NORTHERN GOSHAWK FOOD HABITS IN MINNESOTA:
AN ANALYSIS USING TIME-LAPSE RECORDING SYSTEMS

by

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CHAPTER I

GENERAL INTRODUCTION

In the western Great Lakes region (WGLR), which includes the northern forest portions of Michigan, Minnesota, and Wisconsin, and the southern forest portions of Ontario, the northern goshawk (*Accipiter gentilis*; hereafter referred to as goshawk) is listed as a migratory non-game bird of management concern by the U.S. Fish and Wildlife Service (Region 3), and as a Species of Concern (or Sensitive Species) by the U.S. Forest Service (Region 9).

Current management guidelines for goshawks (e.g., Reynolds et al. 1992) are in part based on the assumption that goshawk populations are limited by food availability. In the WGLR, management guidelines include managing for the species' prey (Kennedy and Andersen 1999). Currently, there is no reliable description of what goshawks prey on in the WGLR (Dick and Plumpton 1998, Kennedy and Andersen 1999). Past studies (e.g., Eng and Gullion 1962, Martell and Dick 1996) have relied on indirect methods of assessing species composition of the diet of goshawks in the WGLR, and, as such, may have provided an inaccurate description of the breeding season diet.

The primary objective of this study included describing the breeding season diet of goshawks in Minnesota using a direct observation technique (i.e., time-lapse video photography). Time-lapse video recording systems were used to collect food habits information for northern goshawks in Minnesota during the 2000, 2001, and 2002 breeding seasons. I identified species and frequency of prey delivered to nests, quantified prey diversity, diet equitability and similarity among nests, and quantified provisioning rates and biomass of prey delivered to nests. Furthermore, I examined relationships between prey diversity and composition, diet equitability, biomass delivered, and delivery rate among nests.

Results from this study are presented in Chapter IV. In Chapter IV, I identify prey composition, biomass, prey diversity, equitability, dietary overlap, and similarity of diet among northern goshawk breeding areas using food habits information collected by means of time-lapse video photography. Results presented in Chapter IV will be submitted for publication. The authors on all papers will be: Smithers, Brett L., Clint W. Boal, and David E. Andersen.

CHAPTER II

PROJECT SUMMARY AND LITERATURE REVIEW

Abstract

Time-lapse video recording systems were used to collect food habits information for northern goshawks (*Accipiter gentilis*) in Minnesota during the 2000, 2001, and 2002 breeding seasons. A total of 4,871 hours of video footage was reviewed, and 652 prey deliveries were recorded, of which 450 (69.0%) were identified to species. Goshawks in the study area preyed on 8 categories of mammals and 31 categories of birds. Overall, mammals comprised 55.1% (n = 359) and birds comprised 33.3% (n = 217) of identified prey items. Red squirrel (*Tamiasciuris hudsonicus*), eastern chipmunk (*Tamias striatus*), and snowshoe hare (*Lepus americanus*) were the dominant mammals identified in the diet, while American crow (*Corvus americanus*), ruffed grouse (*Bonasa umbellus*), and diving ducks (*Aythya* spp.) were the dominant avian prey delivered to nests. Mammals accounted for 61.3% of biomass delivered, and avian prey items accounted for 38.7% of prey biomass. Overall, prey diversity and diet equitability was low, and there was high dietary overlap among nests within the study area. The mean number of prey delivered per nestling per day among nests decreased with brood size ($F_{2,252} = 35.46$, $P < 0.05$). Similarly, biomass delivered per nestling per day among nests decreased with brood size ($F_{2,251} = 3.04$, $P = 0.049$), and biomass delivered per nestling per day varied among nests ($F_{13, 240} = 1.73$, $P = 0.056$). Repeated measures analyses indicated that the number of

prey delivered per nestling per day ($F_{2,6} = 9.43$, $P < 0.05$) and biomass delivered per nestling per day ($F_{2,6} = 5.96$, $P = 0.038$) varied with brood size.

Goshawks depredated a variety of mammalian and avian species, but red squirrels and chipmunks were the dominant prey among all nests, accounting for 66% of identified prey and 46% of all prey deliveries. This suggests sciurids are a key breeding season prey species for goshawks in Minnesota. Furthermore, the patterns of prey and biomass delivery rates relevant to brood sizes suggest prey availability may be limiting goshawk reproduction in the WGLR.

Introduction

The northern goshawk (*Accipiter gentilis*; hereafter referred to as goshawk) is a large, forest-dwelling raptor generally 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, Boal et al. 2001). Goshawks are generalist foragers with diets reflecting the diversity of available prey species (Opdam 1975, Widen et al. 1987, Kenward and Widen 1989, Kennedy 1991, Boal and Mannan 1994). Goshawks prey on a variety of mammalian and avian prey during the breeding season, though regionally goshawks may prey on a few key prey species. Moreover, fluctuations in prey abundance and availability may limit goshawk populations on a regional scale. In the western Great Lakes region (WGLR), goshawks are currently listed as a migratory non-game 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). Current management strategies for goshawks in the WGLR include managing for the species' prey.

Goshawk research within the last decade has been conducted primarily in western North America (Boal et al. 2003). Consequently, there is little published literature pertaining to goshawk ecology in the WGLR. In Wisconsin, Rosenfield et al. (1998) assessed goshawk nest-site habitat and breeding distribution, and Erdman et al. (1998) assessed productivity, population trend, and status of goshawks. In the Upper Peninsula of Michigan, Lapinski (2000) examined habitat use and productivity. In Minnesota, goshawk research has focused on assessing nesting and foraging habitat characteristics (Martell and Dick 1996, Boal et al. 2001), and more recently, inventory methodology (Roberson 2001). Within the WGLR, little information exists regarding food habits of goshawks.

Diet studies of goshawks are necessary to understand their food habits on a regional scale (Storer 1966, Kenward and Widen 1989), and diet information is important for effective management. Current management strategies for northern goshawks in the southwest U.S. includes managing for the species' prey (Reynolds et al. 1992), which is also a component of management plans in the WGLR. Studying raptor diets can also provide valuable information on prey distribution, abundance, behavior, and vulnerability (Johnson 1981). Food habits of goshawks have been examined in New York (Meng 1959, Grzybowski and Eaton 1976), Pennsylvania (Meng 1959), California (Bloom et al. 1986, Keane and Morrison 1994), New Mexico (Kennedy 1991), Arizona (Boal and Mannan 1994), Nevada (Younk and Bechard 1994), Oregon (Reynolds and Meslow

1984, Thrailkill 2000), Washington (Watson et al. 1998), and Alaska (Lewis 2001), and results from these studies suggest that the diet of goshawks varies regionally.

Methods used in goshawk food habits research has included collection and identification of prey remains in pellets or discarded remains of prey items under nest trees and/or in the nest area and direct observations of prey deliveries to nests (Meng 1959, Grzybowski and Eaton 1976, Allen 1978, Bosakowski and Smith 1992). Indirect methods of assessing the diet of raptors (e.g., through pellet analysis or prey remains) may underestimate both the number of prey delivered and species composition (Collopy 1983, Marti 1987, Bielefeldt et al. 1992). Snyder and Wiley (1976) found that collections of remains and pellets from nests gave biased estimates of the diets of red-shouldered hawks (*Buteo lineatus*). Similarly, Schipper (1973) showed that birds and mammals are underestimated in prey remains of harriers (*Circus* spp.), and Bielefeldt et al. (1992) found that studies based on prey remains of Cooper's hawks (*A. cooperii*) were biased towards avian items. Food habits studies of goshawks in Arizona showed that indirect methods of assessing diet underestimated both the number of prey genera and size of prey identified in the diet when compared to direct observation (Kennedy 1991, Boal and Mannan 1994). Other biases inherent in pellet analyses result from underestimation of number of large prey items consumed. Furthermore, some raptors return to large kills for several meals (Bowles 1916, Brown and Amadon 1968). As such, large prey items have a greater chance of being consumed by more than one sibling (Marti 1987). Consequently, prey remains may be distributed in pellets of several siblings and the adults (Bond 1936, Collopy 1983), and the number of larger prey species eaten may be overestimated when pellet analysis alone is used to determine food habits. Ziesemer (1981) found, among goshawk prey, that birds remains were more readily found because of scattered feathers. Indirect methods may fail to detect large prey that may have been scavenged (Marti 1987). Moreover, disturbance to nests while collecting remains can lead to nest abandonment or possible depredation given that repeated visits might lead predators to the nests of some raptors (Marti 1987).

Direct observation may be the best technique to use for collecting breeding season food-habits information for species whose pellets do not provide accurate representation of their diet (Marti 1987). Collopy (1983) found that direct observation of nests provided the best method of estimating biomass of prey consumed for golden eagles (*Aquila chrysaetos*), as both the number and size of prey delivered to nests can be accurately determined.

An alternative to direct observation is the use of time-lapse video photography to collect breeding season diet information. Video photography provides a unique tool for collecting large volumes of high quality food habits data with low time and labor costs. Video photography has been used to collect diet information for gyrfalcons (*Falco rusticolus*) (Jenkins 1978, Hovis et al. 1985, Booms and Fuller 2003), peregrine falcons (*Falco peregrinus*) (Enderson et al. 1973), bald eagles (*Haliaeetus leucocephalus*) (Hunt et al. 1992, Warnke et al. 2002), and golden eagles (Hunt 1977). Recent studies have shown that direct methods of assessing diet of raptors using time-lapse video photography may provide the most unbiased description of the breeding season diet (Gronnesby and Nygard 2000, Lewis 2001, Booms and Fuller 2003). Gronnesby and

Nygard (2000) identified 70% of prey consumed by goshawks using video monitoring equipment and concluded the technique provided better quantitative information on prey selection than alternative techniques. Similarly, Lewis (2001) found that video monitoring systems provided an effective method of collecting food habits information for northern goshawks in southeastern Alaska.

