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INFLUENCE OF SITE QUALITY AND STAND DENSITY ON GOSHAWK HABITAT IN SOUTHWESTERN FORESTS

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Abstract. Current management guidelines for the Northern Goshawk (*Accipiter gentilis*) in the Southwest call for a mosaic habitat consisting of approximately 10 percent of the forest area in grass-forb/shrubs, 10 percent in 2.5–12.7 cm trees, 20 percent in 12.7–30.5 cm trees, 20 percent in 30.5–45.7 cm trees, 20 percent in 45.7–61.0 cm trees, and 20 percent in 61.0 cm and greater trees. This habitat mosaic was conceived as convenient categories to describe a generally balanced, ecologically sustainable, forest ecosystem. In reality, however, the vegetative structural percentages vary. We describe how differences in site quality and stand density affect vegetative structural stage percentage and forest age.

Key Words: *Accipiter gentilis*; forest regulation; Northern goshawk; site quality; stand density, SDI; vegetative structural stages.

A goshawk scientific committee developed recommendations for managing the Northern Goshawk (*Accipiter gentilis*) in the southwestern United States (Reynolds et al. 1992). These recommendations focused on developing and maintaining forest conditions to provide habitat for sustaining goshawks and their key prey species. The recommendations defined size, location, stand structure, woody debris, and soil condition requirements for nest, post-fledging family, and foraging areas. Stand structure included such properties as the proportion and distribution of six different diameter classes or vegetative structural stages (VSS), and number of large (>46 cm) trees, snags, and down logs per ha.

Reynolds et al. (1992) recommended a mosaic of vegetative structural stages interspersed throughout the post-fledging family and foraging areas in small, less than 1.7 ha patches to form a balanced, ecologically sustainable, uneven-aged forest. Vegetative structural stage is a generalized description of forest structure and age based on the majority of trees in a specific diameter class within the forest (Table 1). The mosaic included patches ranging from grass-forb/shrub to old forests, with a high priority on sustaining as much as 40 percent of the area in mature and old forests. The recommended average proportion was about 10 percent of the goshawk management area (14,820 ha) in grass-forb/shrubs, 10 percent in 2.5–12.7 cm (1–5 in.) trees, 20 percent in 12.7–30.5 cm (5–12 in) trees, 20 percent in 30.5–45.7 cm (12–18 in) trees, 20 percent in 45.7–61.0 cm (18–24 in) trees, and 20 percent in 61.0 cm (24 in) and greater trees.

In this paper, we examine how differences in site quality and stand density influence VSS percentage and forest age. This paper also describes the impacts of varying VSS proportions within goshawk management areas to goshawk habitat and their key prey species.

FOREST DEVELOPMENT

Reynolds et al.'s (1992) recommended VSS and forest mosaic can be approached by traditional, even-aged area regulation. Area regulation consists of dividing the forested post-fledging family and foraging areas into as many ≤1.7 ha patches as there are years in the expected life of a forest (forest age) and regenerating an equal percentage of the forest each entry period (Smith 1986). The entry period could vary from 10 to 20 years depending upon existing forest conditions.

Three basic principles apply to area regulation. First, structural stages become important to sustain a forest over time, even where the desired condition is to have large, old trees. Second, new trees must be established at regular intervals to sustain the desired structural stages in a forest through time. Third, forests are dynamic. Trees regenerate and grow at different rates and die at different ages, resulting in a forest that is constantly changing over time (Oliver and Larson 1990).

Four variables that affect VSS distribution and forest age are: (1) length of stand establishment period, (2) site quality, (3) stand density, and (4) tree longevity.

STAND ESTABLISHMENT

Length of stand establishment varies by species, regeneration method (natural or planting), amount and kind of forest floor disturbance, and climatic variation. The observed stand establishment period (or years in VSS 1) for ponderosa pine (*Pinus ponderosa*) forests can range from 15 years on a highly productive site to 30 years on

TABLE 1. VEGETATIVE STRUCTURAL STAGES AND THEIR DIAMETERS

Vegetative structural stage	Forest description	Diameters[1] (cm)
1	Grass-forb/Shrub Opening	0–2.5
2	Seedling/Sapling	2.5–12.7
3	Young	12.7–30.5
4	Mid-aged	30.5–45.7
5	Mature	45.7–61.0
6	Old	>61.0+

[1] Tree diameter measured at 1.4 m above ground level.

a poor site. Generally, south- to west-facing, dryer slopes with shallow soils require the longest seedling establishment period; north-facing, more mesic sites with deeper soils require the least time. Under similar topographic and soil conditions, sites where annual precipitation is usually less require more time than when moisture is more plentiful.

SITE QUALITY

Site quality influences tree growth and varies greatly in the Southwest. Site quality denotes the relative productivity of a site for a particular tree species (Ford-Robertson 1971). Factors that influence site quality include soil characteristics, mineral composition, slope, aspect, microclimate, and tree species (Daniel et al. 1979). Site index is useful to help quantify site quality, and refers to the average height of dominant and codominant trees in a stand at an arbitrarily chosen age. Minor (1964) developed site index curves for ponderosa pine in northern Arizona, measuring age at 1.4 meters above ground level using a chosen base age of 100 years. For example, a site index of 70 (a tree 21.3 m [70 ft] tall at 100 years of age at 1.4 m above ground level) is considered about average for ponderosa pine in the Southwest. Thus, the length of time required for trees in each VSS is a function of site quality and stand density (Table 2).

A forest growth simulator model (Edminster et al. 1991) was used to project diameter growth per decade (Table 2) for two key stand densities: (1) Stand density index (SDI) 113 (25% of maximum SDI 450 for ponderosa pine); and (2) 157 SDI (35% of maximum SDI). The first level is considered to be the onset of competition between trees, whereas the second is the lower limit of full site occupancy (Long and Daniel 1990). Stand density index is the number of trees at an average stand density of 25.4 cm (10 in) (Daniel et al. 1979, Lilliholm et al., this volume).

During modeling, the growth of 500 ponderosa pine seedlings and 4 large reserve trees (trees > 46 cm dbh) were simulated over a 320-year period at SDIs of 113 and 157. Four reserve trees were allowed to die (snag creation) at stand age 30, and thereafter thinning from below, to the specified SDI, was allowed at 20-year intervals, starting at stand age 40 years.

Generally, seeding/sapling and young trees have a faster diameter growth rate than mature and old trees (Table 2). The time it took for a tree to move through one VSS ranged from 11 to 59 years for 25% maximum SDI, and from 11 to 95 years for 35% maximum SDI depending on the site quality and VSS. Also, it takes longer to grow through a stage on the low productivity sites than on high productivity sites; the exception was VSS 3 on average and high sites.

STAND DENSITY

Stand density influences tree diameter growth. On sites with the same site quality, tree diameter growth will vary with different management intensities. For example, the number of years in VSS 4, 5, and 6 are longer for the higher stand density (35% SDI) than for the lower stand density (25% SDI). The growth simulator model showed no differences in number of years for VSS 2. The seedling establishment period for low (30 years), average (20 years), and high (15 years) site quality was assumed to be equal for the two densities.

Stand density and site quality also influence VSS percentage and the time required to achieve the desired forest structure for goshawks and their prey species (Tables 3 and 4). One desired forest structure condition is to maintain 40% of the goshawk post-fledging family and foraging areas in VSS 5 and 6 to sustain moderate to high populations of key prey species. These older age classes maintain the most species at an abundant population level (10 of 12 species found in ponderosa pine forests: i.e., woodpeckers, chipmunks, tassel-eared squirrels) (Reynolds et al. 1992). Since forest stands reach VSS 5 and 6 from 30 to 70 years earlier in stands with lower density (25% SDI), the desired forest structure could be maintained for a longer period of time. Older-aged stands (>200 years) are also more frequently used as goshawk nest sites. Because nest sites have a higher density of large trees, these areas should be managed for even higher density stands (43% SDI).

Actual VSS percentage varies from the recommended 10-10-20-20-20-20 (Reynolds et al. 1992). For example, the VSS percentage for a low quality site with 25% SDI is 12-9-18-17-23-21 and for a high quality site with 25% SDI, VSS is 9-6-22-19-22-22 (Table 3).

TABLE 2. ESTIMATED DIAMETER GROWTH AND NUMBER OF YEARS IN EACH VEGETATIVE STRUCTURAL STAGE (VSS) FOR DIFFERENT QUALITY PONDEROSA PINE SITES AND STAND DENSITIES IN THE SOUTHWEST

Vegetative structural stages	Site quality[1]	Stand density[2]			
		Diameter growth per decade (cm)		Approximate years in each VSS	
		25% Max SDI	35% Max SDI	25% Max SDI	35% Max SDI
1	Low	Seedling	Seedling	30	30
	Average	estabishment	establishment	20	20
	High	period	period	15	15
2	Low	4.32	4.32	24	24
	Average	6.86	6.86	15	15
	High	9.40	9.40	11	11
3	Low	3.68	3.05	48	58
	Average	4.83	4.32	37	41
	High	4.75	4.24	37	42
4	Low	3.48	2.79	44	55
	Average	4.06	3.25	38	47
	High	4.83	3.63	32	42
5	Low	2.59	1.60	59	95
	Average	3.63	2.44	42	63
	High	3.99	2.97	38	51
6	Low	1.52	1.27	—[3]	—[3]
	Average	2.08	1.70		
	High	2.52	2.08		

[1] Site quality (Minor 1964). Low = 50 SI (SI = site index – dominant tree height at 100 years), Average = 70 SI, High = 90 SI.
[2] Stand density index (SDI) is the number of trees of average stand diameter of 25.4 cm. 25% max SDI = onset of competition; 35% max SDI = lower limit of full site occupancy.
[3] Years in VSS 6 depends on the selected forest age.

TREE LONGEVITY

Tree longevity influences forest life expectancy and forest age required to achieve desired forest structure. The lifespan of trees varies within and between species. For example, the oldest known living ponderosa pine tree in the Southwest was found to be 742 years old (Swetnam and Brown 1992), whereas the average life expectancy of most ponderosa pine is closer to 200 years or less (Pearson 1950, White 1985, Covington and Moore 1991). Life expectancy for Engelmann spruce (*Picea engelmannii*) ranges from 250–450 years (Alexander and Shepperd 1990). The life expectancy of the typical tree would be more appropriate to set targets for sustaining forests then the age of the oldest tree. Tree species and

TABLE 3. ESTIMATED DIAMETER GROWTH, YEARS IN VEGETATIVE STRUCTURAL STAGE, ACCUMULATED AGE, AND PERCENT OF LANDSCAPE IN EACH VSS FOR PONDEROSA PINE ON LOW, AVERAGE, AND HIGH QUALITY SITES WHERE STAND DENSITY IS 113 SDI (25% MAX SDI)[1]

Site quality		Vegetative structure stages					
		VSS 1	VSS 2	VSS 3	VSS 4	VSS 5	VSS 6[2]
Low (50 SI)	Diameter growth/decade	0	4.32	3.68	3.48	2.59	1.52
	Years (Acc-years)[3]	30 (30)	24 (54)	48 (102)	44 (146)	59 (205)	55 (260)
	% in VSS	12	9	18	17	23	21
Average (70 SI)	Diameter growth/decade	0	6.86	4.83	4.06	3.63	2.08
	Years (Acc-years)[3]	20 (20)	15 (35)	37 (72)	38 (110)	42 (152)	48 (200)
	% in VSS	10	8	18	19	21	24
High (90 SI)	Diameter growth/decade	0	9.40	4.75	4.83	3.99	2.52
	Years (Acc-years)[3]	15 (15)	11 (26)	37 (63)	32 (95)	38 (133)	37 (170)
	% in VSS	9	6	22	19	22	22

[1] Maximum stand density index for ponderosa pine is 450.
[2] Number of years in VSS 6 is determined by selecting a growth period that is approximately 20% of forest age.
[3] Number of years in VSS and accumulated years.

TABLE 4. ESTIMATED DIAMETER GROWTH, YEARS IN VEGETATIVE STRUCTURAL STAGE, ACCUMULATED AGE, AND PERCENT OF LANDSCAPE IN EACH VSS FOR PONDEROSA PINE ON LOW, AVERAGE, AND HIGH QUALITY SITES WHERE STAND DENSITY IS 157 SDI (35% MAX SDI)[1]

Site quality		Vegetative structural stages					
		VSS 1	VSS 2	VSS 3	VSS 4	VSS 5	VSS 6[2]
Low (50 SI)	Diameter growth/decade	0	4.32	3.05	2.79	1.60	1.27
	Years (Acc-years)[3]	30 (30)	24 (54)	58 (112)	55 (167)	95 (262)	65 (327)
	% in VSS	9	7	18	17	29	20
Average (70 SI)	Diameter growth/decade	0	6.86	4.32	3.25	2.44	1.70
	Years (Acc-years)[3]	20 (20)	15 (35)	41 (76)	47 (123)	63 (186)	44 (230)
	% in VSS	9	7	18	20	27	19
High (90 SI)	Diameter growth/decade	0	9.40	4.24	3.63	2.97	2.08
	Years (Acc-years)[3]	15 (15)	11 (26)	42 (68)	42 (110)	51 (161)	39 (200)
	% in VSS	7	6	21	21	25	20

[1] Maximum stand density index for ponderosa pine is 450.
[2] Number of years in VSS 6 is determined by selecting a growth period that is approximately 20% of forest age.
[3] Number of years in VSS and accumulated years.

longevity must be considered when considering an older forest age.

By decreasing or increasing forest age, VSS percentage is changed. For example, if the forest age on the low productive site was lowered from 327 to 250 years, the VSS percentage would change from 9-7-18-17-29-20 to 12-10-23-22-33-0 (Table 4). VSS 6 may not be achievable if a 327-year forest age is not ecologically sustainable. This should not influence goshawks, given the average life expectancy of ponderosa pine and that sites with low productivity (SI $\leq$ 50) account for only 2.3% (N = 4 national forests) of ponderosa pine stands in the Southwest (USDA 1993). Planning for forest ages less than 200 years, however, could negatively impact goshawks and their prey populations. Regardless of site quality or stand density index (25% or 35%), forests less than 200 years will not provide for the older classes (VSS 5 and 6) (Tables 3 and 4). Suitable goshawk nesting habitat is commonly composed of older trees (>200 years) in the VSS 5 and 6. Prey species like the Red-naped Sapsucker (*Sphyrapicus nuchalis*) and Williamson's Sapsucker (*Sphyrapicus thyroideus*) would lose 66% of the forest structure conditions that maintain high populations (Reynolds et al. 1992). Forests without VSS 5 and 6 would also not provide the large snags that are used by other nesting-cavity prey species.

SUSTAINING GOSHAWK HABITAT

Not all structural stages are equally important for the goshawk and its prey species, but all structural stages are equally important for a forest to become established and to sustain itself from the grass-forb/shrub stage (VSS 1) with seedlings through the old forest stage (VSS 6). The traditional area even-aged method of regulating a forest can be applied successfully to sustain a forest with the mosaic of VSS that will meet the habitat needs of the goshawk and its key prey species.

Of 12 goshawk prey species found in ponderosa pine forests, openings (VSS 1) are of no importance to 5 prey species (i.e., sapsuckers, tassel-eared squirrel), and important to 1 prey species (cottontail) for maintaining high populations. For only 1 prey species (tassel-eared squirrel) found in the ponderosa pine forests younger-aged forests (VSS 3) are important, and only when larger,

TABLE 5. APPROXIMATE PERCENT IN EACH VEGETATIVE STRUCTURAL STAGE (VSS) AND FOREST AGE THAT CAN BE EXPECTED TO OCCUR IN GOSHAWK POST-FLEDGING FAMILY AND FORAGING AREAS OF AVERAGE SITE QUALITY FOR PONDEROSA PINE FOREST TYPE AND MANAGEMENT INTENSITIES (REYNOLDS ET AL. 1992)

Management intensity	Percent in each vegetative structural stage						Forest age (years)
	VSS 1	VSS 2	VSS 3	VSS 4	VSS 5	VSS 6	
No management[1]	10	10	80	0	0	0	200
Minimal	9	13	20	17	20	21	233
Moderate	10	10	19	17	20	24	204
Intensive	10	8	18	17	21	26	194

[1] Unthinned ponderosa pine stand at Fort Valley Experimental Forest (Reynolds et al. 1992). An unthinned stand, using GENGYM growth and yield model, never grew beyond VSS 3 with a 200-year forest age (Ronco et al. 1985, Edminster et al. 1991).

older trees are available for nesting and seed sources (Reynolds et al. 1992).

Under varying management options, VSS percentages never attain 10-10-20-20-20-20. The youngest forest age (shorter time span) occurs under intensive management; oldest forest age (longest time span) occurs under minimal management (Table 5). Minimal management level is characterized by trees that are significantly competing with one another. When management intensities are at moderate and intensive levels, trees develop without significant competition. Without management, however, unthinned ponderosa pine stands of average site quality are unlikely to grow beyond the young forest structural stage (VSS 3), even after 200 years (Ronco et al. 1985, Edminster et al. 1991).

To provide the desired forest conditions of large old trees over 40% of the goshawk management area and small forest openings for prey species and tree regeneration, entry periods for management activities (i.e., harvesting, fire, etc.) would need to be about every 20 years for the moderate level. An expected level of management intensity (stand density) must be determined prior to establishing the desired VSS proportions and forest age.

The recommended 10-10-20-20-20-20 VSS percentage is now being considered as a hard-and-fast rule by those implementing and reviewing timber sale projects. However, the 10-10-20-20-20-20 distribution was intended to describe approximate percentages of each VSS throughout the post-fledging family and foraging areas to sustain suitable goshawk habitat (Reynolds et al. 1992). The achievable VSS percentage should be determined by considering existing local factors that influence forest establishment and growth, expected management intensity, and tree longevity.

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Resource Ecology

MACROHABITAT SELECTION BY NESTING NORTHERN GOSHAWKS: IMPLICATIONS FOR MANAGING EASTERN FORESTS

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Abstract. Macrohabitat data from 16 Northern Goshawk (*Accipiter gentilis*) nest sites and 70 random sites in the New York–New Jersey Highlands were analyzed. Variables included distances to human habitation, paved road, water, wetlands, and forest openings, elevation, and slope, slope location, and slope aspect. Univariate tests revealed that macrohabitat was important to nest site selection in goshawks, since several variables were significantly different than random sites (distance to human habitation, paved roads, and elevation). In addition, slope aspect data revealed that nesting on southern aspects (SW, S, SE) was avoided. A full-model discriminant function analysis (DFA) was used to determine the extent of overlap between random sites and nest sites. The DFA was able to correctly classify 69% of nest sites and 79% of random sites, further demonstrating that macrohabitat plays an important role in nest site selection. A management model using stepwise DFA revealed that distance to paved road and elevation were the most important discriminating variables. These variables indicated that the goshawk may be an area-sensitive species, since smaller forest tracts bounded by paved roads were not used for nesting.

Key Words: *Accipiter gentilis*; area sensitive species; discriminant function analysis; macrohabitat; nest site selection; Northern Goshawk.

Most habitat studies of Northern Goshawks (*Accipiter gentilis*) in western Northern America have emphasized microhabitat features of the nest site, such as basal area, stand densities, canopy cover, or shrub cover (Hennesey 1978, Reynolds et al. 1982, Hall 1984, Moore and Henny 1983, Crocker-Bedford and Chaney 1988, Kennedy 1988, Hayward and Escano 1989). In the eastern deciduous forest biome, Speiser and Bosakowski (1987) found that macrohabitat (landscape level) features were also important parameters in nest site selection of Northern Goshawks when compared to random sites. Macrohabitat was also found to be an important component of nest site selection for Red-tailed (*Buteo jamaicensis*) (Speiser and Bosakowski 1988) and Red-shouldered hawks (*B. lineatus*) (Bosakowski et al. 1992a). In the East, wilderness forests are typically much smaller and are impacted more by highways, rights-of-way, and suburban development. As such, the suitability of nest sites may be highly influenced by the presence of these macro features of the environment. Thus, management plans based on microhabitat alone may include many unsuitable areas for nesting.

