assumes that the 30 nest sites and their distribution were representative of all nest sites still not found in the Forest. The logic for the model predicted only on vegetation (Model II) was identical (Table 5).

The correlation between the ten vegetation classes and 15 elevation classes was low, producing a Goodman and Kruskal's τ_b (Blalock 1979) of only 0.26. Because of this, Model III incorporated both factors. The ten elevation classes where no goshawk nest sites were found (see Table 1) were discarded from further consideration, and every remaining possible combination of vegetation and elevation in the study area was determined from the digital maps. The number of goshawk nest sites observed and expected in each combination of elevation and vegetation was also determined by simple inspection of the maps. As before, the differences produced when subtracting the expected from the observed nest site count for each combination were sorted to generate an orderly search sequence. This model is represented by Table 6.

Whereas the first three models were based on probability, Model IV used a new heuristic approach. We devised a fourth model because the simple models based on elevation and vegetation did not incorporate PFA characteristics and all the models appeared to delimit too much of the forest to be of practical value.

Given our experience with the previous models, we defined three broad probability classes based on the combined categories of vegetation and elevation used in Model III. Class 1 consisted of areas where the observed–expected difference was positive or zero. These were locations where odds of finding goshawk nest sites would be no worse than expected. Class 2 consisted of those areas where nest sites were observed, but where

TABLE 5. ORDER OF SEARCH ACCORDING TO MODEL II. ORDER IS DETERMINED BY RANKING OBSERVED − EXPECTED DIFFERENCES FROM HIGH TO LOW

		Known goshawk nest sites (N = 30)	
Order of search	Vegetation class	Observed	Observed minus expected
1	Mixed conifer (high density)	8	5.63
2	Ponderosa pine (high density)	6	4.58
3	Ponderosa pine (low density)	3	1.83
4	Ponderosa pine/mixed conifer transition	2	1.19
5	Aspen/conifer	2	0.69
6	Aspen	1	0.67
7	Mixed conifer (low density)	1	−0.03
8	Pinyon pine/juniper	4	−0.45
9	Ponderosa pine/juniper transition	0	−0.53
10	Nonforested	3	−13.60

TABLE 6. ORDER OF SEARCH ACCORDING TO MODEL III. ORDER IS DETERMINED BY RANKING OBSERVED − EXPECTED DIFFERENCES FROM HIGH TO LOW. LD = LOW DENSITY; HD = HIGH DENSITY; TRANS. = TRANSITION

Order of search	Known goshawk nest sites (N = 30)		Nesting site vegetation class	Elevation class (m)
	Observed	Observed minus expected		
1	4	3.21	Ponderosa pine (HD)	2500–2650
2	2	1.62	Mixed conifer (HD)	2500–2650
3	3	1.31	Pinyon pine/juniper	2500–2650
4	1	0.87	Aspen	2950–3100
5	2	0.84	Mixed conifer (HD)	2800–2950
6	1	0.80	Ponderosa pine/mixed conifer trans.	2800–2950
7	1	0.78	Mixed conifer (HD)	2350–2500
8	1	0.76	Ponderosa pine (LD)	2650–2800
9	1	0.74	Ponderosa pine (LD)	2500–2650
10	1	0.67	Aspen/conifer	2800–2950
11	1	0.66	Ponderosa pine (LD)	2950–3100
12	1	0.63	Ponderosa pine/mixed conifer trans.	2650–2800
13	1	0.59	Mixed conifer (LD)	2800–2950
14	1	0.53	Nonforested	2950–3100
15	1	0.52	Aspen/conifer	2500–2650
16	1	0.49	Mixed conifer (HD)	2650–2800
17	2	0.46	Mixed conifer (HD)	2950–3100
18	1	0.32	Ponderosa pine (HD)	2650–2800
19	1	0.23	Ponderosa pine (HD)	2350–2500
20	0	−0.05	Aspen	2350–2500
21	0	−0.07	Mixed conifer (LD)	2350–2500
22	0	−0.08	Ponderosa pine/mixed conifer trans.	2950–3100
23	0	−0.09	Aspen	2500–2650
24	0	−0.12	Mixed conifer (LD)	2500–2650
25	2	−0.12	Nonforested	2500–2650
26	0	−0.15	Aspen	2650–2800
27	0	−0.18	Mixed conifer (LD)	2650–2800
28	0	−0.20	Aspen	2800–2950
29	0	−0.26	Aspen/conifer	2950–3100
30	0	−0.32	Aspen/conifer	2350–2500
31	0	−0.40	Ponderosa pine/mixed conifer trans.	2350–2500
32	0	−0.45	Mixed conifer (LD)	2950–3100
33	0	−0.45	Ponderosa pine (LD)	2800–2950
34	0	−0.47	Ponderosa pine/mixed conifer trans.	2500–2650
35	0	−0.48	Ponderosa pine (LD)	2350–2500
36	0	−0.52	Aspen/conifer	2650–2800
37	0	−1.02	Nonforested	2800–2950
38	0	−1.11	Ponderosa pine/juniper trans.	2650–2800
39	1	−1.49	Pinyon pine/juniper	2350–2500
40	0	−1.72	Nonforested	2650–2800
41	0	−4.83	Nonforested	2350–2500

