FORAGING AND NESTING HABITAT OF BREEDING MALE NORTHERN GOSHAWKS IN THE LAURENTIAN MIXED FOREST PROVINCE, MINNESOTA

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Abstract: We used radiotelemetry to examine foraging habitat preferences of 17 breeding, male northern goshawks (*Accipiter gentilis*) in Minnesota from 1998–2000. We assessed habitat preference using radio relocation points and 50-m radius buffers of radio relocation points. Our data suggested that foraging male goshawks used early-successional upland conifer stands (≥25 yrs old), early-successional upland deciduous stands (≥50 yrs old), late-successional upland conifer stands (≥50 yrs old), and late-successional upland deciduous stands (≥50 yrs old) more frequently than expected based on the abundance of these vegetation types in the landscape. The 2 most available stand types, early-successional upland deciduous (<25 yrs old) and all ages of late-successional lowland conifer stands, were used less than expected by foraging goshawks. Late-successional lowland deciduous stands (≥50 yrs old) were used in proportion to availability. Although analysis of relocation points suggested early-successional upland deciduous stands (25–49 yrs old) and late-successional upland conifer stands (≥50 yrs old) were used in proportion to availability, analysis of buffers around relocation points indicated that these stand types were also used more than expected by foraging goshawks. Regardless of vegetation community type, stands used by goshawks were structurally similar with high canopy and understory stem densities, high canopy closure, substantial shrub cover, and large amounts of woody debris. Nest stands consisted of taller and larger diameter canopy trees and fewer understory trees than foraging stands, but stands were otherwise similar in structural features, suggesting goshawks used similar stands for nesting and foraging but that they tended to select the most mature stands for nesting. A commonality among nesting and foraging stands was the presence of open spaces between the canopy and understory foliage, and between understory and shrub layer foliage. In our study area, these spaces may have served as relatively unobstructed flight paths where foraging and nesting stands possessed stem densities at the upper end of that reported for goshawk habitat.

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The northern goshawk (*Accipiter gentilis*) is a large raptor associated with mature deciduous, coniferous, or mixed forests (Bright-Smith and Mannan 1994, Siders and Kennedy 1996, Beier and Drennan 1997, Squires and Reynolds 1997). Possible impacts of timber harvest on goshawks has led to concern for the species' status (Kennedy 1997, Martin 1998). The goshawk has been proposed for listing several times under the U.S. Endangered Species Act, and its status has been (and still is) the object of considerable litigation (Peck 2000). A particular point of contention is the conclusion that the northern goshawk is a habitat generalist (Reynolds et al. 1992), which has been reflected in forest management plans (Reynolds et al. 1992) and environmental impact statements (U.S. Forest Service 1995). This conclusion, however, has been questioned by state and federal agencies and nonprofit organizations (*Center for Biological Diversity* and *Sierra Club* v. *U.S. Forest Service*, No.02-16481 [9th Circuit Court opinion No. CV-00-01711-RCB issued 18 November 2003]).

Management plans designed to reduce the potential for goshawk population declines (e.g., Reynolds et al. 1992) focused on managing forest structure to provide nest sites and/or foraging habitat. Habitat management, however, presupposes an understanding of the species' habitat use and needs (Garshelis 2000). Unfortunately, most habitat use information for goshawks is based on nest stand descriptions (Reynolds et al. 1982, Squires and Reynolds 1987, Siders and Kennedy 1996, Rosenfield et al. 1998) or nesting habitat

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preferences (Bosakowski and Speiser 1994, Hargis et al. 1994, Squires and Ruggiero 1996, Daw and DeStefano 2001, McGrath et al. 2003). But suitable foraging habitat is possibly more important to goshawks because without which they cannot provision nestlings and successfully reproduce (Widen 1989). However, few studies have used radiotelemetry to examine goshawk habitat patterns within their home ranges (Kenward 1982, Austin 1993, Bright-Smith and Mannan 1994, Iverson et al. 1996, Lapinski 2000), and there is little information on structural characteristics of preferred foraging sites (Kenward 1982, Widen 1989, Beier and Drennan 1997).

To begin to address these and other information gaps in the Laurentian Mixed Forest Province (LMFP) of the western Great Lakes region (WGLR) of North America, we began a study of goshawk ecology in Minnesota in 1998. Our primary objectives were to examine foraging and nesting habitat preferences of breeding goshawks in the LMFP. Because almost all food provisioning from pre-incubation through the later stages of nestling development is done by male goshawks (Boal and Mannan 1996), we assessed foraging habitat preferences of mated males. We assumed the primary activity of male goshawks during the nestling and fledgling period of the breeding cycle was prey provisioning, and we assumed that relocation points were related to foraging activities. We examined foraging habitat use and preference at 2 scales. First, we examined use vs. availability of stand types and ages within individual goshawk home ranges. Second, we examined structural characteristics of those stands used by goshawks. We then examined structural characteristics of nest stands and compared them to those of foraging stands to develop a clearer understanding of the range of forest conditions required by breeding goshawks in the LMFP of Minnesota.