In this paper, we present an analysis of goshawk nest sites in the Northeast to determine which macrohabitat features are important components of nest site selection.

STUDY AREA AND METHODS

The study area was in the Highlands Physiographic Province of northern New Jersey and southeastern New York (315,780 ha) and was described in detail in Speiser and Bosakowski (1987) and Bosakowski et al. (1992b). Goshawk nests were located in the study area from 1976–1989. In addition to our own searches, we pursued all reports of possible goshawk nesting from *Records of New Jersey Birds*, local naturalists, and forestry personnel.

Habitat data were collected as described in Bosakowski et al. (1992b) for 16 Northern Goshawk nests and for 70 random sites described in Speiser and Bosakowski (1988). Macrohabitat variables included distances to human habitation, paved road, water, wetland (>0.5 ha), and forest opening (>1 ha), and elevation, slope (over a 150-m baseline centered through the site), slope location rating (0 = no slope, 1 = lower slope, 2 = middle slope, 3 = upper slope) and slope aspect (8 classes).

All data were analyzed on a personal computer using NCSS software version 5.03 (Number Cruncher Statistical Software, Kaysville, Utah). Univariate tests were run separately for each variable comparing nest sites and random sites with an F-test and t-test. An unequal variance t-test was used (Winer 1971) when F-test results indicated significant differences in variance ($P < 0.05$). All variables were tested for normality using the test described by D'Agostino (1990). Random site variables were found to be non-normal, so all data were square root-transformed. This transformation normalized the data set prior to multivariate analysis.

The first stage in model building was to construct a correlation matrix to determine any problems of collinearity among variables. Titus and Mosher (1981) used a cut-off value of $r < 0.6$ to eliminate multicollinearity. Because the highest simple correlation in this study was only 0.54, all variables were retained for inclusion in a full-model discriminant function analysis (DFA). Discriminant scores were automatically

TABLE 1. MACROHABITAT VARIABLES FROM RANDOM SITES AND NEST SITES OF NORTHERN GOSHAWKS WITH UNIVARIATE COMPARISONS

	Random site (N = 70)		Nest site (N = 16)			
	$\bar{X}$	SD	$\bar{X}$	SD	F-test P value	t-test P value
Distance to (m)						
Paved road	501.9 ±	452.7	1170.6 ±	652.3	0.079	0.000
Human habitation	730.1 ±	516.5	1052.2 ±	634.7	0.314	0.034
Water source	250.8 ±	201.9	212.2 ±	106.2	0.004	0.288
Wetland	564.2 ±	552.0	326.8 ±	370.0	0.080	0.084
Forest opening	238.1 ±	210.0	263.8 ±	116.8	0.008	0.508
Elevation (m)	273.1 ±	84.2	342.9 ±	62.8	0.155	0.003
Slope (degrees)	8.67 ±	5.84	9.50 ±	8.15	0.108	0.637
Slope location (rank 0–3)	1.14 ±	1.12	1.06 ±	0.77	0.074	0.786

rescaled to a probability scale (0–1) by the NCSS program and were plotted to show the extent of group separation.

RESULTS

STATISTICAL RESULTS

Nest sites and random sites were significantly different for several macrohabitat variables (Table 1). Distance to paved road, distance to human habitation, and elevation were significantly different when comparing means. Unequal variances were found for distance to water and distance to forest opening, with nest sites showing lower variation in each case. Goshawks nested in all but southern aspects (SW, S, SE) (Fig. 1), resulting in a significantly different distribution from random sites (Kolmogorov-Smirnov Test, 2-tailed, $D = 0.875$, $P < 0.05$).

FULL-MODEL DISCRIMINANT FUNCTION ANALYSIS

Full-model DFA of the macrohabitat variables correctly classified 78.6% of the random sites and 68.8% of the goshawk nest sites. Conversely, there were 15 misclassified random sites (21.4%) and 5 misclassified nest sites (31.3%) (Table 2). Discriminant scores from all sites were plotted to show the pattern of separation between the groups as well as to demonstrate the pattern of overlap that resulted in misclassified sites (Fig. 2).

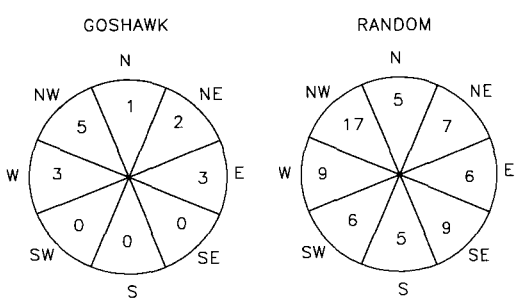

FIGURE 1. Slope aspects of Northern Goshawk nest sites and random sites. No aspect was determined for two nest sites and six random sites on level ground.

MANAGEMENT MODEL

Following the suggestion of Mosher et al. (1986), we also used a stepwise DFA to determine the most important discriminating variables in habitat selection. This test revealed that two of the original eight variables retained nearly the same Wilks' lambda value (Table 3), and that the prediction (classification) accuracy was also nearly the same. In this case, the nest site predictions remained the same, but one less random site was misclassified as a nest site.

DISCUSSION

Our results with discriminant models showed that goshawks do not select macrohabitat at random, as the majority of nest sites and random sites were correctly classified. Since random sites should include the whole spectrum of available habitat (suitable, marginal, and unsuitable habitat), a certain degree of overlap is expected between random site data and nest site data (Fig. 3). This overlap region includes all of the sites that the models had difficulty segregating between random and nest sites, which are typically known as misclassified sites (Fig. 2). Thus, the misclassified random sites included habitat that was both suitable and marginal for goshawk nesting, whereas the misclassified nest sites represented sites with marginal habitat for goshawks.

Overall, these results suggest that goshawks are selecting certain macrohabitat features for nesting in eastern forests, which means that nest site selection is not based entirely on forest stand

TABLE 2. SUMMARY OF FULL-MODEL DISCRIMINANT FUNCTION ANALYSIS OF SQUARE ROOT-TRANSFORMED MACROHABITAT VARIABLES FROM NORTHERN GOSHAWK NEST SITES AND RANDOM SITES

Variables	Canonical coefficients		
	Random site	Nest site	F-Prob
Distance to			
Paved road	0.286	0.427	<0.001
Human habitation	0.088	0.080	0.858
Water source	0.206	0.179	0.669
Wetland	0.329	0.316	0.727
Forest opening	0.029	0.097	0.308
Elevation	2.544	2.870	0.031
Slope	1.236	0.968	0.370
Slope location	−2.085	−1.992	0.440
(Constant)	−30.80	−39.69	
Wilks' Lambda = 0.7065			

characteristics. Additional investigations of Red-tailed Hawks (Speiser and Bosakowski 1988) and Red-shouldered Hawks (Bosakowski et al. 1992a) in the same study area also showed significant macrohabitat selection by these sympatric raptors, albeit each species exhibited different macrohabitat preferences. For the goshawk, this selectivity results in only a fraction of the total study area that is suitable macrohabitat for nesting, an important point for management and conservation in eastern forests. If the avoidance of southern aspects for nesting that we noted for 16 nests is verified with larger sample sizes, it may be possible to eliminate approximately 37.5% of management areas from future nest searches or habitat management.

The remote nature of goshawk nest sites was characterized by significantly longer distances to paved roads and human habitation. Higher elevations were also selected, possibly because the largest wilderness areas occurred only at higher elevations in the study area. These results indi-

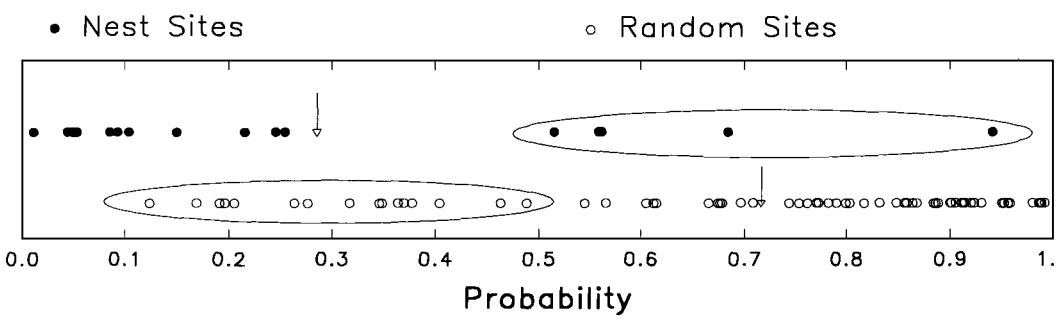

FIGURE 2. Discriminant score distribution for full-model DFA macrohabitat model of nest sites (N = 16) and random sites (N = 70). Data indicate probability of a site being a random site with arrows indicating group means. Circled sites represent the misclassified sites.

TABLE 3. SUMMARY OF STEPWISE DISCRIMINANT FUNCTION ANALYSIS (MANAGEMENT MODEL) OF SQUARE ROOT-TRANSFORMED MACROHABITAT VARIABLES FROM NORTHERN GOSHAWK NEST SITES AND RANDOM SITES

Variables	Canonical coefficients		
	Random site	Nest site	F-Prob
Distance to paved road	8.06	11.84	<0.001
Elevation	114.2	119.7	0.004
(Constant)	−144.7	−167.5	
Wilks' Lambda = 0.7253			

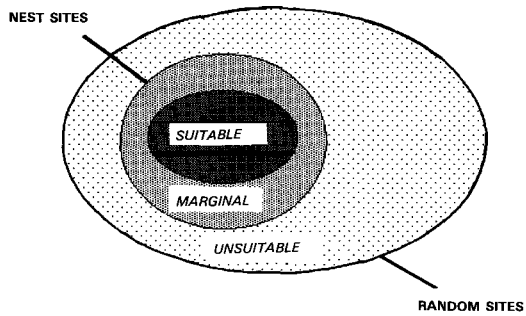

FIGURE 3. Random site and nest site domains for discriminant models in relation to habitat suitability.

cate that the goshawk is an area sensitive species, requiring large blocks of forested habitat since the study area was very nearly covered by contiguous forest. Robbins et al. (1989) demonstrated that area sensitivity was a phenomenon for many breeding bird species in the eastern deciduous forest. In our study, goshawks rarely nested in smaller forest tracts, which underscores the important effect of macrohabitat on breeding bird occurrence in eastern forests. In eastern forests this effect appears to stem from encroaching urbanization.

As a management model for eastern forests, the stepwise DFA indicated that only two of the original eight variables (distance to paved road and elevation) are needed to predict suitable macrohabitat for nesting goshawks. This reduction in the number of variables could speed the search for suitable macrohabitat and managers could apply these two variables to a sampling grid-system of random points on study area maps. With the advent of Geographic Information Systems and digital elevation models, rapid identification of suitable nesting areas is now possible and there may be less need to eliminate variables from consideration. Once suitable macrohabitat blocks have been identified, it would be prudent to conserve these areas from logging and development to preserve mature and old-growth stands which are preferred for nesting (Speiser and Bosakowski 1987).

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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

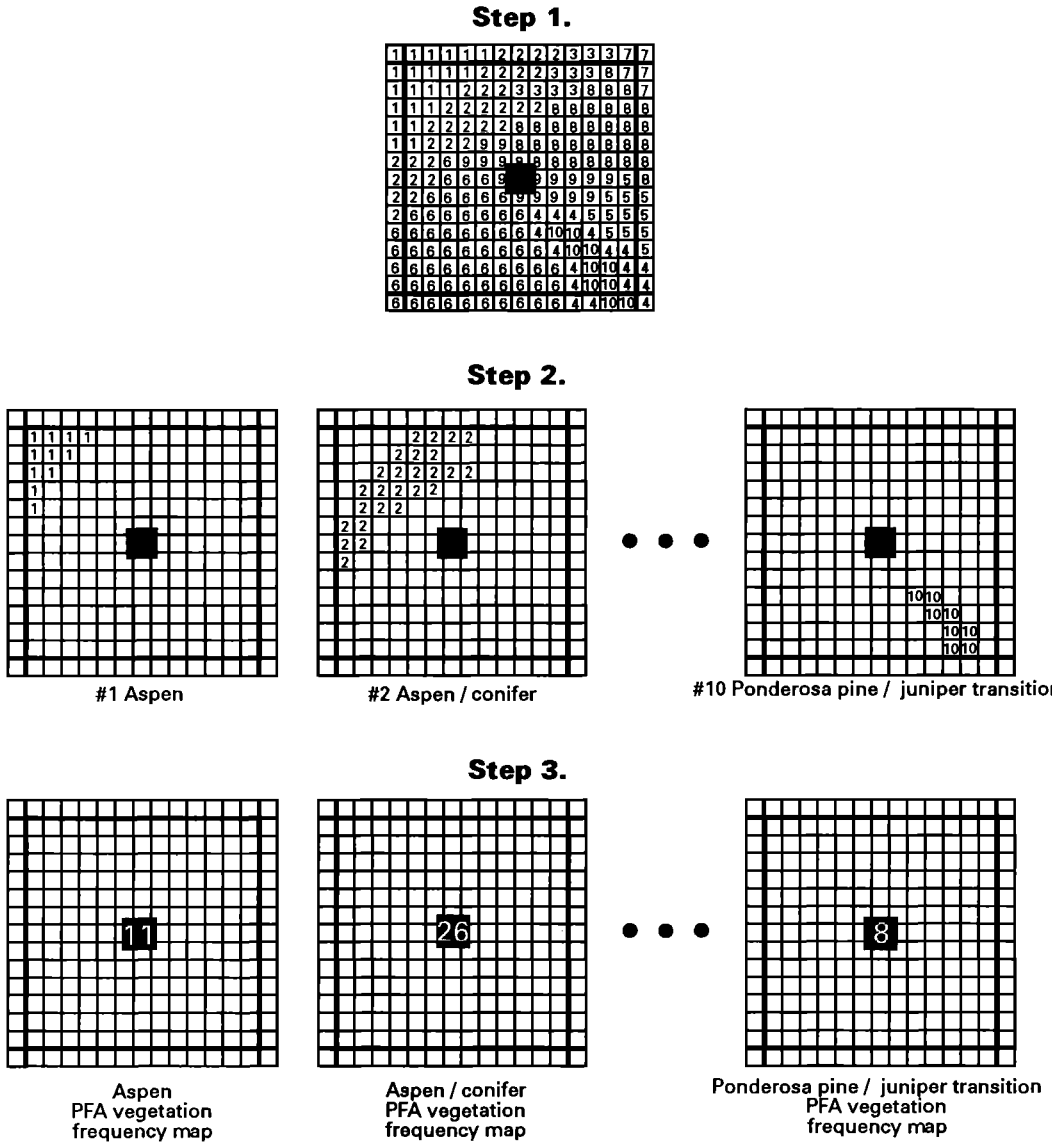

FIGURE 1. PFA value calculation for a single cell in the vegetation map is a three step process. In performing this calculation for every cell in the study area, the "sliding window" is placed over each cell successively, and the three step process is repeated. Step 1: A sliding window defining the PFA 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

Order of search	Elevation class	Known goshawk nest sites (N = 30) 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

Order of search	Vegetation class	Known goshawk nest sites (N = 30) 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) Observed	Observed minus expected	Nesting site vegetation class	Elevation class (m)
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.

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HABITAT USE BY BREEDING MALE NORTHERN GOSHAWKS IN NORTHERN ARIZONA

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Abstract. We radio-tagged and followed five and nine male Northern Goshawks (*Accipiter gentilis*) during the breeding seasons of 1991 and 1992, respectively, to evaluate their use of different forest conditions in managed ponderosa pine (*Pinus ponderosa*) forests in northern Arizona. Sufficient data for habitat analyses were collected for 11 birds located a total of 734 times. Mean size of the home ranges was 1758 ha (SD = 500 ha, range 896–2528 ha) calculated by the minimum convex polygon method, and 1530 ha (SD = 477 ha, range 859–2321 ha) calculated by the 95% harmonic mean method. We compared use (i.e., number of hawk locations) of several categories of forest conditions to the availability (i.e., % of area of home range) of these categories for three different overlays (canopy closure, edge, and diversity) generated from LANDSAT data. Most (≥6) of the 11 birds used the categories in the three overlays approximately in proportion to their availability. Six of the 11 birds used at least one category on one of the overlays nonrandomly. Of these, three hawks used forests with relatively closed canopies more than expected; three used areas with relatively open canopies less than expected; four used woodland >200 m from edge more than expected; and one used areas with a high diversity of categories less than expected. When the categories of canopy closure were ranked for each bird on the basis of relative preference, average rank of preference increased with increasing canopy closure.

Key Words: *Accipiter gentilis*; habitat use; home range; LANDSAT imagery; Northern Goshawk.

Efforts to maintain habitat for the Northern Goshawk (*Accipiter gentilis*) in managed forests in western North America have focused on retaining stands of relatively large, old trees for nesting sites (Reynolds 1987). More complete conservation strategies for goshawks also need to address environments used for other activities, such as foraging (Reynolds 1983, Crocker-Bedford 1990). Current recommendations for managing forests for Northern Goshawks in the southwestern U.S. call not only for maintaining nest stands, but also for developing forest environments that support a variety of their prey species in a 2430 ha-area surrounding each nest (Reynolds et al. 1992).

Information from North America about the kinds of forest conditions used by foraging goshawks is limited. Fisher and Murphy (1986) radio-tracked a breeding pair of goshawks in Utah and concluded that the male occupied habitat nonrandomly by foraging predominantly in mature stands of Douglas-fir–white fir (*Pseudotsuga menziesii-Abies concolor*) forest. Austin (1993) radio-tracked ten goshawks (five males and five females) in northern California and found that they occupied meadows and stands of seedlings and saplings less than expected, and mature forest stands (dominant trees ≥ 52 cm in diameter at breast height, canopy closure ≥40%) more than expected, based on availability.

Kenward (1982) found that the European goshawk (*A. g. gentilis*) spent a disproportionately large amount of time in woodlands during the breeding season in agricultural areas of England and Sweden. In Sweden, goshawks used woodlands within 200 m of edge but avoided both unbroken woodland and extensive open areas (Kenward 1982). Widén (1989) radio-tracked goshawks in an intensely managed boreal forest in Sweden that contained a patchwork of stands of differing ages. Widén (1989) found that males and females both foraged in relatively large (>40 ha) tracts of forest >60 years of age.

Our objective in this study was to compare the availability and use of different forest conditions within the home ranges (Johnson 1980) of nesting male goshawks during the breeding season. Our statistical null hypothesis was that male goshawks used forest conditions within their home ranges randomly.

METHODS

STUDY AREA

The study was conducted on the North Kaibab Ranger District (NKRD), Kaibab National Forest, on the Kaibab Plateau in northern Arizona. The district encompasses ca. 259,000 ha and is located north of Grand Canyon National Park. Elevation of the NKRD ranges from 1060 to 2800 m. Topography of the plateau is typified by gentle slopes interspersed with shallow to deep drainages. Vegetation on the plateau is characterized by mixed-conifer forest (white fir, blue spruce [*Picea pungens*], Douglas-fir, and quaking aspen [*Populus tremuloides*]) at the highest elevations, ponderosa pine forest between 2075–2500 m, and pinyon-juniper-oak woodland (*Pinus edulis-Juniperus* spp.-*Quercus* spp.) at lower elevations. A detailed description of the plateau is given by Rasmussen (1941). We selected hawks to study that nested in areas dominated by ponderosa pine (about 99,200 ha on the plateau).