CHAPTER III

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. 3.1). Annual precipitation averages 60-70 cm. Elevation in the study area ranges from 330 to 560 m, and vegetative communities include pine forests, mixed-hardwood forests, boreal forests, and second-growth forests (Daniel and Sullivan 1981, Almendinger and Hanson 1998). Coniferous tree species occurring throughout the study area include white pine (*Pinus strobus*), jack pine (*P. banksiana*), red pine (*P. resinosa*), northern white cedar (*Thuja occidentalis*), tamarack (*Larix laricina*), balsam fir (*Abies balsamea*), eastern hemlock (*Tsuga canadensis*), white spruce (*Picea glauca*), and black spruce (*P. mariana*). Deciduous hardwood tree species include black ash (*Fraxinus nigra*), green ash (*F. pensylvanica*), sugar maple (*Acer saccharum*), red maple (*A. rubrum*), mountain maple (*A. spicatum*), northern red oak (*Quercus borealis*), basswood (*Tilia americana*), American elm (*Ulmus americana*), big-toothed aspen (*Populus grandidentata*), quaking aspen (*P. tremuloides*), American beech (*Fragus grandifolia*), paper birch (*Betula papyrifera*), yellow birch (*B. lutea*), pin cherry (*Prunus pensylvanica*), and black cherry (*P. serotina*). Peatland and marshland wetland community types are also represented within the study area.

Throughout the northern Great Lakes region, most of the forest types are far different from those of a century ago (Stone 1997). Depending on location, the presettlement species growing on well-drained, medium to fine-textured soils of northern Minnesota were predominantly shade-tolerant conifers including white pine, eastern hemlock, and northern white-cedar, and shade-tolerant hardwoods dominated by sugar maple, red maple, yellow birch, and basswood (Coffman et al. 1983, Kotar et al. 1988, Albert 1995). During the late 19th century, logging, initially of conifer species, created conditions for slash-fueled wildfires that swept over large areas of the region, destroyed advanced regeneration of the former species, and resulted in "brushlands" comprised predominantly of aspen suckers and stump sprouts of associated hardwood species (Graham et al. 1963).

Common forest management practices in the study area include clear-cutting, shelterwood, and seed-tree methods. Both even-aged and uneven-aged forest management practices occur within the study area. The goal of even-aged management has traditionally been to produce timber economically and within the shortest time period (Society of American Foresters 1981). Even-aged practices result in trees of approximately the same age and size (Hunter 1990, Lorimer 1990). Even-aged management has resulted in large areas of early-successional, aspen-dominated forests, harvested primarily for pulpwood. Due primarily to logging practices, mixed stands of early successional species, such as aspen and birch are the dominant tree species in the study area, and these stands are generally from 51 to 60 years old (Minnesota Forest Resources Council 2000).

Equipment

I used both VHS and 8-mm time-lapse video recording systems during the 2000 and 2001 breeding seasons, but only VHS systems in 2002. Both color and black-and-white cameras were used during the 2000 and 2001 breeding seasons, but only color VHS cameras were used in 2002.

The 8-mm systems consisted of an 8-mm camera (Sony® model M-350, Fuhrman Diversified, Inc., Seabrook, TX, USA), a time-lapse recorder, and a black-and-white LCD monitor. Video recorders were placed in weatherproof cases, and coaxial video cables were used to convey power to, and images from, the cameras.

The two VHS systems that were used in 2000 and 2001 consisted of a color video camera, a time-lapse recorder, and a portable 12.7 cm black-and-white television (TV). For a complete description of this system, see Lewis (2001).

During the 2002 breeding season, I used six time-lapse video recording systems. Each video recording system consisted of a color camera (Model CCM-660W, Clover Electronics®, Los Alamitos, CA, USA) mounted in a weatherproof housing (21 x 80 mm) with a 3.6 mm wide angle lens, a programmable 960-hour time-lapse video recorder (Model SL 800, Security Labs®, Noblesville, IN, USA), a 12 VDC to 115 VAC high-efficiency 140-Watt power inverter (Part No. 22-145, Radio Shack®, Fort Worth, TX, USA), a DC accessory outlet (Part No. 270-1527A, Ratio Shack®, Fort Worth, TX, USA) rated at 10 amps, and a 30.5 m section of 4-pin video cable (Part No. CA100R, Clover Electronics®, Los Alamitos, CA, USA). A hand-held 58.4 mm LCD color monitor (Part No. 16-3050, Radio Shack®, Fort Worth, TX, USA) was used to view the image from the camera during installation and to program the recorder. Each recorder was placed in a 58.4 cm (width) x 41.9 cm (length) x 12.7 cm (height) plastic Rubbermaid™ box. Storage boxes were painted camouflage. Power to each recorder was supplied by two, deep-cycle marine batteries (12-volt DC) connected in parallel.

Accessibility to most nests was limited. As such, batteries and recorders were transported to monitored nests using an all-terrain vehicle (ATV), hand cart, or an external frame backpack.

Installation and maintenance of video-monitoring equipment

Spring nest inventories began in early to mid-April in all years. Known and potential nest areas were searched using established procedures (Kennedy and Stahlecker 1993, Roberson 2001). Nests were considered active if one of the adults was observed in an incubating posture (Speiser 1992, Ward and Kennedy 1996), or an adult was seen or heard in the nest area. Monitored nests were selected based on accessibility and spatial distribution.

For statistical comparison, nests where food habits information was collected were considered as sampling units. Nests were opportunistically selected from a sample of all known active nests based on accessibility and location. Thus, nests used in this study were not randomly selected from the population of nests within the study area. Because of limited breeding season food habits information for the STE breeding area due to equipment problems in 2000, additional food habits information was collected at this breeding area in 2002. With the exception of the STE breeding area, breeding season information was not collected at any nest for more than one breeding season. Nests where food habits information was collected were distributed throughout the study area, and were located on State, Federal and private lands. These data represent food habits information collected at a subset of goshawk nests within the study area. Because of the uncertainty whether these data are representative of goshawks within the WGLR, whether these results can be extended to the WGLR as a whole is unknown.

Northern goshawks will aggressively defend their nest when threatened (Beebe 1976, Bloom 1987). To reduce stress to the adult goshawks and reduce risk of injury to the hawk or person accessing the nest, adult females, and, if present, adult males were trapped using a dho-gaza trap with a live great-horned owl (*Bubo virginianus*) (Bloom 1987, 1992). Adult goshawks were hooded to calm them, and banded using U.S. Fish and Wildlife Service lock-on leg bands.

Nest trees were climbed using a ladder, tree spikes, and harness. VHS cameras were installed on nest trees within 0.5 to 0.6 m of the nest; 8-mm cameras were installed on an adjacent tree up to 9 m from the nest. Video recorders for each system were placed approximately 30 m from the base of each camera tree. Recorders were programmed to capture 15.5 hrs of video footage daily (i.e., 0530-2100 hrs.). Recorders were programmed at the 48-hr setting (1.3 fields/sec) or the 72-hr setting (0.8 fields/sec) to optimize the amount of tape used per maintenance session and battery life.

Maintenance of video-monitoring equipment required routine visits (i.e., 2 to 3 visits per week) throughout the breeding season to change discharged batteries and videotapes with fully charged batteries and blank tapes. I attempted to minimize disturbance to adults and nestlings by crouching low or kneeling while changing tapes and batteries, and leaving the nest area immediately following each maintenance session. All recording systems were covered with camouflage material to reduce chances of theft and/or damage.

Video footage review and analysis of diet frequency data

Three references (softball, tennis ball, golf ball) and a 30-cm ruler were video recorded in each nest. These recordings were used for calibration purposes and were used for making size and biomass estimates of prey items when species identification was not possible.

Goshawks may cache prey and deliver cached prey items to nests more than once (Johnson 1981). In order to obtain a non-biased estimate of number and composition of prey delivered to nests, I attempted to quantify cached prey based on subjective measures. I noted the condition and time of delivery when assessing whether or not the item had been cached. The condition of each prey item delivered to nests was assessed based on a subjective measure of decomposition and pelage or feather condition. Flesh color was used to assess decomposition, with brightly colored flesh indicating a fresh delivery and darker colored flesh (e.g., dark red to gray) indicating a possible cached prey item. In addition, missing portions (e.g., head, legs, wings) of each prey item were used to identify cached prey items. I also noted the time of delivery when a prey item was suspected as a cached prey item, and if the suspected cached prey item was removed from the nest by the female goshawk prior to delivery. Prey items delivered consecutively that were in sub-standard condition (i.e., flesh appeared dark in color), or the same species with similar missing parts and similar pelage or feather condition were categorized as cached prey. I reviewed previous video footage to compare species, condition, and time of delivery to assign prey to the cached category. Thus, identification of cached prey items were assigned based on a successive, iterative process that included comparing prey items using flesh, pelage or feather condition, and time of delivery from review of video footage. For each delivery event, prey items were designated as either a cached or new prey item accordingly.

Prey identification

Food habits data were reviewed at the end of each field season. Tapes were reviewed using a VHS or 8-mm player and a 41 cm color television. A comprehensive list of prey delivered to nests was generated. Information obtained from review of video footage included identifying prey composition, delivery rates (e.g., number of prey delivered/day/nestling/nest), and biomass of prey delivered to nests. In addition, frequency and proportion of prey delivered to nests were quantified, and diversity of prey delivered to nests within the study area was estimated. Prey categories were defined based on prey items identified to family, genus, or species.

Age and biomass estimation

I assigned avian prey to age categories (e.g., adult, juvenile, or nestling) based on plumage and amount of sheathing on flight feathers (i.e., remiges, retrices; Reynolds and

Meslow 1984). Items with unsheathed (i.e., completely grown) feathers were assigned to the adult category; items with feathers partially in sheath were categorized as juveniles. Nestlings were those individuals with completely sheathed feathers or down (Lewis 2001). Avian prey unidentifiable to family, genus, or species were categorized as nestlings, juveniles, or adults using the criteria described above, and were assigned to the "unknown bird" category. Diagnostic features (e.g., feet, bill, fur, feathers) were used to distinguish among taxa.

I categorized avian prey unidentifiable to family, genus, or species into three *a priori* size classes (SC) following Kennedy and Johnson (1986) and Storer (1966) using familiar species as reference points (Bielefeldt et al. 1992): SC1 = 9.6 g (e.g., chestnut-sided warbler-sized prey item, *Dendroica pensylvanica*), SC2 = 77.3 g (e.g., American robin-sized prey item, *Turdus migratorius*), and SC3 = 576.5 g (e.g., ruffed grouse-sized prey item, *Bonasa umbellus*). Similarly, I categorized mammalian prey unidentifiable to family, genus, or species into three *a priori* size classes: SC1 = 23.3 g (e.g., deer mouse-sized prey item, *Peromyscus maniculatus*), SC2 = 192.2 g (e.g., red squirrel-sized prey item, *Tamiasciurus hudsonicus*), and SC3 = 1360.8 g (e.g., snowshoe hare-sized prey item, *Lepus americanus*).