STUDY AREA

Our study area encompassed most of northern Minnesota within the LMFP (Minnesota Department of Natural Resources 1997; Fig. 1). Goshawks were distributed from Itasca State Park in the west, Jay Cooke State Park and private lands in the east, and the cities of International Falls to the north and Sebeka to the south. A majority of goshawk nests was on or near the Chippewa National Forest. Study area elevation is approxi-

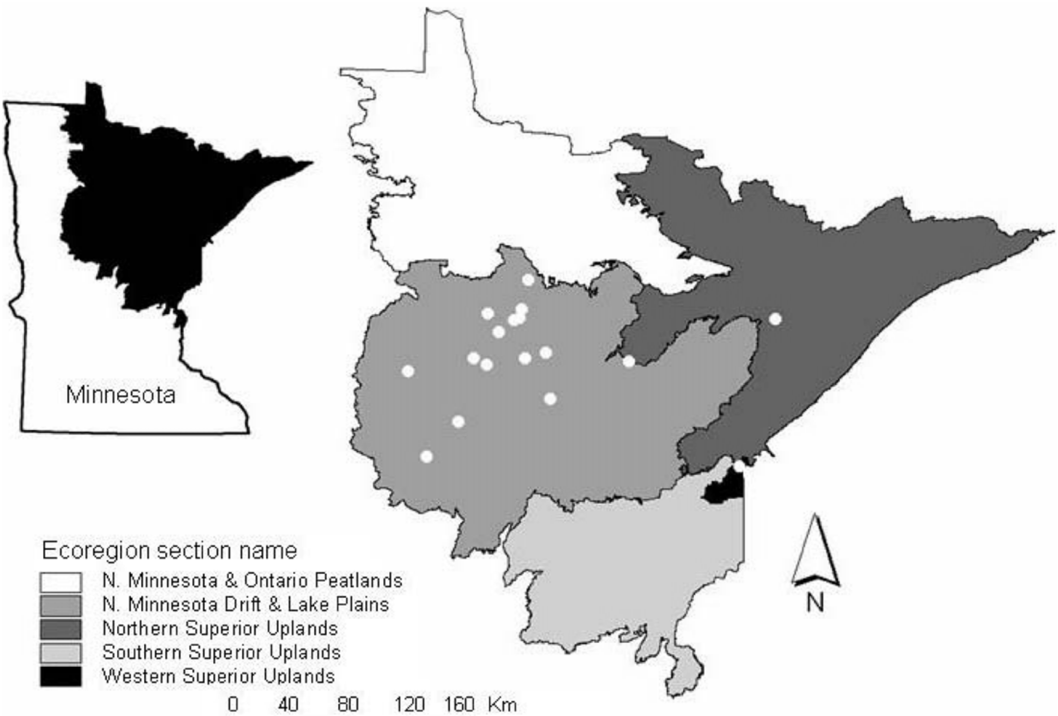

Fig. 1. Solid white circles denote the distribution of radiotagged male northern goshawks in the Laurentian Mixed Forest Province, Minnesota, USA, 1998–2000.

mately 200–400 m. Historical mean summer and winter temperatures were 18°C and –11°C, respectively, with maximum and minimum temperature records of 40°C and –46°C. The study area was dominated by pine, mixed-hardwood, boreal, and second-growth forests (Tester 1995). Early-successional stands included jack pine (*Pinus banksiana*), balsam fir (*Abies balsamea*), white spruce (*Picea glauca*), quaking aspen (*Populus tremuloides*), big-toothed aspen (*P. grandidentata*), balsam poplar (*P. balsamifera*), paper birch (*Betula papyrifera*), and yellow birch (*B. lutea*). Late-successional stands included white pine (*Pinus strobus*), red pine (*P. resinosa*), tamarack (*Larix laricina*), lowland black spruce (*P. mariana*), northern white cedar (*Thuja occidentalis*), sugar maple (*Acer saccharum*), red maple (*A. rubrum*), northern red oak (*Quercus borealis*), basswood (*Tilia americana*), black ash (*Fraxinus nigra*), and green ash (*F. pensylvanica*). Wetland community types were interspersed among forest stands.

METHODS

We did not systematically survey for breeding goshawks, so known breeding pairs in a single year were likely a small proportion of all goshawks breeding in the study area. However, we captured and radiotracked selected goshawks from all known nesting goshawks in Minnesota during the breeding seasons of 1998–2000 (Boal et al. 2003). We selected breeding male goshawks on the basis of logistical feasibility of trapping at the nest site and the nest site location within the study area. We attempted to include goshawks from nests across the LMFP of northern Minnesota to represent the range of landscape types of known nests (Boal et al. 2003). Because our sample was not randomly selected, our inferences are limited to our sample.

Data Collection

We used dho-gaza traps with a live or plastic replica great horned owl (*Bubo virginianus*) as a lure to capture adult goshawks (Bloom 1987). Male goshawks often are difficult to capture at nest sites because they spend most of their time foraging away from the nest. To facilitate capture of male goshawks, we set dho-gaza traps prior to or at sunrise, but we kept the lure hidden until the male goshawk returned to the nest, usually to deliver prey. We exposed the lure upon return of the male goshawk, after which, the male and female goshawks were captured. Once captured, we hooded goshawks to reduce handling stress, banded them with a U.S. Geological Survey leg band, and outfitted them with a TW-3 radio transmitter (Biotrack, Inc., Dorset, UK) in a backpack attachment (Buehler et al. 1995). Mention of trade names does not indicate that the authors' institutions either endorse these products or discriminate against products not mentioned.

