Winter foraging habitat of Northern Goshawks in northern Arizona

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DISCLAIMER

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INTRODUCTION

Since 1982, when the Forest Service listed the northern goshawk as a sensitive species in the southwestern United States, nest stands (≥ 8-ha) have been protected from timber harvest (Reynolds 1983). Despite this protection, Crocker-Bedford (1990) found that goshawk reproduction in southwestern forests declined following timber harvesting in adjacent areas, perhaps because logging gave a competitive advantage to open-forest raptors, made hunting more difficult, or decreased the abundance of prey. In response, Reynolds et al. (1992) recommended managing these forests for abundant populations of the 14 species that are the goshawk's primary prey. However, the Arizona Game and Fish Department (1993) and the US Fish and Wildlife Service (Spear 1993) argued that because accipiter hawks are adapted to forage in forested habitats, prey availability (as determined by forest structure) is more crucial than prey abundance.

Working in ponderosa pine in northern Arizona, Beier and Drennan (1997) found that during the breeding season goshawks apparently did not select foraging sites based on prey abundance, indeed, abundances of some prey were lower on used than on contrast plots. Goshawks selected foraging sites that had higher canopy closure ($\underline{P} = 0.006$), greater tree density ($\underline{P} = 0.001$), and greater density of trees > 40.6 cm dbh ($\underline{P} < 0.0005$) than on contrast plots. During winter, goshawks are under greater thermal stress, most avian prey have migrated, and most mammalian prey are hibernating. Under these very different conditions, goshawks may select foraging habitats that differ markedly from those we described for the breeding season. However, there are no studies on habitat selection by northern goshawks in winter in North America.

There have been 14 quantitative studies of goshawk diet in North America; all of these have been restricted to the breeding season (summarized by Drennan 1995). There is no information, from anywhere in North America, on winter food habits. Indeed, although there are anecdotal observations of goshawks in Northern Arizona during winter, no quantitative information exists on the extent to which wintering goshawks remain on their nesting territories, or migrate long or short distances to other vegetation types.

The objectives of this study were to

1. contrast vegetation structure, prey abundance, and physiographic parameters at Used Plots (centered on accurate walk-ins on wintering goshawks) with parameter values at nearby paired plots with no evidence of goshawk use.
2. determine whether goshawks nesting in ponderosa pine move to other areas during winter.
3. determine what goshawks eat in winter.

The first objective was the main focus of the study, and followed the same general methods as our previous study of habitat selection by northern goshawks during the breeding season (Beier and Drennan 1997).

METHODS

Study Area

The study area was on the Mogollon Plateau in northern Arizona, and included the northern portions of the Coconino National Forest and southern portions of the Kaibab National Forest. Elevations of areas used by goshawks ranged from about 2000 to 2600m, with gentle topography over most of the plateau. The climate was cool with an early summer drought. During 1964-1993, Flagstaff (elevation 2125 m) had a mean annual precipitation of 54 cm (including 196 cm of snowfall during Dec-Mar) and mean annual temperature of 7.6 C. Average daily low and high temperatures were -10 and 5 C in January, and 10 and 28 C in July (Natl. Oceanic and Atmos. Adm. 1993). Both winters of the study were near normal in temperatures, but winter 1995-96 was one of the driest on record with only 50 cm of snowfall.

The forest was dominated by ponderosa pine (Pinus ponderosa). At lower elevations, pinyon pine (P. edulis), alligator juniper (Juniperus deppeana), Utah juniper (J. osteosperma), and Gambel oak (Quercus gambelli) were common understory trees. At higher elevations and on north-facing slopes, limber pine (P. flexilis) and Douglas-fir (Pseudotsuga menziesii) were co-dominant with ponderosa pine, and aspen (Populus tremuloides) occurring in the understory or in small pure stands. Except in areas of dense pine or oak seedlings, understories were generally open. Common understory species included lupine (Lupinus spp.), New Mexican locust (Robinia neomexicana), Arizona rose (Rosa arizonica), buckbrush (Ceanothus fendleri), snakeweed (Gutierrezia spp.), Oregon grape (Berberis repens), showy aster (Aster commutatus), and grasses such as Arizona fescue (Festuca arizonica), mountain muhly (Muhlenbergia montana), and mutton bluegrass (Poa fendleriana). Plant names follow Kearney and Peebles (1964).