I calculated mass for nestlings following Bielefeldt et al. (1992). I used 100% of the adult mass for nestlings that fell within SC1, I used 65% of the adult mass for nestlings that fell within SC2, and I used 55% of the adult mass for nestlings that fell within SC3. As such, nestlings were assigned to the following size and weight categories (NSC) using adult mass: (1) NSC1 (9.6 g), (2) NSC2 (50.3 g), and (3) NSC3 (317.1 g).

Similarly, juvenile and adult avian prey that were unidentifiable to family, genus, or species were assigned to the following categories (ASC) based on size using adult mass: (1) ASC1 (chestnut-sided warbler-sized prey items, 9.6 g), (2) ASC2 (American robin-sized prey items, 77.3 g), and (3) ASC3 (ruffed grouse-sized prey items, 576.5 g). Furthermore, I assigned mammalian prey to age categories (i.e., adult or juvenile) based on size (Bieledfeldt et al. 1992). Mammalian prey were assigned to the following size and weight categories (MSC) using adult mass: (1) MSC1 (deer mouse-sized prey items, 23.3 g), and (2) MSC2 (red squirrel-sized prey items, 192.2 g).

Biomass of identified prey items was defined as an estimate of the average live mass of a prey item delivered to nests (Bielefeldt et al. 1992). Moreover, biomass was calculated using the average mass of each prey category multiplied by the number of occurrences (Steenhof 1983, Marti 1987). Biomass estimates were computed using prey identified to family, genus, or species, and I used the mean mass of both sexes because of problems associated with determining sex of prey delivered to the nest (Reynolds and Meslow 1984, Lewis 2001). Mass for prey delivered to nests was estimated using published references pertaining to identification, distribution, and body mass of species occurring in the study area (Gunderson and Beer 1953, Timm 1975, Burt and Grossenheider 1980, Daniel and Sullivan 1981, Dunning 1984, Jones and Birney 1988, Dunning 1993, Dunn and Garrett 1997, Griggs 1997, Dunn 1999, Sibley 2000).

I calculated mass of juvenile red squirrel, chipmunk, snowshoe hare, and cottontail rabbit using 95% of the adult mass. Moreover, I used juvenile mass for red squirrel, chipmunk, snowshoe hare, and cottontail rabbit prey categories that I could not categorize by age. Mammals smaller than a chipmunk (e.g., deer mouse-sized prey items) were assumed to be adults.

For the diving duck category, I estimated mass for individual prey items using the mean value of the average mass of male and females in the diving duck category (e.g., genus *Aythya*) from Dunning (1984). Species considered were canvasback (*Aythya valisineria*), redhead (*A. americana*), ring-necked duck (*A. collaris*), greater scaup (*A. marila*), and lesser scaup (*A. affinis*).

Prey diversity, equitability, and similarity analysis

I used Ecological Methodology 6.1 (Exeter Software, Setauket, NY, USA) to calculate prey diversity, diet equitability, and diet overlap. I calculated prey diversity and equitability using prey identified to family, genus, or species.

Prey diversity

I calculated prey diversity for the study area (i.e., pooling frequency data across all nests and years), and for individual nests (i.e., grouping frequency data by nest). Moreover, I calculated prey diversity for the study area using ungrouped prey categories (i.e., using each prey category identified to family, genus, or species separately). I used generalized prey categories, as described below, to calculate prey diversity for individual nests.

Due to small sample size, I omitted the domestic prey (*n* = 1) and miscellaneous mammal (*n* = 1) categories from diversity analysis. Given that only one prey delivery was recorded at the DTR breeding area before the nest failed, I omitted DTR data from diversity, equitability, and similarity analyses. Moreover, given the paucity of data collected at the STE00 breeding area during the 2000 breeding season, I pooled data collected for this breeding area with data collected at this site during the 2002 breeding season.

I calculated prey diversity using Williams (1964) and MacArthur's (1972) modified form of the Simpson's index (Simpson 1949) ($1/D$), where $D = \Sigma p_i^2$, and p_i is the relative proportion of each member of the community being investigated. The Simpson's index is a nonparametric measure of heterogeneity that makes no assumptions about the shape of species-abundance curves (Krebs 1999, Pielou 1969). The value of $1/D$ varies from 1 to s, the number of species in the sample, and is interpreted as the number of equally common species required to generate the observed heterogeneity of a sample (Krebs 1999).

I generalized prey composition for individual nests by grouping prey into eleven generalized prey categories. Prey were assigned to the following prey categories: (1) small mammals (e.g., red squirrel, chipmunk, mammals smaller than a chipmunk); (2) blackbirds (*Family: Icteridae*), crows, and bluejays; (3) snowshoe hare and cottontail rabbit; (4) grouse; (5) diving ducks (*Aythya* spp.); (6) other aquatic and terrestrial waterbirds (e.g., American coot, *Fulica americana*, green heron, *Butorides virescens*, genus *Calidris*, common goldeneye, *Bucephala clangula*, mallard, *Anas platyrhynchos*); (7) passerines; (8) woodpeckers; (9) raptors; (10) domestic prey; and, (11) miscellaneous mammals (e.g., longtail weasel, *Mustela frenata*).

I calculated Pearson correlation coefficients (r) using generalized prey categories and delivery rate variables, and because of differences in sample size in the number of prey delivered among nests, I standardized the data by converting frequencies to proportions.

Diet equitability

I calculated diet equitability using Smith and Wilson's index of evenness (Smith and Wilson 1996, cited in Krebs 1999) using the equation:

$$E_{\text{var}} = 1 - \left(\frac{2}{\pi}\right)\left[\arctan\left\{\frac{\sum_{i=1}^{s}\left(\log_e(n_i) - \sum_{j=1}^{s}\log_e(n_j)/s\right)^2}{s}\right\}\right]$$

where E_{var} = Smith and Wilson's index of evenness,

n_i = Number of individuals in species i in sample (i = 1,2,3,4,…s),

n_j = Number of individuals in species j in sample (j = 1,2,3,4,…s),

s = Number of species in entire sample.

The Smith and Wilson index of evenness is based on the variance in abundance of species, is independent of species richness, and is sensitive to both rare and common species (Krebs 1999).

Dietary overlap

Dietary overlap is the degree to which sampling units (e.g., breeding areas) overlap in proportions of prey delivered to nests during the breeding season. 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 usually scaled from zero to one, where zero overlap indicates dissimilarity in resource use, and one indicates complete overlap (Krebs 1999).

I calculated dietary overlap among nests using prey identified to family, genus, or species. I standardized the data by converting prey numbers to proportions, and calculations were made using generalized prey categories (see Prey diversity). I estimated overlap of diet among nests using the simplified Morisita's index of overlap (Krebs 1999) with the equation:

$$C_H = \frac{2\sum_{i}^{n} p_{ij}\, p_{ik}}{\sum_{i}^{n} p_{ij}^2 + \sum_{i}^{n} p_{ik}^2}$$

where C_H = Simplified Morisita Index of overlap (Horn 1966) between breeding area j and breeding area k,

p_{ij} = Proportion resource i is of the total resources used by breeding area j,

p_{ik} = Proportion resource i is of the total resources used by breeding area k,

n = Total number of resource states (i = 1, 2, 3, . . . n).

Cluster analysis

Cluster analysis was performed on prey proportions using average linkage clustering as described by Romesburg (1984) and cited in Krebs (1999) and McGarigal (2000). I used the un-weighted pair-group method using arithmetic averages (UPGMA) (Sneath and Sokal 1973) as suggested by Romesburg (1984). Calculations were made using Euclidian distances, and I standardized data by using proportions. Calculations were made using generalized prey categories (see Prey Diversity), and I used STATISICA (StatSoft, Inc., Version 6.0) for all calculations.

Delivery rate analysis

Delivery rate analysis included calculating the 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. In addition, biomass delivered per day, biomass delivered per nestling per day, and biomass delivered per day at nests with one, two, and three nestlings were calculated. Calculations were made using prey delivered to nests from hatching to 5 days post-fledging (i.e., from 0 to 45 days). For calculations, I used 40 days as the estimated fledging date. I pooled data collected at the STE breeding area during the 2000 and 2002 breeding seasons, and given the paucity of data collected at the DTR breeding area, I deleted this nest from delivery rate and biomass analyses.

For repeated measures analyses, and because of missing data among breeding areas, I used mean values for delivery rate data collected over 5-day intervals starting at time interval 2 (i.e., at day 10) and ending at time interval 8 (i.e., at day 40).

Frequency data were standardized by nestling age, and nestling age was estimated following Boal (1994) using video footage. Hatching dates were derived by backdating from estimates of nestling age. At nests with multiple young, I assigned hatching dates based on the estimated date of hatch of the oldest nestling (Warnke et al. 2002). I grouped delivery rate data by nest and nestling age, and I calculated the number of prey delivered and total hours of footage collected for each day. I examined temporal change in mammalian and avian prey delivered to nests over 5-day intervals throughout the breeding season.

Statistical analysis

Biomass of prey delivered per day per nest was transformed by taking the logarithm of biomass delivered per day and adding one (Fowler et al. 1998, Zar 1999).

I used analysis of variance (ANOVA) to examine relationships between delivery rate variables and brood size using log transformed data. 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).

Delivery rate data were recorded through time. Because observations within breeding areas were not independent, I tested for differences in provisioning rates among breeding areas using a repeated measures ANOVA. I used data collected at 9 breeding areas, and I deleted 6 breeding areas from repeated measures analyses. Because of possible violation of the sphericity assumption, I examined differences in provisioning rates among nests using multivariate repeated measures ANOVA, and I compared these results with the univariate results (Zar 1999). The General Linear Model module (STATISTICA, Version 6.0) was used for all repeated measures analyses.

