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NORTHERN GOSHAWK DIET IN MINNESOTA: AN ANALYSIS USING VIDEO RECORDING SYSTEMS

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ABSTRACT.—We used video-recording systems to collect diet information at 13 Northern Goshawk (*Accipiter gentilis*) nests in Minnesota during the 2000, 2001, and 2002 breeding seasons. We collected 4871 hr of video footage, from which 652 prey deliveries were recorded. The majority of prey deliveries identified were mammals (62%), whereas birds (38%) composed a smaller proportion of diet. Mammals accounted for 61% of biomass delivered, and avian prey items accounted for 39% of prey biomass. Sciurids and leporids accounted for 70% of the identified prey. Red squirrel (*Tamiasciurus hudsonicus*), eastern chipmunk (*Tamias striatus*), and snowshoe hare (*Lepus americanus*) were the dominant mammals identified in the diet, while American Crow (*Corvus brachyrhynchos*) and Ruffed Grouse (*Bonasa umbellus*) were the dominant avian prey delivered to nests. On average, breeding goshawks delivered 2.12 prey items/d, and each delivery averaged 275 g for a total of 551 g delivered/d. However, daily ($P < 0.001$) and hourly ($P = 0.01$) delivery rates varied among nests. Delivery rates ($P = 0.01$) and biomass delivered ($P = 0.038$) increased with brood size. Diversity and equitability of prey used was similar among nests and was low throughout the study area, most likely due to the dominance of red squirrel in the diet.

KEY WORDS: *Northern Goshawk;* Accipiter gentilis; *diet; Minnesota; prey diversity; red squirrel;* Tamiasciurus hudsonicus.

DIETA DE *ACCIPITER GENTILIS* EN MINNESOTA: UN ANÁLISIS BASADO EN SISTEMAS DE GRABACIÓN EN VIDEO

RESUMEN.—Empleamos sistemas de grabación en video para recolectar información sobre la dieta de *Accipiter gentilis* en 13 nidos ubicados en Minnesota durante las temporadas reproductivas de 2000, 2001 y 2002. Obtuvimos 4871 hr de grabación, a partir de las cuales registramos 652 entregas de presas. La mayoría de las presas entregadas que identificamos fueron mamíferos (62%), mientras que las aves (38%) representaron una proporción menor de la dieta. Los mamíferos y las aves representaron el 61% y el 39% de la biomasa entregada, respectivamente. Los sciúridos y lepóridos representaron el 70% de las presas identificadas. Los mamíferos predominantes identificados en la dieta fueron *Tamiasciurus hudsonicus, Tamias striatus* y *Lepus americanus,* mientras que las aves llevadas a los nidos predominantemente fueron *Corvus brachyrhynchos* y *Bonasa umbellus.* En promedio, los individuos nidificantes entregaron 2.12 presas/d, y cada entrega tuvo un promedio de 275 g, para un total de 551 g entregados/d. Sin embargo, las tasas diarias ($P < 0.001$) y horarias ($P = 0.01$) de entrega de presas variaron entre nidos. Las tasas de entrega ($P = 0.01$) y la biomasa entregada ($P = 0.038$) incrementaron con el tamaño de la nidada. La diversidad y equitabilidad de las presas consumidas fueron similares entre nidos y bajas a través del área de estudio, probablemente debido a la dominancia de *T. hudsonicus* en la dieta.

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The Northern Goshawk (*Accipiter gentilis*) is a large, forest-dwelling raptor generally associated with mature deciduous, coniferous, or mixed forests (e.g., Bright-Smith and Mannan 1994, Siders and Kennedy 1996, Beier and Drennan 1997, Squires and Reynolds 1997). Goshawk research in North America has been conducted primarily in the western half of the continent (Boal et al. 2003). Consequently, there is little published literature describing ecology of the species in the Western Great Lakes Region (WGLR) of North America, where it is currently listed as a Migratory Nongame Bird of Management Concern by the U.S. Fish and Wildlife Service (Region 3) and as a sensitive species by the U.S. Forest Service (Region 9) due to loss of habitat (Reynolds et al. 1992).

Depending on region, season, and availability, goshawks capture a wide variety of prey and are considered prey generalists (Squires and Reynolds 1997, Squires and Kennedy 2005). Although breeding-season diet composition has been studied for many populations (e.g., Meng 1959, Grzybowski and Eaton 1976, Boal and Mannan 1994, Younk and Bechard 1994, Lewis 2001), site-specific studies of diet are necessary for developing management strategies for goshawk populations at regional and local levels (e.g., Reynolds et al. 1992). A number of records exist of prey items collected opportunistically at goshawk nests in the WGLR (Eng and Gullion 1962, Apfelbaum and Haney 1984, Martell and Dick 1996), but these reports are anecdotal and provide a prey list rather than a quantitative assessment of food habits (Roberson et al. 2003).

