FORAGING ECOLOGY AND PARENTAL BEHAVIOR OF RED-TAILED HAWKS SYMPATRIC WITH NORTHERN GOSHAWKS ON THE KAIBAB PLATEAU, ARIZONA

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A Thesis

Submitted in Partial Fulfillment

Of the Requirements for the Degree of

Master of Science

in Forestry

Northern Arizona University

December 2002

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ABSTRACT

FORAGING ECOLOGY AND PARENTAL BEHAVIOR OF RED-TAILED HAWKS SYMPATRIC WITH NORTHERN GOSHAWKS ON THE KAIBAB PLATEAU, ARIZONA

ANGELA E. GATTO

To examine how two raptors, the red-tailed hawk (*Buteo jamaicensis*) and the northern goshawk (*Accipiter gentiles*, designated as a sensitive species by the USDA Forest Service) might potentially compete with one another, I studied the food habits and behaviors of red-tailed hawks, on the Kaibab Plateau, Arizona, during the breeding season May-July 1998, 1999, 2000 and 2001. Nest trees of red-tailed hawks were climbed to collect prey remains and pellets at the end of the breeding season (August - October 1998-2001) and I collected prey remains and pellets from the base of nest trees during site visits (May-July 2000 and 2001). I collected and identified prey remains and pellets from 42 red-tailed hawk nests to create a prey species list and determine the composition of red-tailed hawk diet. To compare red-tailed hawk diet with that of northern goshawks I calculated niche breadth using Levin's equation. Levin's equation is a measurement of food niche breadth as a fraction from 0 – 1. A diet with a larger fraction indicates that an animal is a feeding generalist, whereas a smaller fraction indicates that the animal is a feeding specialist. Annual food niche breadth for red-tailed hawks averaged 0.57 per year, average niche breadth for northern goshawks was 0.32, suggesting that red-tailed hawks were relative feeding generalists and northern goshawks

were relative specialists. Many of the species that made up the diet of red-tailed hawks were also present in northern goshawk diet.

In addition to food habits I recorded behaviors related to parental care at red-tailed hawk nests and northern goshawk nests by observing the following behaviors: prey delivery, nest attendance, and vegetation delivery rates. I collected 1258 hours of behavioral information using video and blind surveillance of 17 different pairs of nesting red-tailed hawks and 204 hours on 3 different pairs of nesting northern goshawks during the breeding season (May-July 1999 and 2001). The behavior of red-tailed hawks was consistent between years and nests. I found no evidence of differences in behavior between red-tailed hawks and northern goshawks. I found high dietary overlap and behavior similarity between red-tailed hawks and northern goshawks on the Kaibab Plateau, Arizona.

ACKNOWLEDGMENTS

I would like to thank my committee, Russell P. Balda, Paul Beier, and Carol L. Chambers who maintained a constant open door policy for me. I would like to thank Andi Hales, Tobias M. Rhomer, and Frank LaSorte for their help in the field. I would also like to thank my volunteers of 2000 Eric White and Ian a.k.a. Monkey Boy Hildner, without whom I would have had much less data,. I would like to thank the Rocky Mountain Research Station for providing funding, and all the individuals associated with the Flagstaff, AZ. station especially William Block, Joseph Ganey, Roy Lopez and Diane Prince. I would like to thank Richard T. Reynolds and the northern goshawk crews of 2000 and 2001, especially Shelly Bayard and Susan Salafsky. I would like to give a special thanks to the Rocky Mountain Research Station statistician Rudy M. King. I would like to thank the people close to me who had to listen to me whine, my grandparents, Sandra Perkinson, and Cody Carter. And lastly I would like to thank Teryl G. Grubb, who believed it could happen.

"The 1% inspiration that provides the discovery makes the other 99% of the endeavor that is tedious and frustrating worth the effort."

Molly Stock

"When the last individual of a race of living things breeds no more another heaven and earth must pass before such a one can begin."

William Bebee

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CHAPTER 1

INTRODUCTION

Fire suppression, timber harvesting, and livestock grazing have changed the ponderosa pine (*Pinus ponderosa*) forests in the southwest over the past 100 years. The mature forest structure with open understory that existed before Euro-American settlement has been altered to dense stands (2108 trees/ha) of small trees (<25 cm dbh), and large openings (>3 acres) have been created by timber harvesting and crown fires (Weaver 1951, Cooper 1960, Covington and Moore 1994).