I examined temporal change in the ratio of mammals to birds delivered over a 5-day interval using a goodness-of-fit procedure. Because of failure to meet parametric assumptions, I used a Kruskall-Wallas single-factor ANOVA to examine differences among nests regarding the number of mammals and birds delivered over 5-day intervals. I examined variation in the number of mammals and birds delivered per day among nests throughout the breeding season (i.e., within a 45-day period from hatching to fledging) using a single-factor ANOVA. I grouped the frequency data by nest and nestling age. I examined changes in number of mammals and birds delivered to nests over 5-day intervals throughout the breeding season using a single-factor ANOVA, and I grouped frequency data by nest, pooling data over 5-day intervals based on nestling age. Because the number of mammals and birds delivered to nests did not meet parametric assumptions, I examined correlative relationships between the number of mammals and birds delivered per day throughout the breeding season and nestling age using non-parametric procedures. As such, I calculated Spearman rank correlation coefficients (r_s) for these variables.

An alpha of 0.05 was used for all statistical tests. Values in parentheses are standard errors of means, unless indicated otherwise.

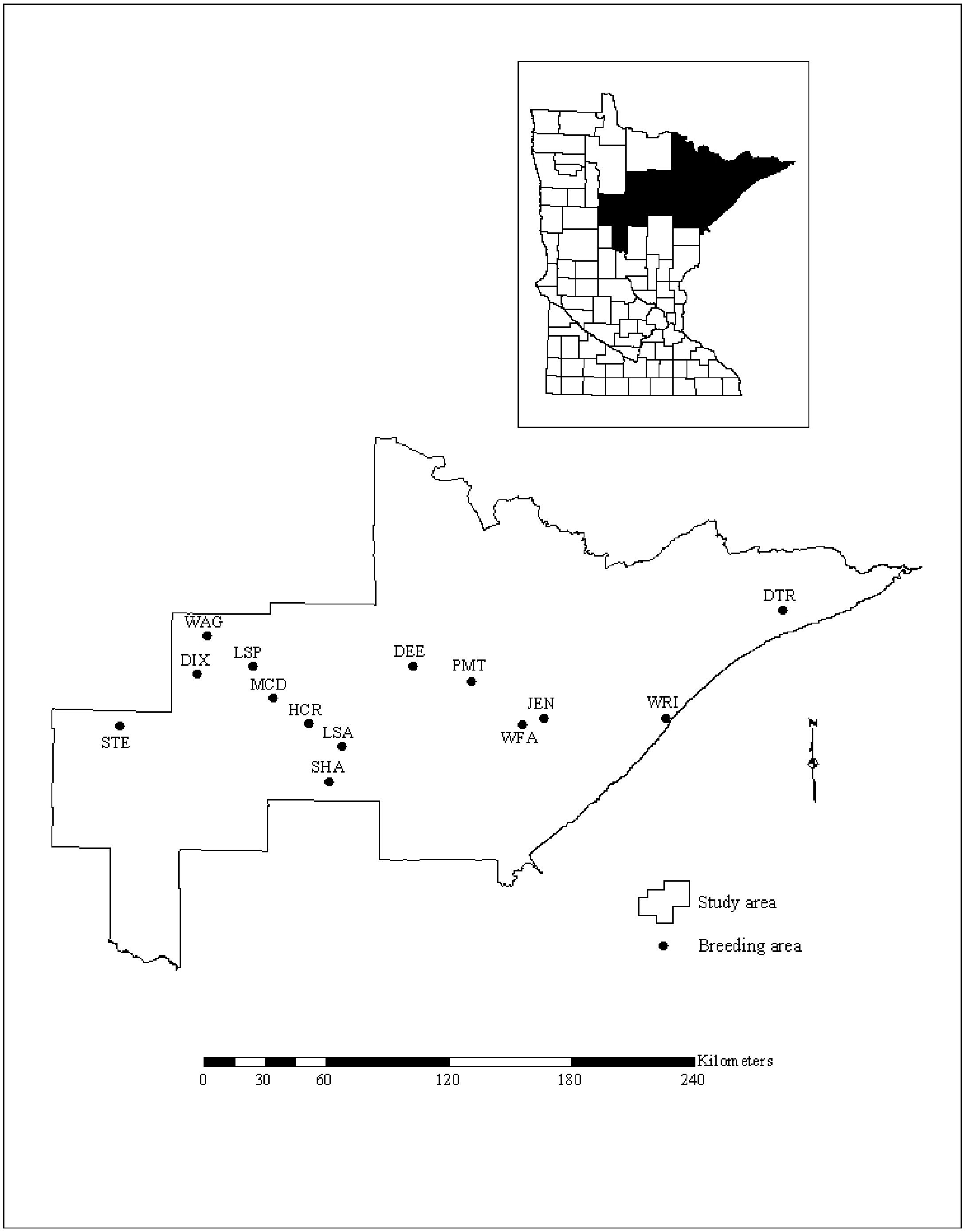

Figure 3.1. Study area and distribution of northern goshawk breeding areas in Minnesota where food habits information was collected during the 2000, 2001, and 2002 breeding seasons.

CHAPTER IV

RESULTS

Installation of video monitoring equipment

Video recording of food habits began in May and ended in August for most nests in all years (Table 4.1). Video monitoring systems were installed at three, five, and seven active goshawk nests during the 2000, 2001, and 2002 field seasons, respectively. On average, cameras were installed when chicks were 8 (± 1.18) days old (range = 1 to18 days). A total of 4,801 hrs (320 ± 42 hrs/nest; 398 days total) of video footage was reviewed. An average of 12 hours (± 13 min) of video footage was collected daily at each nest (Table 4.1).

Reproductive success

The average hatch date for all nests and years was 28 May within the study area. The average fledging date for all nests and years was 4 July, and the average number of days from hatch to fledging was 38.2 (± 2.02). Of all active nests monitored during the 2000, 2001, and 2002 breeding seasons (*n* = 15), 80% (*n* = 12) successfully fledged young. On average, 2.1 (± 0.21) young were produced per active nests (*n* = 15), while 1.6 (± 0.23) nestlings survived to fledge from successful nests (*n* = 12) across the study area (Table 4.1). I documented 5 cases of nestling mortality most likely due to food deprivation and/or exposure to inclement weather. Of the fourteen breeding areas where food habits information was collected, two nests failed due to mammal predation and one nest failed due to an unknown cause.

Prey analysis

Video footage review and prey analysis

A total of 711 delivery events was recorded at 13 goshawk nests (i.e., known breeding areas) within the study area. Of the 711 prey items delivered, 59 (8.3%) were previously cached items. Thus, 652 new prey items were recorded. Seventy-six prey items (11.7%) were un-identifiable to class *Aves* or class *Mammalia* and 97 prey items (14.9%) were unidentifiable to family, genus, or species. Of the prey items identified to class or lower taxa (*n* = 576), four were identified to family, 20 (3.5%) were identified to genus, four prey items were classified as unknown ducklings, and 450 (69.0%) prey items were identified to species. Thirty-eight prey categories (i.e., prey items identified to class, family, genus, or species) were identified. Eight categories of mammals and 30 categories of birds were depredated by goshawks in the study area. By frequency of occurrence, 55.1% (*n* = 359) of the diet was comprised of mammalian prey items, while 33.3% (*n* = 217) of identified prey were birds (Table 4.2). One domestic chicken (*Galus* spp.) was identified in the diet at one breeding area. Inclusion of this outlier influenced biomass estimates and was omitted from analysis.

Dominant mammalian prey identified in the diet included red squirrel (31%), eastern chipmunk (15%), and snowshoe hare (5%), while American crow (6%), ruffed grouse (5%), and diving ducks (2%) were the dominant avian prey delivered to nests by frequency of occurrence (Tables 4.2-4.3).

Seventy-four percent (*n* = 161) of avian prey items were classified as nestling (27.5%; *n* = 60), juvenile (9.6%; *n* = 21), or adult (36.7%; *n* = 80), and 73.7% (*n* = 264) of mammalian prey items were classified as either juvenile (24.3%; $n = 87$) or adult (49.4%; $n = 177$) (Table 4.4).

Of the avian prey unidentifiable to family, genus, or species, and identified as nestlings ($n = 33$), 55% ($n = 18$) were in the NSC1 category, 42% ($n = 14$) were in the NSC2 category, and 3% ($n = 1$) were in the NSC3 size category. Of the avian prey unidentifiable to family, genus, or species and identified as adults ($n = 47$), 38% ($n = 18$) were in the ASC1 category, 49% ($n = 23$) were in the ASC2 category, and 13% ($n = 6$) were in the ASC3 category. Of the mammalian prey unidentifiable to family, genus, or species, 47% ($n = 8$) were in the MSC1 category and 53% ($n = 9$) were in the MSC2 category (Table 4.2).

Change in frequency of prey delivered throughout the breeding season

The ratio of mammals to birds delivered to nests across the study area varied ($\chi^2_8 = 15.93$, $P = 0.043$, Fig. 4.2). The number of mammals delivered per day did not vary among nests ($H_{13} = 18.16$, $P = 0.152$); however, the number of birds delivered per day did vary ($H_{13} = 25.42$, $P = 0.023$). The number of mammals delivered over a consecutive 5-day interval varied when grouped by day (e.g., nestling age) and pooled across nests ($H_8 = 26.00$, $P = 0.001$). Similarly, the number of birds delivered over a 5-day interval varied when data were grouped by nestling age and pooled across nests ($H_8 = 23.09$, $P = 0.003$). The number of birds delivered per day per nest was negatively correlated with nestling age (Spearman rank correlation coefficient, $r_s = -0.32$, $P < 0.05$) when pooled across nests and years. The ratio of mammals to birds that were delivered to nests over 5-day intervals varied at the WAG breeding area ($\chi^2_6 = 14.24$, $P = 0.027$, Table 4.5). In general, the proportion of mammalian prey in the diet was highest during the later stages of the breeding season across the study area. The proportion of sciurids identified was consistently high throughout the breeding season (Fig. 4.2).