Methods used in goshawk food habits research have included indirect (i.e., identification of prey remains or contents of regurgitated pellets) and direct observations of prey deliveries to nests (Meng 1959, Grzybowski and Eaton 1976, Bosakowski and Smith 1992, Boal and Mannan 1994). Indirect methods of assessing raptor diet can lead to biased results (e.g., Bielefeldt et al. 1992), whereas direct methods should provide the least-biased results (Collopy 1983, Marti 1987, Boal and Mannan 1994). During the breeding seasons of 2000–02, we used videography as a modified method of direct observation of prey deliveries to examine diet of Northern Goshawks in northern Minnesota.

METHODS

Study Area. The study area was located in the Laurentian Mixed-Forest Province of north-central and northeastern Minnesota (46°50′N, 92°11′W) as described by Boal et al. (2001) and Roberson (2001; Fig. 1). The study area elevation ranged from ca. 200–400 m. Mean summer and winter temperatures were 18°C and −11°C, respectively, and maximum and minimum temperature records for the region were 40°C and −46°C, respectively (Daniel and Sullivan 1981). Annual precipitation averaged 60–70 cm. The study area was dominated by pine, mixed-hardwood, boreal, and second-growth forests with wetland community types interspersed among forest stands (Tester 1995).

Goshawk Nests. Nests included in this study were considered as sampling units and were selected from all known occupied nests in the study area (Boal et al. 2001). With the exception of one nest, where few data were collected during 2000, diet information was not collected at any nest for more than one breeding season. Nests were selected randomly within the constraints of accessibility and to include different land ownerships. Thus, our sample is not truly random and may not be representative of the goshawk population of our study area. However, to examine the applicability of our diet data to the goshawk population as a whole, we examined prey diversity and overlap among nests. High overlap and low diversity would suggest prey use was similar among goshawk pairs and that our data were representative of the population in general.

Video Recording. We used VHS (Model SL 800, Security Labs®, Noblesville, IN U.S.A.) and 8-mm video recording systems (Sony® Model M-350, Fuhrman Diversified, Inc., Seabrook, TX U.S.A.) with color or black-and-white cameras (Model CCM-660W, Clover Electronics®, Los Alamitos, CA U.S.A.). Cameras were installed on nest trees within 0.6 m of the nest or, for cameras with zoom lenses, on an adjacent tree up to 9 m from the nest. Video recorders were placed in weatherproof cases ca. 30 m from the base of each camera tree. Coaxial-video cables were used to convey power to and transmit images from the cameras. Recorders were programmed to record from 0530–2100 H (15.5 hr of footage) at the 48-hr (1.3 frames/sec) or the 72-hr (0 8 frames/sec) setting to optimize the amount of tape used per sampling session and battery life. We replaced tapes and batteries every 3–4 d.

Prey Identification. To identify prey delivered to nests, we reviewed video footage until a prey delivery occurred, then advanced frame by frame and freeze-framed to facilitate prey identification. We identified avian and mammalian prey by morphological features and developed a list of prey species delivered by goshawks to all nests (Table 1). Goshawks may cache prey and retrieve cached prey items (Boal and Mannan 1994), which could bias estimates of delivery rates and proportional use of species in the diets. We attempted to identify cached prey on basis of a successive, iterative process that included comparing prey items using flesh color, pelage or feather condition, and time of delivery from review of video footage, and then remove those items thought to be cached from analysis.

Age and Biomass Estimation. We assigned avian prey to age categories (e.g., adult, juvenile, or nestling) based on plumage (e.g., feathers and down) and amount of sheathing on flight feathers (Reynolds and Meslow