We tracked goshawks using ground-based triangulations (1998) and from aircraft (1998–2000) as described in Boal et al. (2003) and using methods described by Samuel and Fuller (1994). We conducted aerial tracking primarily from a Cessna 172 RG with 2 RA-2A, 2-element antennas (Telonics, Inc., Mesa, Arizona, USA) that were wing-mounted and a R4000 receiver (Advanced Telemetry Systems, Isanti, Minnesota, USA). Because of the substantial distances we had to cover (28.5 ± 29.6 km between nests; Boal et al. 2003), we flew a circuit of the radiotagged goshawks, relocating each goshawk in sequence. Although we were unable to assess relocation error, based on our estimated location and walk in recovery of dead birds ($n = 6$) and test transmitters ($n = 12$), we believe our relocation accuracy was within approximately 100 m (Boal et al. 2001. Home range and habitat use of northern goshawks (*Accipiter gentilis*) in Minnesota, Final Report, Minnesota Cooperative Fish and Wildlife Research Unit, St. Paul, USA).

We plotted the estimated goshawk positions obtained by aerial telemetry onto aerial photographs carried in the aircraft. Following each flight, we used ArcView 3.1 (Environmental Systems Research Institute 1999) to plot estimated relocation points onto Digital Orthogonal Quadrate coverages of each goshawk breeding area. From these coverages, we derived Universal Transverse Mercator (UTM) coordinates for each relocation point. We estimated minimum convex polygon (MCP) home-range sizes using the Movement 1.1 ArcView Spatial Analyst Extension (Hooge and Eichenlaub 1997) after screening the data for post-breeding movements using area-observation curves (Odum and Kuenzler 1955). A full description of our methods for telemetry and home-range calculation is presented in Boal et al. (2003).

Foraging Stand Preferences

We use habitat terminology as defined by Hall et al. (1997). We examined stand preferences within home ranges and structural characteristics of those stands. Because we focused on stand types within the home range of individual goshawks, we assumed all stand types within home ranges were available for use by goshawks.

We used Geographic Information System (GIS) digital coverages of stand types and age classes to identify stand types used compared to their relative availability within the MCP home range of each goshawk. We used goshawk relocation points and MCP estimates of home ranges as reported in Boal et al. (2003). Digital coverages were provided by the U.S. Forest Service, Minnesota Department of Natural Resources, and various county land offices. For all data sets, stand type polygons had a minimum resolution of approximately 0.5 ha. We merged coverages from the different sources into a single coverage with the Geoprocessing Extension of ArcView 3.1. We pooled cover types into a common inventory classification system of stand types, which we then placed into a hierarchical categorization system. The first hierarchical level was either an early or late-successional stage community (Krebs 2001), the second level was forest community type, and the third level was an age categorization based roughly on growth rates to a harvestable age. Final categories were early-successional lowland–deciduous (ELD), early-successional lowland–conifer (ELC), and early-successional upland–conifer (EUC), all in stand ages of <25 yrs and ≥25 years. Late-successional lowland–conifer (LLC), late-successional lowland–deciduous (LLD), late-successional upland–conifer (LUC), and late-successional upland–deciduous (LUD) were all in stand ages of <50 years and ≥50 years. A primary concern over goshawk management in the WGLR has centered on harvest practices of early-successional, upland–deciduous (EUD) communities (e.g., aspen [*Populus* spp.], birch [*Betula* spp.]) and the influence they may have on goshawks. EUD stands were harvested extensively in our study area, with harvest rotations as short as 40 yrs. Therefore, to better investigate age-related preferences of this community type by goshawks, we separated this stand type into 3 age categories: <25 yrs, 25–49 yrs, and ≥50 yrs. We placed nonforested areas (e.g., open areas, wetlands) into a category termed OTHER.

Once the stand types were categorized based on the above hierarchical criteria, we queried the database for proportions of each stand type within each MCP home range. We overlaid goshawk relocation points onto the coverage and queried the database for the stand type at each relocation point. To account for error in determining goshawk locations, we also assessed the proportions of different stand types within a 50-m radius buffer around each location point. Buffer sizes were based on the accuracy of our estimated ground-based and aerial locations of test transmitters and of dead birds that were recovered (Boal et al. 2001. Home range and habitat use of northern goshawks (*Accipiter gentilis*) in Minnesota, Final Report, Minnesota Cooperative Fish and Wildlife Research Unit, St. Paul, USA). We then compared the proportional availability of the stand types within the corresponding MCP home range for each goshawk to (1) the stand type at relocation points, and (2) proportions of stand types within the buffer circles around relocation points.

There are several procedures for estimating and testing inferences about habitat selection. Although different methods may be appropriate for a given data set, they may produce different results (McClean et al. 1998, Erickson et al. 2001). Consistency or divergence of results among methods, however, may facilitate interpretation of the data. Therefore, we used 2 methods to examine use vs. availability for goshawks. Our telemetry data comprised a design III, in which home ranges and resource availability data were available for each radiomarked animal (Erickson et al. 2001). One widely used method for design III data is compositional analysis, a method that is resilient to variations in small sample sizes by using each individual animal as the sampling unit but for which data inferences apply to the population (Erickson et al. 2001). We used compositional analysis to provide a ranking of habitat types according to use.

As a second method, we used Bailey 95% Confidence Intervals (CI), which can be more informative than tests of statistical significance (Cherry 1996, Johnson 1999). We derived confidence intervals following a χ^2 goodness-of-fit test as described by Neu et al. (1974). We applied this method to our sample population by summing statistics as described by White and Garrott (1990). This resulted in the individual animals being the experimental units, similar to compositional analysis. Although inferences from the CIs can only be applied to the sample examined, the method allows for assessment of use and avoidance. If the proportion of a stand type fell below or above the 95% CI, we concluded that goshawk used that cover type more or less than expected, respectively.