Telemetry

Personnel from the USDA Forest Service and Arizona Game and Fish Department had located nests of goshawks throughout the Kaibab Plateau prior to this study. We chose hawks to study based on four criteria: sex of the bird, topography and roads in the area around the nest, and forest type. Only males were studied because they provide between 80% and 90% of the prey consumed by the nestlings and because females spend the first half of the nestling period on or near the nest (Schnell 1958, Snyder and Wiley 1976, Reynolds and Meslow 1984, Kennedy 1991). Males were chosen from nests in areas that were relatively flat (although all areas were transversed by drainages), were dominated by ponderosa pine, and had a good system of roads. Flat areas with good roads were chosen to allow easy access to an entire home range. The hawks studied were not chosen randomly and therefore their use of forest conditions may not reflect that of the population of goshawks on the plateau.

Birds were trapped with falling-end Swedish goshawk traps (Kenward and Marcstrom 1983) and dhogaza traps (Clark 1981, Bloom 1987). Captured goshawks were banded with a US Fish and Wildlife Service band and a color band, and fitted with a two-stage radio transmitter (model TW-2 from BIOTRACK). The transmitters had posture-sensitive activity switches, weighed around 10 g, (less than 2% of the body weight of the birds), and were attached to tail feathers (Kenward 1978).

We located marked birds from 13 June–10 August 1991 and 8 June–9 August 1992. Monitoring began at least 36 hours after the radios were attached to allow the birds to become accustomed to the transmitter. During 1991, we tracked birds for one 4-hour period a day and attempted to locate the birds every half hour during this period. We rotated the 4-hour period so that each bird was monitored at different times of the day. In 1992, we attempted to locate each bird twice a day. Locations were obtained so that they were evenly distributed among all daylight hours. The change in data collection was made to maximize the number of statistically independent locations (Schoener 1981, Swihart and Slade 1985a) we could collect.

Locations were obtained by one of two methods: triangulation and direct observation. All observations of marked birds were recorded directly onto US Geological Survey (USGS) topographic maps. For locations obtained by triangulation, two observers with hand-held yagi antennas approached the bird until the sound of the signal at a specified gain value became distorted (ca. 50–200 m away). The observers then took positions which gave an angle to the bird between the two observers of 45–135 degrees. The observers then recorded the bearing to the bird and mapped their location on 7.5″ USGS topographic maps with the aid of a compass and by pacing to identifiable topographic features. Location of the bird was assumed to be where the two bearings crossed. Actions were coordinated between the observers with hand-held radios. Activity switches on the transmitters allowed observers to avoid attempting to triangulate on moving birds. Observers did not approach within 200 m of the nest while radio-tracking because the presence of humans near the nest caused the male to remain in the area, disrupting his normal activities.

Estimation of Location Error

We estimated the error associated with triangulations by following a protocol similar to that described by White and Garrott (1990) for estimating error of locations from airplanes. Transmitters were placed in a variety of topographic positions, stand conditions, and microsites to simulate locations of goshawks. Microsites included brush piles, logs, snags, and tree branches 0–10 m from the ground. The locations of the "test" transmitters were mapped by pacing and/or triangulating from known locations and visible topographic features. The error associated with the mapped locations of the test transmitters was small because they were placed near features that were clearly identifiable on topographic maps.

A pair of observers who did not place the test transmitter then located it by triangulation, following the procedure outlined above. Locations based on triangulation were converted to Universal Transverse Mercator (UTM) coordinates. The UTM coordinates of the triangulated position were then compared to the UTM coordinates of the position mapped by the team placing the transmitter. The distance between the triangulated position and the mapped position was then calculated and considered the error associated with location of that test transmitter. This distance incorporates error associated with triangulation and error associated with mapping the location of the observers. An average error for test transmitters was calculated for each year. We assumed that the average error associated with the location of the test transmitters was similar to the error associated with the location of hawks. Distances also were calculated from each observer to the triangulated location of the test transmitters and the hawks.

Home range

Sizes of home ranges were calculated using the minimum convex polygon (MCP) (Mohr 1947) and harmonic mean (HM) (Dixon and Chapman 1980) methods. All data, regardless of the time interval between consecutive locations, were used for the MCP calculations because this method does not require statistically independent locations (Swihart and Slade 1985b). For 1991, HM home ranges were calculated with a subset of the data that was not autocorrelated. We selected the subset by calculating the time to independence to the nearest 15 min using the Schoener ratio (Schoener 1981, Swihart and Slade 1985a), and then selecting locations that were separated by the minimum time to independence for each bird (60–135 min). All data for 1992 were used to calculate HM home ranges because the time between locations was much greater than the maximum time to independence determined in 1991. The grid size used in the calculation of harmonic mean home ranges was larger than the average error associated with the locations. Area-observation curves (Odum and Kuenzler 1955) were generated for each home range to ensure that the average increase in home range size was below 5% for the last ten locations recorded (Fuller and Snow 1988).

Habitat Categories

Digital elevation data (DEM) for the Kaibab Plateau were obtained from the USDA Forest Service, Kaibab National Forest. These data were used to create a slope map for the study area so that we could examine goshawk use of topographic positions. The slope map was classified into seven slope categories (1 = 0–2%, 2 = 3–5%, 3 = 6–10%, 4 = 11–15%, 5 = 16–20%, 6 = 21–25%, and 7 = >26%).

Satellite imagery from LANDSAT 5 was obtained from 22 June 1991. This scene included no cloud cover over the study area. We used the satellite imagery to identify forest conditions within the home ranges of the goshawks we studied. Our general approach was to classify the imagery and then assess what the classes represented with aerial photographs. We allowed the computer to search for "natural" groupings of spectral properties (i.e., an unsupervised classification [Jensen 1986:215]) produced by the reflectance in bands 3, 4, and 5. This procedure was conducted in the Geographical Resources Analysis Support System (GRASS) with a maximum likelihood discriminant analysis classifier. Cell size was 30-m by 30-m for all analyses.

Fifteen classes with different spectral signatures were delineated. We overlaid a map of the 15 classes on a sample of aerial photographs taken in July 1991 (scale 1:8000) to ascertain visually what the classes represented in terms of forest conditions. We found that, with one exception, the classes (1–15) corresponded to a continuum of increasing forest density. Our relatively small sample of hawk locations prevented us from evaluating use of 15 different classes so we lumped the classes into five categories that broadly represented the following forest conditions: (1) bare ground or occasional trees, (2) open savannah-like conditions, (3) open overstory with a dense deciduous understory (this category was the exception mentioned above and was distinguished primarily on the basis of vegetative composition), (4) moderate overstory, and (5) dense overstory.

We then used the aerial photos to define each of the five categories on the basis of canopy closure and to estimate how consistently measures of canopy closure separated the five categories. We chose canopy closure to define the categories because this measure appeared to reflect a major difference among the categories and could be estimated from aerial photos. For each home range for which aerial photos were available (N = 7), one photo was randomly chosen for examination. We first outlined the areas of all five categories on the seven photos. We then estimated canopy closure by measuring the amount of intercept of tree crowns along 199 lines each 20 mm long. The lines were randomly placed on the photos with the restrictions that they fall within the boundary of one category and not be within 2.5 cm of the edge of the photos. The later restriction was to reduce the effects of lens distortion. We used a single eyepiece magnifier (7× lens) with a 20-mm bar scale on an attached reticle to make the measurements. Canopy closure was calculated as the percent of the 20-mm line intercepted by tree crowns.

The five categories were defined to maximize the percent of line estimates in each category that would be correctly classified. Definitions were (1) 0–15% canopy closure (CC); (2) 15–33% CC; (3) <33% ponderosa pine canopy closure with a dense understory of aspen, oak, or locust; (4) 34–55% CC; and (5) >55% CC.

TABLE 1. Accuracy Matrix for the Classification of LANDSAT Imagery into Canopy Closure Categories within Northern Goshawk Home Ranges on the Kaibab Plateau, Northern Arizona, 1991–1992. Table Compares Agreement Among Categories Identified in an Unsupervised Classification of LANDSAT Imagery and Measurements of Canopy Closure Made on Aerial Photos

LANDSAT categories		Aerial photo canopy closure			
		<15%	15–33%	34–55%	>55%
<15%	31[1]	0.84	0.13	0.03	0.00
15–33%	52	0.13	0.72	0.15	0.00
34–55%	47	0.00	0.19	0.79	0.02
>55%	69, 37[2]	0.00	0.03	0.14	0.83

[1] Number of canopy closure estimates used to calculate percentages.
[2] Number of canopy closure estimates used to calculate percentages and number of stands of dense seedlings/saplings measured.

The accuracy of defining the five categories on the basis of canopy closure was estimated as the percent of the total number of line estimates for each category that fell in the ranges given above. One problem we noted was that dense, pure stands (>0.36 ha) of seedlings and small trees were classified as >55% CC. We measured the area of the dense, young stands on the sample of aerial photographs to obtain an estimate of how much they contributed to the total area of the >55% CC category (N = 37 patches totalling 40.0 ha) and added this to percent misclassification. Based on these estimates, we determined that measures of canopy closure from aerial photographs accurately defined 84% of the <15% CC category, 72% of the 15–33% CC, 79% of the 34–55% CC, and 83% of the >55% CC (Table 1). The category with <33% ponderosa pine overstory with an understory of oak, locust, or aspen occurred too rarely to assess accuracy adequately or to use in statistical analyses, so it was lumped with the 15–33% CC category.

Because measures of canopy closure from aerial photographs likely overestimate canopy closure on the ground (Brunnell and Vales 1989), we made some preliminary measurements on the ground to quantify the potential bias. Sixty-nine transects, each 100 m long, were laid out in areas representing four categories (17 in the <15% CC, 34–55% CC, and >55% CC categories, and 18 in the 15–33% CC category). Areas sampled and position of the transects were chosen randomly. Canopy closure was estimated along the transects by determining the percent of each transect that was covered by crowns of overstory trees (i.e., crown intercept). Preliminary measurements on the ground confirmed that our canopy closure categories represented areas with increasing canopy closure, but suggested that our measurements from aerial photographs overestimated canopy closure (measurements of canopy closure from the ground: <15% CC, $\bar{X}$ = 4.1%, range = 0–11.8%; 15–33% CC, $\bar{X}$ = 15.4%, range = 0–32.1%; 34–55% CC, $\bar{X}$ = 34.7%, range = 17.4–49.7%; >55% CC, $\bar{X}$ = 48.3%, range = 22.2–78.2%).

The map of canopy closure categories (i.e., canopy closure overlay) was used as a base map to create a habitat diversity overlay, a basic habitat overlay, and an edge overlay. The diversity map was created by performing a 5 × 5 cell neighborhood analysis on the canopy closure overlay. Each cell was approximately 30 m on a side so this analysis counted the number of different canopy closure categories found in a 2.25-ha square centered on a cell. Areas that were uniform (1 CC category), or had low (2 CC categories), moderate (3 CC categories), or high (4 or 5 CC categories) diversity were outlined on the diversity overlay.

The basic habitat overlay (HAB) was created by a two-step process. First an overlay was made by smoothing the original canopy closure overlay from the LANDSAT data. Smoothing consisted of two iterations of a 3 × 3 cell neighborhood analysis in which each cell of the new overlay was assigned the value of the most commonly occurring class in the 9-cell neighborhood. The smoothed overlay was then combined with a map from the USDA Forest Service that showed areas that were dominated by pinyon-juniper woodland. The resulting map (HAB) was equivalent to the smoothed habitat map except that all pinyon-juniper woodland was assigned a new value. The area of pinyon-juniper was too small to allow its inclusion in the statistical analyses, so based on its average canopy closure it was lumped with the 15–33% CC category.

The HAB overlay was used as the starting point to create the edge overlay. The 34–55% CC and >55% CC categories from the HAB overlay were lumped as "woodland" and the remainder of the classes were lumped as "open areas." The edge overlay was created by defining five new categories: open areas, woodland within 50 m of an open area, woodland 50–100 m from an open area, woodland 100–200 m from an open area, and woodland >200 m from an open area.

Analysis of Habitat Use

We included all independent locations of goshawks that were perched or observed flying below the canopy in the analyses of habitat use. We do not know what portion of the locations represented foraging behavior because we could not determine what the birds were doing in most instances. We assumed that our data would reflect the relative value of the categories for foraging. We made this assumption because we collected data during the nestling and fledgling periods, when foraging demands are highest and males must capture prey for the female and nestlings in addition to satisfying their own needs.

Analyses of use versus availability were conducted for each bird at two scales for each overlay, and then trends in relative preference among all birds were evaluated for each overlay. For the first scale, we compared the number of hawk locations in each habitat category (i.e., use) to the number expected if the hawks were using the categories randomly (i.e., based on the availability of the categories in the MCP home range). Second, we compared the area of each habitat category in 90-m radius circles centered on the locations of birds (i.e., used) to the area of each category available (i.e., expected) in the MCP home range. A radius of 90 m was chosen for three biological reasons and one practical reason. First, information from Europe suggests that *A. g. gentilis* may forage near edges (Kenward 1982) and we did not want to throw out all locations near edges (e.g., Call et al. 1992). Second, for some overlays, as many as three or four habitat categories occurred within 90 m of a hawk location and, given the error associated with triangulations, assigning all the weight to one category could bias the results. Third, goshawks do not forage only at a single point but scan the surrounding area for potential prey. This idea is supported by Kenward (1982), who found that attack flights averaged 54 m from perch to prey in woodland and 103 m in open areas. Finally, the value of 90 m was chosen because it was an even multiple of the 30-m cell size.

A chi-square goodness of fit test was used to test use vs. availability for the habitat and slope categories for individual birds, as discussed by Thomas and Taylor (1990). When chi-square tests were significant ($P < 0.05$), Bonferoni 95% confidence intervals were calculated to determine which categories differed from expected (Neu et al. 1974). For the 90-m circle analyses, the observed value for the chi-square test was calculated for a habitat category by summing the proportion of the area of each circle that was in that habitat category.

Patterns of habitat preference among all birds were evaluated by averaging the rank preferences of all hawks for each habitat category (i.e., a Friedman's test [Ott 1988]) as discussed by Alldredge and Ratti (1992) and Conover (1980) with one modification. Instead of testing the rank of the difference between the percent used and the percent available for each category, as done by Alldredge and Ratti (1992), we tested the rank of the relative preference (Chesson 1983) for each category. We used relative preference, as defined below, because it accounted for differences in availability of each habitat category among birds, and allowed us to compare the ranks of relative preferences among birds with different home ranges.

Relative preference (RP) was defined for each bird as follows:

$$RP = \frac{O_i/E_i}{\sum_{i=1}^{n} (O_i/E_i)},$$

where O_i = the observed proportional use of habitat category i, E_i = the expected proportional use of habitat category i, and n = the number of habitat categories used by one bird.

The resulting preference values have a range of 0 to 1 and sum to 1 for each bird. These values were ranked for each bird so that the least "preferred" habitat was given a value of 1 and the most "preferred" a value of 4 or 5 depending on the number of habitat categories. Mean ranks were then compared among habitat categories. When the Friedman's test was significant (i.e., a difference among mean ranks was detected), Fisher's least significant difference was calculated to determine which mean rankings differed significantly. For the remainder of the paper when we discuss which habitats are most or least preferred we shall be referring explicitly to the relative preference as defined above.

TABLE 2. SIZE OF HOME RANGE AS CALCULATED BY THE MINIMUM CONVEX POLYGON (MCP) AND HARMONIC MEAN (HM) METHODS, AND AVERAGE PERCENT INCREASE FOR THE LAST 10 LOCATIONS IN AREA-OBSERVATION CURVES (A/O%) FOR 11 MALE NORTHERN GOSHAWKS ON THE KAIBAB PLATEAU, NORTHERN ARIZONA, 1991–1992

			MCP home range		95% HM home range[1]	
Bird	Year studied	A/O (%)	Size (ha)	N	Size (ha)	N
66	1991	0.0	2444	86	2322	55
136	1991	3.3	1502	87	1041	39
141	1991	4.1	2528	59	1939	47
223	1992	3.7	1450	36	1020	35
237	1991	0.2	1630	42	1279	40
273	1992	0.0	1454	80	1191	80
274	1991	0.2	1478	68	1889	45
285	1992	0.3	2139	84	1903	79
333	1992	0.0	2190	59	1559	59
339	1992	2.8	897	60	860	60
342	1992	0.1	1623	73	1830	72
191	1992	68.4[2]	431	13	518	13
239	1992	NA[3]	14	9	393	9
292	1992	5.3	178	32	1439	32

[1] Sample sizes in this column are also sample sizes used for habitat analyses.
[2] Birds with % A/O >5.0 were not included in results of home range or habitat portion of this study.
[3] Not applicable.

TABLE 3. RANKS OF RELATIVE PREFERENCE OF FOUR CANOPY CLOSURE CATEGORIES FOR 11 MALE NORTHERN GOSHAWKS DURING BREEDING SEASONS OF 1991–1992 ON THE KAIBAB PLATEAU, NORTHERN ARIZONA (1 = LEAST PREFERRED AND 4 = MOST PREFERRED)

	Percent canopy closure[1]			
Bird	<15%	15–33%	34–55%	>55%
66	1/1	3/3	2/2	4/4
136	1/1	3/3	2/2	4/4
141	1/1	3/2	2/3	4/4
223	2/2	1/1	3/3	4/4
237	1/1	3/3	4/2	2/4
273	1/1	2/2	4/4	3/3
274	1.5/2	1.5/1	3/3	4/4
285	1/1	2/2	3/3	4/4
333	3/1	2/3	1/2	4/4
339	3/3	2/1	1/2	4/4
342	1/1	2/2	4/4	3/3

[1] Ranks are presented for locations/90-m circle.

RESULTS

ERROR

The average error associated with triangulations was 98.3 m (N = 48 test transmitters, SD = 134.0) in 1991, and 68.5 m (N = 116 test transmitters, SD = 58.2) in 1992, probably because the observers were better trained in 1992. In 1991, observers were significantly closer to test transmitters when they took bearings ($\bar{X}_t$ = 80.3 m, SD = 60.9) than they were to birds when they took bearings ($\bar{X}_b$ = 183.6 m, SD = 145.3, $P < 0.001$), but in 1992 there was no difference in this distance ($\bar{X}_t$ = 158.8, SD = 84.5, $\bar{X}_b$ = 162.9, SD = 82.6, $P > 0.5$). The average error associated with the locations was less than the numbers given above because 45.7% of the locations were determined from direct observations.

HOME RANGE

Transmitters were attached to five birds in 1991 and nine birds in 1992. Twelve of the 14 marked birds successfully fledged young in the year they were studied. Area-observation curves indicated that we obtained a sufficient number of locations to calculate home ranges for 11 birds (Table 2).

The average size of the MCP home ranges for the 11 birds was 1758 ha (SD = 500, range 896–2528; Table 2). The average size of the 95% HM home ranges was 1530 ha (SD = 477, range 859–2321; Table 2).

HABITAT USE

The number of locations used for the habitat analyses for each bird was the same as the number of locations used to calculate the 95% HM home-ranges ($\bar{X}$ = 55.5, SD = 16.0, range 35–80; Table 2).

Slope

There was no preference for slope among the birds studied. Only one of the 22 tests on individual birds showed any difference between use and availability of slope categories.

Locations

Eight of the 11 birds used the canopy closure categories in proportion to their occurrence, whereas the remaining three birds used areas with >55% CC more than expected and areas with <15% CC less than expected ($P < 0.02$). One of these birds also used areas with 34–55% CC less than expected. Six of the 11 birds used the edge categories randomly, and the remaining five birds used them nonrandomly. Four of these five birds used open areas (all areas with <34% CC) less than expected, one used areas between 50–100 m from edge less than expected, one used areas between 100–200 m from edge more than expected, and two used areas >200 m from edge more than expected ($P < 0.05$). Only one of the 11 birds used the diversity categories nonrandomly and this bird used areas of high diversity less than expected.