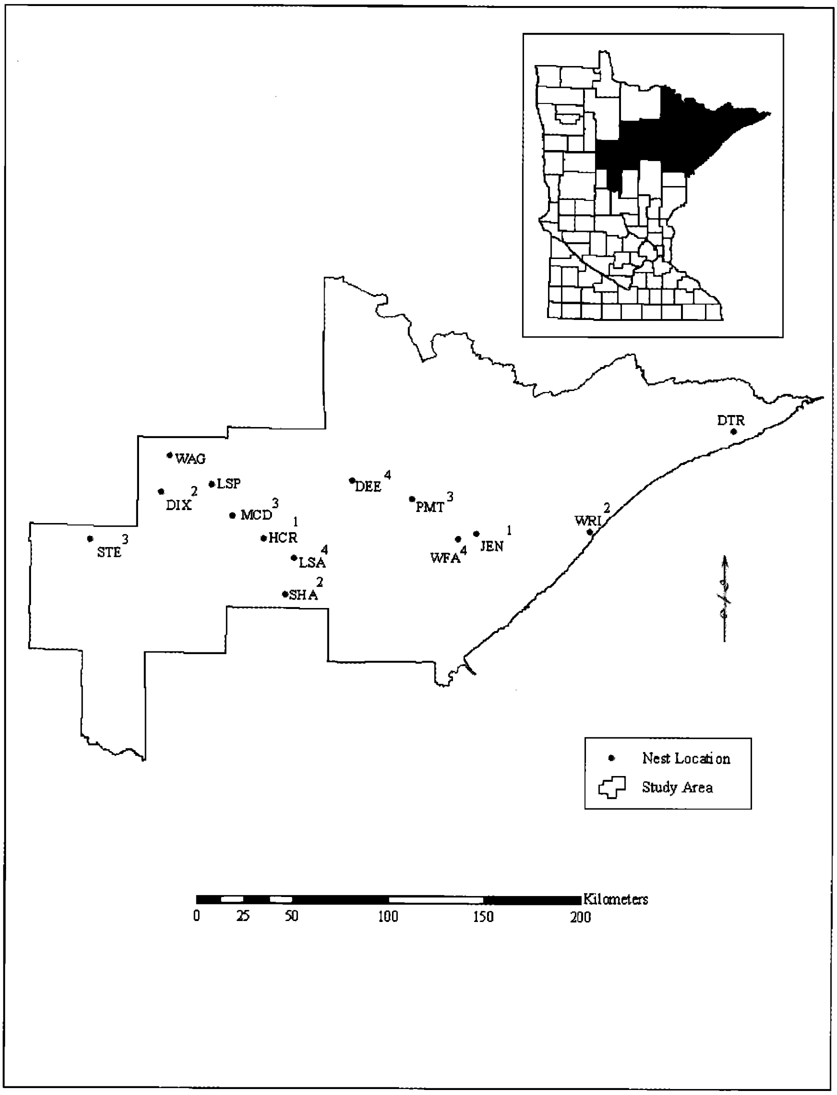

Figure 1. Study area and distribution of Northern Goshawk nests in Minnesota where food habits information was collected during the 2000–02 breeding seasons. The three-letter designations indicate individual nests. Breeding season diet information collected at the DTR breeding area was omitted from all analyses because of nest failure. Breeding areas with similar prey composition are indicated with the same superscripts. Superscripts indicate cluster number (see Fig. 2).

1984). We categorized mammalian prey as adults or juveniles based on size (Bielefeldt et al. 1992). Because of difficulty in estimating age of small mammals, we considered all mammals smaller than chipmunks to be adults. Biomass for partial prey items was calculated using the proportion of prey delivered to nests, and proportions were estimated qualitatively (e.g., 50% of adult size).

We estimated biomass for prey identified to family, genus, or species and used the mean mass of both sexes (Reynolds and Meslow 1984, Lewis 2001). Biomass estimates were based on published information on mammalian and avian species occurring in the study area (Burt and Grossenheider 1980, Jones and Birney 1988, Dunning 1993, Dunn and Garrett 1997, Dunn 1999, Sibley 2000). We calculated mass for nestlings following Bielefeldt et al. (1992) using 100% of the adult mass for warbler-sized species, 65% of the adult mass for robin and jay-sized species, and 55% of the adult mass for large birds such as grouse. We calculated mass of juvenile red squirrel (*Tamiasciurus hudsonicus*), eastern chipmunk

Table 1. Number, percent occurrence, and biomass of mammalian and avian prey delivered to Northern Goshawk nests (N = 13) in Minnesota, 2000–02. Values represent pooled number of prey identified at nests during the 2000, 2001, and 2002 breeding seasons.