the observed–expected difference was negative. These were areas where observation indicated that the probability of finding goshawk was greater than zero, but where the odds were less than expected, given the area to be searched. Class 3 consisted of areas where nest sites were not observed.

We used the PFA information to stratify areas belonging to each of the three probability classes. The goal of this refinement was to determine areas within each probability class that had PFA characteristics closely resembling the PFA characteristics of the nest sites. In preparation for this step, the average PFA vegetation frequency counts were determined for cells in the study area belonging to each of the three probability classes individually (Table 7). The cell counts for each vegetation class were then standardized using the mean and standard deviation of cell counts across the three combined classes (Table 7).

Using this prepared standardized PFA information, an algorithm was utilized to assign each grid cell in the map to a predicted "nest site similarity class". The algorithm generated three indicators for every cell in the study area. The first indicator placed the cell into either Class 1, Class 2, or Class 3, depending on the

TABLE 7. VEGETATION COMPOSITION OF POST FLEDGLING FAMILY AREAS (PFA) FOR THREE BROAD PROBABILITY CLASSES AND NEST SITES USED IN MODEL IV. VALUES USED TO NORMALIZE FREQUENCIES ARE ALSO SHOWN

PFA vegetation class component	Mean grid cell frequency				Normalizing values (pooled classes 1 through 3)	
	Class 1 (cells)	Class 2 (cells)	Class 3 (cells)	Nest sites (cells)	$\bar{X}$ (cells)	SD
Aspen	5.1	0.7	4.2	4.4	3.4	12.69
Aspen/conifer	12.4	4.7	14.4	24.7	10.7	13.59
Pinyon pine/juniper	12.1	40.3	18.0	10.3	23.1	31.87
Ponderosa pine (high density)	11.6	10.3	15.0	30.8	12.4	15.51
Mixed conifer (low density)	10.0	1.3	9.7	6.6	7.2	14.42
Mixed conifer (high density)	19.4	3.2	38.7	39.0	21.4	31.80
Nonforested	53.1	85.8	36.4	24.2	57.3	42.44
Ponderosa pine (low density)	10.6	7.8	10.6	7.3	9.7	11.95
Ponderosa pine/mixed conifer transition	8.4	5.9	10.5	15.9	8.4	8.76
Ponderosa pine/juniper transition	10.3	1.5	6.8	4.0	6.3	12.21

observed–expected difference associated with the cell's vegetation and elevation class. The second indicator was the observed–expected difference itself, rounded off to an integer. The third was a "flag" that indicated whether the cell had PFA vegetation composition characteristics similar to one of the 30 nest sites, or more similar to the average PFAs of either Class 1, Class 2, or Class 3 (see Table 7). Euclidean distance was used to measure similarity; the smaller the Euclidean distance the greater the similarity. Table 8 shows the search order built from these indicators.