Foraging and Nest Stand Structure

Understanding the structural characteristics of stands used by goshawks for foraging and nesting

Table 1. Mean and standard errors for stand measurements at 128 northern goshawk relocation points, northern Minnesota, USA, 1998–2000.

	Stand type[a]											
	EUC		EUC		LUC		LUD		LLC		LLD	
Variable	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
Canopy tree crown height (m)	14.7	0.4	16.4	0.3	16.8	0.7	15.1	0.3	15.6	0.3	14.9	0.8
Canopy tree canopy bottom (m)	6.5	0.3	8.2	0.2	9.2	0.3	7.3	0.2	7.6	0.3	6.1	0.5
Canopy tree dbh (cm)	21.0	0.7	20.3	0.4	24.6	0.7	22.5	0.5	22.6	0.8	19.6	1.3
Canopy tree density (stems/ha)	570.0	72.0	660.0	337.0	805.0	114.0	685.0	45.0	1,030.0	188.0	665.0	114.0
Canopy closure (%)	53.0	4.6	73.0	2.2	79.0	3.8	85.0	2.6	70.0	6.3	86.0	5.3
Basal area (ha)	37.6	2.9	40.9	1.9	50.0	3.8	41.2	2.3	55.3	8.7	37.4	6.0
Understory crown height (m)	5.4	0.2	5.7	0.1	5.7	0.2	6.1	0.1	6.0	0.3	5.8	0.2
Understory canopy bottom (m)	2.5	0.1	3.0	0.0	2.6	0.1	3.0	0.1	2.7	0.2	3.0	0.1
Understory dbh (cm)	5.6	0.0	6.0	0.6	5.3	0.1	6.3	0.9	5.9	0.2	5.0	0.2
Understory tree density (stems/ha)	545.0	139.0	965.0	111.0	635.0	165.0	780.0	99.0	525.0	180.0	1,715.0	374.0
Shrub height (m)	1.7	0.1	1.5	0.0	1.3	0.2	1.4	0.1	1.3	0.1	1.4	0.2
Debris (km/ha)	1.8	0.2	1.8	0.2	1.9	0.4	1.6	0.2	2.4	0.5	1.5	0.3
Debris dbh (cm)	16.8	0.4	17.6	0.3	17.0	0.4	19.1	0.4	18.8	0.7	17.2	0.9
Debris height (cm)	19.0	2.2	11.4	1.6	10.1	1.5	11.9	1.2	15.4	2.4	5.2	1.9
Snags/ha	264.0	45.0	125.0	12.0	191.0	28.0	128.0	17.0	212.0	56.0	125.0	43.0
Snag dbh (cm)	18.6	0.7	21.6	0.9	27.4	2.3	28.9	2.7	21.1	1.6	31.9	4.1
Snag height (m)	7.0	0.5	6.8	0.4	8.2	0.8	7.3	0.7	8.7	0.8	7.7	1.6

[a] Stand types: EUC = early-successional upland conifer (n = 15), EUD = early-successional upland deciduous (n = 50), LUC = late-successional upland conifer (n = 15), LUD = late-successional upland deciduous (n = 36), LLC = late-successional lowland conifer (n = 8), and LLD = late-successional lowland deciduous (n = 4).

requires quantitative characterization of those features. To describe foraging stand structure, we randomly selected 8 (≈25%) of the relocation points for each male goshawk that we radiotracked. Following fledging or failure of nests, we also visited nest stands to measure structural characteristics of the stands. At each foraging and nest stand, we conducted an array of measurements to describe the structural features and amounts of living and dead vegetation present (Table 1). We measured characteristics of living and dead vegetation within a randomly oriented, 100-m-long, 2-m-wide belt transect (0.02 ha) centered on the nest tree or relocation point estimate. We measured diameter at breast height (DBH) of all woody vegetation (e.g., trees, snags). We considered trees that were >2.54 cm and <10 cm DBH as understory trees and trees that were ≥10 cm DBH as canopy trees. We calculated canopy and understory stems per ha based on the number of stems in each category within the 0.02-ha strip transect. We assessed canopy closure by averaging readings obtained at 10-m intervals beginning and ending 10 m from the start and finish of each transect. We used a 10-factor prism to estimated basal area at 25-m intervals along the transect, and we then averaged the 5 readings. We measured height of foliage top and bottom for canopy and understory trees with a clinometer, and we categorized shrub height into 0.5-m increments. We considered any woody stems >2.54 cm as down woody debris and measured diameters, total length within the transect, and height above ground. We converted our measures of total length of woody debris within a transect to km per ha.

We categorized each stand by stand type as described above. We used paired t-tests (Zar 1999) to compare nest trees to trees within nest stands, and nests stands to foraging stands within individual goshawk home ranges. We used correlation analysis to examine nest placement in relation to canopy characteristics (Zar 1999).

RESULTS

We radiotagged 18 male goshawks, but 1 radio failed early on. Digital coverages of stand information were available for only 10 of the remaining 17 male goshawks, but 2 breeding season home ranges were available for 1 of those 10 goshawks. This allowed us to assess male goshawk use vs. availability of stand types within 11 breeding season home ranges. However, telemetry-based relocations were available for all goshawks, allowing us to visit stands within all 17 goshawk home ranges to assess foraging stand characteristics.