PREY CATEGORY	COMMON NAME	*N*	PERCENT	BIOMASS (g)	PERCENT
Mammals					
Tamiasciurus hudsonicus	red squirrel	202	31.0	38046	23.6
Tamias striatus	eastern chipmunk	95	14.6	8108	5.0
Lepus americanus	snowshoe hare	31	4.8	41027	25.5
Sylvilagus floridanus	eastern cottontail	7	1.1	7654	4.8
Sciurus carolinensis	eastern gray squirrel	3	0.5	1679	1.0
Peromyscus spp.		2	0.3	47	0.0
Family: Muridae		1	0.2	18	0.0
Mustela frenata	long-tailed weasel	1	0.2	210	0.1
Unknown mammal (MSC1)[a]		8	1.2	186	0.1
Unknown mammal (MSC2)[a]		9	1.4	1720	1.1
Birds					
Corvus brachyrhynchos	American Crow	37	5.7	14515	9.0
Bonasa umbellus	Ruffed Grouse	33	5.1	18448	11.5
Aythya spp.	diving duck	12	1.8	11360	7.1
Cyanocitta cristata	Blue Jay	8	1.2	664	0.4
Fulica americana	American Coot	6	0.9	3338	2.1
Turdus migratorius	American Robin	3	0.5	205	0.1
Quiscalus quiscula	Common Grackle	3	0.5	341	0.2
Family: Icteridae	blackbird	3	0.5	189	0.1
Picoides spp.	woodpecker	3	0.5	199	0.1
Dryocopus pileatus	Pileated Woodpecker	3	0.5	861	0.5
Unknown duckling		4	0.6	400	0.2
Butorides virescens	Green Heron	2	0.3	420	0.3
Perisoreus canadensis	Gray Jay	2	0.3	142	0.1
Agelaius phoeniceus	Red-winged Blackbird	2	0.3	105	0.1
Strix varia	Barred Owl	1	0.2	394	0.2
Buteo platypterus	Broad-winged Hawk	1	0.2	455	0.3
Genus: *Calidris*		1	0.2	73	0.0
Bucephala clangula	Common Goldeneye	1	0.2	900	0.6
Accipiter cooperii	Cooper's Hawk	1	0.2	439	0.3
Gallus spp.	domestic chicken[b]	1	0.2		
Coccothraustes vespertinus	Evening Grosbeak	1	0.2	59	0.0
Pipilo erythrophthalmus	Eastern Towhee	1	0.2	41	0.0
Genus: *Euphagus*		1	0.2	63	0.0
Accipiter gentilis	Northern Goshawk	1	0.2	820	0.5
Picoides villosus	Hairy Woodpecker	1	0.2	66	0.0
Charadrius vociferus	Killdeer	1	0.2	97	0.1
Anas platyrhynchos	Mallard	1	0.2	1082	0.7
Sitta canadensis	Red-breasted Nuthatch	1	0.2	10	0.0
Seiurus aurocapillus	Ovenbird	1	0.2	19	0.0
Catharus fuscescens	Veery	1	0.2	31	0.0
Unknown nestling		33	5.1	1190	0.7
Unknown bird (ASC1)[a]		18	2.8	173	0.1
Unknown bird (ASC2)[a]		23	3.5	1778	1.1
Unknown bird (ASC3)[a]		6	0.9	3459	2.1
Items not identified to class *Mammalia* or *Aves*		76	11.7		

[a] MSC1 = mouse-sized prey item; MSC2 = red squirrel-sized prey item; ASC1 = warbler-sized prey item: ASC2 = robin-sized prey item; ASC3 = Ruffed Grouse-sized prey item.
[b] Omitted from analysis.

(*Tamias striatus*), snowshoe hare (*Lepus americanus*), and eastern cottontail (*Sylvilagus floridanus*) using 95% of the adult mass; if ages could not be determined reliably, we assigned juvenile masses to these species.

To estimate biomass of unidentified prey, we pooled unidentified birds into three *a priori* size classes (SC) following Storer (1966) and Kennedy and Johnson (1986) that represented average mass of common species in our study area: SC1 = 10 g (e.g., warbler-sized), SC2 = 77 g (e.g., robin-sized), and SC3 = 576 g (e.g., Ruffed Grouse [*Bonasa umbellus*]-sized). Similarly, we pooled unidentified mammal prey into two *a priori* size classes: SC1 = 23 g (e.g., mouse-sized) and SC2 = 192 g (e.g., squirrel-sized).

Prey and Biomass Delivery Rates. We calculated delivery rates on the basis of number of prey delivered per day, number of prey delivered per nestling per day, and number of prey delivered per day at nests with one, two, and three nestlings. We calculated biomass estimates in the same manner. We calculated mean delivery rates over 5-d intervals from hatching to 5 d post-fledging (i.e., from 0–45 d).