Mean rank of relative preference of the canopy closure categories increased with increasing canopy closure (T_2 = 9.28, df_1 = 3, df_2 = 30, P <

TABLE 4. MEAN RANK OF RELATIVE PREFERENCE OF FOUR CANOPY CLOSURE CATEGORIES FOR 11 MALE NORTHERN GOSHAWKS DURING THE BREEDING SEASONS OF 1991–1992 ON THE KAIBAB PLATEAU, NORTHERN ARIZONA

	Percent canopy closure					
Analysis	<15%	15–33%	34–55%	>55%	N	P[1]
90-m circles	1.36A	2.09B	2.73C	3.82D	11	0.001
Locations	1.50A	2.23AB	2.64B	3.64C	11	0.001

[1] Friedman test of ranks of relative preference. Differences between means followed by same letter were not significant (Fisher's least significant difference).

0.001; Tables 3, 4). No difference in relative preference was shown for woodland with regard to distance from open areas, but open areas (<34% CC) were preferred less than woodland (areas with ≥34% CC) ($T_2 = 6.56$, $df_1 = 4$, $df_2 = 40$, $P < 0.001$; Table 5). There was also no difference in relative preference for the diversity categories ($T_2 = 2.45$, $df_1 = 3$, $df_2 = 30$, $P > 0.1$).

90-m radius circles

Only one bird used areas with >15% CC less than expected ($P < 0.02$). Only three birds occupied edge categories nonrandomly. Two used open areas less than expected and one used woodland >200 m from edge more than expected ($P < 0.05$). Only one bird used areas of high diversity less than expected.

Mean rank of relative preference of the canopy closure categories increased with increasing canopy closure ($T_2 = 18.50$, $df_1 = 3$, $df_2 = 30$, $P < 0.001$; Tables 3, 4). There was no clear pattern in relative preference for woodland categories with respect to distance from open areas, but open areas were preferred less than woodland areas ($T_2 = 10.49$, $df_1 = 4$, $df_2 = 40$, $P < 0.001$; Table 5). There was no difference in preference among the categories of the diversity overlay ($T_2 = 1.36$, $df_1 = 3$, $df_2 = 30$, $P > 0.25$).

DISCUSSION

HOME RANGE

The sizes of home ranges found in this study are intermediate compared with those found by Eng and Gullion (1962) in Minnesota (one male, 1272 ha), Kennedy (unpubl. data) in New Mexico (three males, $\bar{X} = 2106$, range 1696–2837 ha), and Austin (1993) in California (five males, $\bar{X} = 2425$ ha, range 1083–3902). However, comparisons among these studies should be done with caution because the hawks were tracked for different periods of time and/or different methods were used to calculate home range size.

HABITAT USE

The main pattern we found in the use of forest conditions by goshawks was that mean rank of relative preference of all hawks increased with increasing canopy closure. Potential explanations for this trend are the availability of prey (Kenward 1982, Reynolds et al. 1992) and the morphological adaptations of goshawks that presumably make them well adapted for hunting in forests. Fisher and Murphy (1986) and Austin (1993) also found that goshawks used forests with closed canopies more than open woodlands or meadows.

The pattern of use of canopy closure categories suggested by the ranking of relative preferences was not significant in most hawks when analyzed individually. The following factors may have reduced our ability to detect significant habitat preferences at the individual bird level: (1) goshawks were more easily observed in open areas than in forests and about half of our locations were direct observations; (2) goshawks were more easily located when they were near roads (usually relatively open areas near edges); (3) our sample of locations for each bird was relatively small; (4) some individuals may not have strong habitat

TABLE 5. MEAN RANK OF RELATIVE PREFERENCE FOR DISTANCE FROM OPEN AREAS (<34% CANOPY CLOSURE) FOR 11 MALE NORTHERN GOSHAWKS DURING THE BREEDING SEASONS OF 1991–1992 ON THE KAIBAB PLATEAU, NORTHERN ARIZONA

	Woodland distance from open areas						
Analysis	Open	0–50 m	>200 m	50–100 m	100–100 m	N	P[1]
90-m circles	1.09A	2.91B	3.45BC	3.59BC	3.95C	11	0.001
Locations	1.27A	3.18B	3.23B	3.54B	3.73B	11	0.001

[1] Friedman test of ranks of relative preference. Differences between means followed by same letter were not significant (Fisher's least significant difference).

preferences within their home ranges; and (5) goshawks may select habitat on the basis of conditions we did not measure. Significant trends at the individual bird level also may have been obscured by the error associated with our locations, the uncertainty about what the birds were doing when we located them, and the error introduced when we smoothed the basic habitat overlay. Smoothing results in small patches potentially being misclassified.

MANAGEMENT RECOMMENDATIONS

Tree harvest methods that create large areas with sparse tree cover are potentially detrimental to Northern Goshawks, especially if the percent of open forests (<34% CC as measured from aerial photos) in a home range is greater than 35% (the mean found in this study). Therefore, in areas being managed for Northern Goshawks, selection cuts and other harvest methods that leave a substantial portion of the canopy intact should be favored. Reynolds et al. (1992) recommended maintaining 40% canopy closure over 60% of a proposed foraging area (2187 ha) for each pair of nesting goshawks. We can not directly evaluate the specific values recommended by Reynolds et al. (1992) because we made our measurements of canopy closure from aerial photos, but our findings support the general idea of maintaining relatively high canopy closure over a significant portion of areas managed for foraging goshawks.

Our investigation examined only males during the breeding season. Much information on habitat use is needed, especially on females, immatures, and wintering males before a more complete assessment of goshawk habitat requirements can be made. Future researchers should be aware that, as Kenward (1982) and Reynolds et al. (1992) suggested, goshawk habitat selection may be a function of habitat selection by prey species. For this reason, detailed diet analyses should be done in conjunction with studies of habitat use and prey availability if we are to understand more fully the requirements of the Northern Goshawk.

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HOME RANGES AND HABITATS OF NORTHERN GOSHAWKS IN EASTERN CALIFORNIA

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Abstract. We conducted a 3-summer telemetry study of nesting Northern Goshawks (*Accipiter gentilis*) (N = 10) to determine stand structure, landscape patterns, and geographic features that characterize home ranges. We subdivided home range use into two phases of the breeding season, the nestling phase and post-fledging phase, because home ranges of adult males and females showed significant expansion after the young had fledged. Nearly all birds incorporated areas into their home ranges that were spatially distant from the nest stand, which resulted in higher vegetative diversity within the nestling-phase home ranges than would be expected from random home range placement. Home range locations used by perched goshawks were similar to nest sites, and both had greater canopy cover, greater basal area, and more trees per ha than a random sample from the study area. Thus, perched goshawks tended to be in well-canopied stands with large trees that were in proximity to a variety of vegetation types and seral stages. Nest sites were significantly closer to water sources than random study area points, and home range configurations were influenced by the location of water. Goshawk management strategies should include the potential home range as well as the nest site. Our data suggest that a goshawk can incorporate vegetation types and water sources as far as 3.5 km from the nest stand into its home range. Within this potential use area, emphasis should be placed on creating or maintaining vegetative diversity. Mature forests should be retained around water sources, along forest-open edges, and throughout the potential foraging area.

Key Words: *Accipiter gentilis*; adaptive kernel; habitat use; home range; Northern Goshawk.

Much of the current knowledge of habitat use by the Northern Goshawk (*Accipiter gentilis*) has been taken from nest sites (e.g., Reynolds et al. 1982, Moore and Henny 1983, Kennedy 1988, Patla 1990). Little is known about habitat characteristics that define the rest of the home range, that is, the area used by individuals for foraging and resting as well as for care of young. Prior to the development of goshawk management recommendations for the southwestern United States (Reynolds et al. 1992), goshawk management in timber resource areas was generally limited to the retention of an uncut buffer of mature timber around nest sites, ranging from a recommended 8 ha (Reynolds et al. 1982) to 49 ha (Fowler 1988).

The emphasis placed on nest sites is justified because the nest or a nearby alternate nest is used by goshawks for many years (Palmer 1988). Protection of the nest and alternate nests provides a reasonable long-term management strategy. However, even though a nest site is protected, the remainder of the home range is frequently subjected to habitat alteration. If certain habitat components are needed by breeding goshawks in areas other than the immediate nest sites, then habitat alterations could eventually cause the decline of this species even though nest sites are protected.

Our study was prompted by the need to provide better management guidelines for goshawk home ranges within areas of timber management on the Inyo National Forest in eastern California. Beginning in 1979, goshawk nests on the Inyo National Forest were protected from timber harvests by delineating a 16-ha buffer around each known nest when the boundaries of each sale were mapped. This area was enlarged for all sales after 1987 to meet the guidelines of the Inyo National Forest Land Management Plan, which called for either a 40.5-ha buffer around the nest or two 20-ha buffers around the currently occupied nest and an alternate nest. One of our concerns was whether small, isolated buffers were sufficient to meet the needs of nesting goshawks, or whether other components within the home ranges needed to be considered. We needed to know where goshawks foraged in relation to their nests and what habitats were used for foraging, in order to make meaningful recommendations for extending management over areas larger than the nest buffers.

We investigated goshawk home range use at the microhabitat and landscape level. At the microhabitat level, we focused on the forest stand structure associated with goshawk telemetry locations within their home ranges. Other studies have shown that nest sites are typically in stands with large trees and dense canopies (e.g., Hall 1984, Speiser and Bosakowski 1987, Hayward and Escano 1989). We wanted to determine whether these conditions were also characteristic of areas used within home ranges.

At the landscape level, we were interested in vegetation patterns and landscape features that might influence the size, location, and configuration of home ranges. In particular, we wanted to determine whether home ranges were influ-

enced by the location of large blocks of mature timber, the amount of vegetative diversity, the availability of interior habitat or habitat edge, the location of open areas, and the presence of water.

The objectives of our study were (1) to determine stand structure, landscape patterns and key geographic features that influence the size, location, and configuration of goshawk home ranges; and (2) to develop management recommendations focused on home range management rather than nest site management.

METHODS

Study Area

The study area is approximately 440 km^2 of forested habitat on the Inyo National Forest, located east of Yosemite National Park near the California–Nevada border. Elevations range from 2000–2700 m. Extensive tracts of Jeffrey pine (*Pinus jeffreyi*) are interspersed with stands of lodgepole pine (*Pinus contorta*), big sagebrush (*Artemisia tridentata*), aspen (*Populus tremuloides*), and pumice flats sparsely vegetated with grasses and forbs. Red fir (*Abies magnifica*) is the dominant vegetation within the narrow elevational band of 2600–2700 m along the eastern Sierra slope. Red fir is also found in Jeffrey pine and lodgepole pine stands on many north- and east-facing slopes.

Most stands in the study area have 1–3 age classes of trees and a shrub or grass-sedge understory. The dominant ground vegetation in Jeffrey pine stands is bitterbrush (*Purshia tridentata*). A sparse cover of grasses (*Sitanion hystrix, Stipa occidentalis*) and sedge (*Carex rossii*) occur in lodgepole pine stands. Forest canopies tend to be open due to xeric conditions imposed by poor soils and climate (20–40 cm annual rainfall).

Much of the landscape has been modified by timber harvests, mostly through the removal of large diameter overstory trees, leaving mid-seral stage stands. Clearcuts are uncommon and are restricted to patches <16 ha.

For the purpose of this paper, older seral stages of timber will be referred to as "old growth." A formal old growth definition has not been developed for the Inyo National Forest, but old growth Jeffrey pine is typically >250 years old, with ocular-estimate canopy closures rarely >40%. Lodgepole pine old growth is >200 years old, with canopy closures between 30–50%. Red fir old growth is >250 years old, with canopy closures between 35–60%. Timber compartment stands identified as old growth on the Inyo National Forest (Inyo National Forest unpubl. stand record cards) are mostly 15–60 ha in size except for the 486-ha Indiana Summit Research Natural Area, managed for old growth Jeffrey pine, and a 900-ha tract of red fir, lodgepole pine, and white fir (*Abies concolor*).

Home Ranges

Home range and habitat use data were derived from radiotelemetered goshawks during the summer seasons of 1986–1988. We captured goshawks using a dho-gaza with a Great Horned Owl (*Bubo virginianus*) lure in the vicinity of active nests (Hamerstrom 1963, Bloom et al. 1992). Each goshawk was banded with a US Fish and Wildlife Service leg band. Radio transmitters were attached to the backs of the birds with teflon tubing fitted around the wings. The 28-g transmitters had a life expectancy of 7 months.

We created a grid overlay for 1:24,000-scale USGS maps of the study area and used the grid coordinates in calculating goshawk locations. The spacing of 1 mm between grid lines corresponded to 26 m on the ground. Telemetry locations were obtained by two observers using Telonics 2A (Mesa, Arizona) and Advanced Telemetry Systems (Isanti, Minnesota) receivers and 5-element yagi antennae mounted in two truck beds. Simultaneous bearings were taken from two locations, and the estimated location of the bird was calculated by triangulation (White and Garrott 1990) using the two bearings and the known grid coordinates of the observers. We took bearings on each goshawk at 15-min intervals for 1.5 hr. Each bird was monitored every 2–3 days at a randomly selected time between 08:00–14:00.

To determine errors associated with location estimates, the observers estimated the location of a transmitter placed at 20 random locations by an independent party. The observers were on average 718 ± 368 (SD) m from the transmitter during these tests, and the mean error in location was 102 ± 66 m. The error associated with estimation of goshawk locations may have been somewhat lower, since during monitoring the observers were on average closer to the goshawks ($\bar{X}$ = 465 ± 292 m) than to the test transmitter. By proportional extrapolation, the mean error in estimating goshawk locations was 66 m.

Home ranges were calculated using an adaptive kernel method (Worton 1989) developed by J. Baldwin (USDA Forest Service, Pacific Southwest Experiment Station, Berkeley, California, pers. comm.). This method is based on Anderson's (1982) definition of home range: the probability of finding an animal at a particular location on a geometric plane, given a bivariate probability density function for that animal. The kernel method is a non-parametric technique that estimates the probability density function from a data set of known locations, using a data smoothing function similar to the Fourier transformation employed by Anderson (1982). The adaptive kernel method differs from the Fourier transformation and from fixed kernel methods in that the magnitude of the smoothing parameter is changed depending on the concentration of data points. Areas with a low concentration of points have less weight than frequently used areas, thereby rounding off finger-like extensions of the home range that are caused by a few location points (Worton 1989). All of these methods calculate a three-dimensional volume for the bivariate probability function from which contours can be selected that represent a given percentage of the volume, or a given percentage of the sample points. For the adaptive kernel method, our contours were constructed to represent a percentage of the sample points.

Contour intervals that represented 95% and 50% of each goshawk telemetry data set were constructed at

the 1:24,000 scale and traced onto mylar overlays of the study area. We calculated home range estimates for the entire monitoring period from late June to mid September. However, we found that these home range estimates were misleading because they included areas that were not used by the adults until the young had fledged. Also, these estimates masked information on home range shifts and range expansion that occurred after the young had fledged. A division of the monitoring period into two phases, nestling and post-fledging, provided a more sensitive discrimination of home range use, and separated the restricted, nest-oriented home ranges of the earlier period from the broader areas used later in the breeding season. Since observations at the nests indicated that all young had fledged by the end of July, we used 1 August to delineate the two periods and calculated nestling-phase and post-fledging-phase home range estimates for each bird.

Landscape Patterns

Landscape patterns were compared between nestling-phase home ranges, post-fledging-phase home ranges, and a random sample of artificial home ranges within the study area. Artificial home ranges were created by placing a circle with an area of 9.04 km^2 at random points within all available habitat of the study area. The centers of the artificial home ranges were grid coordinates that were generated randomly from the entire study area. The size of the circle corresponded to the mean size of the 95% polygons for the nestling-phase and post-fledging-phase home ranges. Within each randomly-placed circle and within the 95% contour of each home range, we recorded the number of vegetation types per km^2, total number of vegetation units (patches) per km^2, percent of home range in inventoried old growth, length of forest-open edge per km^2, distance to water, and distance to a forest opening greater than 20 ha. Vegetation types were qualitatively differentiated on the basis of the most abundant overstory and understory species (Mueller-Dubois and Ellenberg 1974) and seral stage (Mayer and Laudenslayer 1988). Vegetation boundaries were delineated using aerial photogrammetry and were field verified. Old growth acreages were derived from a comprehensive old growth inventory conducted on Inyo National Forest in 1989-1990 (Inyo National Forest, unpubl. data).

All distance measurements were taken from 1:24,000 orthophotos with a map wheel. Since the home range polygons were not circular, we developed the following criteria for selecting the point from which distances to water and forest openings were measured. For nestling-phase home ranges, distances were measured from the nest, whether or not the nest was the geometric center of the range. If the range contained other polygons besides the polygon containing the nest, we measured distances from the center of the other polygons and averaged the values. The center of each polygon was the midpoint of the longest axis bisecting the polygon. For post-fledging-phase home ranges, we measured distances from the center of the 50% contour located inside the 95% contour. In the majority of cases, the home range was a cluster of 2–3 polygons, so 2–3 distance measures were taken and averaged.

We noted whether home ranges encompassed or were in proximity to human developments, but did not quantify these relationships. Principal developments were the town of Mammoth Lakes (pop. 10,000), highways, developed campgrounds, and major dirt roads.

Stand Structure

As a means of evaluating stand structure used within home ranges and at nests, we collected data at three types of sites: nest sites, sites within the home ranges other than nest sites, and sites located at random within the study area. The nest site data included the nests of the radio-tracked birds and all other known goshawk nests within the study area. The home range data set was a stratified random sample of all radio telemetry locations other than nest sites for the three summer seasons of study. We stratified the data to ensure that some locations were derived from all ten birds that were monitored. The sample was taken from the entire monitoring period. Random sites were selected by generating random x,y coordinates from the study area grid overlay.

Plot size used to measure stand structure variables was 0.04 ha. At each nest we collected data at five plots to include local variation in stand structure parameters. One plot was centered on the nest tree and the remaining plots were located 30 m from the tree in each of the cardinal directions.

Home range telemetry points were located in the field using the estimated grid locations placed over the study area map. We began collecting data at home range locations prior to selecting a method for determining the error associated with estimation of these points. We assumed that our error ranged from 25–75 m from the true locations of the birds and collected data at two plots at random distances between 25–75 m from the calculated telemetry location. The stand structure values obtained from both plots were then averaged. These distances proved to be close to the 66 m error that we calculated later. The two points also helped capture some of the variation found within the forest stands. Time constraints did not permit collecting data at more than two plots per location. We located the random sites in the field and collected data in the same manner as at home range sites, using two plots located 25–75 m from each random point.

Habitat parameters collected in each plot for all three site types were used to assess stand density and the amount of standing and down dead material. These included number of trees in five diameter classes (1–15 cm, 16–27 cm, 28–45 cm, 46–61 cm, and >62 cm), basal area, percent canopy cover, percent slope, aspect, and number of snags and down logs within each plot. Basal area data were collected with a 20-factor basal area prism. Percent canopy cover was the average of four ocular estimates made within the major quarters of each circular plot. Percent slope was taken with a clinometer. At nest sites we also took data on nest tree diameter at breast height (dbh) (cm), nest tree height (m), and height of nest (m) within the tree. The dbh measurements were taken with a logger's tape. Tree and nest heights were derived from a clinometer reading taken at a known distance from the tree bole.