Foraging Stand Preference

We pooled all ELC and ELD stands, <25-yr-old stands of EUC, and <50-yr-old stands of LUD and

Table 2. Foraging habitat use vs. availability by male northern goshawks breeding in Minnesota, USA, 1998–2000. Assessment based on compositional analysis using stand types at relocation points and within 50-m radius buffered relocation points, compared to proportional availability of stand types within home ranges. Ranks: 0 = least preferred, 10 = most preferred.

Stand type[a]	Points	Buffered points	Mean[b] rank	Mean proportion available
EUC ≥ 25 yr	7	9	8.0	3.9
EUD < 25 yr	3	6	4.5	18.0
EUD 25–49 yr	8	4	6.0	5.6
EUD ≥ 50 yr	10	10	10.0	11.6
LUC < 50 yr	0	0	0.0	5.0
LUC ≥ 50 yr	9	8	8.5	2.5
LLC < 50 yr	1	1	1.0	6.6
LLC ≥ 50 yr	6	5	5.5	19.4
LUD ≥ 50 yr	5	3	4.0	4.9
LLD ≥ 50 yr	4	7	5.5	1.9
Other	2	2	2.0	20.6

[a] Stand types: EUC = early-successional upland conifer, EUD = early-successional upland deciduous, LUC = late-successional upland conifer, LLC = late-successional lowland conifer, LUD = late-successional upland deciduous, LLD = late-successional lowland deciduous. OTHER = open space, wetlands, EUC < 25 yr, LUD < 50 yr, LLD < 50 yr, all early lowland conifer, and early lowland deciduous stands.
[b] Mean of point and buffered point ranks.

Table 3. Foraging habitat use vs. availability of male northern goshawks breeding in Minnesota, USA, 1998–2000. Assessment based on Baileys 95% CIs comparing stand types at relocation points and within 50-m radius buffered relocation points to availability of stand types within goshawk home ranges.

Stand type[a]	Lower	Upper	Mean proportion availability	Use vs. available[b]
Relocation points				
EUC ≥ 25 yr	9.2	14.9	4.3	more
EUD < 25 yr	8.5	14.0	18.6	less
EUD 25–49 yr	6.9	11.9	6.0	more
EUD ≥ 50 yr	15.5	22.3	11.8	more
LUC < 50 yr	5.4	10.1	5.3	more
LUC ≥ 50 yr	6.7	11.7	2.6	more
LLC < 50 yr	2.1	5.3	5.6	less
LLC ≥ 50 yr	10.3	16.2	20.4	less
LUD ≥ 50 yr	4.0	8.1	5.5	no difference
LLD ≥ 50 yr	0.6	2.8	2.0	no difference
OTHER	6.1	10.9	17.9	less
Buffered relocation points				
EUC ≥ 25 yr	9.8	15.5	4.2	more
EUD < 25 yr	9.1	14.7	18.5	less
EUD 25–49 yr	4.2	8.4	6.0	no difference
EUD ≥ 50 yr	17.1	24.1	11.7	more
LUC < 50 yr	5.5	10.2	5.3	more
LUC ≥ 50 yr	6.4	11.3	2.6	more
LLC < 50 yr	1.9	5.0	6.5	less
LLC ≥ 50 yr	10.2	16.0	20.5	less
LUD ≥ 50 yr	5.1	9.6	4.5	more
LLD ≥ 50 yr	0.7	2.9	2.0	no difference
OTHER	5.6	10.3	18.2	less

[a] Stand types: EUC = early-successional upland conifer, EUD = early-successional upland deciduous, LUC = late-successional upland conifer, LLC = late-successional lowland conifer, LUD = late-successional upland deciduous, LLD = late-successional lowland deciduous. OTHER = open space, wetlands, EUC < 25 yr, LUD < 50 yr, LLD < 50 yr, all early lowland conifer, and early lowland deciduous stands.
[b] If the mean proportional availability of a stand type falls below or above the 95% CI, the conclusion is that the stand type was used more or less than available, respectively.

LLD into the OTHER category because they collectively constituted a small proportion of stand types (4.3%). This left 11 stand types for habitat use assessment. The results of the home-range-level analysis were remarkably consistent regardless of the analytical method we used, or whether we examined relocation points or buffered relocation points (Tables 2, 3).

EUD ≥50 yrs old was the highest-ranked stand type based on compositional analysis, regardless of whether we used relocation points or buffered relocation points (Table 2). Likewise, the 95% CI method indicated EUD ≥50-yr-old stand type was preferred by goshawks, whether based on point locations or point buffers (Table 3). Mature, EUD ranked eighth and fourth using points and buffers, respectively, and was identified as a preferred stand type when using points. However, when examining buffered points, goshawks used this stand type in proportion to availability. Both analytical methods indicated young EUD stands appeared to be avoided (Tables 2, 3).

LUC stands ≥50 yrs old were highly ranked and were preferred independent of analytical method and scale. LLD stands ≥50 yrs old ranked in the middle of the range of stand types and, as such a ranking would suggest, the 95% CI method indicated the stand type was used proportional to availability. LLC, one of the most available stand types in goshawk home ranges, ranked in the middle (≥50-yr-old stands) to very low (<50-yr-old stands; Table 2), and the 95% CI method indicated this stand type was avoided regardless of age (Table 3). Likewise, the OTHER category was near the bottom of rankings and was used less than proportionally available.