Prey Diversity and Overlap. We calculated prey diversity for the study area using ungrouped prey categories (i.e , using each prey category identified to family, genus, or species separately). Because samples were smaller when examining individual nests, we generalized prey into similar species categories (Lewis 2001) to calculate prey diversity for individual nests. The generalized prey categories for among-nest diversity assessment were: (1) Sciurids, (2) blackbirds and Corvids, (3) Leporids, (4) Ruffed Grouse, (5) diving ducks (*Aythya* spp.), (6) water and shore birds, (7) passerines, (8) Picidae, (9) Falconiforms, (10) miscellaneous mammals (e.g., long-tailed weasel [*Mustela frenata*]).

We calculated prey diversity using Williams (1964) and MacArthur's (1972) modified form of the Simpson's index (Simpson 1949) and diet equitability using Smith and Wilson's index of evenness (Smith and Wilson 1996). We used prey identified to family, genus, or species to estimate diet overlap among nests with the Simplified Morisita's Index of Overlap (Krebs 1999). Overlap measures are designed to measure the degree that two species share a set of common resources or utilize the same parts of the environment (Lawlor 1980). Overlap measures are scaled from zero to one, where zero overlap indicates dissimilarity in resource use, and one indicates complete overlap (Krebs 1999). We also assessed similarity in prey use among nests with cluster analysis using average linkage clustering (Romesburg 1984, Krebs 1999, McGarigal et al. 2000). As suggested by Romesburg (1984), we used the un-weighted pair-group method using arithmetic averages (UPGMA).

Statistical Analysis. We used analysis of variance (ANOVA) to examine relationships between delivery rate variables and brood size using log-transformed data (Zar 1999). Biomass of prey delivered per day per nest was transformed by taking the logarithm of biomass delivered per day and adding 1.0 (Zar 1999). Normality of experimental error was tested using the Shapiro-Wilk test procedure, and assumptions regarding homogenous variances were tested using Levene's test (Zar 1999). We examined differences in the number of mammals and birds delivered among nests over 5-d intervals, because of missing data among sampled days, with a Kruskal-Wallis single-factor ANOVA (Zar 1999). Because observations within breeding areas were not independent, we examined differences in provisioning rates among breeding areas with multivariate repeated measures ANOVA. We used the General Linear Model (GLM) module of STATISTICA (Version 6.0, StatSoft, Inc., Tulsa, OK U.S.A.) for all statistical analyses except calculation of diet overlap and similarity, for which we used Ecological Methodology 6.1 (Exeter Software, Setauket, NY U.S.A.). An alpha level of $P = 0.05$ was used for all statistical tests, and we present means and standard errors.

RESULTS

Video Recording and Prey Identification. We installed video monitoring systems at three, five, and seven occupied goshawk nests during the 2000, 2001, and 2002 field seasons, respectively. We placed cameras at nests when nestlings were ca. 8 d old (±1.18; range = 1–18 d). One of the 15 nests failed within 3 d of camera placement and was removed from analysis. Due to camera malfunctions, we were only able to collect 16 hr of footage at one of the nests in 2000. We placed a camera at the 2002 nest of the same pair, but pooled data from both years as one nest area for analysis. Thus, our sample of 4801 hr ($\bar{x} = 320 \pm 42$ hr/nest) of video footage is derived from 13 nesting pairs of goshawks.

We identified 59 (8.3%) of 711 prey deliveries as being retrievals of cached items. Of the 652 fresh prey deliveries, we identified 451 (69%) to the species level, 20 (3%) to genus, four to family (1%), and four (1%) as unidentifiable ducklings (Table 1). Eighty (12%) birds and 17 (3%) mammals were unidentifiable beyond class, and we were unable to identify 76 (12%) deliveries. The majority of prey deliveries identified to at least class ($N = 576$) were mammals (62%), whereas birds (38%) comprised a smaller proportion of diet.

When considering only those deliveries identified to family or finer resolution (i.e., to genus or species; $N = 476$), the dominant prey species were red squirrels (41.2%), eastern chipmunks (19.8%), American crows (7.7%), Ruffed Grouse (6.9%), and snowshoe hares (6.5%). No other individual species accounted for >5% of identified prey. As a group, Sciurids and Leporids ($N = 338$) accounted for 70% of the identified prey. Among mammals, 51.8% were adults, 25.4% were juveniles, and we were unable to estimate age for 22.8%. Of the birds, 36.7% were adults, 9.6% were juveniles, 27.5% were nestlings, and we could not reliably estimate age for 26.2%.

Biomass. In context of the prey species and biomass proportion used by goshawks in our study, the delivery of one domestic chicken (*Gallus* spp.) was unusual and the mass would dramatically influence biomass estimates for avian prey. We therefore considered it an outlier and deleted it from biomass estimates.