Landscape-scale movements

We captured adult goshawks at nest sites during 1994-1995. We attached a radio transmitter to each bird with a backpack harness made from 6-mm-wide tubular teflon ribbon. Packages averaged 22 g, or about 3.3% and 2.2% the average body mass of males and females, respectively.

To determine long-distance movements of animals, we conducted both ground and aerial radio-tracking. Birds radio-tagged in 1994 were radio-tracked throughout the summer; thus we knew that they remained in or near the nest stand throughout the summer. The goshawks tagged in spring 1995 were only occasionally radio-tracked until December 1995 (when all but one were found near their capture site); we believe (but have only sporadic observations to confirm) that these birds were resident throughout summer 1995.

Each goshawk was radio-tracked throughout the following winter to determine if it remained near the nest site, and to determine extent of any long-distance movements. We carried out aerial homing (Mech 1983) about once a week, and usually found each bird on each flight. With 2 ground crews (of 2 persons each) we obtained additional locations (about 1 per bird per week) from the ground.

Winter Diet

We tried two methods to determine winter diet. First, we looked for pellets at night roosts. To do this we followed individual birds until they settled down at dusk. We noted the tree in which the goshawk settled and flagged 2 trees about 30-50m from the bird, and recorded the bearing from the flagged trees to the bird. On the following morning, we returned before dawn, checked both bearing trees to confirm that the night roost had not changed, and waited about 50m away for the bird to wake up, regurgitate (we hoped), and begin its daily movements. After the telemetry signal indicated that the bird had moved, we walked under the night roost and looked for pellets.

Our second method involved walking in on goshawks when their telemetry signal indicated that they had made a kill. Mercury tipswitches in each transmitter caused a fast pulse rate when the transmitter was horizontal (as on a flying bird) and a slow rate when the transmitter is vertical (as on a perched bird). We presumed that the focal goshawk was foraging when periods of fast pulse rate <3 minutes in duration (usually accompanied with variation in signal strength and direction) alternated with periods of slow pulse rate <12 minutes in duration. When this pattern changed to about 4-5 minutes of predominantly fast pulse rate (occasionally interrupted by 1-5 seconds of slow pulse rate) with no change in azimuth (and usually little change in signal strength), we presumed that the goshawks had just made a kill and was starting to eat its prey. We then walked in (protocol below) and attempted to determine the prey species.

Micro-habitat selection

To obtain precise and accurate locations on foraging goshawks, teams of two persons tracked individual birds for periods of 1-6 hours between 5 December 1994 and 15 March 1995 and 10 December 1995 and 15 March 1996. Using the flight and perch durations reported by Kenward (1982), Widén (1984), and Kennedy (1991), we presumed that the focal goshawk was foraging when periods of fast pulse rate <3 minutes in duration alternated with periods of slow pulse rate <12 minutes in duration. To minimize disturbance, the trackers stayed together until they were <200 m from an apparently foraging bird. Then the observers split up, maintaining 2-way radio contact, until their bearings formed a 60 to 120° angle from their position to the goshawk. These bearings were monitored and followed out until the signal volume suggested they were each about 100 m from the goshawk. Then the observers quietly walked out their bearings, pacing their distance until their paths intersected. If the paced length of an azimuth line exceeded 150m and we did not see the goshawk flush, we did not use the point as a plot center and we left that bird for >4 hours. Because goshawks often flew while the observers were trying to move into an optimum angular configuration, most walk-in attempts failed. On average about 10 hours (including failed attempts) were required for a 2-person crew to obtain a location. At least 48 h elapsed between all locations used as plot centers for an individual goshawks.

Error associated with our walk-ins was 21.9 m based on 23 walk-ins on transmitters placed by a third person in forested habitat; however, in >85% of walk-ins we made visual observations of the focal goshawk and hence there was little or no error in most locations.