There were 2 stand types that the analytical methods diverged on in terms of ranking and use or avoidance (Tables 2, 3). LUD >50 yrs old was ranked low by compositional analysis, but the 95% CI method indicated it was used in proportion to availability when examining relocation points, and it was preferred when examining buffered points. Likewise, <50-yr-old LUC was the lowest ranked of all stand types, yet it was a preferred stand type based on 95% CIs.

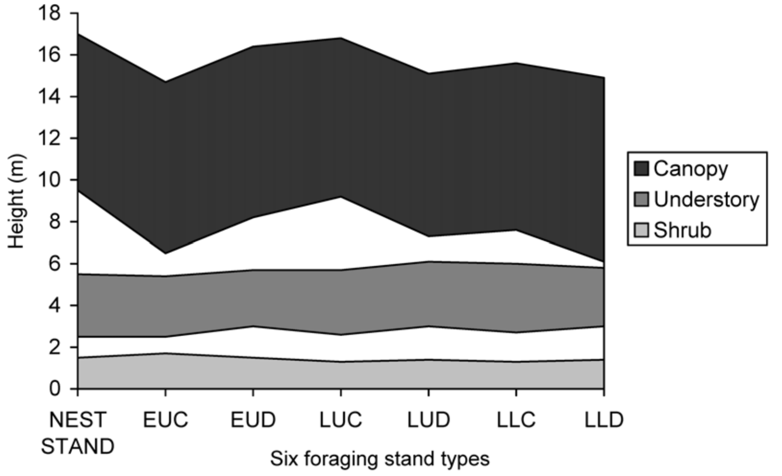

Fig. 2. Vertical heights of canopy, understory, and shrub layers and the unobstructed layers in between at nest stands (n = 26) and foraging stands (n = 128) used by male northern goshawks during the breeding season in Minnesota, USA, 1998–2000. Vegetative community of foraging stands indicated by EUC = early-successional upland conifer (n = 15), EUD = early-successional upland deciduous (n = 50), LUC = late-successional upland conifer (n = 15), LUD = late-successional upland deciduous (n = 36), LLC = late-successional lowland conifer (n = 8), LLD = late-successional lowland deciduous (n = 4).

Stand Structure

Foraging Stands.—We inventoried 128 foraging stands that represented 6 stand types. Rather than any substantive differences in habitat characteristics measured at stands used by goshawks, the most notable result was the similarity in stand structure across stand types (Table 1, Fig. 2). Canopy tree crown height averaged 14.7–16.8 m, and the bottoms of canopies averaged 6.1–9.2 m. Understory tree crowns averaged 5.5–6.1 m. Depending on stand type, this resulted in a 1.1–3.5-m space between the bottom of the overstory and top of the understory trees. An exception to this occurred among late-successional lowland deciduous stands, where the open space averaged only 0.3 m. There was also 1.3–1.6 m of open space between the bottom of the understory canopy and top of the shrub layer in all stand types except early-successional upland conifer stands (Fig. 2). These relatively unobstructed spaces between vegetation layers and the heights at which they occurred were consistent among stand types.

Mean dbh also was similar among canopy trees, ranging from 19.6 to 24.6 cm (Table 1). Canopy-tree stem-density was highly variable and ranged from 570/ha to 1,030/ha, with densities lowest among early-successional upland conifer stands and highest among late-successional lowland conifer stands. Snags were numerous but variable, ranging from 125/ha to 245/ha. Mean canopy closure among all stand types ranged from 53 to 86%. Foraging stands contained from 1.5 to 2.4 km/ha of down woody debris, averaging 16.8–19.1 cm in diameter. Down woody debris typically was 5.2–19.0 cm above the ground, and mid-way through the decay process.

Nest Stands.—We located 65 individual goshawk nest trees within the 43 nesting stands. Overall, 94% of goshawk nests were built in deciduous trees, most of which were quaking aspen (*Populus tremuloides*; 75%) and paper birch (*Betula papyrifera*; 12%). Deciduous trees were the most frequently used species for nest trees, even in nest stands characterized as being early-successional conifers (nest trees = 100% deciduous species) or late-successional conifers (nest trees = 71% deciduous species). Most nest stands were early-successional upland deciduous stands (58.1%) and late-successional upland conifer stands (25.6%). Fewer nests were located in late-successional upland deciduous stands (11.6%) and early-successional upland conifer stands (4.7%).

We assessed structural characteristics for 26 goshawk nest stands. Nests were placed in the tallest trees (21.9 ± 6.0 m) available in stands (17.1 ± 3.5 m; t_{25} = 4.45, P = 0.0002). Nests were also in the largest diameter trees (39.0 ± 12.3 cm) available in stands (23.9 ± 6.9; t_{25} = 9.68, P < 0.0001). Height of nests was positively correlated with height of the nest tree (r = 0.773) and height of the bottom of the nest tree canopy (r = 0.685). Nest stands were multistoried with canopy crowns averaging 17.0 ± 6.2 m and the bottom of the canopy at 9.5 ± 4.7 m above the ground. The top of the understory averaged 5.5 ± 2.5 m, leaving a relatively unobstructed 4-m layer between the canopy and understory foliage (Fig. 2). Similarly, the bottom of the understory was at 2.5 ± 1.7 m, leaving another, albeit narrow, unobstructed layer above the shrub cover (Fig. 2). Mean dbh for nest-stand canopy trees (nest trees included) was 24.4 ± 12.0 cm, and stem densities appeared relatively high, ranging from 625 ± 177 to 900 ± 353 stems/ha depending on stand type, with an average of 815 ± 254 stems/ha. When canopy and understory trees were pooled, mean stem density was 1,196 ± 343 stems/ha.

