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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 dho-gaza 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 BIO-TRACK). 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 habitat 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
156	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.

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).

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.

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 < 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).

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).

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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