We used only these precise walk-in locations as centers of Used Plots. We also obtained less-precise locations of goshawks from airplane flights (1/week, mentioned above) and ground triangulation at distances >150 m from the goshawk (1-5/week). Contrast Plots were located in forested habitat about 500 m from each used plot center and >200 m from any previous location for that bird (including the less-precise locations). Within these contraints, we determined the direction by spinning a compass dial to obtain a random direction. If all potential locations at a 500-m distance were <200 m from other locations or in unforested habitat, we continued as far out as 1000 m from the paired used plot, but always within the minimum convex polygon home range of the goshawk. We choose a 500 m offset because 8-hour monitoring sessions of goshawks in 1992 showed that individuals tended to used several activity areas, each with a radius of about 300 m (unpublished data).

Prey Abundance

We indexed prey abundance at each used plot and its paired contrast plot on the same day, usually one day (maximum = 4 days) after the goshawk location was obtained. Because plots were sampled within a short period of the time after they were used by the goshawk, we assumed that the same prey population available to the goshawk was sampled. We indexed abundance of avian prey with 50 m fixed-radius point counts, counting all birds heard or seen within 3 minutes. Point-counts were conducted at the plot center and at 100 m from the plot center at 60, 180, and 240°. We conducted three sets of point counts; one immediately following establishment of the plots (i.e., reflecting conditions 30 minutes after goshawk use), one in the evening, and one in the morning. We grouped avian prey into three classes for analysis, using body masses in Terres (1991). Large birds (75-145 g) included American robin (Turdus migratorius), Steller's jay (Cyanocitta stelleri), northern flicker (Colaptes auratus), mourning dove (Zenaidura macroura), Lewis' woodpecker (Melanerpes lewis), and Clark's nutcracker (Nucifraga columbiana). Medium birds (30-62 g) included hairy woodpecker (Picoides villosus), western bluebird (Sialia mexicana), and evening grosbeaks (Coccothraustes vespertinus). Small birds included pine siskin (Carduelis pinus), pygmy nuthatch (Sitta pygmaea), and dark-eyed junco (Junco hyemalis).

We indexed abundance of diurnal small mammals by walking a 1200 m transect covering each plot. Along this transect we counted tracks and visual observations of Abert squirrels and lagomorphs. We also attempted live trapping, infrared scanners, pellet group counts (for cottontails), and counts of clipped terminal twigs from ponderosa pine (for Abert squirrels) none of which provided enough detections for analysis.

Vegetation Structure

We sampled habitat structure on 1.77-ha (75-m radius) plots, using the same plot centers as for the prey surveys, sampling along 6 radii (0, 60, 120, 180, 240, and 300°) to give greater weight to vegetation near the plot center (the goshawk location on Used plots). We used Biltmore sticks and diameter tapes to measure diameters of all trees within 1 m of each radius. We measured both canopy closure and ground cover by point intercept at 91 points (plot center and every 5 m along each radius); vertical sighting tubes insured that canopy closure was measured directly overhead. We counted the numbers of shrubs and saplings intercepted by the diameter and radial segments. We tallied all large (≥ 30.5 cm dbh) snags and all large logs (≥30.5 cm in diameter at midpoint and ≥ 2.4-m long) on a 50x50 m square subplot; the larger area was necessary to adequately sample these rare elements. We also recorded slope (%), aspect (to nearest multiple of 45°), and topographic position (flat, midslope, ridge, or drainage bottom).

Analysis of Habitat Selection

We examined frequency distributions and used compositional analysis (Aebischer et al. 1993) to test for differences between used and contrast plots in aspect, topographic position, and percent ground cover. Compositional analysis is appropriate for analysis of a categorical habitat trait with >2 categories that the proportional usages in each category must sum to 100%. For all other variables, we computed the difference in prey abundance indices and vegetation parameters between each Used Plot and its paired Contrast Plot, and then averaged these differences separately for each goshawk. Using the bird as the sampling unit, we used t-tests to test whether the mean difference across birds differed from zero. Before statistical analyses, we applied a square-root transformation to all counts and an arcsine square root transformation to canopy closure percentages (Zar 1996).

RESULTS

Site Fidelity in Winter

We radio-tracked 6 adult goshawks during winter 1994-95 and 7 adult goshawks during winter 1995-96 (Table 1). One of these birds (the Fort Valley Male) disappeared for most of the winter, and could not be located even on telemetry flights ranging up to 25 miles from his nest area, extending to the lower margins of the pinyon-juniper belt and into nearby canyons that fall below the Mogollon Rim. He reappeared near his nest site only once during the entire winter, but returned to Fort Valley in spring 1996.