Foraging Nest Stand Comparisons.—We compared stand characteristics between nest stands and foraging stands used by radiotagged goshawks within individual goshawk home ranges ($n = 15$). Nest stand canopy trees were greater in diameter (27.2 ± 0.9 cm) than those in foraging stands (22.2 ± 3.4 cm; $t_{14} = -2.94$, $P < 0.01$), and they were of greater height (18.2 ± 3.7 m) than those in foraging stands (15.7 ± 2.9 m; $t_{14} = -6.17$, $P < 0.0001$). The bottom of the canopy foliage was higher above the ground in nest stands ($x = 9.2 \pm 2.5$ m) than foraging stands ($x = 7.6 \pm 1.5$ m; $t_{14} = -3.18$, $P < 0.007$). Understory stem density was also lower at nest stands (535 ± 295 stems) than foraging stands (845 ± 380 stems; $t_{14} = 3.06$, $P < 0.008$). Nest stands and foraging stands were otherwise similar in structural features. Canopy closure, often reported as being high at goshawk nest sites, was similar among nest stands (74.6 ± 8.2%) and foraging stands (72.7 ± 14.5%; $t_{14} = -0.62$, $P = 0.546$).

DISCUSSION

Foraging Stand Preferences

When foraging, breeding male goshawks in the LMFP of northern Minnesota used old and mature forest stands to an extent greater than expected on the basis of availability. The exception to this was lowland conifers, which goshawks used less than expected regardless of stand age class. Goshawks also used young forest stands and open areas less than expected on the basis of availability. This demonstrated preference for older age classes by goshawks is consistent with reports on breeding-season habitat use by goshawks in coniferous forests of the western United States (Austin 1993, Bright-Smith and Mannan 1994, Beier and Drennan 1997), nonbreeding goshawks in boreal forests of Sweden (Widen 1989) and Finland (Tornberg and Colpaert 2001), and year-round use in coniferous forests of southeast Alaska (Iverson et al. 1996).

North-central Minnesota underwent notable changes from the historical landscape, with the ratio of forested land to nonforested land declining from 1.72:1.00 in 1977 to 1.63:1.00 in 1990 (Minnesota Forest Resources Council 2000). The composition and relative abundances of tree species has also changed. LUC (i.e., red pine [*Pinus resinosa*] and white pine [*P. strobus*]) decreased markedly from historical records, whereas aspen has increased substantially (Minnesota Forest Resources Council 2000). Thus, the decrease of upland–conifer communities may be interpreted as being offset by the increase of aspen. However, <50% of the remaining LUC stands are ≥50 yrs old (Minnesota Forest Resources Council 2000).

Preferential use of older forest stands and the reduced abundance of these stands in the landscape may influence goshawks through prey availability. For example, red squirrels (*Tamiasciurus husdonicus*) prefer coniferous forests (Steele 1998, Bayne and Hobson 2000), and they were the dominant prey of goshawks in our study area (Smithers 2003). Decreases in amount and age of conifer stands might reduce abundance of this important prey species. However, red squirrels will also occupy aspen and mixed coniferous-deciduous stands (Yahner 1987, Bayne and Hobson 2000). More information is needed on prey availability in these stand types to determine their relative importance as a source of prey

Assessing the influences of landscape changes on goshawks in our study area is speculative without experimentation. Given the apparently low breeding density of goshawks in the LMFP and their large home-range sizes, which often encompasses multiple property ownerships (Boal et al. 2003), landscape experiments would be difficult to implement. However, a possible alternative is quasi-experiments as suggested by DeStefano (1998) and Kennedy (1998) where a sample of male breeding goshawks could be radiotracked for several years to document their foraging pattern responses as forest stand manipulations occur.

Foraging Stand Structure

Similar to goshawks in Arizona (Beier and Drennan 1997), foraging male goshawks in our study used areas that were typified by a relatively high stem density of mature deciduous or coniferous trees. Goshawks in our study also used stands with consistently high canopy closure, as has been observed in other studies (Austin 1993, Bright-Smith and Mannan 1994, Beier and Drennan 1997). Foraging stands had dense understories and, often, a large amount of shrub cover, which may influence local prey abundance. Distribution, density, and overwinter survival of snowshoe hares (*Lepus americanus*) have been associated with understory density independent of stand species type (Litvaitis et al. 1985, Wirsing et al. 2002). Likewise, ruffed grouse (*Bonasa umbellus*) survival rates were lowest in areas where understory cover was sparse (Gullion and Alm 1983). Stands used by foraging goshawks in our study also had large amounts of down woody debris, which may increase the abundance of some forest floor vertebrates (Butts and McComb 2000) or facilitate midden construction and, hence, increased red squirrel density. However, dense vegetation was suspected of reducing prey availability and reducing or precluding breeding goshawks in some areas (Reynolds et al. 1992, DeStefano and McClosky 1997). Thus, the combination of understory vegetation and down woody debris may result in relatively abundant prey in foraging stands, but it may also limit availability of those prey species to goshawks.