Biomass delivered to nests

A total of 161 kg of avian and mammalian prey were identified at goshawk nests in the study area across all years. The average size of prey per delivery per day varied among nests ($H_{13} = 26.94$, $P = 0.013$, range = 209 to 487 g; Table 4.6). The mean estimated prey mass for avian prey delivered to nests was 292 g (range = 10 to 1,082 g), and the mean mass for mammalian prey items delivered to nests was 275 g (range = 18 to 1,361 g). The mean prey mass for both avian and mammalian prey identified in the diet was 281 g (± 13.7, 95% CI = 254 to 308 g). Mean biomass delivered per day per nest was 551 g (± 50.3) (Table 4.6) and did not differ among nests ($F_{13, 240} = 1.71$, $P = 0.06$). The average mass of prey delivered per day was 264 g (± 16.6) when pooled across all nests and years. When prey items delivered to nests were pooled across all nests and years, mammals accounted for 99 kg (61.3%) of biomass delivered, while avian prey items accounted for 62 kg (38.7%) of biomass delivered. Furthermore, total biomass for unknown mammalian prey items was estimated to be 2 kg (*n* = 17), while total biomass for unknown avian prey was estimated to be 7 kg (*n* = 80) (Table 4.2).

Snowshoe hare (25.5%), red squirrel (23.6%), and chipmunk (5.0%) accounted for 54.1% of mammalian biomass delivered to nests, while ruffed grouse (11.5%), American crow (9.0%) and diving ducks (7.1%) accounted for 27.6% of identified prey (Table 4.2).

Biomass per nestling

On average, 322.9 g (± 31.9) were delivered per nestling per day per nest (Table 4.6). Biomass delivered per nestling per day varied among nests ($F_{13, 240} = 1.73$, $P = 0.056$). However, biomass delivered per nestling did not vary with nestling age ($F_{44, 209} = 0.85$, $P = 0.729$). Biomass delivered per nestling was positively correlated with the number of mammals delivered per day (Pearson correlation coefficient, $r = 0.38$, $P < 0.05$) and with number of prey delivered per hour ($r = 0.34$, $P < 0.05$).

I documented five cases of nestling mortality most likely due to food deprivation and/or exposure to inclement weather. Those nests where nestling mortality was documented, and with sufficient number of observations per day per breeding area for statistical comparison ($n = 2$), had more biomass delivered per nestling per day ($\bar{x} = 440.01 \pm 112.38$ g) than at breeding areas where nestling mortality was not documented ($n = 7$) ($\bar{x} = 348.96 \pm 32.69$ g). Repeated measures ANOVA indicated that biomass delivered per nestling over 5-day intervals did not vary at mortality and non-mortality breeding areas ($F_{1,7} = 0.003$, $P = 0.957$). The mean number of prey delivered per nestling per day at nests where nestling mortality was documented was lower ($\bar{x} = 1.09 \pm 0.16$) than at breeding areas where nestling mortality was not documented ($\bar{x} = 1.46 \pm$

0.07). However, repeated measures ANOVA indicated the number of prey delivered per nestling over 5-day intervals did not vary at mortality and non-mortality nests ($F_{1,7}$ = 3.41, $P = 0.107$).

Delivery rate analysis

The number of prey delivered per day ($F_{13,253} = 3.44$, $P < 0.001$, Table 4.6), and the number of prey delivered per hour ($F_{13,250} = 2.31$, $P = 0.01$) varied among nests. The number of prey delivered per hour per day was negatively correlated with nestling age ($r = -0.459$, $P < 0.05$) while deliveries per hour per day was positively correlated with biomass delivered per day ($r = 0.64$, $P < 0.05$).

The number of prey delivered per nestling per day varied among nests ($F_{13,240}$ = 4.89, $P < 0.05$). The number of prey delivered per nestling per day was positively correlated with biomass delivered per nestling ($r = 0.56$, $P < 0.05$). On average, and across all nests, 1.3 (± 0.1) prey items were delivered per nestling per day (Table 4.6).

Prey provisioning

The number of prey deliveries per day increased with brood size ($F_{2,271} = 5.23$, $P = 0.01$). On average, 1.8 (± 0.1) prey were delivered per day at nests with one nestling, 2.3 (± 0.1) prey were delivered per day at nests with two nestlings, and 2.5 (± 0.2) prey were delivered per day at nests with three nestlings (Table 4.7). The number of mammals delivered per day at nests with one, two, and three nestlings did not vary among nests

($H_{13} = 18.16$, $P = 0.152$); however, the number of birds delivered per day varied with brood size among nests ($H_{13} = 25.42$, $P = 0.02$).

Prey delivery rate was positively associated with brood size. The number of prey delivered per nestling per day varied among nests with one, two, and three nestlings ($F_{2,251} = 35.46$, $P < 0.05$). There was an inverse relationship between brood size and the number of prey delivered per nestling per day ($r = -0.43$, $P < 0.05$). On a per nestling basis, 1.9 (± 0.1) prey items were delivered per day to nests with one nestling, 1.2 (± 0.1) prey items were delivered per day to nests with two nestlings, and 0.9 (± 0.1) prey items were delivered to nests with three nestlings (Table 4.7).

Biomass delivered per nestling per day decreased with brood size ($F_{2,251} = 3.04$, $P = 0.049$). On average, 509 g (± 84.3) were delivered per day to nests with one nestling, 555 g (± 42.5) were delivered per day to nests with two nestlings, and 756 g (± 107.2) were delivered per day to nests with three nestlings (Table 4.7). This translates to a mean biomass delivered per nestling per day of 509 g (± 84.3) at nests with one nestling, 278 g (± 3.2) at nests with two nestlings, and 252 g (± 35.8) at nests with three nestlings (Table 4.7).

Repeated measures analyses indicated that the number of prey delivered per nestling per day ($F_{2,6} = 9.43$, $P = 0.014$) and biomass delivered per nestling per day ($F_{2,6} = 5.96$, $P = 0.038$) varied with brood size.

Prey diversity, equitability, and dietary overlap

Overall, the diversity of prey delivered to nests and prey equitability was low for the study area when data were pooled across nests and years, as indicated by a reciprocal of the Simpson diversity index ($1/D$) of 4.28 and a Smith and Wilson evenness index (E_{var}) equal to 0.30. Similarly, diversity among nests was low, with a mean value of $1/D$ equal to 3.77 (± 0.41, range = 2.09 to 7.35) (Table 4.8). The mean value of E_{var} for all nests was 0.56 (± 0.04, range = 0.36 to 0.80).

The frequency of red squirrel and chipmunk delivered to nests influenced prey diversity and evenness values. Low prey diversity and evenness values were attributed to a preponderance of these two species delivered to nests.

The proportion of small mammals delivered to nests was negatively correlated with prey diversity ($r = -0.98$, $P < 0.05$); however, the proportion of hares and rabbits, ducks, avian prey typically associated with water (excluding diving ducks), passerines, and woodpeckers were positively correlated with prey diversity.

Dietary overlap and cluster analysis

There was high dietary overlap among nests within the study area (Table 4.9). Overall, there were 6 breeding areas that were similar in both the species and proportion of generalized prey categories delivered to nests. Moreover, cluster analysis indicated there were two clusters of nests that exhibited similar prey composition and proportion of generalized prey categories delivered to nests (Fig. 4.3). The highest degree of similarity of diet was found at the STE, PMT, and MCD breeding areas. The WAG and LSP breeding areas exhibited the highest degree of dissimilarity of diet among all nests (Table 4.9), and there was no apparent relationship between overlap measures and spatial distribution of nests within the study area (Fig. 3.1).

Table 4.1. Video monitoring effort and hatch and fledging success summary for goshawk nests in Minnesota, 2000-2002. Nests where the number of young that fledged was not obtained are indicated as "NA" (i.e., not applicable).

Nest ID	Hatch date[a]	No. hatched	No. fledged	Camera installation date	Total days recorded	No. hours recorded
DIX	27-May-02	3	NA[b]	29-May-02	18	223 : 16
DTR	8-Jun-01	3	NA[b]	8-Jun-01	7	75 : 49
DEE	24-May-02	3	NA[b]	30-May-02	22	284 : 23
HCR	4-Jun-01	1	1	15-Jun-01	33	415 : 10
JEN	1-Jun-01	3	2	10-Jun-01	27	243 : 53
LSA	20-May-00	2	2	24-May-00	34	454 : 57
LSP	4-Jun-02	3	2	4-Jun-02	18	224 : 48
MCD	11-Jun-02	2	2	28-Jun-02	27	269 : 20
PMT	23-May-02	2	2	30-May-02	51	713 : 26
S00	24-May-00	1	1	28-May-00	13	147 : 13
S02	4-Jun-02	1	1	13-Jun-02	39	468 : 43
SHA	19-May-02	2	2	28-May-02	25	307 : 39
WAG	19-May-00	3	1	28-May-00	28	340 : 23
WFA	31-May-01	1	1	7-Jun-01	17	138 : 57
WRI	3-Jun-01	2	2	14-Jun-01	39	493 : 08
Total	-	32	19	-	398	4801 : 05
Mean	28-May	2.13	1.58	5-Jun	27	320 : 04
SE	-	0.21	0.23	-	2.96	-

[a] The hatch date was estimated by age of nestlings as determined by their size and feather patterns during camera installation and after review of video footage following Boal (1994).

[b] Indicates those nests that failed.

Table 4.2. Number, percent occurrence, and biomass of mammalian and avian prey delivered to northern goshawk nests (*n*=13) in Minnesota, 2000-2002. Values represent pooled number of prey identified at nests for the 2000, 2001, and 2002 breeding seasons.

Prey Category	Common Name	*n*	%	Biomass (g)	%
Mammals					
Tamiasciurus hodsonicus	Red squirrel	202	31.0	38,046	23.6
Tamias striatus	Eastern chipmunk	95	14.6	8,108	5.0
Lepus americanus	Snowshoe hare	31	4.8	41,027	25.5
Sylvilagus floridanus	Eastern cottontail	7	1.1	7,654	4.8
Sciurus carolinensis	Eastern gray squirrel	3	0.5	1,679	1.0
Peromyscus spp.		2	0.3	47	0.0
Family: Muridae		1	0.2	18	0.0
Mustela frenata	Longtail weasel	1	0.2	210	0.1
Unknown Mammal (MSC1)[a]		8	1.2	186	0.1
Unknown Mammal (MSC2)[a]		9	1.4	1,720	1.1
Birds					
Corvus brachyrhynchos	American crow	37	5.7	14,515	9.0
Bonasa umbellus	Ruffed grouse	33	5.1	18,448	11.5
Aythya spp.	Diving duck	12	1.8	11,360	7.1
Cyanocitta cristata	Blue jay	8	1.2	664	0.4
Fulica americana	American coot	6	0.9	3,338	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.	wood pecker	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[a]	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	1,082	0.7

Table 4.2. Cont.