We estimated the total biomass of all prey deliveries at nests as 161 kg. The mean mass for both avian and mammalian prey was 281 g (±13.7, 95% confidence interval = 254–308 g). Although average mass of avian prey ($\bar{x}$ = 292 g; range = 10–1082 g) was similar to that for mammalian prey (275 g; range = 18–1361 g), avian prey accounted for only 39% of biomass delivered whereas mammals accounted for 61% of biomass delivered. Snowshoe hare (25%), red squirrel (24%), Ruffed Grouse (11%), American Crow (9%), diving ducks (7%), chipmunk (5%), and eastern cottontail (5%) accounted for 86% of biomass used by goshawks. No other species accounted for ≥5% of biomass.

Delivery Rates. Breeding goshawks delivered 2.12 (±0.14) prey per day (i.e., 0.14 deliveries/hr), each delivery had a mean mass of 275 g (±20 g), for a total of 551 g (±50 g) delivered per day. However, daily ($F_{13,253}$ = 3.44, $P < 0.001$) and hourly ($F_{13,250}$ = 2.31, P = 0.01) delivery rates varied among nests.

1.3 (±0.1) prey items were delivered per nestling per day, but delivery rates increased with brood size ($F_{2,271}$ = 5.23, P = 0.01). Daily prey delivery rates were 1.8 (±0.1) at nests with one nestling, 2.3 (±0.1) at nests with two nestlings, and 2.5 (±0.2) at nests with three nestlings. Despite the increase in prey deliveries among nests with larger broods, there was an inverse relationship between brood size and the number of prey delivered per nestling per day ($r = -0.43$, $P < 0.05$). Each nestling in single broods received a mean of 1.8 (±0.1) prey items per day, whereas each nestling in broods of two received only 1.2 (±0.1) prey items per day, and each nestling in broods of three received only 0.9 (±0.1) prey items per day.

322 g (±32 g) of biomass were delivered per nestling. However, we observed a pattern of biomass delivered to broods of different sizes that was similar to that of number of prey delivered to broods of different sizes; biomass delivered per nestling per day ($F_{2,6}$ = 5.96, P = 0.038) varied with brood size. On average, daily biomass delivered was 509 g (±84 g) to nests with one nestling, 555 g (±42 g) to broods of two, and 756 g (±107 g) to broods of three. Despite greater amounts of biomass being provided to larger broods, this resulted in nestlings in single broods receiving 509 g (±84 g) of biomass per day, whereas nestlings in broods of two each received 278 g (±3 g) of biomass per day and nestlings in broods of three each receiving 252 g (±36 g) per day.

Dietary Overlap. The diversity and equitability of prey delivered to nests was low for the study area, as indicated by a reciprocal of the Simpson diversity index ($1/D$) of 4.28 and a Smith and Wilson evenness index (E_{var}) of 0.30. Similarly, diversity among nests was low, with a mean value of $1/D$ = 3.77 (±0.41, range = 2.09–7.35). The mean value of E_{var} for all nests was 0.56 (±0.04, range = 0.36–0.80). Low prey diversity and evenness values may be attributable to goshawk diet being dominated by red squirrels and chipmunks in our study. Similarly, there was high dietary overlap (>0.8) among breeding pairs of goshawks in our study (Table 2), although one nesting area (LSP; Table 2) appeared to be measurably different from the rest. Cluster analysis indicated there were two groups of breeding goshawk diets that exhibited similar prey composition and proportion of use (Fig. 2) although, again, one nest (LSP; Fig. 2) appears to be an outlier. There was no apparent relationship between overlap measures and spatial distribution of nests across the study area (Fig. 1, 2).

DISCUSSION

Mammals were the dominant prey of breeding goshawks in Minnesota, with red squirrels and eastern chipmunks appearing to be the most important species in terms of both number delivered and biomass. These two species alone accounted for 62% of all prey identified to at least family and 51% of prey identified to at least class. Several studies have documented red squirrels as important prey for goshawks (Squires and Kennedy 2005) throughout their range. They may be especially important during the winter when other prey may be less available (Widén et al. 1987). Squirrels dominated goshawk diets in Sweden in terms of number (79%) and biomass (56%) during winters of both high and low squirrel abundance (Widén et al. 1987). Diet information for winter goshawks in the WGLR is not available, but the extensive use of red squirrels during the summer and the patterns of

Table 2. Dietary overlap values using the Simplified Morisita's Index of Overlap. Values range from 0 (no overlap) to 1 (complete overlap). The data presented were generated from prey frequency data collected at Northern Goshawk nests (N = 13) in Minnesota during the 2000, 2001, and 2002 breeding seasons. The three letter codes designate specific goshawk nests.