Prior to statistical analyses, all variables were examined for normality and transformed when appro-

TABLE 1. SELECTED LANDSCAPE ATTRIBUTES FOR GOSHAWK NESTLING-PHASE RANGES, POST-FLEDGING RANGES, AND RANDOM CIRCLES WITHIN THE STUDY AREA

Landscape attribute	Nestling-phase ranges		Post-fledging ranges		Random	
	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD
No. of veg types/km	1.4	1.2	0.8	0.8	0.6	0.2
No. of patches/km	2.3	0.9	1.7	0.5	1.2	0.4
Km edge/km	1.1	0.7	1.2	0.3	0.9	0.4
Dist. to water (km)	1.2	0.9	2.2	1.2	2.7	1.2
Dist. to openings >20 ha (km)	0.7	0.6	0.6	0.3	0.7	0.6
Proportion of range in old growth	0.17	0.29	0.09	0.12	0.09	0.09

priate. The square root transformation was applied to all count data, and an arcsine square root transformation was done for canopy closure proportions. Normal probability plots for the transformed data were linear, indicating that the transformations were appropriate. Univariate ANOVA procedures were used to test for stand structure and landscape level differences. We used Tukey's studentized range tests to determine which group or groups were responsible for any significant differences detected with the ANOVA tests.

RESULTS

We radio tracked eight females and two males over the three summer seasons of the project: two females and one male in 1986, three females in 1987, and three females and one male in 1988. These ten adults were associated with six territories. Two of the territories were monitored twice, but with different females and alternate nests. The male in 1986 was the mate of a monitored female in the same year, and the male in 1988 was associated with the nest used by a monitored female in 1987. A female from 1987 was recaptured and followed again in 1988 but the second year of data was omitted from all statistical analyses and home range estimates. The number of telemetry locations per bird ranged from 35-56 during the nestling phase ($\bar{X} = 44 \pm 7$) and from 48–107 locations during the post-fledging phase ($\bar{X} = 64 \pm 18$). For the entire monitoring period, the mean number of telemetry locations was 108 ± 17 per bird.

HOME RANGES

All home range estimates presented are for the areas of the 95% polygons. Home ranges for all ten adults for the entire monitoring period averaged 15.5 ± 8.9 km^2. The seven female home ranges averaged 13.4 ± 8.1 km^2, and the two male ranges were 17.9 km^2 and 30.1 km^2.

After approximately 1 August, we noted a significant range expansion (one-tailed paired-sample t-test, $t = 2.4$, $df = 9$, $P = 0.04$). This expansion was not correlated with the number of telemetry points associated with each bird (adjusted $r^2 = 0.12$). All but one female expanded their home ranges. Female home ranges increased from a mean of 5.2 ± 3.9 km^2 (range = 0.7–7.8 km^2) during the nestling phase to 10.2 ± 8.2 km^2 after the young had fledged (range = 1.1–24.6 km^2). The two males also expanded their ranges, from 3.4 km^2 to 16.2 km^2, and from 9.5 km^2 to 28.4 km^2. One female's range decreased from 7.8 km^2 during the nesting period to 1.1 km^2 after the young had fledged.

Four of the ten goshawks showed complete range shifts after the young fledged. The most extreme case was the shift of one female to an area 9 km from her nest. Her post-nesting range had roughly a 90% overlap with another radio-tracked female. The female who did not expand her range shifted her area of use by approximately 6 km to the vicinity of a playing field. This female exhibited the same range shift in two consecutive breeding seasons.

In relationship to human activities other than timber harvests, the 50% polygon for one nesting range included a 20-unit campground. Three of the post-nesting ranges were divided by a 4-lane highway, and one post-nesting range included a playing field adjacent to the town of Mammoth Lakes.

LANDSCAPE PATTERNS

We compared landscape patterns between three groups: nestling-phase home ranges ($N = 10$), post-fledging-phase home ranges ($N = 10$) and randomly-placed circles ($N = 10$). Using ANOVA and $\alpha = 0.1$, we detected significant differences in the number of vegetation types per km^2 between the 3 groups ($F = 2.53$, $df = 29$, $P = 0.1$). A Tukey's studentized range test at $\alpha = 0.1$ indicated that nestling-phase home ranges had on average a greater number of vegetation types per km^2 than the random circles. The mean number of vegetation types per km^2 for post-fledging phase ranges was less than that found in nestling-phase home ranges and greater than that found in random circles, but was not statistically dif-

ferent from either of these groups (Table 1). There was no significant difference in the number of patches per km^2 (F = 2.29, df = 27, P = 0.12), although we noted a trend similar to that found with vegetation types; nestling-phase home ranges had the greatest number of patches per km^2 and random circles had the lowest number (Table 1). As measured by these two variables, goshawk home ranges during the nestling phase appeared to contain more vegetative interspersion than would be expected if their ranges had been located at random in the study area. After the young had fledged, home ranges tended to maintain higher vegetative diversity than expected.

The configurations of nearly all home ranges supported this conclusion, since seven out of the ten monitored birds had areas of concentrated use that were spatially distant from the nest stand during the nestling phase (Fig. 1). These areas were disjunct polygons of the 95% home range area and contained vegetation types and seral stages that were not present in the polygon around the nest.

For two birds, this additional polygon included a large pumice flat (a different pumice flat for each bird). In four cases, the second polygon added seral stages of Jeffrey pine that were not present within the nesting polygon, and in the remaining case, the second polygon added riparian vegetation.

During the post-fledging phase, eight of the ten birds had disjunct home ranges at the 95% level. There were three instances where the additional clusters of telemetry points were associated with water sources and riparian vegetation, two which added extensive edge along large pumice flats, one that added old growth not present in the nest polygon, one that added moderately stocked young forest, and one that added a baseball field adjacent to mature forest.

One female selected a vegetatively diverse area approximately 3.5 km east of her nest rather than including more of the available old growth that surrounded her nest. This caused her post-nesting range to be two disjunct use areas divided by a 4-lane highway (Fig. 2). The majority of telemetry points for this female were along a forest-pumice flat edge and in the adjacent stand of old growth. There were no other active goshawk territories within the old growth around her nest that might have caused her to forage elsewhere. However, her range overlapped that of a second monitored female who used the same pumice flat and surrounding forest.

These disjunct polygons were not an artifact of our monitoring method of taking six consecutive readings per day. When we calculated the home ranges using one location per day, we ob-

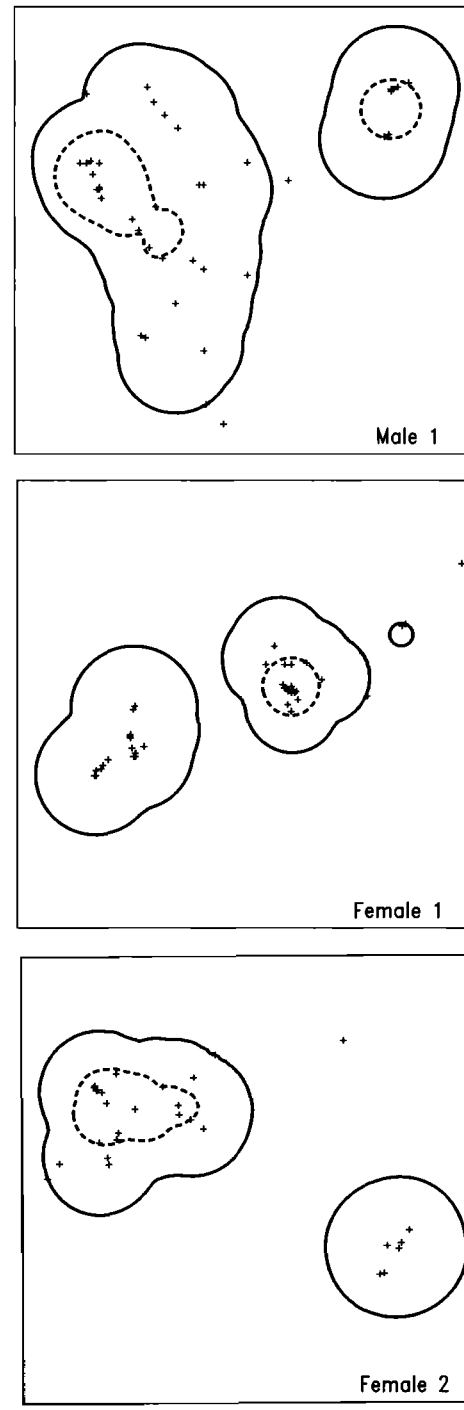

FIGURE 1. Examples of three goshawk nestling-phase home ranges from eastern California, showing clustering of telemetry points and disjunct polygons representing 95% (solid lines) and 50% (dashed lines) of telemetry locations.

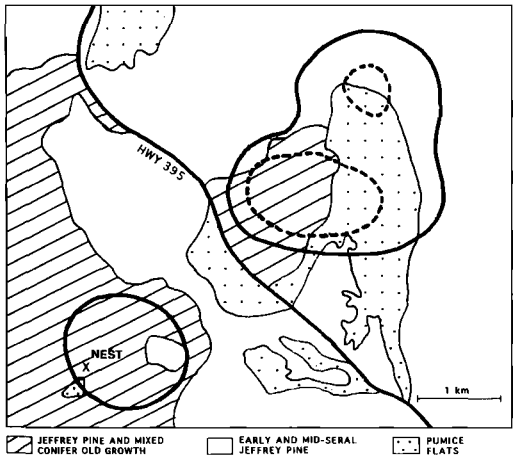

FIGURE 2. Post-fledging phase home range of a female goshawk in eastern California, showing selection for forest edge along a large pumice flat. The solid and dashed lines encompass 95% and 50% of the telemetry locations, respectively.

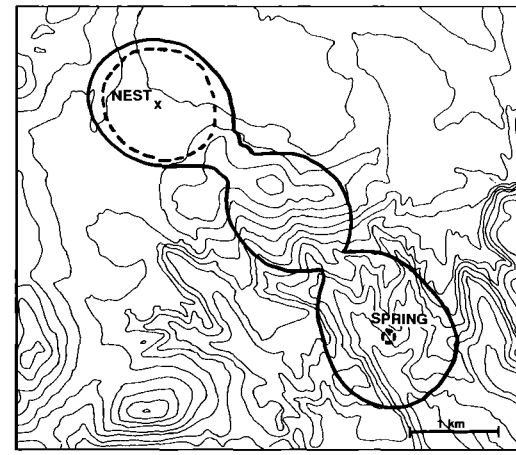

FIGURE 3. Nestling-phase home range of a female goshawk in eastern California, showing elongation of the home range to include the nearest source of water, 3.5 km from the nest. The solid and dashed lines encompass 95% and 50% of the telemetry locations, respectively. Note that a portion of the 50% contour is around the spring.

served polygons that maintained the same spatial arrangement and similar configuration as the home range estimates generated from six consecutive locations per day.

We also detected significant differences between the three groups in the distance to water ($F = 3.22$, $df = 29$, $P = 0.06$). The nests were on average closer to permanent water sources (springs and small streams) than were the centers of the post-fledging ranges or the artificial home range circles (Table 1). Six birds had water within the polygon containing the nest, and in one case, the home range polygon was extremely elongated to include a spring located 3.5 km from the nest (Fig. 3). In this case, 50% of the locations were divided between the nest stand and this spring. One female did not use the permanent water within her nest polygon, presumably because it flowed through open meadows, but she consistently used a water source 3.3 km from her nest in mature Jeffrey pine, thereby creating a second polygon that defined her home range at the 95% level (Fig. 4).

Stand Structure

We collected stand structure data at 20 nests, 63 home range sites (telemetry locations), and 102 random sites within the study area. The nest data set included three situations where data were collected on more than one nest in a territory (alternate nests). The inclusion of these nests may affect the assumption of independence. We included these nests because they were not in the same vegetation polygon as the active nest and our banding records indicated they were used by different females.

Five of the eight variables examined with ANOVAs were significantly different at $\alpha = 0.05$: basal area ($F = 47.74$, $df = 184$, $P < 0.01$), canopy cover ($F = 31.66$, $df = 184$, $P < 0.01$, pole-sized trees 16–27 cm dbh ($F = 11.55$, $df = 184$,

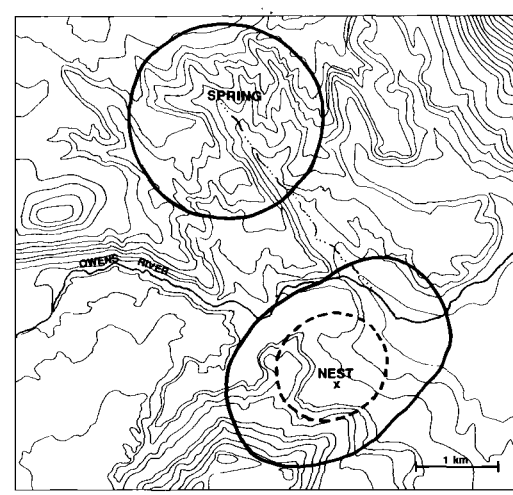

FIGURE 4. Nestling-phase home range of a female goshawk in eastern California, showing use of a water source located approximately 3.3 km north of the nest. The solid and dashed lines encompass 95% and 50% of the telemetry locations, respectively.

TABLE 2. STAND STRUCTURE VARIABLES FOR GOSHAWK NEST SITES, USE SITES WITHIN HOME RANGES, AND RANDOM SITES WITHIN THE STUDY AREA

Variable	Nest sites		Home ranges		Random	
	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD
Basal area (m^2/ha)[1]	37	9	39	12	26	13
Canopy cover (%)[1]	31	13	34	16	21	15
Slope (%)	12	11	7	9	10	13
Timber class (trees/ha)[2]						
1	16.1	11.6	11.6	11.0	10.1	10.1
2[1]	6.9	7.9	6.5	5.2	4.2	3.8
3	3.5	1.8	3.4	2.7	2.6	2.8
4[1]	1.8	1.0	1.7	1.5	1.0	1.0
5[1]	1.3	0.7	1.2	1.2	0.8	1.0

[1] Indicates differences in mean values between random sites and the two goshawk data sets (alpha = .05/3) using Tukey's studentized t-test.
[2] Timber classes correspond to the following dbh sizes: timber class 1: 1–15 cm; timber class 2: 15–27 cm; timber class 3: 28–45 cm; timber class 4: 46–61 cm; timber class 5: >62 cm.

$P < 0.01$), and the two largest tree diameter classes ($F = 18.42$ and $F = 47.74$, df = 184, $P < 0.01$). Goshawk nest sites and the surrounding home range telemetry points had greater basal area, more canopy cover, and more trees in these three diameter classes than the random plots in the study area (Table 2). For all of the above variables, the Tukey's test for differences among means separated the random plots from the home range telemetry plots and the nest sites (df = 27, $P < 0.05$) but did not distinguish between the home range plots and the nest sites. Forest structure selected by goshawks within their foraging ranges was similar to forest structure within the nest stands, and both differed significantly from random plots.

NEST TREE CHARACTERISTICS

Goshawk nests were in lodgepole pine, Jeffrey pine, and red fir, with a mean tree height of 28.0 ± 6.73 m and a mean dbh of 87.2 ± 27.2 cm. The average diameter was within the largest diameter class used in this study and was therefore in the upper range of tree diameters found within the study area. The mean nest height was 11.6 ± 2.33 m. Canopy cover immediately around the nest tree averaged 29% ± 12.6%.

DISCUSSION AND MANAGEMENT IMPLICATIONS

Goshawk home ranges in our area tended to be located in areas with high vegetative and seral diversity, especially during the nestling phase. The disjunct nature of many of the home ranges appeared to increase the number of vegetation types incorporated into the birds' foraging areas. By using areas that were geographically removed from their nest stands, goshawks were able to include vegetation types and patterns that were generally uncommon, such as riparian vegetation, wet meadows, and old growth stands adjacent to meadows or pumice flats.

Nest sites and telemetry locations were associated with forest stands that had higher basal area, more canopy cover, and more trees per ha than the study area average. The telemetry locations were not necessarily foraging locations, because bearings were taken when the signals were stationary, and represented times when the birds were perched. Our telemetry data indicated that perched goshawks tended to be found in well-canopied stands with large trees. These locations may have provided hunting perches, thermal cooling, or protective cover.

The proximity of these locations to a variety of vegetation types and seral stages may have been related to prey availability. Reynolds et al. (1992) reported a medium to high degree of vegetative interspersion for 13 of 14 selected goshawk prey species. Although we lack dietary information for our monitored goshawks, 12 of the prey discussed in Reynolds et al. (1992) are found in our area. The selection of areas with high diversity corresponds to the degree of interspersion used by common goshawk prey species.

Goshawk home ranges in our area were influenced by the location of permanent springs and small streams. The value of water for goshawks has been variously reported in the literature. Speiser and Bosakowski (1987) found no significant difference in the proximity of water to goshawk nests and random plots, and Crocker-Bedford and Chaney (1988) reported that only 8 out of 43 nests were <1 km from water. Other studies have reported distances of <275 m (Shuster 1980), <600 m (Reynolds et al. 1982), and <1 km (Kennedy 1988).

In areas where permanent streams and springs are uncommon, it may be difficult for all nesting goshawks to establish territories in proximity to

water. In these situations, the nearest available well-canopied water source should be viewed as potentially within the range of active nests that are not near water. Our study indicated that goshawks could incorporate water sources into their home ranges from as far as 3.5 km away.

Goshawks nested in stands that were substantially more open than those used in other geographic areas. The mean canopy closure of 29% at nest sites is far below the values of 88%, 81%, 79%, 63% and 60% found in northwestern California (Hall 1984), northern California (Saunders 1982), northern Arizona (Crocker-Bedford and Chaney 1988), northwestern Utah (Hennessy 1978), and eastern Oregon (Reynolds et al. 1982), respectively. Dissimilar methods in measuring canopy cover may account for some of the difference.

Regardless of the absolute values, goshawks in our study selected stands that were denser than the average available, both for nesting and foraging, as measured by basal area, canopy closure, and the number of trees in all five diameter classes. Although absolute values may not be applicable to all geographic areas used by goshawks, the selection for stands with the most canopy cover and largest diameter trees can be translated to the site potential for different regions.

Goshawk management that focuses solely on nest sites assumes that goshawks are not selective in their use of habitats other than nest location. Yet our study indicates that goshawks select areas that are vegetatively diverse for foraging, including numerous aggregations of mature trees for nest stands and perch sites. Timber harvests on the Inyo National Forest typically remove the overstory, but numerous aggregations of mature timber are left for archeological site protection, deer hiding cover, snag recruitment, and riparian habitat. Although goshawk management is primarily limited to nest site buffers, these other management actions have resulted in the retention of mature timber and more vegetative diversity than would be expected under most prescriptions using overstory removal. All goshawk territories associated with timber sales have been active for approximately two-thirds of the years since the harvests, based on our nesting records over the past 14 years. Typically these territories have produced 2–3 young per nest.

Timber harvests can be compatible with goshawk conservation if key features such as permanent water sources, well-canopied stands of mature trees, and mature forest edge are provided within potential goshawk home ranges. Home range configurations cannot be determined with telemetry, but our data suggest that vegetation types and water sources as far as 3.5 km from the nest stand can be viewed as potential foraging range, especially if these features are not present near the nest.

An effective goshawk conservation strategy would consider the potential home range associated with each nest site. Within this area, emphasis should be placed on creating or maintaining vegetative diversity, retaining mature timber around permanent water sources and along forest-open edges, and ensuring that a portion of the range provides forest stands that have structural attributes similar to those found at the nest site for each particular geographic area. These mature stands would provide adequate perch sites near or within selected foraging areas. We recommend that timber harvests be designed to create a juxtaposition of seral stages, including mature forests, rather than leaving large tracts of homogeneous, mid-seral stage stands.