Prey Category	Common Name	*n*	%	Biomass (g)	%
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	1,190	0.7
Unknown bird (ASC1)[b]		18	2.8	173	0.1
Unknown bird (ASC2)[b]		23	3.5	1,778	1.1
Unknown bird (ASC3)[b]		6	0.9	3,459	2.1
Items not identified to class *Mammalia* or *Aves*		76	11.7		

[a] Omitted from analysis

[b] 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

Table 4.3. Number and proportion of dominant prey delivered to goshawk nests in Minnesota, 2000-2002. Prey categories consituting ≥ 2% of the identified prey by frequency of occurrence were considered as dominant prey categories.

		Mammals[a]						Birds[b]							
Nest ID	*n*[c]	RSQ	%	CHM	%	SSH	%	RGR	%	CRW	%	AYT	%	No. prey items not identified to class	Total mammals delivered
DEE	65	20	30.8	3	4.6	2	3.1	2	3.1	9	13.8	2	3.1	4	28
DTR	1	-	-	-	-	-	-	-	-	-	-	-	-	-	1
DIX	38	18	47.4	6	15.8	-	-	4	10.5	-	-	-	-	6	24
HCR	42	16	38.1	7	16.7	2	4.8	4	9.5	-	-	-	-	-	31
JEN	34	9	26.5	8	23.5	2	5.9	4	11.8	-	-	-	-	5	21
LSP	47	6	12.8	1	2.1	-	-	1	2.1	-	-	2	4.3	4	9
LSA	53	16	30.2	10	18.9	3	5.7	2	3.8	10	18.9	-	-	7	29
MCD	47	18	38.3	5	10.6	3	6.4	1	2.1	4	8.5	-	-	2	26
PMT	75	28	37.3	3	4.0	6	8.0	2	2.7	7	9.3	1	1.3	8	43
SHA	66	21	31.8	8	12.1	3	4.5	2	3.0	-	-	-	-	23	34
S00	16	2	12.5	-	-	-	-	-	-	4	25.0	-	-	3	2
S02	46	16	34.8	9	19.6	2	4.3	-	-	2	4.3	3	6.5	4	31
WAG	52	15	28.8	6	11.5	7	13.5	6	11.5	-	-	3	5.8	4	30
WFA	14	5	35.7	2	14.3	1	7.1	1	7.1	1	7.1	-	-	1	8
WRI	56	12	21.4	27	48.2	-	-	4	7.1	-	-	1	1.8	5	41
Total	652	202		95		31		33		37		12		76	358

[a] The following mammalian prey categories correspond to the species of prey identified: RSQ = red squirrel, CHM = eastern chipmunk, SSH = snowshoe hare

[b] The following avian prey categories correspond to the species of prey identified: RGR = ruffed grouse, CRW = American crow, AYT = diving ducks (e.g., *Aythya* spp.)

[c] Total number of prey delivered per nest.

Table 4.4. Age composition (percent) of prey delivered to northern goshawk nests in Minnesota, 2000-2002.

		Birds								Mammals					
Nest ID	n^a	Nestlings		Juveniles		Adults		Unk. Age		Juveniles		Adults		Unk. Age	
DEE	60	15	(25.0)	-	-	14	(23.3)	4	(6.7)	3	(5.0)	16	(26.7)	8	(13.3)
DTR	1	-	-	-	-	-	-	-	-	-	-	1	(100.0)	-	-
DIX	32	1	(3.1)	1	(3.1)	3	(9.4)	3	(9.4)	2	(6.3)	18	(56.3)	4	(12.5)
HCR	42	3	(7.1)	-	-	5	(11.9)	3	(7.1)	6	(14.3)	13	(31.0)	12	(28.6)
JEN	29	-	-	1	(3.4)	5	(17.2)	2	(6.9)	10	(34.5)	7	(24.1)	4	(13.8)
LSP	43	20	(46.5)	3	(7.0)	7	(16.3)	4	(9.3)	4	(9.3)	5	(11.6)	-	-
LSA	46	1	(2.2)	6	(13.0)	7	(15.2)	3	(6.5)	14	(30.4)	12	(26.1)	3	(6.5)
MCD	45	4	(8.9)	-	-	8	(17.8)	7	(15.6)	4	(8.9)	16	(35.6)	6	(13.3)
PMT	68	4	(5.9)	4	(5.9)	4	(5.9)	12	(17.6)	15	(22.1)	14	(20.6)	15	(22.1)
SHA	43	4	(9.3)	-	-	2	(4.7)	3	(7.0)	5	(11.6)	23	(53.5)	6	(14.0)
S00	13	2	(15.4)	2	(15.4)	4	(30.8)	3	(23.1)	-	-	2	(15.4)	-	-
S02	42	5	(11.9)	-	-	1	(2.4)	5	(11.9)	5	(11.9)	5	(11.9)	21	(50.0)
WAG	48	1	(2.1)	2	(4.2)	9	(18.8)	6	(12.5)	6	(12.5)	14	(29.2)	10	(20.8)
WFA	13	-	-	1	(7.7)	4	(30.8)	-	-	2	(15.4)	5	(38.5)	1	(7.7)
WRI	51	-	-	1	(2.0)	7	(13.7)	2	(3.9)	11	(21.6)	26	(51.0)	4	(7.8)
Total	576	60		21		80		57		87		177		94	

[a] Total number of prey identified to class *Aves* or class *Mammalia.*

Table 4.5. Summary of changes in mammals and birds delivered to goshawk nests (*n* = 13) in Minnesota over 5-day intervals during the 2000, 2001, and 2002 breeding seasons. The * indicate change in frequency of mammals and birds delivered to nests ($P < 0.05$). Calculations were made using data collected from hatching to 5 days post fledging and standardized by day (e.g., nestling age).

Nest ID	*df*	χ^2	*P*	
DEE	5	5.38	0.37	
DIX	3	0.90	0.83	
HCR	5	2.29	0.81	
JEN	7	5.07	0.65	
LSP	3	4.11	0.25	
LSA	3	4.11	0.17	
MCD	5	4.96	0.40	
PMT	7	8.70	0.28	
SHA	5	6.12	0.29	
STE	7	10.90	0.14	
WAG	6	14.24	0.03	*
WFA	5	5.96	0.31	
WRI	5	5.06	0.41	

Table 4.6. Number of prey and biomass delivered per day during the breeding season at northern goshawk nests in Minnesota, 2000-2002.

Nest ID	*n*[a]	Biomass /delivery (Mean ± SE)	Biomass delivered /day (Mean ± SE)	Biomass /nestling (Mean ± SE)	Deliveries/ day (Mean ± SE)	Deliveries /nestling (Mean ± SE)	Brood Size
DEE	60	279 ± 41	829 ± 187	322 ± 70	3.10 ± 0.3	1.31 ± 0.2	3 → 2[b]
DIX	32	218 ± 29	410 ± 74	168 ± 32	2.24 ± 0.2	0.95 ± 0.1	3 → 2[c]
HCR	42	220 ± 45	514 ± 170	514 ± 170	2.21 ± 0.3	2.33 ± 0.3	1
JEN	29	246 ± 65	417 ± 110	196 ± 54	1.73 ± 0.2	0.85 ± 0.1	3 → 2[c]
LSA	46	327 ± 49	628 ± 112	314 ± 56	1.83 ± 0.2	1.02 ± 0.1	2
LSP	43	235 ± 50	561 ± 181	204 ± 63	2.61 ± 0.3	1.04 ± 0.1	3 → 2[c]
MCD	45	274 ± 51	522 ± 117	261 ± 58	2.00 ± 0.2	1.00 ± 0.1	2
PMT	68	330 ± 51	686 ± 99	343 ± 50	2.25 ± 0.2	1.17 ± 0.1	2
S00	13	209 ± 48	272 ± 70	272 ± 70	1.23 ± 0.2	1.40 ± 0.2	1
S02	42	260 ± 57	416 ± 113	416 ± 113	1.67 ± 0.2	1.75 ± 0.1	1
SHA	43	247 ± 49	532 ± 105	266 ± 53	2.87 ± 0.3	1.50 ± 0.2	2
WAG	48	487 ± 68	996 ± 186	584 ± 170	2.13 ± 0.2	1.23 ± 0.2	3 → 1[c]
WFA	13	303 ± 97	395 ± 142	395 ± 142	1.40 ± 0.2	1.40 ± 0.2	1
WRI	51	209 ± 36	531 ± 121	266 ± 60	2.47 ± 0.4	1.38 ± 0.2	2
Mean	41.07	275	551	323	2.12	1.31	
SE	4.12	20	50	32	0.14	0.10	

[a] Total number of prey identified to class *Aves* or class *Mammalia.*

[b] Nestling mortality due to nestling falling out of nest.

[c] Nestling mortality most likely due to food deprivation and/or exposure to inclement weather.

Table 4.7. Number of prey and biomass deliverd per day during the breeding season at northern goshawk nests in Minnesota with 1, 2, and 3 nestlings, 2000-2002.

Brood Size	No. prey delivered/day (Mean ± SE)			Deliveries/nestling (Mean ± SE)			Biomass delivered/day (Mean ± SE)			Biom delivered/ (Mean ±	
1	1.78	±	0.13	1.89	±	0.12	509	±	84	509	±
2	2.25	±	0.11	1.19	±	0.05	555	±	43	278	±
3	2.47	±	0.17	0.85	±	0.06	756	±	107	252	±

Table 4.8. Diversity, equitability, and number of prey categories identified in the diet of northern goshawks in Minnesota, 2000-2002. Diversity and equitability indices were calculated using prey identified to genus, species, class, or family.

Nest ID	$1/D$[a]	E_{var}[b]	No.[c] Prey Categories Identified
WFA	4.57	0.80	7
LSP	7.35	0.79	10
DIX	2.09	0.76	3
DEE	4.81	0.61	16
JEN	4.02	0.56	7
MCD	3.41	0.53	10
WAG	5.12	0.51	10
PMT	3.25	0.50	10
HCR	2.94	0.49	6
SHA	2.36	0.46	5
LSA	4.28	0.45	9
STE	2.27	0.43	5
WRI	2.58	0.36	8
Mean	3.77	0.56	8.15
SE	0.41	0.04	0.91

[a] $1/D$ =Simpson's Reciprocal Index of Diversity

[b] E_{var} = Smith and Wilson's Evenness Index

[c] Number of prey items identified to genus, species, family or class.