	DEE	DIX	HAC	JEN	LSP	LSA	MCD	PMT	SHA	STE	WAG	WFA	WRI
DEE	1	0.774	0.834	0.886	0.666	0.976	0.924	0.951	0.797	0.951	0.845	0.968	0.79
DIX		1	0.986	0.952	0.524	0.871	0.934	0.905	0.988	0.901	0.834	0.844	0.996
HAC			1	0.988	0.592	0.917	0.97	0.948	0.989	0.938	0.902	0.899	0.987
JEN				1	0.632	0.947	0.979	0.969	0.959	0.953	0.939	0.941	0.954
LSP					1	0.622	0.639	0.629	0.56	0.634	0.771	0.628	0.549
LSA						1	0.973	0.993	0.893	0.991	0.882	0.988	0.885
MCD							1	0.989	0.956	0.984	0.904	0.955	0.946
PMT								1	0.932	0.994	0.912	0.98	0.917
SHA									1	0.928	0.869	0.864	0.993
STE										1	0.889	0.964	0.917
WAG											1	0.893	0.845
WFA												1	0.857
WRI													1

squirrel use during winter in other areas (Widén et al. 1987) suggest this species may be of year-round importance to goshawks in the region. In terms of biomass, snowshoe hares also appear to be important for goshawks in our study area, accounting for 25% of the biomass delivered to nests. Rabbits and hares are also used extensively by goshawks throughout their range (Squires and Kennedy 2005).

Ruffed Grouse comprised 5% of prey deliveries and 11% of biomass delivered to goshawk nests during a 3-yr period of relatively low grouse abundance (Smithers 2003). There is anecdotal evidence that at least some goshawks in Minnesota may rely more heavily on Ruffed Grouse than other prey during some time periods (Eng and Gullion 1962, Apfelbaum and Haney 1984). Eng and Gullion (1962) focused on Ruffed Grouse mortality and did not assess proportional use of grouse in the diet of goshawks, and Apfelbaum and Haney (1984) reported on prey remains collected at a single nest in northern Minnesota. Because of the difficulties in accurately quantifying the extent of grouse predation by goshawks (Eng and Gullion 1962) and the biases associated with determining raptor diets based on prey remains (Smithers 2003), the results of these studies need to be interpreted cautiously. We suspect that the previous research on goshawk diet for our study area, all collected by indirect methods (Eng and Gullion 1962, Apfelbaum and Haney 1984, Martell and Dick 1996), may overestimate the proportion of birds, especially large birds such as grouse, and underestimate the proportion of mammals in goshawk diets.

Qualitative review of the data suggests the mean delivery rate of 0.14 deliveries/hr to nests in our study was less than that observed in Arizona (0.25 deliveries/hr; Boal and Mannan 1994), Nevada (0.31 deliveries/hr; Younk and Bechard 1994) and two areas of southeast Alaska (0.30 and 0.23 deliveries/hr; Lewis 2001). However, although mean biomass per delivery in our study (275 g) was less than that in Arizona (307 g/delivery) where Leporids and Sciurids were the dominant prey (Boal and Mannan 1994), it was greater than the two areas of Alaska (214 g and 173 g/delivery), where birds were the dominant prey (Lewis 2001).

Our study indicates that goshawks with larger broods provision with greater delivery rates and biomass. Biomass per nestling was similar between broods of two and three (16.3–18.0 g/hr), but only