ACKNOWLEDGMENTS

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POST-FLEDGING AREAS IN NORTHERN GOSHAWK HOME RANGES

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Abstract. In 1984, 1986 and 1988, we studied the movement patterns of eight (4 in 1984, 2 in 1986, 2 in 1988) Northern Goshawks (*Accipiter gentilis*) nesting in the Jemez Mountains of north-central New Mexico to estimate nesting season home range size and identify areas of concentrated use, particularly those areas used by the family after fledging until the young are independent (post-fledging areas [PFAs]). Female home ranges were significantly ($P = 0.025$) smaller ($\bar{X} = 569.3 \pm 473.1$ ha [SD]; $N = 5$) than male range sizes ($\bar{X} = 2106.3 \pm 634.5$ ha; $N = 3$). Core areas were approximately 32% of the home range area ($\bar{X} = 348.2 \pm 321.6$ ha). Female core areas were significantly ($P = 0.025$) smaller ($\bar{X} = 167.9 \pm 128.5$ ha) than male core areas ($\bar{X} = 648.7 \pm 334.9$ ha). We monitored the movement patterns of 16 juveniles from six nests that were fitted with transmitters at 21 days of age during 1992. During the early fledgling-dependency period (week 1–4 after fledging) 88.1% of the juveniles' locations ($N = 193$) occurred within 200 m of the nest and 99.5% of the locations occurred within 800 m of the nest. However, during the last four weeks of the fledgling-dependency period only 34.3% of the locations ($N = 108$) were within 200 m and 75.9% of the locations were within 800 m of the nest (a 167.9-ha circle would have a radius of 731.5 m). These observations support the existence of a PFA in north-central New Mexico and suggest that nesting habitat include both the nest site and a PFA.

Key Words: *Accipiter gentilis*; habitat management; harmonic mean; home range; Northern Goshawk; post-fledging area.

Much of our knowledge of raptor habitat use is restricted to nest sites. This is especially true for forest-dwelling species, whose activities away from the nest site are difficult to observe. The Northern Goshawk (*Accipiter gentilis*) occurs in a wide variety of forest types throughout North America and Eurasia (Kenward 1982, Speiser and Bosakowski 1987, Hayward and Escano 1989, Widén 1989). Although goshawk populations in Europe appear to be increasing (Bijlsma 1989), concern exists about its population status in North America, particularly in timber harvest areas (Reynolds et al. 1992). Prior to the publication of the management recommendations for the southwestern U.S. (Reynolds et al. 1992), management of goshawk habitat in North America was limited to establishing <20-ha protective buffers around nest sites (Reynolds 1983). Nest sites are a focal point for the goshawk's activities associated with courtship, incubation and the nestling stage. However, many goshawk activities critical to recruitment and survival—foraging, parental care of fledglings and roost sites—may occur away from the nest site and these activity areas need to be considered in goshawk management plans.

Currently, the only reliable way to identify goshawk activity areas (or areas of concentrated use) is to use radio-telemetry methods combined with home range estimators. This type of analysis requires considerable care to minimize the well known problems that can arise with this approach (White and Garrott 1990). Using these techniques, goshawk home range size and foraging habitat have been described for wintering birds in Europe (Kenward and Widén 1989, Widén 1989). Little radio-telemetry data are available for North American birds. Thus, little information is available on nesting season home range and areas of concentrated use within this home range.

The aim of our study was to estimate nesting season home range size and identify areas of concentrated use, particularly those areas used by the family after fledging until the young are independent (post-fledging areas [PFAs]). In addition, we evaluate the movement patterns of fledgling goshawks to determine if the PFA described by Reynolds et al. (1992) represents the area used by the fledglings until independence.

METHODS

STUDY AREA

The study examined goshawk activity areas within approximately 650,000 ha of forested lands in the Jemez Mountains in north-central New Mexico. The Jemez Mountains were formed by volcanic activity and are dissected by steep-walled canyons formed by the erosion of volcanic tuff. Elevations ranged from 1200–3900 m. The average annual precipitation is 45 cm, 75% of which occurs from May through October. Ponderosa pine (*Pinus ponderosa*), Douglas-fir (*Pseudotsuga menziesii*), and white fir (*Abies concolor*) are the most prevalent forest types found over the study area. Subalpine grassland, spruce-fir, pinyon-juniper, juniper-grassland, and riparian woodlands are also present (see Kennedy [1988] for a more detailed study area

TABLE 1. DURATION OF TRACKING PERIOD AND NUMBER OF SEPARATE LOCATIONS OF RADIO-TAGGED ADULT NORTHERN GOSHAWKS IN NORTH-CENTRAL NEW MEXICO

Hawk no.	Tracking period	Hours tracking[1]	No. of locations[2]	No. of samples
Male1[3]	6/13/84–8/28/84	44.2	62	12
Female1[3]	6/06/84–8/11/84	27.5	57	10
Female2	6/08/84–8/03/84	30.6	46	10
Female3	7/13/84–8/18/84	21.8	69	7
Male2	7/23/86–10/25/86	94.2	184	18
Female4	7/25/86–9/22/86	36.4	157	9
Male3[3]	6/16/88–8/19/88	57.6	100	14
Female5[3]	6/09/88–5/16/89	183.6	367[4]	57

[1] Does not include time spent in radio-tracking periods during which birds could not be located.
[2] Numbers of locations used to estimate home range; does not include locations that did not meet the 0.5-h separation criteria and had a measurement accuracy of <250 m.
[3] The mate of this bird was radio-tagged.
[4] 174 of these 367 locations were used to estimate nesting season home range (6/9/88–9/30/88) and 193 locations were used to estimate winter home range (10/1/88–5/16/89) (P. L. Kennedy, unpubl. data).

description). The USDA Forest Service, Santa Fe National Forest; USDI National Park Service, Bandelier National Monument; and Los Alamos National Laboratory manage these lands.

ADULTS

We captured adult goshawks at the nest during the nestling period (mid-June to mid-July) with a dho-gaza net using a live Great Horned Owl (*Bubo virginianus*) as the lure (Bloom 1987). All hawks were in adult plumage and their sex was determined by morphometric measurements. Eight hawks were captured, banded and affixed with a tail-mount (N = 6, Biotrack, Inc., Dorset, UK) or back-pack type (N = 2, L&L Electronics, Mahomet, IL, USA) transmitter (Kenward 1987) that weighed <3% of their body weight (tail-mounts = 15 g and back-packs = 20 g). All transmitters had posture-monitoring switches (Kenward 1987) to detect flight and non-flight behavior.

We began monitoring the marked birds 1–2 days after capture. Hawks were monitored simultaneously by a minimum of two observers on the ground using a mobile null peak system (Kenward 1987, Equipment manufactured by Televilt HB, Storå, Sweden and Custom Electronics, Urbana, IL, USA). Yagi antennae were used to obtain a general location of the bird from a distance and the null peak antennae were used to acquire more accurate bearings once an observer was within 0.4 km of the bird. Two to three bearings were made on perched birds simultaneously by 2–3 observers on foot or in a car. Observer locations were plotted on U.S. Geological Survey (USGS) 7.5-minute quadrangle maps. Bird location and the measurement error associated with each location was estimated from these field data using program FIXX (G. A. Rinker, pers. comm.). FIXX is a program to triangulate and analyze radio-telemetry data as described in the Appendix.

We monitored four hawks in 1984, two hawks in 1986 and two hawks in 1988 (Table 1). Each bird was monitored continuously for a 2–6 hour period, a minimum of once per week, until transmitters were molted or failed (5 weeks to 11 months after attachment; Table 1). The beginning of each sampling period was systematically selected from four periods of the day (05:00–09:00, 09:00–13:00, 13:00–17:00, and 17:00–21:00) to ensure diurnal coverage throughout the season. Since the same bird was not monitored for more than one year, there is no measure of within-bird variation.

During each sample period, the signal of a systematically chosen bird was continuously monitored. Perching and flight bouts were timed to the nearest second. After every flight we attempted to record the bird's location. We defined a flight as a period when the fast pulse lasted at least 5 sec. This definition was determined by monitoring the behavior of trained falconry birds temporarily equipped with transmitters and by spending several hours simultaneously radio tracking and visually observing birds near nests. With some training, field personnel could consistently identify flights by changes in volume and pitch of the signal combined with a signal direction change (Kenward 1987).

We used the harmonic mean (HM) method in Program HOME RANGE (Samuel et al. 1985b) to delineate size and shape of each goshawk's home range. We chose this home range estimator because it (1) is nonparametric, (2) is not as sensitive to number of locations as are other estimators, and (3) is commonly used to estimate home range size of raptors. Details on this estimator and its limitations are described in White and Garrott (1990).

We identified the boundaries of the home range of each bird with the 75% and 95% isopleths. The 75% and 95% contours define the area in which we expect to find a hawk 75% and 95% of the time, respectively. We identified core areas using the method described by Samuel et al. (1985a), where the core area is defined as the portion of the hawk's home range that exceeds an equal-use pattern. This was done by comparing the observed use pattern within the home range with that expected from a uniform pattern of use using the core area analysis in Program HOME RANGE (Samuel et al. 1985b). The difference in ordered cumulative distribution functions was tested with a one-sided Kolmogorov goodness-of-fit procedure (Daniel 1978). Core areas were identified by outlining those areas within the home range where use exceeded that expected from a uniform distribution.

A nesting season (brood rearing) home range was estimated for all birds and a winter home range was

estimated for one bird that was monitored for 11 months. This bird's nesting home range was based on data collected from the time of attachment until 30 September 1988, and the winter home range was based on the remaining locations (Table 1). Only locations that were separated by a minimum of 0.5 hour and had a measurement error of ≤250 m (see Appendix for details on estimating measurement errors of the birds' locations) were used in the HM calculations. The accuracy stipulation resulted in censoring approximately 25% of the locations that met the 0.5 h separation criteria. Measurement error was used primarily as an aid in discarding inaccurate locations; these errors were not used to calculate the total error associated with the home range estimates.

Fledglings

Examination of female home range characteristics suggests a PFA exists that surrounds the nest site and is substantially larger than the nest site. If the fledglings restricted their activity to the nest site, we would expect most of their locations to be within 178.5 m of the nest (the radius of a 10-ha circle). If a PFA exists and is approximately 168 ha (average female core area), we would expect the fledglings to occur at any distance from the nest tree up to 731.5 m from the nest. To account for mapping error we rounded these distances to 200 m and 800 m, respectively in the analysis of the fledgling location data.

To determine the areas used by juveniles after fledging ($\bar{X}$ = 42 days of age; J. M. Ward and P. L. Kennedy, unpubl. data) and until independence ($\bar{X}$ = 92 days of age, J. M. Ward and P. L. Kennedy, unpubl. data), we monitored the movement patterns of 16 juveniles from six nests that were fitted with tarsal-mounted transmitters (Advanced Telemetry Systems, Inc., Isanti, MN) at 21–25 days of age during 1992. We defined independence as the first time a juvenile spends more than three consecutive days at least 2 km from the nest. This is comparable to the definitions of independence used by Marquiss and Newton (1981) and Kenward et al. (1993a) for European Sparrowhawks (*A. nisus*) and goshawks, respectively. These juveniles were from the same population but were not offspring of the radio-tagged adults. Only one of the six nests used in this phase of the study was used previously by the radio-tagged adults.

The tarsal-mounted transmitters weighed 9 g, had mortality switches, and were designed to drop off after three months. After transmitter attachment, the birds were located every 2–3 days by one or two observers from the ground or from the air with the same telemetry equipment used for the adults. One location was obtained for each bird during each sampling period. Each bird was monitored until (1) the transmitter failed, (2) the transmitter detached from the tarsus, (3) the bird died, (4) the bird left the study area, or (5) the study was terminated (14 October 1992). Unlike the adults in which the majority of locations were obtained via triangulation, most (82.7%) of the juvenile locations were based on visual or auditory observations of the birds at close range (≤75 m). The measurement accuracy of the juvenile triangulated locations was not estimated.

To evaluate the area used by the fledglings, we measured the linear distance from the nest to each location and assumed the locations represented radii of circles around the nest. Using radii to estimate the fledglings' area of use assumes that space is used in a uniform circular fashion. We did not use the harmonic mean estimator to estimate home range size for the fledglings because <20 locations were obtained for the majority of the fledglings. Locations obtained after the birds were independent were not included in any analyses.

Statistical Analyses

The areas defined by the 95% and core area contours were analyzed for gender differences using a Kruskal-Wallis test (CoHort Software 1990). To evaluate the influence of our sampling design on the area estimates, we used linear regression (CoHort Software 1990) to see if there was a significant positive relationship between home range size and the number of sample periods.

A Chi-square analysis (PROC FREQ; SAS Institute, Inc. 1989) was used to determine if the distance fledglings traveled from the nest varied with age. Observations were categorized into four, 2-week age classes and six distance categories (0–50 m, 51–100 m, 101–200 m, 201–400 m, 401–800 m, and >800 m) for this analysis. This analysis is based on movement data collected on 15 of the 16 fledglings (Table 2). This analysis treats juveniles as the experimental unit and not nests; consequently it assumes that juvenile movements are independent of the movements of their siblings, which may or may not be realistic. For all hypothesis tests, $P \leq 0.05$ was considered significant.

RESULTS

Adults

We monitored each hawk from 21.8–83.6 hours for a total of 325.9 hours for all eight hawks. The number of locations used to estimate each hawk's nesting home range varied from 46–184 ($\bar{X}$ = 106 ± 57 [SD]) (Table 1). The home range size did not increase with increasing numbers of sample periods ($r = 0.2$, $P = 0.64$). Based on observed reproductive behavior, all hawks were territorial adult breeders. We simultaneously tracked both members of two mated pairs (Male1–Female1 and Male3–Female5). In addition, Female4 and Female5 were breeders on the same territory in 1986 and 1988, respectively.

Female nesting home ranges (N = 5), as defined by the 95% HM contour, varied in size from 95–1292 ha ($\bar{X}$ = 569 ± 473). Female home ranges were significantly (H = 5, df = 1, P = 0.025) smaller than male home ranges (N = 3) which ranged from 1698 to 2837 ha ($\bar{X}$ = 2106 ± 635). The females' 75% HM contour averaged 340 ± 288 ha and the males' 75% HM contour averaged 1273 ± 400 ha.

Goshawk home ranges varied in shape and size and in the number of core areas (Fig. 1). All birds had a core area that included the nest site but two birds had additional core areas that did not include the nest site (Fig. 1B). Only the core areas

TABLE 2. SUMMARY OF RADIO–TELEMETRY INFORMATION FOR NORTHERN GOSHAWK OFFSPRING IN NORTH-CENTRAL NEW MEXICO IN 1992

Bird	Sex	Tracking period	Fledgling age[1] (weeks)	Transmitter life (days)
GARC1	Male	6/9/92–7/11/92[2]	8	33
GARC2	Male	6/9/92–7/15/92[3]	9	37
GARC3	Female	6/9/92–6/21/92[3,8]	5	13
GUAJ1	Male	6/10/92–10/5/92[4]	20	118
GUAJ2	Female	6/10/92–10/14/92[5]	22	127
GUAJ3	Male	6/10/92–9/11/92[6]	17	94
BARL1	Female	6/11/92–9/21/92[4]	18	103
BARL2	Male	6/11/92–9/11/92[7]	17	93
BARL3	Male	6/11/92–10/9/92[4]	21	121
SJ1	Female	6/17/92–10/9/92[4]	20	115
SJ2	Male	6/17/92–8/14/92[3]	12	59
SJ3	Male	6/17/92–7/23/92[3]	9	37
BAC1	Male	6/18/92–10/14/92[5]	21	119
BAC2	Female	6/18/92–9/17/92[6]	17	92
STAB1	Male	6/19/92–8/26/92[4]	13	69
STAB2	Female	6/19/92–9/26/92[6]	18	100

[1] Age of the bird when we obtained the last location.
[2] Bird died.
[3] Transmitter failure (bird seen but signal not picked up).
[4] Transmitter failed or bird dispersed.
[5] Bird tracked until end of study (10/14/92); still in study area at time the study was completed.
[6] Transmitter dropped.
[7] Bird recaptured at Manzano Mountain migration station by HawkWatch International personnel, approximately 150 km SE of the nest site in New Mexico.
[8] Due to small number of locations obtained on this bird, it was not included in Table 3 and the statistical analyses described in text.

that included the nest were used in the statistical analyses. The females' core areas averaged 168 ± 129 ha and were significantly ($H = 5$, $df = 1$, $P = 0.025$) smaller than the males' core areas ($\bar{X} = 649 \pm 335$ ha). The core areas for all adults averaged 31.8% (±3.2) of the total home range area and 60.3% (±7.4) of the utilization volume.

All observations of fledglings occurred within the females' core areas centered around the nest, overlapping extensively with the core areas of mated pairs (qualitatively determined by visual inspection of home range plots). Females were observed regularly perching and roosting near fledglings throughout their core area, and prey deliveries to fledglings from both adults also occurred in this area (P. L. Kennedy, unpubl. data). We suggest the female's core area represents a concentrated-use area for the family from fledging until the young are independent (PFA). Males were observed perching, roosting and hunting in their core areas (the areas not included in the PFA).

FLEDGLINGS

We obtained radio-telemetry information on 16 goshawk offspring ranging from 5 to 22 weeks post-fledging (Table 2). Approximately 69% of the fledgling locations ($N = 301$) occurred within 200 m of the nest and 91.0% of the locations occurred within 800 m of the nest (Table 3). About 83% of these observations ($N = 259$) were visual or auditory observations and the remaining 17% ($N = 52$) were obtained from triangulation on the ground or from aerial surveys. The maximum distance from the nest recorded for a fledgling was 8.8 km. The mean (SD) distances from the nest by week post-fledging were: Week 1, 11.8 m (32.2 m), Week 2, 47.4 m (147.0 m), Week 3, 50.4 m (93.7 m), Week 4, 164.6 m (101.8 m), Week 5, 302.0 m (443.3 m), Week 6, 547.7 m (655.5 m), Week 7, 1330.6 m (2402.7 m), and Week 8, 1955.6 m (1858.5 m). Fledglings moved gradually further away from the nest site with time ($\chi^2 = 226$, $P < 0.001$). During the first four weeks of the fledgling-dependency period, 88.1% ($N = 193$) of the locations occurred within 200 m of the nest and 99.5% of the locations occurred within 800 m of the nest. During the last four weeks only 34.3% of the locations ($N = 108$) were within 200 m of the nest and 75.9% of the locations were within 800 m of the nest.

DISCUSSION

NESTING SEASON HOME RANGE

Similar to other home range estimates for nesting raptors (Becker and Sieg 1987, Bloom et al. 1993, Squires et al. 1993), the nesting ranges of the goshawks in this study varied extensively. This variation can be attributed to variation in

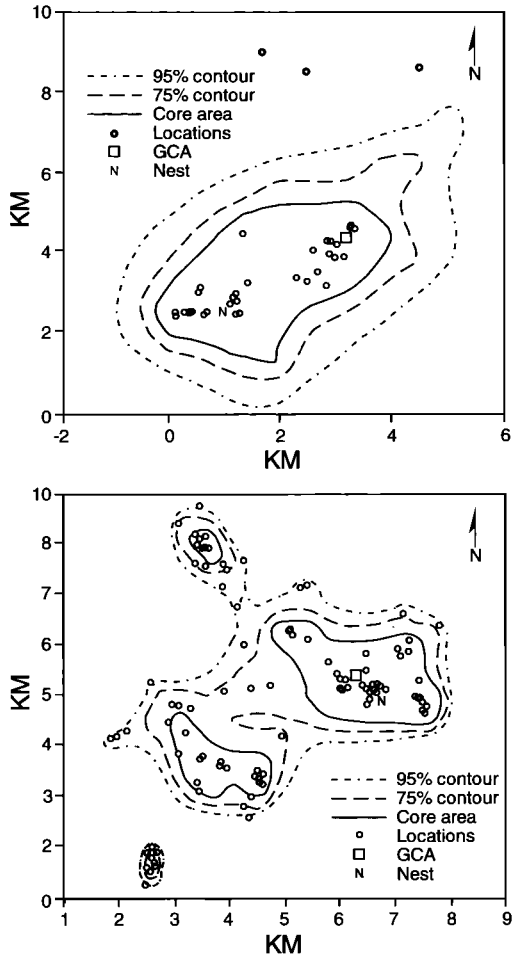

FIGURE 1. Examples of home ranges of male nesting northern goshawks. The axes of the plots reflect the distance from the central point in the study area (0,0) which was arbitrarily chosen as the southwest corner of a USGS 7.5-minute quadrangle. (*Top*) This is an example of a bird (Male1) with one core area, and (*bottom*) a bird (Male2) with multiple core areas. GCA is the geometric center of activity.