All 6 females stayed in ponderosa pine for the winter. Although, all females also stayed in the general vicinity of the nest site (Table 1), 4 of the 6 females expanded their home ranges during winter and spent much of their time at the interface of the ponderosa pine and pinyon-juniper vegetation zones. The other 2 females (Fort Valley and Walker Hill) stayed within their breeding season home range, and were often located at or < 100m from their nest tree.

Only 1 of the 7 males (Volunteer) stayed close to his nest site in ponderosa pine throughout the winter. Of the other 6 males, 1 (Fort Valley) moved at least 15 miles away to an undetermined vegetation type, 1 moved up in elevation into the mixed conifer vegetation type, and 4 moved 5-10 miles and downslope to overwinter in the pinyon-juniper belt. Each of these 6 males revisited the nest area during the winter, either rarely (Ft Valley, Porkchop), occasionally (Whitehorse, Elk Spring, Sitgreaves), or frequently (Walker). However, except for the Volunteer male, the males were never found <100 m from the nest site during winter.

Winter Diet

We made 15 observations of night roost locations of 5 different birds in an attempt to discover pellets and/or prey remains. We did not find any pellets below these roost sites. We found that the birds did not roost in the same area each night unless they had a large prey item. On two separate occasions we made successive daily observations on birds that were in the process of consuming a cottontail rabbit. In both of these cases the birds roosted within 30 m of the carcass each night and required 3 days to consume these cottontails. The cottontail carcasses were frozen hard in the morning which probably prolonged the time required for consumption.

We identified freshly-killed prey on more than one occasion for each of 8 adult goshawks (Table 2). Three birds were observed with cottontail remains on all 4 walk-ins. Three birds had cottontail remains on 3 out of 4 walk-ins. The remaining two birds were observed with Abert squirrel remains on two or more occasions. No individual bird was observed with both Abert squirrel and cottontail carcasses, suggesting that each individual may have specialized on a single large-bodied prey species during winter. Individuals that wintered in pinyon-juniper habitats invariably were found with cottontails, whereas goshawks wintering in ponderosa pine specialized in Abert Squirrels.

Importance of prey abundance and vegetation structure in habitat selection

We sampled 4 pairs of plots for each of 11 goshawks (5 birds in 1994-95 and 6 birds in 1995-96). Vegetation differed only slightly between differences between Used and Contrast plots (Table 3), with Used Plots having more medium-sized trees ($P = 0.06$) and denser canopy closure ($P = 0.06$). Used averaged 50% canopy closure and 230 medium-sized trees per hectare, whereas Contrast Plots averaged 44% canopy closure and 192 medium-sized trees per hectare. Indices of prey abundance were almost identical on Used and Contrast Plots in (Table 4).

DISCUSSION

Goshawk Diet and Site Fidelity in Winter

We failed in our attempt to identify prey remains from goshawk pellets, because we were unable to find locations such as night roosts where pellets could be found. Our observations of birds with freshly-killed prey suggest tnat each individual goshawk specialized in taking cottontails or Abert squirrels, but not both. On most of the 27 observations of goshawks with prey we noted that goshawks were reluctant to flush off a large prey item (cottontail or Abert squirrel) and when they did flush, they were able to fly only a few meters carrying their prey.

Because mantled ground squirrels (the primary prey item on the Kaibab plateau during the breeding season -- Boal and Mannan 1994), chipmunks, and ground squirrels hibernate from November to April (Hoffmeister 1986, Dodd, pers. comm.) and many avian prey move south for the winter, goshawk diet breadth is narrower in winter than in summer. The only mammalian prey available in winter are Abert squirrels, red squirrels, and cottontails. Although our method doubtless was biased toward large prey (a small prey item might be consumed or carried off during the time it took us to infer a kill and then walk in), these observations are the first and only data on winter diet of goshawks. Despite the bias of our prey observations, we suspect that during winter an individual goshawk specializes in either cottontails or Abert squirrels. We believe that goshawks specialize in larger prey in winter because there is no need to transport small prey to the nest site, and because reliance on large items allows the goshawk to feed on a single item for several days while minimizing the energy expense and thermal exposure of flying. This line of speculation is supported by our observations that (a) in winter goshawks usually took about 2.5 days to consume a rabbit or Abert squirrel, and (b) when consuming large prey the goshawk was always found within 50m of the carcass and the pulse interval usually indicated that the goshawk was perched for 2-6 hours and fed for only about 10 minutes every 2-6 hours.