Populations and reproduction of northern goshawks (*Accipiter genitilis*) may be declining because of these alterations to forest structure (Reynolds et al. 1992). Another consequence of these changes in habitat could be to increase competition between open forest raptors such as the red-tailed hawk (*Buteo jamaicensis*) and northern goshawks (Crocker-Bedford 1990, Cranell and DeStefano 1992, Rohner and Doyle 1992).

Interspecific competition for food should be particularly important for birds of prey where coexistence is facilitated by niche diversity and morphological separation (Korpimaki 1987). On the Kaibab Plateau in northern Arizona, the red-tailed hawk and the northern goshawk are two high trophic level raptors that should be partitioning prey and foraging habitat through these mechanisms. Competition for food between northern goshawks and red-tailed hawks could occur where foraging habitat and prey base overlap. The combined loss of habitat with possible encroachment by red-tailed hawks could have negative impacts on northern goshawks.

In this chapter I describe the geographic range, habitat use, behavior, and prey items of red-tailed hawks and northern goshawks. I provide an overview of competition and parental behavior in other raptor species, and describe techniques used to determine the diet of raptors. In chapter 2 I describe, quantify and evaluate the food habits of red-tailed hawks on the Kaibab Plateau for comparison with information known about northern goshawks on the Kaibab Plateau. In the final chapter I describe and evaluate the parental behavior of red-tailed hawks and northern goshawks to determine the potential for competition between these two species.

LITERATURE REVIEW

Red-tailed hawk

The red-tailed hawk breeds from the boreal forests of Alaska and northern Canada to the tropical forests of Central America and the West Indies. Red-tailed hawks are typically associated with open areas interspersed with woodland, and are generally absent from dense forests (Fitch et al. 1946, Preston and Beane 1993).

The red-tailed hawk is in the genus *Buteo*. This genus is characterized as heavy-bodied, broad-winged raptors with short tails adapted for soaring in openings and above the canopy (Clark and Pramstaller 1993). *Buteo* hawks soar regularly and are therefore commonly seen by humans. Soaring is widely thought to be a feeding strategy for these raptors; however, red-tailed hawk soaring is more related to territorial defense (Ballam 1984). Although soaring may contribute to foraging, red-tailed hawks generally forage using a sit and wait approach from perches. Preston and Beane (1993) observed red-tailed hawks hunting in open areas with many available perches. On the Kaibab Plateau it was observed that red-tailed hawks used soaring to hunt along open forest edges (Teryl Grubb, Rocky Mountain Research Station, personal communication).

Red-tailed hawks are feeding generalists, but they typically prey upon rabbits (*Sylvilagus* spp.), black-tailed jack rabbits (*Lepus californicus*), and ground squirrels (*Spermophilus* spp.), (Preston and Beane 1993). Although this is one of the best-studied species of raptors in temperate North America (Eduardo and Temple 1988), there has been little research on red-tailed hawks conducted in northern Arizona on the Kaibab Plateau. The diet of the red-tailed hawk population on the Kaibab Plateau was unknown before this study was conducted.

Northern goshawk

Northern goshawks occur from northeastern Canada to Alaska and southward through the forests of western United States to northern Mexico. Although northern goshawks nest in a variety of habitat types, they select mature forests with large trees on moderate slopes with open understories (Squires and Reynolds 1997).

The northern goshawk is in the genus *Accipiter*. This genus is characterized as short-winged, long-tailed, forest-dwelling raptors (Clark and Pramstaller 1993). The northern goshawk is a powerful hunter well adapted for maneuvering through trees (Squires and Reynolds 1997). Habitat loss and degradation in the form of alteration to the forest structure in southwestern forests has caused concern that the population and reproduction of the northern goshawk may be declining (Reynolds et al. 1992).

Although northern goshawk morphology makes them better adapted to capture avian prey (Ehrlich et al. 1988), studies on the Kaibab Plateau show they prey primarily upon (in descending order of frequency of prey remains found at nest): rabbits and hares, tree squirrels (red squirrels, *Tamiasciurus hudsonicus*, and Abert squirrels, *Sciurus* *aberti*), Steller's jay (*Cyanocitta stelleri*), and northern flickers (*Colaptes auratus*). Mammals accounted for 62% of the prey items and avian prey for 38% (Reynolds et al. 1994, Kaufmann et al. 1994). Boal and Mannan (1994) found that mammals accounted for 76% of the prey items and avian prey 24%.