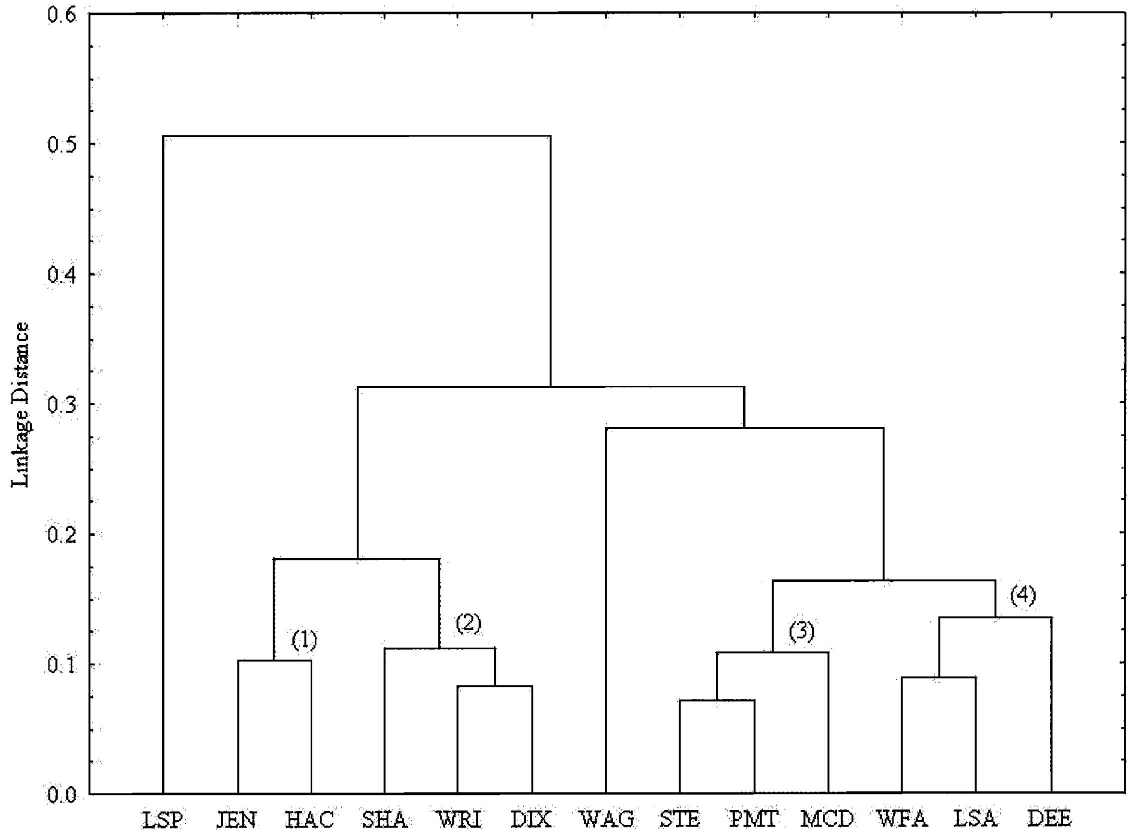

Figure 2. Cluster analysis dendrogram for food habits data collected at Northern Goshawk nests in Minnesota during the 2000, 2001, and 2002 breeding seasons. Parentheses indicate cluster number (see Fig. 1). The LSP and WAG breeding areas exhibited the least similarity of diet composition among breeding areas.

about half as much as that received by nestlings in broods of one (33.0 g/hr). This poses an interesting question regarding energetic aspects of goshawk productivity; what is the minimum biomass/hr necessary to fledge young successfully? The similarity between broods of two and broods of three suggests that, at least in our study area, and at nests with similar prey composition, a minimum of 16–18 g of biomass per hr may be required for successful nesting. However, a finer assessment of nestling energetics would likely require experimentation in a laboratory setting.

Given our prey use and delivery rate data, one can make a generalized prediction of the relative impact of a breeding pair of goshawks in our study area during the 45-d nestling period. With an expected delivery rate of 2.1 prey/d over a 45-d nestling period, ca. 94 prey deliveries can be expected. Based on observed frequencies of prey use, this would translate to the average breeding goshawk pair capturing 29 red squirrels, 14 eastern chipmunks, six American Crows, five snowshoe hares, five Ruffed Grouse, two diving ducks, one cottontail, one Blue Jay, and 31 miscellaneous small birds and mammals. To put this level of predation in context, all of these prey captures would occur within a home range of 6376 ha for a goshawk pair in the study area (Boal et al. 2003).

Composition and richness of prey delivered to nests was similar across the study area, and estimates of prey diversity and equitability were generally low among nests. We suspect the high dietary overlap and similarity of prey use among breeding areas was most likely attributable to the dominance of red squirrels and chipmunks in goshawk diets. However, goshawk diets were dominated by red squirrels and chipmunks, but snowshoe hare, Ruffed Grouse, and American Crow were also important in terms of biomass.

As pointed out by Reynolds et al. (1992), raptor populations are often limited by prey availability and their choice of foraging habitat is predicated on conditions in which prey are abundant and available. Thus, an understanding of goshawk prey species used and the relative importance of those prey species is an important step toward developing management plans for goshawks. By identifying key prey species, as we have done here, forest managers can develop a set of desirable conditions that fosters presence of those species while incorporating structural aspects of known goshawk foraging habitat (e.g., Boal et al. 2001). Those desirable forest conditions can be incorporated into goshawk management plans as one factor of foraging habitat (e.g., Reynolds et al. 1992) and facilitate conservation of the species.

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