In general, female goshawks remained in the ponderosa pine vegetation type in the general vicinity of their nest stands, throughout both winters. Females thus appeared to exhibit more overwinter fidelity to the nest stand than males did. This finding suggests that goshawks do not follow the common pattern in which male birds select nest areas and attract females to them in the spring. This is consistent with the statement by Jones (1979:29) that "when goshawks arrive at their breeding grounds, the female... will select a nesting area and scream to attract a mate." On several occasions during winter, females made alarm calls when we entered nest stands, suggesting that females may defend these site during winter.

Most male goshawks moved 5-10 miles from the nest area, and generally into the nearest patch of pinyon-juniper woodlands, although 1 male moved into the nearest patch of mixed-conifer forest. We would not characterize this movement as latitudinal migration because most birds made return trips to their nesting areas during the winter, rather than establishing a distinct winter range.

We were surprised to observe seasonal movement to and extensive use of pinyon-juniper communities by goshawks, especially males. We speculate that movements of males may be a result of the interaction of

- possible **diet partitioning between male and female goshawks** during the breeding season (Reynolds 1972), extending into the non-breeding season. Reynolds (1972) speculated that, for breeding accipiters, female diets may be broader than those of males (who are smaller than females). In particular, Reynolds speculated that, compared to males, females would make more use of larger prey. Although there is no strong empirical support for this hypothesis, we never documented a male taking an Abert squirrel (including observations during 2 winters and 2 summers), and we have several such observations for both breeding and wintering females. During the breeding season, males seemed to concentrate on smaller prey, such as mantled squirrels, chipmunks, and birds. The fact that male goshawks take rabbits suggests that males can also take the smaller Abert squirrels, but perhaps less frequently than females. If the sexes have evolved diet partitioning during the breeding season, it is reasonable to expect that such differences might persist into winter.
- Such diet partitioning may be exacerbated by **reduced diversity and abundance of prey in winter** (above). Perhaps during winter spatial separation (not simply prey specialization within a common foraging area, as in the breeding season) is needed to avoid otherwise severe effects of intraspecific competition for food.
- the possibility that **females may defend nest sites during winter** (above). Although reduced prey abundance and diversity may be the primary force favoring spatial segregation in winter, female defense of nest sites through the winter could explain why males are the sex that moves.

The observed pattern is consistent with this speculation. By moving to pinyon-juniper and (for 1 male) into mixed-conifer forests, males moved to habitats where they could specialize in taking cottontails (which are more abundant in pinyon-juniper) and red squirrels (which are locally restricted to mixed-conifer and aspen), whereas females could defend the nest site and specialize on Abert squirrels.

There are alternate hypotheses for these male movements. Perhaps males move to pinyon-juniper for the greater abundance of avian prey (pinyon jays, robins, and flickers are all abundant there in winter), or because the smaller-bodied males (with thermally less favorable ratio of mass to radiant surface area) prefer the warmer temperatures in this lower elevation zone. However, these latter explanations fail to explain why at least 1 male moved into a higher elevation area. (With our data we cannot state whether this is a common pattern or an aberration). Nor is the "avian prey hypothesis" consistent with our lack of observations of males taking birds in winter. Of course, these hypotheses are not mutually exclusive, and perhaps they act in concert.

Importance of prey abundance and vegetation structure in habitat selection

The lack of differences between Used and Contrast plots in terms of prey abundance indices was consistent with the finding of Beier and Drennan (1997) that prey abundance was not correlated with foraging sites during the breeding season. However, we were surprised to see no clear pattern of differences between Used and Contrast plots in vegetation parameters. During the breeding season, Beier and Drennan (1997) found that goshawks in the same study area selected foraging sites with higher canopy closure, greater tree density, and greater density of trees >40.6 cm dbh than at contrast plots.