Table 4.9. 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 in Minnesota during the 2000, 2001, and 2002 breeding seasons.

	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

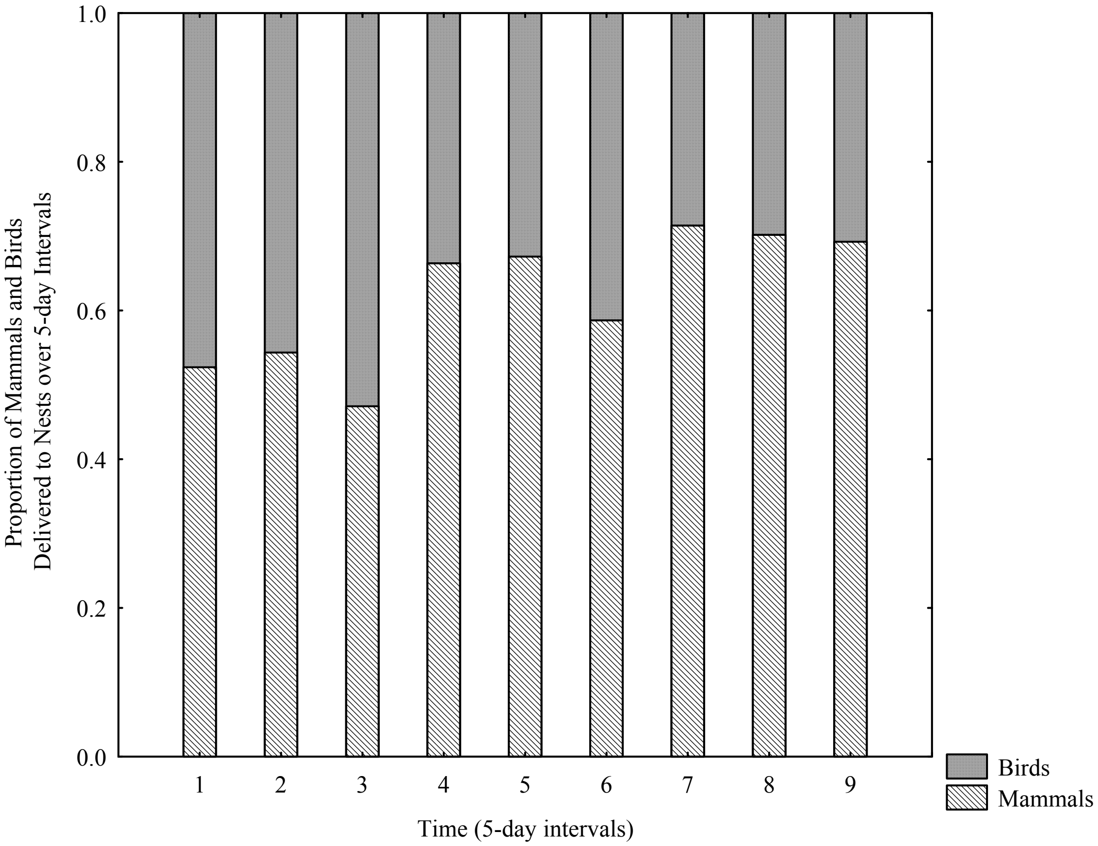

Figure 4.1. Proportion of mammals and birds delivered to northern goshawk nests over 5-day intervals in Minnesota. Results were generated using pooled data from all nests and years. Data were collected during the 2000, 2001, and 2002 breeding seasons.

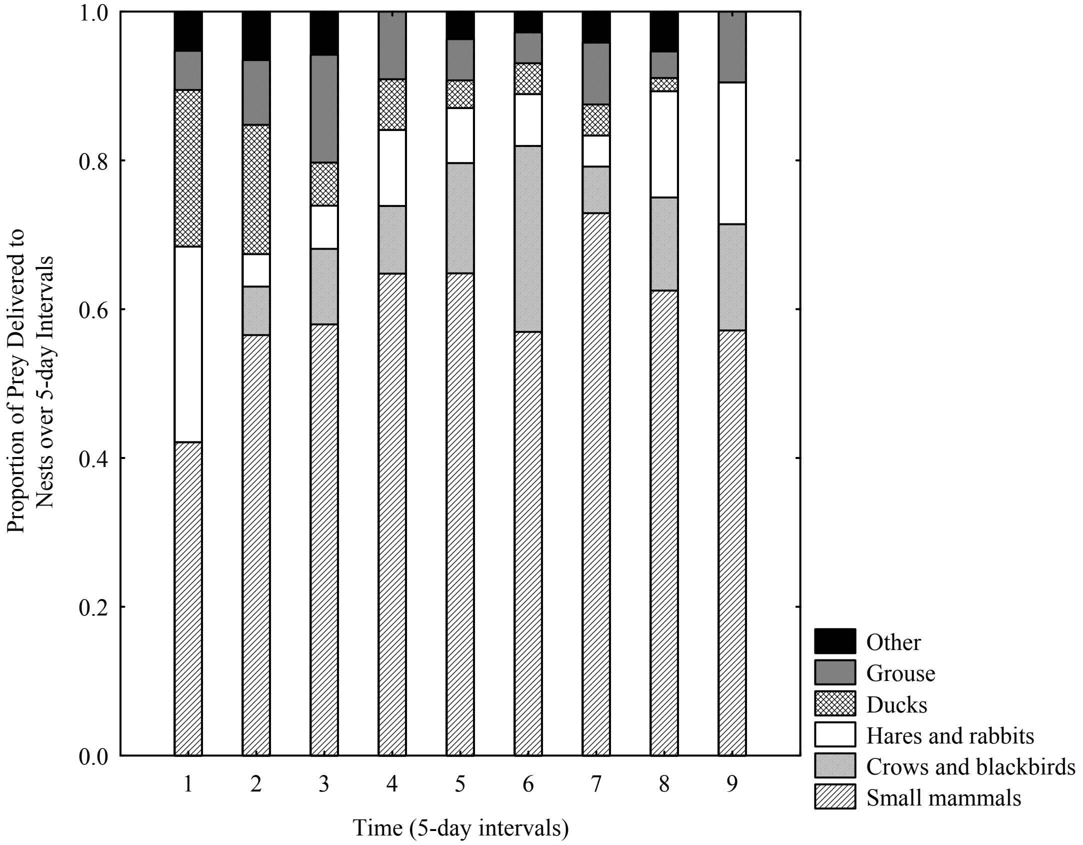

Figure 4.2. Proportion of prey delivered to northern goshawk nests over 5-day intervals in Minnesota. Results were generated using pooled data from all nests and years. Data were collected during the 2000, 2001, and 2002 breeding seasons.

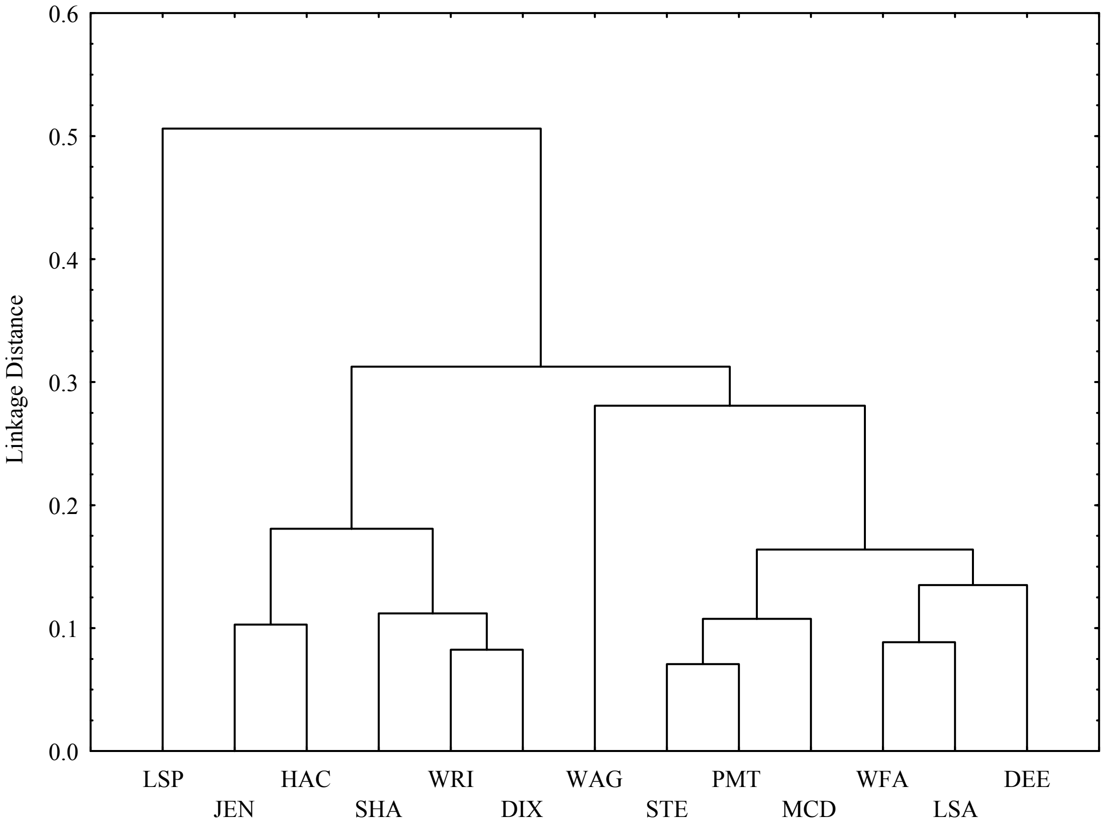

Figure 4.3. Cluster analysis dendrogram for food habits data collected at northern goshawk nests in Minnesota during the 2000, 2001, and 2002 breeding seasons.