RESULTS

Table 9 shows the results of the four models for the entire Forest. The model based on vegetation class requires 49.6% of the forest to be searched to account for 95% of the known nest sites (i.e., 28.5 nests) whereas the elevation-based model requires only 37.0% of the forest be searched to account for the same number. The third model, which takes into consideration both

TABLE 8. ORDER OF SEARCH ACCORDING TO MODEL IV. MODEL LOGIC IS CAPABLE OF PRODUCING MORE CLASSES, BUT ONLY THE FIRST 20 ARE SHOWN IN THE TABLE. (PFA = POST FLEDGLING FAMILY AREA)

Order of search	Known goshawk nest sites observed (N = 30)	Probability class	PFA vegetation composition most similar to	Rounded observed − expected difference[1]
1	4	Class 1	Nest site	3
2	2	Class 1	Nest site	2
3	15	Class 1	Nest site	1
4	4	Class 1	Nest site	0
5	0	Class 1	Class 1	3
6	0	Class 1	Class 1	2
7	1	Class 1	Class 1	1
8	1	Class 1	Class 1	0
9	2	Class 2	Nest site	0
10	1	Class 2	Nest site	−1
11	0	Class 2	Class 1	0
12	0	Class 2	Class 1	−1
13	0	Class 3	Nest site	0
14	0	Class 3	Nest site	−1
15	0	Class 3	Nest site	−2
16	0	Class 3	Nest site	−5
17	0	Class 3	Class 1	0
18	0	Class 3	Class 1	−1
19	0	Class 3	Class 1	−2
20	0	Class 3	Class 1	−5

[1] Values are missing from sequence because they were not obtained in this study area.

TABLE 9. MODEL RESULTS SHOWING HOW MUCH OF THE FOREST REQUIRES SEARCHING TO LOCATE A SPECIFIC NUMBER OF KNOWN GOSHAWK NEST SITES

	Model I—based on elevation			Model II—based on vegetation			Model III—based on vegetation and elevation			Model IV—based on vegetation, elevation, and PFA composition		
Search order	Goshawk nest sites observed (N = 30)	Study area searched (%)	Cumulative study area searched (%)	Goshawk nest sites observed (N = 30)	Study area searched (%)	Cumulative study area searched (%)	Goshawk nest sites observed (N = 30)	Study area searched (%)	Cumulative study area searched (%)	Goshawk nest sites observed (N = 30)	Study area searched (%)	Cumulative study area searched (%)
1	13	9.9	9.9	8	7.9	7.9	4	1.2	1.2	4	0.9	0.9
2	5	5.1	14.9	6	4.7	12.6	2	0.6	1.8	2	0.4	1.2
3	5	6.0	20.9	3	3.9	16.5	3	2.5	4.3	15	6.2	7.4
4	4	8.7	29.6	2	2.7	19.2	1	0.2	4.5	4	4.4	11.8
5	0	1.1	30.7	2	4.4	23.6	2	1.7	6.2	0	0.1	11.9
6	0	1.2	32.0	1	1.1	24.7	1	0.3	6.5	0	0.1	12.0
7	0	2.0	33.9	1	3.4	28.1	1	0.3	6.8	1	0.7	12.7
8	0	2.1	36.0	4	14.8	42.9	1	0.4	7.2	1	0.3	13.0
9	0	2.2	38.1	0	1.8	44.7	1	0.4	7.6	2	0.9	13.9
10	0	4.0	42.2	3	55.3		1	0.5	8.0	1	0.7	14.6
11	3	14.8	57.0				1	0.5	8.5	0	0.2	14.8
12	0	6.7	63.6				1	0.6	9.1	0	<0.1	14.8
13	0	8.2	71.9				1	0.6	9.7	0	4.4	19.2
14	0	13.3	85.1				1	0.7	10.4	0	2.7	22.0
15	0	14.9					1	0.7	11.1	0	1.2	23.0
16							1	0.8	11.9	0	1.0	24.0
17							2	2.3	14.2	0	0.4	24.4
18							1	1.0	15.2	0	0.4	24.8
19							1	1.2	16.3	0	0.2	25.0
20							0	0.1	16.4	0	0.1	25.1[2]
21							0	0.1	16.5			
22							0	0.1	16.6			
23							0	0.1	16.8			
24							0	0.2	16.9			
25							2	3.2	20.1[1]			

[1] Search order continues to 41 (see Table 6). One goshawk nest site would be placed in search order position 39 with a corresponding cumulative forest area value of 92.4%.
[2] List continues, but all known goshawk nests sites have been accounted for.

cell elevation and vegetation class concurrently, provides a much more efficient map product; only 19.3% of the forest needs to be searched to locate 95% of the goshawk nest sites. The fourth model, which added the PFA information to the other two criteria, was the best performer. In this case 95% of the nest sites are found within only 13.7% of the forest.