Two vegetation characteristics differed between Used and Contrast Plots at a level that was nearly statistically significant ($P = 0.06$), with Used sites exhibiting denser canopy closure and having more pole-sized trees (8" to 16" dbh) compared to Contrast Plots. As was the case in summer (Beier and Drennan, 1997), it seems that vegetation structure was more important than prey abundance in microhabitat selection. However, the patterns observed during winter did not approach the statistical significance of the summer patterns, partly because fewer birds were radio-tracked (winter: 11 birds; summer: 16 birds). In addition, pooling data across 2 major vegetation types would decrease statistical power if goshawks select habitats differently in pinyon-juniper forests than they do in ponderosa pine. We will conduct further analyses to consider data from pinyon-juniper vegetation type separately from those in the ponderosa pine type. However, due to the small number of goshawks within each vegetation type, we expect low statistical power in these analyses.

A retrospective power analysis suggests that our study design had approximately 80% power to detect differences of 25% between used and contrast plots in most vegetation parameters (two-tailed, $P = 0.05$). Thus 20% of real differences could escape detection in our study. We had less power to detect differences in the 6 prey indices, with only about 35% power of detecting a 25% increase (one-tailed, under null hypothesis that Used plots had more prey than contrast plots, $P = 0.05$), and 55% power of detecting a 50% increase. Thus real but subtle differences in prey abundance would almost certainly not be detected by our effort.

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Table 1. Number of radiolocations and gross winter movements of 13 goshawks during winters of 1994-1995 and 1995-1996 on the Coconino and Kaibab National Forests.

Bird (territory and sex)	Winter of Observation	Winter Movements
Walker female	Dec 1994-Mar 1995	stayed in ponderosa pine and in vicinity of nest area
Fort Valley female	Dec 1995-Mar 1996	stayed in ponderosa pine and in vicinity of nest area
Devil Dog female	Dec 1995-Mar 1996	stayed in ponderosa pine, but expanded home range to include some pinyon-juniper woodland
Mars Hill female	Dec 1994-Mar 1995	stayed in ponderosa pine, but expanded home range to include some pinyon-juniper woodland
Horseshoe female	Dec 1994-Mar 1995	stayed in ponderosa pine, but expanded home range to include some pinyon-juniper woodland
Volunteer female	Dec 1995-Mar 1996	mostly stayed in ponderosa pine, with several visits to Sycamore Canyon (pine-oak) (5 miles)
Whitehorse male	Dec 1994-Mar 1995	went to higher elevations, in mixed-conifer zone on San Francisco Peaks (about 3 miles); due to inaccessible terrain, we obtained no microhabitat data on this bird.
Volunteer male	Dec 1995-Mar 1996	stayed in ponderosa pine
Walker male	Dec 1994-Mar 1995	about half of locations in pinyon-juniper and half in ponderosa pine, with frequent moves back and forth
Elk Spring male	Dec 1995-Mar 1996	mostly in pinyon-juniper with occasional return visits to ponderosa pine (10 miles)
Sitgreaves male	Dec 1995-Mar 1996	mostly in pinyon-juniper with occasional return visits to ponderosa pine (10 miles)
Fort Valley male	Dec 1995-Mar 1996	disappeared for most of winter; visited nest stand once during winter and returned in spring 1996. due to our inability to locate him, we obtained no microhabitat data on this bird. (over 15 miles).
Porkchop male	Dec 1994-Mar 1995	moved into pinyon juniper with rare return visits to ponderosa pine (about 10 miles)

Table 2. Observations of prey remains during walk-ins for 8 goshawks studied during the winter months (Dec.-Mar.) of 1994-1996 on the Coconino National Forest and Kaibab National Forest.

Bird-territory and sex	date of walk-in	prey observed
Porkchop male	28-Feb-1995	cottontail
	19-Jan-95	cottontail
	10-Jan-1995	cottontail
	21-Feb-1995	unknown
Walker female	7-Feb-1995	Abert squirrel
	30-Dec-1994	no prey observed
	7-Dec-1994	Abert squirrel
	13-Jan-1995	unknown
	5-Dec-1994	no prey observed
Volunteer male	8-Jan-1996	cottontail
	17-Jan-1996	cottontail
	30-Jan-1996	cottontail
	13-Feb-1996	cottontail
Volunteer female	29-Jan-1996	cottontail
	5-Feb-1996	cottontail
	12-Feb-1996	cottontail
	26-Feb-1996	cottontail
Elk Spring male	2-Jan-1996	cottontail
	15-Jan-1996	cottontail
	31-Jan-1996	cottontail
	15-Feb-1996	cottontail
Sitgreaves male	19-Dec-1995	cottontail
	17-Jan-1996	cottontail
	9-Jan-1996	cottontail
	15-Feb-1996	unknown
Fort Valley female	10-Dec-1995	Abert squirrel
	13-Dec-1995	unknown
	25-Jan-1996	Abert squirrel
	18-Feb-1996	Abert squirrel
	4-Jan1996	Abert squirrel
Devil Dog female	18-Dec-1995	unknown
	4-Jan-1996	cottontail
	25-Jan-1996	cottontail
	21-Feb-1996	cottontail