(1) sexual differences in parental care strategies, (2) the experience of the bird with its territory, (3) hunting efficiencies, (4) food requirements (which vary by brood size), and (5) food availability within the territory. Goshawk range size is predicted to decrease with increasing food availability and this relationship is probably a function of the distributions of habitat types in the home range. We do not have information on the habitat distributions within the home ranges of the eight hawks so we cannot evaluate the influence of habitat on home range size in this study area.

The home range sizes in this study were within the range of sizes reported by other investigators who estimated goshawk nesting ranges with a variety of other techniques besides radio-telemetry (Kramer 1955, Eng and Guillion 1962, Brüll 1964, van Beusekom 1972, Reynolds 1983). Home range estimates for hawks from European and North American populations range from 1980 to 3202 ha. Although these estimates are remarkably close to the estimates in this study, generalizations are difficult, and may not be meaningful because of differences in methodologies.

Post-fledging Areas

Home range is an estimate of the area normally used by an animal (White and Garrott 1990). In raptor home range studies, the area within the home range boundary minus the nest site is assumed to represent the adult's foraging area (see Marquiss and Newton 1981, Becker and Sieg 1987, and Squires et al. 1993 as examples). Our results suggest that the nest site is not large enough to encompass all of the other activities associated with brood rearing. In goshawk home ranges in the Jemez Mountains of north-central New Mexico, family activities during the second half of the fledgling-dependency period extend beyond the 10-ha nest site into an area referred to as the PFA (Reynolds et al. 1992).

The PFA surrounds and includes the nest site (see Fig. 9 in Reynolds et al. [1992]) and is estimated to be 168 ha for goshawks nesting in this study area. This size estimate is based on the average core area of the five adult females and the movement data of the 15 fledglings monitored in this study. During the first four weeks of the fledgling-dependency period most of the young hawks' movements occurred in the nest site. However, from four weeks post-fledging until independence the juveniles regularly occurred outside the nest site up to 800–1000 m from the nest. Similarly, Kenward et al. (1993a) observed fledgling European goshawks abruptly increasing the distance they traveled from the nest when they were 3–4 weeks past fledging. Before that age, fledglings were almost always observed within 400 m of the nest. From 3–4 weeks post-fledging until independence (approximately 25 days later) the juveniles frequently occurred up to 1000 m from the nest. Based on these results, we think the average female core area is a reasonable approximation of the area used by the fledglings during the second half of the fledgling-dependency period.

Although we estimate the PFA to average 168 ha in this study area, it probably varies in size as a result of variation in food availability. Kenward et al. (1993b) observed that distances moved

TABLE 3. NUMBER OF OBSERVATIONS (N = 301) OF YOUNG NORTHERN GOSHAWKS (N = 15) AT DIFFERENT DISTANCES FROM THE NEST (N = 5) DURING THE POST-FLEDGING DEPENDENCY PERIOD IN NORTH-CENTRAL NEW MEXICO, 1992

Distance from nest (m)	Weeks after fledging							
	1	2	3	4	5	6	7	8
0–49	38	40	23	4	2	0	0	0
50–99	5	6	15	5	3	2	0	1
100–199	2	8	5	19	10	9	8	2
200–399	0	2	1	16	11	13	1	1
400–799	0	0	1	2	1	8	6	4
≥800	0	1	0	0	2	9	6	9
Total	45	57	45	46	29	41	21	17
Percent of birds in post-fledging area[1]	100	98.2	100	100	93.1	78.0	71.4	47.1

[1] Percentage of observations <800 m from nest.

by juvenile European goshawks after independence were significantly shorter in areas of high food availability as compared to areas of low food availability. Presumably pre-independence movements would demonstrate a similar pattern if juveniles initiate self-feeding prior to independence.

The exact significance of the PFA is unknown, but it may be an area of very high prey availability as compared to other areas within the home range of the nesting pair. As suggested by Kennedy (1988), goshawk nest sites may be selected because they are central points within a localized area of high food availability within the home range of a nesting pair. A PFA of high prey availability would provide more hunting opportunities for young hawks while they are learning to hunt. As noted by Reynolds et al. (1992), the PFA may also be an area that provides additional cover for the inexperienced juveniles to use for avoiding predators and for concealment while learning how to approach prey.

FORAGING AREAS

The 95% HM contour area is an overestimate of the foraging area of goshawks in this study area because a bird only uses portions of the home range in its normal activities. However, until better information is available on the location of specific foraging areas, we estimate the male's foraging area to be 2090 ha (2100 ha minus the 10-ha nest site) and the female's foraging area to be 560 ha (570 ha minus 10 ha). The nest site area is not included in the foraging area because the adults rarely hunt in this area (P. L. Kennedy, unpubl. data). The male's foraging area is larger in size because of his role as primary food provider during brood rearing. Female goshawks in this area were rarely observed hunting until the young were close to fledging and even after the females began hunting, they did not provision the young as frequently as the male (Kennedy 1991).

The core areas were not excluded from the foraging area estimates because we have no information to suggest that the adults do not hunt in these areas of concentrated use. In fact, our observations suggest the male's core area (excluding the nest site) represents preferred hunting areas used by him throughout brood rearing and the female's core area includes hunting areas she regularly uses after the young fledge.

MANAGEMENT IMPLICATIONS

We concur with management guidelines developed by Reynolds et al. (1992) that management of goshawk nesting habitat in the southwestern U.S. should include the three components of the goshawk home range: nest site, PFA, and foraging area. In north-central New Mexico the sizes of these areas are estimated to be 10 ha, 168 ha and 2090 ha, respectively. Nest sites need to be managed to provide habitat for the breeding activities that occur from courtship through fledging. The PFA needs to be managed to provide sufficient cover and prey for the fledglings, and the foraging area should be managed for enhancing prey populations exploited by the adults.

The forest conditions needed to provide these areas in the southwestern U.S. and management guidelines for maintaining these conditions are discussed in detail in Reynolds et al. (1992). Because of the preliminary nature of our results, we suggest the acreages presented in this study only be used as guides in the absence of site-specific data on goshawk activity areas.

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APPENDIX

Bird locations are triangulated using the known positions of two observers and their simultaneous measurements of bearing direction to the bird. The coordinates (x_0,y_0) of the bird are given in terms of the coordinates (x_1,y_1) and (x_2,y_2) of the two observers and the measured bearing angles θ_1 and θ_2 as

$$x_0 = \frac{y_2 - y_1 + x_1\cot\theta_1 - x_2\cot\theta_2}{\cot\theta_1 - \cot\theta_2}$$

$$y_0 = \frac{x_2 - x_1 + y_1\tan\theta_1 - y_2\tan\theta_2}{\tan\theta_1 - \tan\theta_2}, \qquad \text{(A1)}$$

where θ_1 and θ_2 are measured clockwise from a convenient common origin (e.g., magnetic north). We assume that the observer coordinates are known exactly, and that the bearing angles are each subject to uncorrelated uncertainties of magnitude $\delta\theta_1 = \delta\theta_2 = \delta\theta$. These assumptions lead to uncertainties in the computed bird coordinates of magnitude

$$(\delta x_0)^2 \cong \left(\frac{\partial x_0}{\partial\theta_1}\delta\theta_1\right)^2 + \left(\frac{\partial x_0}{\partial\theta_2}\delta\theta_2\right)^2 = \frac{(x_0 - x_1)^2\sin^4\theta_2 + (x_0 - x_2)^2\sin^4\theta_1}{\sin^2\theta_1\sin^2\theta_2\sin^2(\theta_2 - \theta_1)}(\delta\theta)^2$$

$$(\delta y_0)^2 \cong \left(\frac{\partial y_0}{\partial\theta_1}\delta\theta_1\right)^2 + \left(\frac{\partial y_0}{\partial\theta_2}\delta\theta_2\right)^2 = \frac{(y_0 - y_1)^2\cos^4\theta_2 + (y_0 - y_2)^2\cos^4\theta_1}{\cos^2\theta_1\cos^2\theta_2\sin^2(\theta_2 - \theta_1)}(\delta\theta)^2. \qquad \text{(A2)}$$

The standard bearing uncertainty $\delta\theta$ is estimated by analyzing the errors in repeated observations of known transmitter locations. To estimate $\delta\theta$ in this study, we attempted to determine the direction to a transmitter placed at 50 random locations by an independent assistant. The standard deviation of differences between observed and true bearings was 5°. Visual observations (approximately 20% of the total) were assumed to have $\delta\theta = 0$. If the true field errors are constant, independent of location and observer, and well-represented by our adopted value of $\delta\theta$, then our procedure yields results equivalent to repeated measurement and statistical analysis of the actual field bearings (White and Garrott 1990). Our procedure is more efficient than attempting to obtain statistical samples for every field observation. In the present context, it yields better results because it is rarely possible to make a statistically significant number of repetitions in the field.

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TERRITORY OCCUPANCY AND HABITAT PATCH SIZE OF NORTHERN GOSHAWKS IN THE SOUTHERN CASCADES OF CALIFORNIA

BRIAN WOODBRIDGE AND PHILLIP J. DETRICH

Abstract. We monitored annual occupancy of forest patches by nesting Northern Goshawks (*Accipiter gentilis*) in the southern Cascades Mountains in northern California. Goshawks typically used 3–9 alternate nests distributed among 1–5 different forest stands ranging from 4.1 to 115 hectares in size, and showed low fidelity to individual nest trees or stands. Mean distance between alternate nests was 273 ± 68.6 m. Alternate nests and nest stands were grouped into nest stand clusters, which for monitoring purposes were the equivalent of territories. Nest stand clusters ranged from 10 to 114 hectares in size, and were occupied 74% (±5.5) of years monitored. Occupancy of nest stand clusters by nesting goshawks was positively correlated with cluster area, with occupancy of clusters <20 ha typically <50%. Reproductive success was not correlated with habitat area. Two patterns of territory occupancy were distinguishable; traditional territories (23) where nesting by goshawks was predictable within finite nest clusters and ephemeral territories (5) where alternate nests were widely scattered and sporadically used. Despite extensive timber harvesting and forest fragmentation within our study area, goshawks occurred at relatively high densities (0.57–1.07 territories per 1000 ha). However, most goshawk territories were associated with the larger remaining patches of mature forest, and occupancy of these patches was positively associated with patch area.

Key Words: *Accipiter gentilis*; forest fragmentation; nesting habitat; Northern Goshawk; territory occupancy.

Habitat suitability for an animal is a function of the structural characteristics and spatial arrangement of habitat patches, as well as the presence of predators, competitors and adequate food resources (Cody 1981). Fragmentation of habitat can influence habitat suitability even if the structure of the remaining habitat patches remains unchanged (Temple and Wilcox 1986). Assessing the effects of habitat fragmentation on large, mobile species such as birds of prey is further complicated by these species' use of multiple patches in a landscape, often using different types of patches to fulfill different life requisites (e.g., nesting versus foraging or cover) (Harris and Kangas 1988).

The structural attributes of forest stands used for nesting by Northern Goshawks (*Accipiter gentilis*) have been described in a variety of forest ecosystems in North America, including eastern deciduous (Speiser and Bosakowski 1987) and western coniferous (Reynolds et al. 1982, Hall 1984, Crocker-Bedford and Chaney 1988, Hayward and Escano 1989) forests, and Great Basin shrubsteppe communities (White and Lloyd 1965, Younk and Bechard, this volume). Although conducted in different communities, these studies and others (summarized in Reynolds 1989, Reynolds et al. 1992) found that a number of structural features were common to goshawk nest stands in most areas. Nest stands are typically composed of large, densely spaced trees, with higher canopy closure and more open understories than the surrounding landscape. The majority of these studies, however, did not consider spatial relationships such as size and distribution of habitat patches, and none used long-term patterns of occupancy of habitat patches by nesting goshawks to assess habitat quality.

Estimates of stand size given by Reynolds (1983) were based on measurement of areas of intensified activity adjacent to nests (nest areas) and did not necessarily reflect the actual size of the forest stands used for nesting. Crocker-Bedford (1990) described the spacing and occupancy of alternate nests within goshawk territories (nest clusters) and reported a relationship between the size of unharvested buffers surrounding nest sites and subsequent occupancy by nesting goshawks. Kennedy (1991) used the movements of radio-marked goshawk family groups to define the post-fledging family area (PFA), an area of concentrated use by the family group after the young left the nest. It is not clear, however, how PFAs were differentiated from nest stands or clusters of nest stands. Estimating the relationship between patch size of nesting habitat and overall territory quality is further complicated when the effects of foraging habitat quality are considered (Crocker-Bedford 1990, Reynolds et al. 1992).

In this study we describe spatial patterns of habitat use by nesting Northern Goshawks at four levels of resolution: nest trees, nest stands, territories (clusters of nest stands), and spacing between territories. At each level we compare spatial attributes to rates of occupancy by nesting goshawks.

STUDY AREA AND METHODS

This study took place in the southern Cascades Mountains of northern California, on the Goosenest Ranger District of the Klamath National Forest. The area was composed of three major forest types. Sierran Montane Forest and Upper Montane Forest (Küchler 1977) occurred at higher elevations and were dominated by red fir (*Abies magnifica*), white fir (*Abies concolor*), ponderosa pine (*Pinus ponderosa*), lodgepole pine (*Pinus contorta*), Douglas-fir (*Pseudotsuga menziesii*), and incense cedar (*Calocedrus decurrens*). Lower elevation forests were comprised primarily of Northern Yellow Pine Forest (Küchler 1977), dominated by ponderosa pine and white fir. Most of the study area was between 1400 m and 2330 m elevation and was relatively dry, with most precipitation falling as snow in winter. The area had a long history of timber harvest, with intensive harvesting occurring as early as 1900 (Laudenslayer and Darr 1990). The resulting forest landscape occurred as scattered patches of unmanaged mature forest dispersed in a matrix of thinned or regenerated stands. Suppression of natural fire within this ecosystem resulted in increased density of fire-susceptible conifer species such as white fir in areas formerly dominated by fire resistant species (ponderosa pine, incense cedar; Biswell 1989, Laudenslayer et al. 1989).

We surveyed for nesting northern goshawks each spring and summer from 1984 to 1992. Our initial sample of territories was derived from Forest Service records and survey transects conducted in areas of potential goshawk habitat. In 1988 we began using broadcast of taped conspecific alarm calls along established transects (Fuller and Moser 1981, Rosenfield et al. 1985, Kennedy and Stahlecker 1993) within two 12,000 hectare survey blocks. We returned annually to all known territories to determine occupancy and reproductive success. We intensively surveyed an area of 1.6 km radius surrounding each previously active nest to locate alternate nest sites. Terminology proposed by Postupalsky (1974) and Steenhof and Kochert (1982) was used to define occupancy and nesting success of goshawk territories. We defined nest productivity as the number of large (minimum 5 week old) nestlings. Each year that a given territory was monitored was termed a territory-year. Alternate nests within territories were typically clumped and could be distinguished from adjacent territories. However, in cases where alternate nests were widely spaced we used simultaneous occupancy of both adjacent territories to distinguish between them. We measured distances between the geometric centers of nest clusters at adjacent territories to estimate nearest-neighbor distances. Locations of occupied nests, alternate nests, and habitat boundaries were mapped each year on aerial photographs (scale 1:13,000).

We defined nest stands as patches of forest that were homogeneous in composition, age, and structure relative to the surrounding forest (Spurr and Barnes 1980) and were used for nesting. Boundaries of most stands were the result of forest management activities and natural features such as meadows and lava flows, and were clearly distinguishable on aerial photographs. Areas of nest stands were measured directly from aerial photographs with a Numonics digital planimeter. We classified a stand as occupied if goshawks built a nest or reused an existing nest within it. We calculated occupancy rates for individual stands by dividing the number of years the stand was occupied by the total number of years the stand was monitored.

Nest stand clusters were defined as the aggregate area of all stands within a territory that were used for nesting, and for monitoring purposes were the equivalent of territories. Nest stand clusters were considered occupied if goshawks attempted to nest, exhibited defensive behavior, or were sighted repeatedly within them. The occupancy rate of each cluster was calculated by dividing the number of years the cluster was monitored by the total number of years the cluster was monitored.

Comparisons of stand and nest cluster size with occupancy rates were made using the Spearman Rank Correlation (Zar 1984). Only stands (N = 71) or clusters (N = 23) with >5 years of monitoring were used in statistical comparisons. We found that five years of monitoring was sufficient to delineate the area of most nest stand clusters. Mean values in the text are presented with standard errors (±SE).

RESULTS

Monitoring

We monitored 141 territory-years at 28 goshawk territories within the study area. Occupancy by at least one adult goshawk was confirmed in 100 (71%) of monitored territory-years, and breeding attempts were observed in 89 (63%). Rates of occupancy and breeding were likely underestimated due to the secretive behavior (Kennedy and Stahlecker 1993) and annual movements of nesting goshawks observed in this study. The sample of monitored territories increased each year of the study, from 18 in 1984 to 28 in 1992. Six territories were monitored for over 10 years, 17 were monitored 5–9, and five were monitored ≤4 years.

Productivity for 84 nesting attempts averaged 1.93 young per attempt (range = 0–4). Eighty-seven percent of observed nesting attempts were successful. Primary causes of nest failure included failed incubation (cause unknown = 7), severe spring storms (2), and predation by Great Horned Owls (2; *Bubo virginianus*). Brood size was reduced in nine successful nest attempts when nestlings fell from the nest or were killed by siblings. Nest success and productivity were probably overestimated because nesting attempts failing prior to the nestling stage and mortalities occurring after fledging were less likely to be detected.

Occupancy of Nest Trees

Territories typically contained more than one nest, most having from 3 to 9. Many of these inactive alternate nests were not observed to be used by goshawks during the study. The mean number of nests actually used during the study was 2.6 (±0.42, range = 1–5) per territory. The reoccupancy rate of individual nest trees was low. Only 37 of 85 (44%) nest attempts were in nests

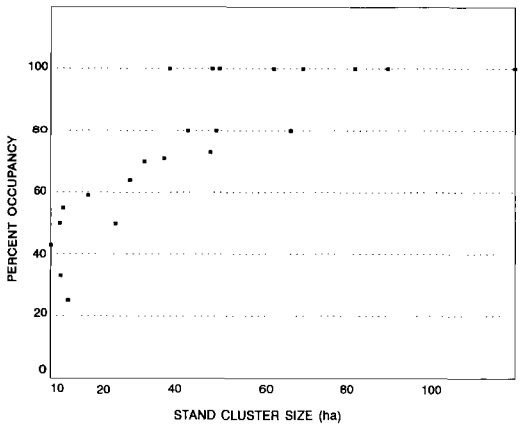

FIGURE 1. Correlation of percent occupancy of goshawk nest stand clusters versus cluster size for 26 territories in the southern Cascades of California, 1984–1992.

used the previous year. The average reoccupancy rate of individual nests at 26 territories over at least 5 years was 49% (±11%). Reoccupancy of alternate nests was highly variable; at some territories goshawks did not re-use the same nest twice in 4–7 years, whereas others used a single nest for 2–6 years and then moved to or built another.