We were not able to compare structural characteristics of foraging stands to what was randomly available in our study area. Thus, we do not know if stands used by foraging goshawks were structurally different from randomly available stands of similar age and species composition. Regardless, the similarity of diameter and heights of canopy trees, canopy closure, stem densities, and horizontal flight corridors among used stands, independent of stand type, was striking and indicative of the structural characteristics of stands used by foraging goshawks in our study area. The maintenance of stands with these structural characteristics as foraging areas may be an important component of managing breeding goshawks (Widen 1989).

Nest Stand Structure

Although it has been suggested that goshawks select nest trees on the basis of availability (Reynolds et al. 1982), aspen and birch trees were clearly the dominant species used by goshawks in Minnesota, even in conifer-dominated nest stands. This may be a pattern in the WGLR; Rosenfield et al. (1998) found 1 of 4 goshawk nests in Wisconsin pine plantations was in an aspen. These results suggests that conservation of large, deciduous trees in all stand types may be important for goshawk management.

Compared to western North America where goshawks nests appear to be primarily on federal lands or on large tracts of land owned by individual timber companies, nests in our study area occurred on a variety of land ownerships, under a variety of management practices. Still, nest sites in our study were consistent in many ways to those reported in western North America. Similar to other studies (Siders and Kennedy 1994, Squires and Ruggiero 1996), we found goshawks nested in the largest trees in nest stands and in stands with high canopy closure.

Average nest stand dbh and height of nest trees in our study were the lowest and among the lowest, respectively, compared to those reported from several studies of goshawk nest stand characteristics reviewed by Siders and Kennedy (1994). These departures may be indicative of the shorter growing seasons in our study area (Tester 1995) and differences in tree species selected for nest placement. However, we found nest stand canopy closure (74.6%) within the range (59.8 to 95.0%) reported by Siders and Kennedy (1994).

Penteriani et al. (2001) suggested a commonality among goshawk nest stands is a variable, but generally low, stem density. Mean nest-stand stem density (stems ≥2.54 cm) in our study (1,196 stems/ha) exceeded or was among the highest of those reported in reviews by Siders and Kennedy (1994) and Penteriani (2002), respectively. The influence of high stem densities on goshawks is unknown, but dense vegetation may influence the distribution, and therefore density, of goshawks (DeStefano and McCloskey 1997, Penteriani 2002). Penteriani (2002) also suggested that goshawk nest choice may be a function of nest support and flight space availability. We found nest and foraging stands had high stem densities and were multistoried, but they consistently had relatively unobstructed horizontal spaces between the shrub and understory layers and the understory and canopy layers. We suspect these relatively unobstructed layers may be important as flight corridors for goshawks while foraging and when returning to the nest while carrying prey.

Foraging – Nest Stand Comparison

Comparison of nest stands to foraging stands can provide insight as to the range of forest conditions required for nesting and foraging goshawks. We found nest stands consisted of taller and larger canopy trees and fewer understory trees compared to foraging stands, but stands were otherwise similar in structural features. This suggests that goshawks use similar stands for nesting and foraging, but they tend to choose the most mature stands for nesting. This may facilitate goshawks conservation in the WGLR in that similar forest management practices may provide nesting and foraging areas.

Our conclusions should be interpreted with the following considerations in mind. First, goshawk home-range sizes are likely influenced by the distribution and size of stand type patches, and different home-range estimators may influence results and interpretation of use vs. availability analyses. We used the MCP home-range estimator, which may include areas not used by goshawks. Second, although goshawks may not typically venture into stand types that are used less than expected, those stand types may be an important component of a goshawk's home range. For example, goshawks seldom venture into young EUD stands, yet these stands are important for production of some prey species (e.g., ruffed grouse; Gullion and Alm 1983). In addition, goshawks may hunt near the interface between adjacent stands. Third, our data and assessment are limited to the breeding season.

The relative use of different stand types by goshawks may vary temporally due to factors such as seasonal differences in prey availability or requirements for thermal or escape cover. Finally, goshawks are widely distributed in North America, but the majority of existing goshawk research has been conducted in the western United States and western Canada (Squires and Reynolds 1997). Regional differences in environmental conditions and forest management practices may make management practices applicable in 1 area ineffective in other areas. Spatial variability in forest conditions, climates, and prey species necessitates that plans to manage forest structure and composition be tailored to local (Fuller 1996) and regional (Andersen et al. 2004) conditions. For example, goshawks in Minnesota will use areas with a comparatively higher stem density than most western studies would suggest. However, the influence of higher stem densities on goshawks is unknown; lessening stem density could have positive effects for goshawks.

MANAGEMENT IMPLICATIONS

Our data are applicable to development of informed landscape-scale management plans for goshawks in the LMFP and may be more generally extended to the WGLR, based on habitat availability and structure of individual stands. Goshawk management should include maintenance or development of stands with high canopy closure and structurally large trees (Andersen et al. 2004, Squires and Kennedy 2005). Stands with high stem density should also have horizontal layers of open space between shrub and understory, and understory and canopy foliage. Conservation of EUD and LUC stand types would likely benefit goshawks, but implementation of these conservation strategies may impact rotation rates of harvested EUD stands that rarely reach maturity under current forest management practices. However, stands not normally used by goshawks (e.g., EUD < 25 yrs, all LLC) may be important for production of some goshawk prey and, therefore, goshawk conservation.

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