Table 3. Vegetation and physical characteristics on 44 1.77-ha plots used by adult goshawks in northern Arizona during December 1994-March 1995 and December 1995-March 1996, and 44 paired contrast plots, averaged across 11 adult goshawks (6F, 5M; each with 4 pairs of plots/goshawk). All inferential statistics are based on numbers of goshawks, not numbers of plots.

Characteristic	Used Plots		Contrast Plots		Difference	P
	Mean	SD	Mean	SD		
Aspect (% of plots)						0.93[a]
N and NE	18	12	20	15	-2.3	
E and SE	9	17	5	10	+4.5	
S and SW	23	21	23	18	0	
W and NW	34	23	36	21	-2.2	
Flat	16	20	16	17	0	
Topographic position (% of plots)						0.65a
ridgetop	0	0	0	0	0	
midslope	61	26	55	29	+7	
canyon bottom	16	20	18	25	-2	
flat	16	16	20	24	-4.5	
% ground cover						0.55[a]
grasses and forbs	3.3	2.6	7.2	6.1	-3.9	
bare ground, incl. roads	7.5	11.5	7.6	13.5	-0.1	
litter	44.7	26.7	40	28	+4.7	
downed wood or stump	1.6	1.3	1.6	1.4	-0.02	
rock (>15 cm long axis)	3.9	1.9	4.8	4.5	-0.9	
% slope	10.5	9.2	8.7	7.1	+1.9	0.57[b]
shrubs & saplings intercepted by 430-m transect	20	37	35	66	-14.5	0.13[b]
% Canopy Closure	50	6.7	44	12.2	+6.2	**0.06**[b]
Large snags/ha	1.1	1.0	1.1	0.8	+0.1	0.92[b]
Large logs/ha	4.0	2.8	4.0	4.0	0	0.58[b]
Trees/hectare:						
total trees (> 10 cm dbh)	704	282	696	391	+8.5	0.94[b]
0-20.3 cm dbh	1178	1259	1243	1389	-65	0.18[b]
20.4-40.6 cm dbh	230	70	192	84	+38	**0.06**[b]
>40.6 cm dbh	32	18	29	16	+3.2	<0.15[b]

[a] compositional analysis using MANOVA of log-ratio-transformed percents (4, 7 d.f. for aspect and ground cover; 3, 8 d.f. for topographic position).

[b] 2-tailed paired-sample t-test (10 d.f.) of the null hypothesis that the mean difference, across 11 birds, is zero.

Table 4. Differences in counts of prey groups between Used and Contrast plots for 11 goshawks sampled in the winter months of 1994-96. Significance level is that of a 2-tailed t-test of the null hypothesis that the mean difference (Used minus Contrast) across 11 birds is zero. Inferential statistics are based on numbers of goshawks, not numbers of plots.

Prey Group	Used Plots		Contrast Plots		Difference	P
	Mean	SD	Mean	SD		
Abert squirrel track counts	5.1	6.6	5.3	6.7	-0.2	0.766
Abert squirrel observations	3.5	7.7	3.9	8.2	-0.4	0.53
Lagomorph track counts	0.2	0.3	0.1	0.2	0.1	0.28
Lagomorph observations	0.1	0.2	0.1	0.2	0	0.72
Large birds	4.4	4.3	4.3	5.3	0.1	0.88
Medium birds	3.1	3.8	3.1	3.4	0	0.98
Small birds	31.5	16.3	32.1	11.7	-0.6	0.81

