Studies in Avian Biology No. 16:75–82, 1994.

POST-FLEDGING AREAS IN NORTHERN GOSHAWK HOME RANGES

PATRICIA L. KENNEDY, JOHANNA M. WARD, GEORGE A. RINKER, AND JAMES A. GESSAMAN

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

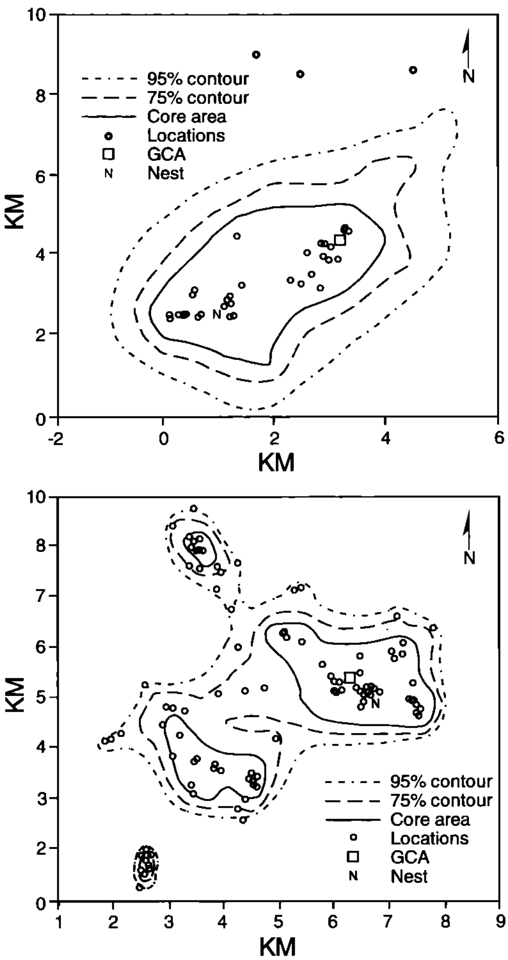

FIGURE 1. Examples of home ranges of male nesting northern goshawks. The axes of the plots reflect the distance from the central point in the study area (0,0) which was arbitrarily chosen as the southwest corner of a USGS 7.5-minute quadrangle. (*Top*) This is an example of a bird (Male1) with one core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

ACKNOWLEDGMENTS

This study was financially supported by Los Alamos National Laboratory's National Environmental Research Park, New Mexico Department of Game and Fish Share With Wildlife Program, USDA Forest Service Region 3, and USDA Forest Service, Santa Fe National Forest. The senior author was on an Associated Western University Graduate Fellowship during 1986–1989. D. Clark, D. Crowe, T. Dean, A. Ebinger, D. H. Fisher, Jr., T. Johnson, D. Kimmey, J. Lavy, J. Leon, J. Longmire, L. Morgan, J. Morrison, D. Ponton, M. Siders. D. Sinton, and R. Warren provided invaluable assistance in locating nests, trapping and banding goshawks and radio-tracking. We thank F. J. Barnes, K. Bostick, D. A. Boyce, Jr., D. DeLorenzo, D. H. Fisher, Jr., T. Hakonson, J. P. Hubbard, B. McKinney, M. Orr, and R. T. Reynolds for their administrative support. T. Dean and O. B. Myers assisted with database development and graphics. Comments from G. Hayward and an anonymous reviewer improved the manuscript substantially.

LITERATURE CITED

BECKER, D. M., AND C. H. SIEG. 1987. Home range and habitat utilization of breeding male Merlins. Can. Field–Nat. 101:398–403.

BIJLSMA, R. G. 1989. Goshawk *Accipiter gentilis* and sparrowhawk *A. nisus* in the Netherlands during the 20th Century (English translation). Pp. 67–89 *in* J. T. Lumeij et al. (eds.), Valkerij in Perspectif. Nederlands Valkeniersverbond "Adriaan Mollen"/Stichting Behoud Valkerij, Monnickendam, Netherlands.

BLOOM, P. H. 1987. Capturing and handling raptors. Pp. 99–123 *in* B. G. Pendleton, B. A. Milsap, K. W. Cline, and D. M. Bird (eds.), Raptor management techniques manual. Natl. Wildl. Fed. Sci. Tech. Ser. 10.

BLOOM, P. H., M. D. MCCRARY, AND M. J. GIBSON. 1993. Red-shouldered Hawk home-range and habitat use in southern California. J. Wildl. Manage. 57: 258–265.

BRÜLL, H. 1964. Das leben deutscher greifvogel. Fisher Verlag, Stuttgart, Germany.

COHORT SOFTWARE. 1990. CoStat Statistical Software. Manual Revision 4.0. CoHort Software, Berkeley, CA.