Distribution of Alternate Nests

Spacing and distribution of alternate nests varied widely among territories. Nests in most territories were clumped in two or three adjacent stands, whereas others contained nests scattered in stands up to 2.1 km apart. The mean distance between alternate nests in 65 nest attempts in this study was 273 (±68.6) m, (range = 30–2066 m). This estimate of nest spacing was conservative in that it included only movements actually observed between years. Longer movements were more difficult to detect and were likely underrepresented.

Use of Nest Stands

Goshawk territories typically contained 1–5 different forest stands used for nesting ($\bar{X}$ = 2.4 ± 0.7). Stands used for nesting ranged from 4.1 to 115 hectares in size ($\bar{X}$ = 27.8 ± 5.3 ha, N = 71 stands).

At territories with at least five successive years of monitoring, individual nest stands were occupied by nesting goshawks an average of 46% (±6%) of the years monitored (N = 71). The maximum distance recorded between nest stands was 1.8 km. However, over 85% of alternate nest stands were less than 0.7 km apart ($\bar{X}$ = 0.52 ± 0.11 km, N = 71 stands). Occupancy rates of individual nest stands were positively correlated with stand size (r_s = 0.85, P = 0.001). Smaller stands (<10 ha) typically contained 1–2 nests and were only occasionally occupied by goshawks, whereas larger stands (>20 ha) often contained several nests and were occupied in a high proportion of territory-years.

Nest Stand Clusters

Nest stand clusters ranged from 10.5 to 114 ha in size ($\bar{X}$ = 41.7 ± 5.89, N = 26 territories). The mean occupancy rate of nest stand clusters was 0.74 (±0.055, N = 26). Occupancy rates of 23 nest stand clusters with at least five years of monitoring was positively correlated with cluster size (r_s = 0.88, P = 0.008). Occupancy rates of clusters of <20 hectares were typically <50%. At approximately 40 ha occupancy rose to 75–80%, and was nearly 100% for stand clusters >61 ha (Fig. 1). We found no significant relationship between stand cluster size and productivity (r_s = 0.052, P = 0.819). The mean number of young produced per occupied territory (minimum five year average) was relatively uniform among territories.

Territory Spacing and Density

Nearest-neighbor distances for 21 goshawk territories within intensive survey blocks ranged from 1.3 to 6.1 km, averaging 3.25 ± 0.34 km. Spacing appeared to be reduced around landscape features such as meadows and riparian systems, where goshawk territories were clumped. Eleven territories were located within a 10,230 ha block of Sierran Montane Forest yielding a density of 1.07 territories per 1000 ha, compared with 0.575 territories per 1000 ha in a 10,440 ha block of Upper Montane Forest.

DISCUSSION

Territory use by goshawks in this study was characterized by alternate use of nest sites up to 2.1 km apart, and low fidelity to any particular nest site. Over time the number of nest sites recorded in most territories increased, as did the area of habitat containing them. From 4 to 6 years of monitoring were required to define the actual area used for nesting within most territories. The resulting area of nesting habitat (nest stand cluster) was considerably larger than area estimates derived from a single year (Crocker-Bedford 1990), or measurement of activity centers surrounding individual nests (Reynolds 1983).

Comparison of nest habitat area in this study with results of other studies is complicated by differences in terminology and basic study design. Measurements of nest stands and stand

clusters in this study were made using physical boundaries of nest stands. It is likely that only a small portion of each stand is actually used for nesting in a given year. Reynolds et al. (1992) proposed a hierarchy of spatial components comprising goshawk home ranges: nest area, post fledging family area, and foraging area. Each of these components was based on measurement of goshawk activity and cannot be estimated without radio-telemetry. Estimates of nest habitat area based on observations of nest-tending activities (Reynolds 1983) overlook the possibility that selection of nest sites by goshawks is based at least partially on patch size. Our observations of reduced occupancy in smaller stands suggest that patch size may be an important factor determining quality of nesting habitat.

The post fledging family areas (PFA) described by Kennedy (1991) may be somewhat analogous to nest stand clusters in that the PFA is a larger area encompassing at least one nest site. It is not clear whether the PFAs studied by Kennedy (1991) contained all known nest sites within each territory, or if goshawk pairs moved outside of PFA boundaries in subsequent years. This relationship could be assessed by comparison of PFA boundaries with the distribution of alternate nest sites and the boundaries of nest stands, particularly over a number of years.

Alternate nest sites within most territories appeared as clusters, spatially distinct from nest clusters at neighboring territories. At five territories (18%), however, alternate nests were very widely spaced and territory boundaries were less distinct. Maximum distances between alternate nests at these territories were similar to minimum distances between simultaneously occupied neighboring territories.

Mean occupancy rates of habitat components increased as spatial scale increased from nest trees to nest stands and nest stand clusters. Annual movements of nesting goshawks may have reduced our ability to detect some nest attempts in remote nest sites, resulting in underestimation of occupancy at larger scales (nest stand clusters). Patterns of occupancy at goshawk territories fell into two categories: traditional territories (23), where nesting by goshawks was predictable and typically occurred within finite nest clusters; and ephemeral territories (5), where nesting was sporadic and nest sites were widely distributed. Ephemeral territories were occupied in less than three of five years and appeared to be associated with highly fragmented areas of lodgepole pine and mixed pine stands where extensive tree mortality due to bark beetles (*Dendroctonus* spp.) had occurred. Changes in stand structure in these areas may have resulted in increased density or vulnerability of prey and attracted goshawk pairs to nest in areas where little mature forest habitat was available.

Although occupancy of nest stand clusters was clearly correlated with cluster size, other factors may have affected occupancy of specific clusters by nesting goshawks. Reduction and fragmentation of mature forest habitat may favor early successional competitors and predators such as Red-tailed Hawks (*Buteo jamaicensis*) and Great Horned Owls (Moore and Henny 1983, Johnson 1993) and reduce occupancy by goshawks (Crocker-Bedford 1990). Occupancy of traditional goshawk nests or nest stands by Great Horned Owls, Long-eared Owls (*Asio otus*), Northern Spotted Owls (*Strix occidentalis caurina*), Red-tailed Hawks and Cooper's Hawks (*Accipiter cooperi*) was recorded in this study, but was not associated with territory abandonment by goshawks. In three instances, however, goshawks moved outside of their traditional nest cluster after it was occupied by Northern Spotted Owls.

Despite intensive timber harvest and fragmentation of mature forest, our study area supported high densities of nesting goshawks. Goshawk territories, however, were associated with the larger remaining patches of mature forest, and territory occupancy was positively correlated with the size of nesting habitat patches.

Several factors may act to mitigate the effects of timber harvest and forest fragmentation on goshawk habitat quality in our study area. Timber harvests occurring after the early 1960s typically consisted of commercial thinning, shelterwood, and sanitation prescriptions, resulting in less distinction between harvested areas and remaining mature forest than in large clearcut regimes. Golden-mantled Ground Squirrels (*Spermophilus lateralis*), a primary prey species for goshawks in the southern Cascades (Woodbridge, unpubl. data), are abundant in open habitats (Ingles 1965) and were frequently observed in previously harvested areas. This prey resource could act to offset losses of prey species associated with mature forest. Finally, effects of forest fragmentation on goshawk populations may be less important in forest ecosystems such as the southern Cascades that are naturally fragmented by topography, xeric conditions, and wildfire. Comparison of our results with data collected in different forest ecosystems may provide insights into the relative importance of nesting habitat area.

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DENSITY AND PRODUCTIVITY OF NORTHERN GOSHAWKS: IMPLICATIONS FOR MONITORING AND MANAGEMENT

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Abstract. We studied Northern Goshawk (*Accipiter gentilis*) breeding populations on five study areas on the Fremont, Malheur, and Wallowa-Whitman National Forests in eastern Oregon during 1992 and 1993. We found 50 active territories, with average densities of 0.07 active territories per 100 ha (SE = 0.15, N = 3 study sites) in 1992 and 0.06 (SE = 0.15, N = 5 sites) in 1993. However, densities were variable both between years and among areas within each year, and no consistent patterns were seen based on forest cover type. Productivity (number of young fledged per nest) was also variable between years and among study sites within the same year. Current USDA Forest Service management for goshawks emphasizes reducing tree harvest around specific nest sites or post-fledging family areas (PFAs). Our data, however, show that numbers of nesting goshawks are variable among years, and not all breeding sites will be discovered in a single year of survey. We recommend multiple-year surveys for nesting birds and habitat management on a landscape rather than "per nest" basis.

Key Words: *Accipiter gentilis*; breeding; nesting; Northern Goshawk; Oregon.

Timber harvesting has been implicated as a factor in reducing the number and altering the distribution of nest sites of Northern Goshawks (*Accipiter gentilis*) throughout much of the forested western United States (Reynolds et al. 1982, Crocker-Bedford 1990, Ward et al. 1992). In Oregon, this concern has led the Oregon Department of Fish and Wildlife to place the Northern Goshawk on the state's list of sensitive species.

In the Pacific Northwest, scientific research and public attention has focused on forest ecosystems and wildlife populations on the west side of the Cascade Mountain Range, largely due to concern for the status of Northern Spotted Owls (*Strix occidentalis caurina*). Interest is growing, however, in east-side forest issues, such as timber harvest, forest health, and wildlife habitat. The Northern Goshawk has been identified as a species of special concern and is being considered as a potential indicator of the health of mature ponderosa pine (*Pinus ponderosa*) and mixed conifer forests in eastern Oregon (Marshall 1992).

We studied goshawk populations in eastern Oregon to determine the distribution, density, and productivity of nests in major forest types, describe diet, and make recommendations for goshawk management and monitoring of breeding populations.

METHODS

STUDY SITES

Research took place on three National Forests in eastern Oregon: the Fremont, Malheur, and Wallowa-Whitman. These Forests were located across eastern Oregon and represented a wide spectrum of forest types. Mixed conifer forest (including combinations of ponderosa pine, Douglas-fir [*Pseudotsuga menziesii*], western larch [*Larix occidentalis*], incense-cedar [*Calocedrus decurrens*], sugar pine [*Pinus lambertiana*], and firs [*Abies* spp.]) and forest stands with a large component of ponderosa pine were found on all three Forests. In addition, large expanses of lodgepole pine (*Pinus contorta*) were present on the Fremont National Forest. Topography on all Forests ranged from gently sloping ridges to steep-walled drainages, with elevations between 900–2000 m. Natural openings, such as wet meadows, grasslands, and burns, were distributed throughout the study sites. Partial cuts (shelterwood, overstory removal, commercial thinning) and some clear-cutting were the major tree harvesting practices.

Five survey areas (called Density Study Areas [DSA]) were established on the three National Forests and ranged from 11,500 to 15,500 ha. Two DSAs were located on the Fremont National Forest: the Paisley DSA contained mostly lodgepole pine (80%), with some ponderosa pine (15%) and mixed conifers (5%); the Bly DSA was primarily mixed conifer (70%) and ponderosa pine (30%). Two DSAs were located on the Malheur National Forest: Bear Valley East DSA was dominated by ponderosa pine, with about 25% of the area covered by islands of lodgepole pine and mixed conifers; Bear Valley West DSA was mostly mixed conifer, with about 25% of the area in ponderosa pine. The Spring Creek DSA on the Wallowa-Whitman National Forest was comprised of mixed conifer stands.

SURVEYS

We used survey protocol recommended by Woodbridge (pers. comm.) and Kennedy and Stahlecker (1993) to search for all nesting goshawks within the five DSAs. Survey stations were about 300 m apart and were set up on roads and trails and along transects through roadless areas to obtain complete coverage of each DSA. From mid-May to early August, taped goshawk calls were broadcast through a megaphone (modified Realistic® model 32-2030 coupled to a Sony® walkman model WMA53). Responses to the taped calls and incidental sightings of goshawks were followed by intensive searches to locate nests. Nest locations were marked on topographic maps and aerial photographs.

TABLE 1. NUMBER AND DENSITY OF NORTHERN GOSHAWK NESTING TERRITORIES ON THE FREMONT, MALHEUR, AND WALLOWA-WHITMAN NATIONAL FORESTS IN EASTERN OREGON, 1992–1993

			1992				1993			
Forest	DSA	Primary forest cover	Area (ha)	Known nests	Active territories	Density (active terr./100 ha)	Area (ha)	Known nests	Active territories	Density (active terr./100 ha)
Fremont	Paisley	Lodgepole	8780	3	4	0.046	12,960	6	8	0.062
	Bly	Mixed conifer/ ponderosa					10,627	3	4	0.038
Malheur	Bear Valley East	Ponderosa/mixed conifer	9046	6	8	0.088	9046	6	6	0.066
	Bear Valley West	Mixed conifer/ ponderosa					10,519	8	9	0.086
Wallowa-Whitman	Spring Creek	Mixed conifer	11,396	7	8	0.070	11,396	3	3	0.026

The Paisley, Bear Valley East, and Spring Creek DSAs were surveyed in 1992 and 1993. The Bly and Bear Valley West DSAs were surveyed in 1993 only. In some cases, there was evidence of nesting goshawks (responses by birds to taped calls, repeated observations of defensive adults in an area) but the nest was not found. We included them in our calculations of breeding densities.

Productivity of nests was determined by visiting nest sites in late July and counting nestlings either just before or just after fledging. Nesting phenology dates were based on back-dating from estimated weekly development of juveniles based on plumage characteristics and fledging dates. Prey remains and goshawk pellets were collected under nest trees and at plucking posts and were placed in labeled plastic bags and stored frozen for analysis at a later date.

RESULTS

We found a total of 20 active territories in 1992 and 30 in 1993 (Table 1). Overall density averaged 0.07 active territories per 100 ha (SE = 0.15, N = 3) in 1992 and 0.06 per 100 ha (SE = 0.15, N = 5) in 1993. Densities were variable both between years and among areas within each year. No consistent patterns were seen based on forest cover type (i.e., DSAs dominated by lodgepole pine, ponderosa pine, or mixed conifers).

There was a decreasing trend in productivity (number of young per active territory) from the Fremont National Forest in the south to the Wallowa-Whitman National Forest in the north in 1992 (Table 2). This trend was repeated in 1993, when the Paisley and Bly DSAs on the Fremont and the Bear Valley East and Bear Valley West DSAs on the Malheur were combined ($\bar{X}$ = 1.56 young per nest, SE = 1.15, N = 9 nests for Fremont; $\bar{X}$ = 1.00, SE = 0.96, N = 13 for Malheur; $\bar{X}$ = 0.67, SE = 0.76, N = 3 for Wallowa-Whitman). In some cases, however, productivity was variable between years (e.g., Bear Valley East DSA) and between DSAs on the same Forest (Table 2). Nesting phenology was similar among Forests, with eggs laid in late April to early May, eggs hatched during late May to mid-June, and young fledged from late June to mid-July.

Totals of 119 and 101 prey items were identified in 1992 and 1993, respectively (Table 3). Avian and mammalian species made up 100% of identifiable prey remains. Both percent composition and percent biomass indicated that mammalian prey was more prevalent on the Fremont and Malheur National Forests, whereas avian prey was proportionally larger on the Wallowa-Whitman. However, our sample of prey remains for the Wallowa-Whitman was very low in 1993 because few pairs of goshawks nested.

DISCUSSION

Our estimates of density of goshawk breeding sites in eastern Oregon are probably minimums

TABLE 2. PRODUCTIVITY (NUMBER OF FLEDGLINGS PER KNOWN NEST SITE) OF NORTHERN GOSHAWKS ON THREE NATIONAL FORESTS IN EASTERN OREGON, 1992–1993

Forest	Density study area	1992 $\bar{X}$	1992 SE	1992 N	1993 $\bar{X}$	1993 SE	1993 N
Fremont	Paisley	2.2	0.75	6	2.2	1.08	6
	Bly				0.3	0.76	3
Malheur	Bear Valley East	1.9	0.57	10	0.3	0.72	6
	Bear Valley West				1.6	0.89	7
Wallowa-Whitman	Spring Creek	1.0	0.71	9	0.7	0.76	3

because we may not have found all active territories (Kennedy and Stahlecker 1993). In addition, nest failures early in the breeding season would have precluded us from detecting some active territories. However, our use of survey protocol recommended by Woodbridge (pers. comm.) and Kennedy and Stahlecker (1993) allowed us to obtain complete coverage of all five DSAs with equal effort, and to survey all forest types and seral stages for goshawk nests. Thus, we believe that our estimates of density are relatively accurate and directly comparable among the five study sites.

There was a substantial reduction in numbers of active territories from 1992 to 1993 on the Spring Creek DSA. This trend was also noted elsewhere on the Wallowa-Whitman National Forest (A. Blumton, pers. comm.) and adjacent Boise-Cascade Company lands (M. McGrath, R. Riggs, pers. comm.). This drop in breeding activity may have been due to cold, wet spring weather in northeastern Oregon. Densities of active goshawk territories also varied between DSAs on the same Forest, especially the Paisley and Bly DSAs on the Fremont.

There was a latitudinal trend in productivity, with higher numbers of juveniles fledged from south to north. This may have been a function of diet, as higher proportions of mammals were found in prey remains on the Fremont and Malheur than the Wallowa-Whitman. Bull and Hohman (*this volume*) reported similar productivity and diet results during 1992 from their study area on the Wallowa-Whitman National Forest. A relationship between high productivity and proportionally more mammalian species in the diet is speculative, however, and additional data on diet and productivity are required to draw conclusions.

Current USDA Forest Service management for Northern Goshawks in Region 6 (Oregon and Washington) calls for establishing protected zones around some nest sites (nest sites in areas under current timber harvest contracts are often exempt), where no or reduced timber harvest would take place. These zones are of variable size and often are on the order of 2–12 ha (5–30 acres). More recently, managers have been directed to protect a larger area around goshawk nest sites corresponding to the post-fledging family area (PFA).

Either of these approaches necessitate finding active goshawk breeding sites, and promotes management on a "per nest" basis. Our data show that not all sites are active in all years, and thus searching for goshawk nests in a single season in preparation for potential timber sales could easily overlook territories. This variability between years in nest site use by goshawks could be due to a poor breeding year because of inclement spring weather or some other environmental variable, as we believed happened in northeastern Oregon in 1993. Also, use of alternate nest sites by goshawks or early nest failure

TABLE 3. PERCENT COMPOSITION AND PERCENT BIOMASS OF PREY REMAINS COLLECTED AT NESTS AND PLUCKING SITES OF NORTHERN GOSHAWKS ON THE FREMONT, MALHEUR, AND WALLOWA-WHITMAN NATIONAL FORESTS IN EASTERN OREGON, 1992–1993

Forest	1992 N[1]	1992 Composition (%) Birds	1992 Composition (%) Mammals	1992 Biomass (%) Birds	1992 Biomass (%) Mammals	1993 N[1]	1993 Composition (%) Birds	1993 Composition (%) Mammals	1993 Biomass (%) Birds	1993 Biomass (%) Mammals
Fremont	49	49	51	34	66	47	53	47	27	73
Malheur	44	34	66	16	84	50	60	40	37	63
Wallowa-Whitman	26	62	38	64	36	4	50	50	51	49

[1] N = number of separate prey remains or goshawk pellets examined.

also influences the ability of surveyors to locate all nest sites.

Because of the variability in nest site use by goshawks, we recommend as an absolute minimum that surveys be conducted for at least two, and preferably three or four years in an area before allowing timber harvest. An alternative to the per-nest management approach would be to manage forest habitat on more of a landscape scale. Management plans, such as suggested by Reynolds et al. (1992), consider other forest-dependent species and promote management at a more holistic level. We believe that similar landscape-level recommendations are appropriate to other diurnal and nocturnal raptors.

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