DISCUSSION

We learned several things from the four models. We learned that elevation class was a more efficient predictor of goshawk nest sites than was vegetation class. We learned that vegetation class or elevation class alone were less efficient predictors of goshawk nest site location than was the combination of the two. We also learned that the vegetation composition of the PFA provides a small improvement in the model efficiency when employed as a predictor in a heuristic fashion.

Based on the results of the second and third models, the most important vegetation classes for search are apparently the high density mixed conifer and all the ponderosa pine classes. Ignoring any other factor, 63% of the goshawk nest sites are located within these classes, and their density is greater than expected given the area required to search. Nearly half the known goshawk nest sites are also between 2500 and 2650 m. A nesting site search of this elevation zone has good probability of success as well. If we were limited to searching a small acreage zone with the highest probability of success, we would select high density ponderosa pine and mixed conifer between 2500–2650 m; 20% of the known goshawk nest sites are located in this small percentage (4.8%) of forest.

Although the fourth model places 95% of the known goshawk nest sites within 13.7% of the forest, the model can be improved; nest site slope, aspect, and proximity to water will be variables added in the near future. We expect this information will more completely delimit the high priority search areas.

We are also verifying the model using two methods: ground verification and simulation. To facilitate ground verification, the computer will select random locations within the classes defined by Model IV (see Table 8). To insure adequate coverage, these locations will be allocated proportionally among the spatial areas of each class. We will then visit each in turn and search for goshawk nests using the methods described previously. Nest-finding success rates will then be compared to expected random occurrence rates and evaluated statistically for agreement. Furthermore, nest sites that were located after the modeling process was initiated will be used to validate the predictive value of the model. We will also attempt to verify the models using bootstrap simulation processes described by Willmott et al. (1985). These computationally intensive simulation methods allow for the inclusion of all the training data while withholding half for verification. Estimates of bias and standard error are produced as well.

Should verification prove our fourth model to be sufficiently accurate, it may be possible to predict the goshawk population within the Dixie National Forest and establish confidence intervals for that prediction. Application of this modeling process in forests with different attributes should be attempted and compared to the results obtained within this study area.

LITERATURE CITED

BLALOCK, H. M. 1979. Social statistics. McGraw-Hill, New York, NY.

CROCKER-BEDFORD, C. 1990. Goshawk reproduction and forest management. Wildl. Soc. Bull. 18:262–269.

FIENBERG, S. E. 1980. The analysis of cross-classified categorical data. MIT Press, Cambridge, MA.

KENNEDY, P. L., AND D. W. STAHLECKER. 1993. Responsiveness of nesting Northern Goshawks to taped broadcasts of three conspecific calls. J. Wildl. Manage. 57:249–257.

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. USDA Forest Service, Gen. Tech. Rep. RM-217, Ft. Collins, CO.

SPATH, H. 1980. Cluster analysis algorithms. Halsted, New York, NY.

SPATH, H. 1985. Cluster dissection and analysis: theory, FORTRAN programs, examples. Ellis Horwood, West Sussex, U.K.

US DEPARTMENT OF INTERIOR. 1991. Endangered and threatened wildlife and plants; animal candidate review for listing. Fed. Reg. 56:58804–58836.

WILLMOTT, C. J., S. G. ACKLESON, R. E. DAVIS, J. J. FEDDEMA, K. M. KLINK, D. R. LEGATES, J. O'DONNELL, AND C. M. ROWE. 1985. Statistics for the evaluation and comparison of models. J. Geophys. Res. 90:8995–9005.