DANIEL, W. W. 1978. Applied nonparametric statistics. Houghton Mifflin, New York, NY.

ENG, R. L., AND G. W. GUILLION. 1962. The predation of goshawks upon Ruffed Grouse on the Cloquet Forest Research Center, Minnesota. Wilson Bull. 74:227–242.

HAYWARD, G. D., AND R. E. ESCANO. 1989. Goshawk nest-site characteristics in western Montana and northern Idaho. Condor 91:476–479.

KENNEDY, P. L. 1988. Habitat characteristics of Cooper's Hawks and Northern Goshawks in New Mexico. Pp. 218–227 *in* R. L. Glinski, B. G. Pendelton, M. B. Moss, M. N. LeFranc, Jr., B. A. Milsap, and S. W. Hoffman (eds.), Proceedings of the southwest raptor management symposium and workshop. Natl. Wildl. Fed. Sci. Tech. Ser. No. 11.

KENNEDY, P. L. 1991. Reproductive strategies of Northern Goshawks and Cooper's Hawks in north-central New Mexico. Ph.D. diss. Utah State Univ., Logan, UT.

KENWARD, R. E. 1982. Goshawk hunting behavior, and range size as a function of food and habitat availability. J. Anim. Ecol. 51:69–80.

KENWARD, R. E. 1987. Wildlife radio tagging. Equipment, field techniques and data analysis. Academic Press, London, U.K.

KENWARD, R. E., V. MARCSTRÖM, AND M. KARLBOM. 1993a. Post-nestling behavior in goshawks, *Accipiter gentilis*: I. The causes of dispersal. Anim. Behav. 46:365–370.

KENWARD, R. E., V. MARCSTRÖM, AND M. KARLBOM. 1993b. Post-nestling behavior in goshawks, *Accipiter gentilis*: II. Sex differences in sociality and nest-switching. Anim. Behav. 46:371–378.

KENWARD, R., AND P. WIDÉN. 1989. Do goshawks *Accipiter gentilis* need forests? Some conservation lessons from radio tracking. Pp. 561–567 *in* B.-U. Meyburd and R. D. Chancellor (eds.), Raptors in the modern world. World Working Group on Birds of Prey and Owls, London, U.K.

KRAMER, V. 1955. Habicht und Sperber. Nueu Brehm Bucherei Heft 158. Ziemsen Verlag, Wittenberg Lutherstadt, Germany.

MARQUISS, M., AND I. NEWTON. 1981. A radio-tracking study of the ranging behavior and dispersion of European Sparrowhawks *Accipiter nisus*. J. Anim. Ecol. 51:111–133.

REYNOLDS, R. T. 1983. Management of western coniferous forest habitat for nesting accipiter hawks. USDA Forest Service, Gen. Tech. Rep. RM-102, Ft. Collins, CO.

REYNOLDS, R. T., R. T. GRAHAM, M. H. REISER, R. L. BASSETT, P. L. KENNEDY, D. A. BOYCE, JR., G. GOODWIN, R. SMITH, AND E. L. FISHER. 1992. Management recommendations for the Northern Goshawk in the southwestern United States. USDA Forest Service, Gen. Tech. Rep. RM-217, Ft. Collins, CO.

SAS INSTITUTE. 1989. SAS/STAT user's guide. Vol. 1: ANOVA-FREQ. Version 6. 4th ed. SAS Institute Inc., Cary, NC.

SAMUEL, M. D., D. J. PIERCE, AND E. O. GARTON. 1985a. Identifying areas of concentrated use within the home range. J. Anim. Ecol. 54:711–719.

SAMUEL, M. D., D. J. PIERCE, E. O. GARTON, L. J. NELSON, AND K. R. DIXON. 1985b. User's manual to project home range. For. Wildl. Range Exp. Sta. Tech. Rep. 15, Contrib. No. 259. Univ. of Idaho, Moscow, ID.

SPEISER, R., AND T. BOSAKOWSKI. 1987. Nest site selection by Northern Goshawks in northern New Jersey and southeastern New York. Condor 89:387–394.

SQUIRES, J. R., S. H. ANDERSON, AND R. OAKLEAF. 1993. Home range size and habitat-use patterns of nesting Prairie Falcons near oil developments in northeastern Wyoming. J. Field Ornith. 64:1–10.

VAN BEUSEKOM, C. F. 1972. Ecological isolation with respect to food between sparrowhawk and goshawk. Ardea 60:72–96.

WHITE, G. C., AND R. A. GARROTT. 1990. Analysis of wildlife radio-tracking data. Academic Press, New York, NY.

WIDÉN, P. 1989. Hunting habitats of goshawks *Accipiter gentilis* in boreal forests in Sweden. Holarctic Ecology 8:273–279.

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.