CHAPTER V

DISCUSSION

Studies that have relied primarily on indirect methods to assess the breeding season diet of goshawks in the western Great Lakes region (e.g., Eng and Gullion 1962, Martell and Dick 1996), and in the eastern U.S. (e.g., Meng 1959, Grzybowski and Eaton 1976, Allen 1978, Bosakowski and Smith 1992) may have underestimated the proportion of mammals in the diet. Bosakowski and Smith (1992) reported that of 348 prey items identified in the diet of eastern goshawks, 66% were birds and 34% were mammals, and they suggested mammals were of secondary importance to eastern *Accipiters*. Similarly, Meng (1959) and Grzybowski and Eaton (1976) found that avian prey accounted for 61% of prey collected at 14 and 10 goshawk nests, respectively, in New York and Pennsylvania. Studies that have compared the effectiveness of both direct and indirect methods of diet analysis clearly indicate that indirect methods consistently underestimate the proportion of mammals and overestimate the proportion of birds in the diet (Schipper 1973, Ziesemer 1981, Collopy 1983, Boal and Mannan 1994, Lewis 2001). Opdam (1977), using an indirect method of assessing goshawk diet, reported that small, dark-colored prey remains were consistently overlooked, and generally harder to find. Moreover, Ziesemer (1981) reported that among goshawk prey, avian prey were generally easier to find due to scattering of feathers, and thus were generally over-represented in the diet. Similarly, Bielefeldt et al. (1992) reported that food habits studies of Cooper's hawks based on identification of prey remains were biased towards avian items.

By frequency of occurrence, and for all years of my study, mammals were the dominant prey of goshawks, comprising 50.4% of prey items delivered to nests and 62.3% of prey identified to at least Class. Red squirrel and eastern chipmunk were key prey species. These two species alone accounted for 62% of all prey identified to at least Family and 51% of prey identified to at least Class. Prey categories that accounted for > 5% of the biomass delivered to nests included red squirrel, chipmunk, snowshoe hare, American crow, ruffed grouse, and diving ducks. Collectively, these prey accounted for 81.7% of the biomass delivered to nests.

Delivery rates were most likely related to prey abundance and availability, though there were undoubtedly many factors influencing the rate at which prey were delivered to nests across the study area. My results suggest the number of prey delivered per hour per day varied with nestling age and brood size. Other studies have also reached this conclusion with other species. Olsen et al. (1998) found that male provisioning rates for peregrine falcons were positively correlated with brood size, and Estes and Mannan (2003) reported that delivery rates at urban and rural Cooper's hawk nests varied with nestling age.

The number of prey delivered per day varied among nests and, on average, 2.12 prey were delivered per day (0.18 deliveries/hr) to nests (Table 4.6). This was lower than that reported in Arizona (0.25 deliveries/hr; Boal and Mannan 1994), Nevada (0.31 deliveries/hr; Younk and Bechard 1994) and Alaska (0.28 deliveries/hr; Lewis 2002).

Brood sizes may play a role in the delivery rates, but such data were not provided in these studies with which I can compare my results.

Given these prey use data and delivery rate data, I can make a generalized prediction of the relative impact of a breeding pair of goshawks in my study area during the 45-day nestling period. With an expected delivery rate of 2.1 prey/day over a 45-day period, approximately 94 prey deliveries can be expected. Based on observed frequencies of prey use, this would translate to the average breeding goshawk pair delivering 29 red squirrels, 14 eastern chipmunks, 6 American crows, 5 snowshoe hares, 5 ruffed grouse, 2 diving ducks, 1 cottontail, 1 blue jay, and 31 miscellaneous small birds and mammals. To put this level of predation in context, all of these prey would have been taken from within a home range averaging 6,376 ha for a goshawk pair in the study area (Boal et al. 2003).

Undoubtedly, prey size was influenced by many factors. Prey size is generally correlated with body size in *Accipiters* (Reynolds and Meslow 1984), with larger species preying on larger prey. Jaksic (1983) found that raptor body weights were positively correlated with mean vertebrate prey mass among five raptor assemblages. Moreover, Bosakowski and Smith (1992) reported that eastern goshawks generally preyed on larger prey, presumably due to their larger size. In New York and New Jersey, Bosakowski and Smith (1992) reported a mean prey mass of 366 g, with avian prey averaging 332 g and mammalian prey averaging 443 g. Reynolds and Meslow (1984) reported mean prey mass of 307 g, with an average of 148 g for avian prey and 445 g for mammalian prey in northeastern Oregon. In contrast to these findings, the average mass of prey delivered to nests in my study area was 282 g (± 14 g), with an average of 292 g for avian prey and 275 g for mammalian prey. Goshawks in my study area clearly preyed on smaller mammalian prey items than reported elsewhere. The observed discrepancy can most likely be explained by taking into account that the aforementioned studies used pellet and prey analysis to collect breeding season diet information. As described above, larger prey are most often over-represented when indirect methods are used to assess breeding season diet of raptors. As such, estimates of biomass delivered to nests in these studies may be biased towards larger mammalian and avian prey. Furthermore, prey size varies regionally and is most likely influenced by species that are locally abundant and available.

Within the study area, mean biomass per delivery per day varied among nests. The rate at which prey were delivered to nests may have been influenced by the size of prey captured. Goshawks that rely heavily on small prey to provision their young (e.g., red squirrel and chipmunk) would likely exhibit higher delivery rates given various brood sizes. However, in contrast, the mean biomass per delivery among nests was not correlated with delivery rate ($r = -0.04$, $P > 0.05$), which suggests that as delivery rate increased, prey size did not increase or decrease.

For a foraging male goshawk to feed its sedentary mate or offspring, the cost of carrying prey from the capture site to the nest influences the profitability of capturing prey of various sizes, and differs depending on whether the goshawk is foraging for itself or for its young and mate (Sonerud 1992). As mentioned above, the size of prey delivered to nests may have influenced delivery rates within the study area. Similarly, delivery rates may have been related to foraging distances, with more prey being delivered per unit time at breeding areas with smaller male breeding season home ranges. Kenward (1982) demonstrated that goshawks had smaller foraging ranges in areas of high prey densities and suitable foraging habitat. In contrast, Kennedy (1991) found that goshawks foraged at greater distances in fragmented areas, where prey was presumably less abundant or available. Undoubtedly, within the estimated foraging area of a goshawk, prey densities vary. Within their home ranges, goshawks may rely heavily on those areas that support high densities of prey. Kenward (1982) suggested that goshawks have partially benefited where humans have created a patchwork of fields and woods out of contiguous forests by increasing the availability of certain prey species. Prey may be more susceptible to predation in fragmented landscapes due to higher encounter rates with predators along forest-clearing interfaces. However, in fragmented landscapes, access to areas of suitable foraging habitat may require extended flights, thus requiring more energy per capture and reducing the overall efficiency of the predator. At a given distance from the nest, prey items with energy values below a certain level may not be worth transporting to the nest. In single-prey loaders, this load-size effect may result in selection of prey that maximize energy expended per energy gained. Thus, smaller prey would be consumed, while larger prey would be delivered to the nest (Sonerud 1992). Selective carrying of large prey to the nest and consumption of small prey has been documented for several species of birds of prey (Rudolph 1982, Masman et al. 1986).

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. In the study area, goshawks preyed primarily on red squirrel, chipmunk, snowshoe hare, ruffed grouse, and American crow, and there was high dietary overlap and similarity among breeding areas (Table 4.9; Fig. 4.3). The observed degree of high overlap and similarity in both the number and species of prey delivered to nests within the study area was most likely attributed to the proportion of the diet composed of red squirrel and chipmunk. Other studies have reported goshawks (Opdam 1977) and Cooper's hawks (Estes and Mannan 2003) subsisting on a few eurytopic species in highly fragmented landscapes.

Within the study area, fledging success may have been related to delivery rates and biomass delivered per nestling. Delivery rates varied at nests with one, two, and three nestlings, and both frequency of prey delivered per day and total biomass delivered per day increased with brood size (Table 4.7). On average, 2.1 (± 0.21) nestlings were produced per active nest (*n* = 15), while 1.6 (± 0.23) nestlings per successful nest survived to fledge across the study area (*n* = 12 nests; 80%; Table 4.1). Fledging success was lower than that reported in studies conducted in Wisconsin and the western United States, but was similar to that reported in New York and New Jersey. Among five studies in the western United States (e.g., McGowan 1975, Kennedy 1989, Boal and Mannan 1994, Bull and Hohmann 1994, Reynolds and Meslow 1994), an average of 2.13 fledglings (range = 1.4 to 2.7) were produced per successful nest (Boal et al. 2001). Moreover, Speiser (1992) reported that goshawks in New York and New Jersey fledged 1.4 young per active nest. Erdman et al. (1998) reported 1.6 and 2.1 young fledged from active (*n* = 184) and successful (*n* = 135) nests, respectively, from 1968 to 1992 in

Wisconsin. Low diversity, small prey size, and low delivery rates coupled with a potential increase in time spent foraging by the male goshawk, may explain why only 1.6 (± 0.23) fledglings per nest survived to fledge in my study area.

Breeding season diet information collection in this study occurred when ruffed grouse densities were known to be low (DNR Status of Wildlife Populations Fall 2002 Report, J. Hines, pers. comm.). Ruffed grouse and snowshoe hares experience population fluctuations that follow an approximately 10-year cycle. Thus, the observed frequency of grouse and snowshoe hare delivered to nests in the study area may not represent the proportional use of these species throughout their respective population cycles. If goshawks are opportunistic foragers, then prey densities and availability should affect foraging strategies. In Finland, Linden and Wikman (1983) found that goshawk numbers declined following known declines in its primary prey, hazel grouse (*Bonasa bonasa*). However, Widen (1997) suggested the relationship between grouse abundance and goshawk reproductive success could not be described as a simple numerical response, citing work conducted in the late 1970s and early 1980s. Although they used indirect methods with the previously discussed biases, some studies have documented goshawks preying heavily on ruffed grouse during the breeding season (Eng and Gullion 1962, Bosakowski and Smith 1992), and ruffed grouse may constitute a greater proportion of goshawk diet in years when grouse densities are high. The biological significance of population interactions and regulation between the goshawk and cyclic prey is poorly understood. During the 2000, 2001, and 2002 breeding seasons when grouse densities were known to be low, goshawks in the study area relied heavily on red squirrel and chipmunk to provision their young. Although goshawks are often touted as preying heavily on grouse, my study is similar to a number of others indicating sciurids and leporids are more substantial components of goshawk prey (Bloom et al. 1986, Boal and Mannan 1994, Doyle and Smith 1994, Younk and Bechard 1994, Keane 1994, Patla 1997).

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