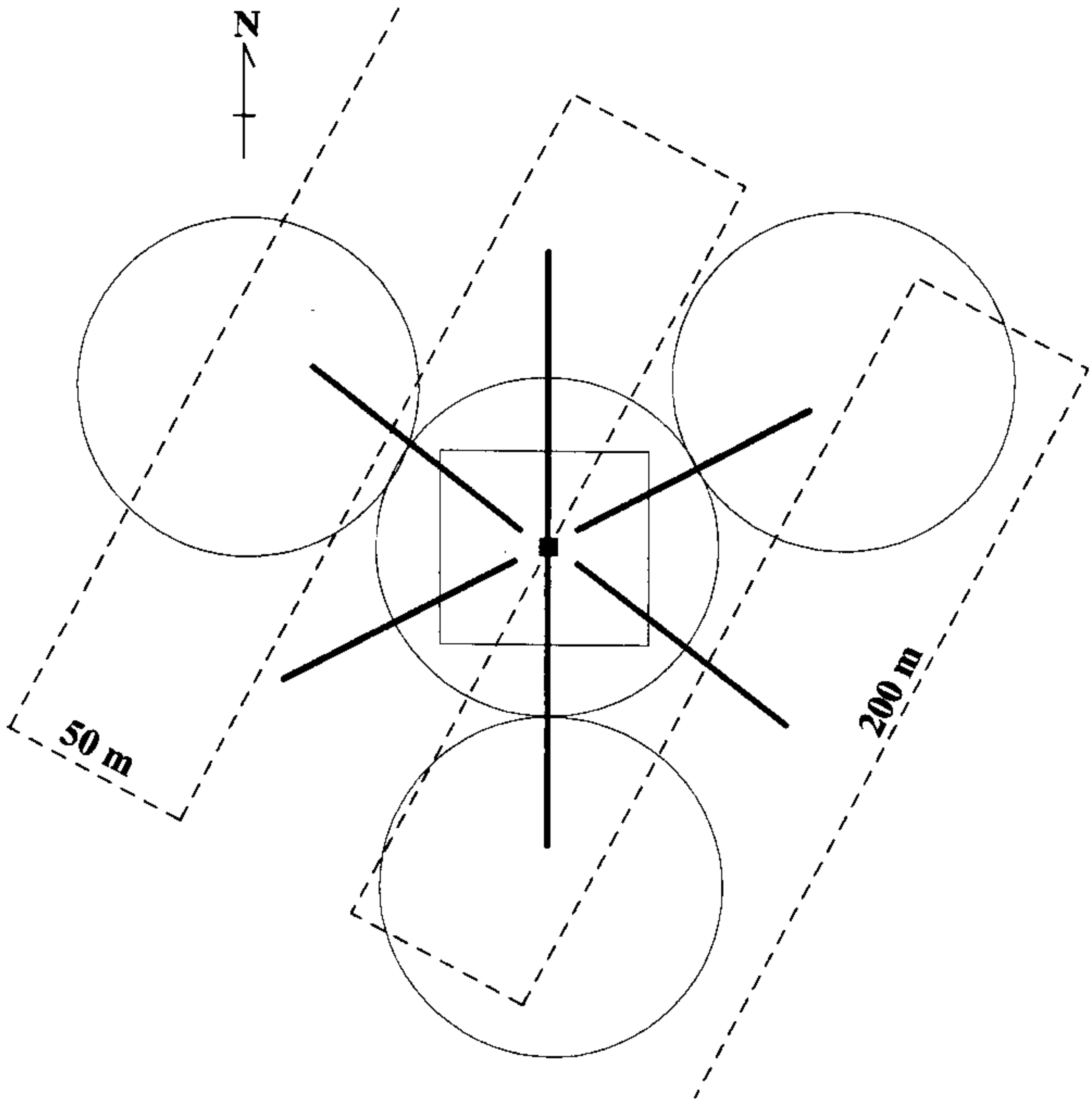

Figure 1. Layout of plots for sampling vegetation and prey abundance. Small filled square = plot center (goshawk location on Used Plots); open square = 50 x 50 m plot for snags and logs; circles = 50-m radius plots for avian point-counts; thick lines (one 150-m and four 70-m) = belt transects for trees (ground cover and canopy closure was assessed every 5 m along center lines); dashed line = 2000-m transect for sign of Abert squirrels and cottontails (randomly oriented with respect to the rest of the plot).