Competition and/or Partitioning of Resources in Raptor Species

The difference in morphological structure and resultant foraging behavior between red-tailed hawks and northern goshawks allows for the possibility of resource partitioning between the two species. However, habitat changes in southwestern forests (Covington and Moore 1994) may have reduced niche partitioning and may lead to increased competition between the two species. In order to demonstrate the potential for competition it is necessary to show that the presence of one species inhibits the foraging success of the other (Minot 1981). Recently created forest openings have led to an increase of red-tailed hawks in habitat used by northern goshawks (Crocker-Bedford 1990). Red-tailed hawks could be affecting northern goshawk foraging success, therefore creating competition between the two species. Orians and Willson (1964) have described three ways competition could be resolved: (1) one species competitively eliminates the other; (2) the two species partition resources through habitat selection and/or territorial defense; or (3) the two species coexist sympatrically with overlapping territories.

Interspecific competition of red-tailed hawks with other raptors has been well documented. Marti and Lochert (1995) concluded that great horned owls (*Bubo viginianus*) were nocturnal counterparts of red-tailed hawks and time of foraging activity seemed to be the most important factor differentiating the niches of these two species.

Bosakowski and Smith (1992) studied diet overlap of seven raptor species, and confirmed that time and type of habitat reduced competition among owls and hawks. They also found that competition between *Accipiter*s and *Buteo*s was reduced by a difference in prey selection. *Buteo*s selected a higher number of mammals in their diet while *Accipiter*s selected a higher number of avian prey in their diet. However, Bosakowski and Smith (1992) considered seven species in a large area (forests in 8 counties of 3 states), so there may be different interactions when there are only two species in a smaller area. Each species may be selecting specific prey.

Preston (1990) observed the interaction of northern harriers (*Circus cyaneus*) with red-tailed hawks, and found that the foraging distribution for red-tailed hawks was based predominately on perch availability. Perch availability was also a separating factor in relation to Swainson's hawk (*Buteo swainsoni*) habitat use as compared to sympatric red-tailed hawks (Rothfels and Lein 1983, Janes 1994, Bosakowski et al. 1996). Time, prey and habitat structure have all contributed to red-tailed hawks coexisting sympatrically with other raptor species. It is unknown whether these behaviors may lead to the avoidance of competition with sympatric northern goshawks on the Kaibab Plateau.

Food Habits of Raptors

Niche breadth and niche overlap can be used to measure and estimate the degree of competition (Lawlor 1980, Greene and Jaksic 1983). Coexisting species segregate their feeding niches primarily by differences along three dimensions: the habitat used for foraging, the kind of food eaten, and the time of day that foraging occurs (Marti and Lochert 1995). Not only what a raptor eats, but how, when and where it obtains its food is also important in niche separation (Johnson 1981). Foraging ecology can also affect interspecific interactions of competing predators. Raptor communities with high dietary overlap and lack of prey partitioning show food-limited breeding success, greater agonistic behavior, and territoriality (Bosakowski and Smith 1992). These behaviors observed in other raptors may be occurring between red-tailed hawks and northern goshawks on the Kaibab Plateau.

Parental Behaviors of Raptor Species

Competition between northern goshawks and red-tailed hawks could occur where foraging habitat and prey base overlap. To resolve competition the two species may partition resources through habitat selection and/or territorial defense or coexist sympatrically with overlapping territories (Orians and Willson 1964). During times of prey stress, nest behavior by both adults and young of some raptors (e.g., peregrine falcon, *Falco peregrinus*, and spotted owl *Strix occidentalis*, Enderson et al. 1973, Laymon 1991) are subject to change. The food requirements of breeding birds, including red-tailed hawks and northern goshawks, generally peak as young develop from hatchlings to fledglings (Skutch 1976, O'Connor 1984). In socially monogamous species with altricial or semi-altricial young, males usually provision the family for most of the nestling phase of the breeding cycle (Silver et al. 1985), while females remain at the nest to feed and protect the brood. Nestling growth, mortality rates and post-fledging survival are influenced by the frequency of food deliveries to the nest (e.g., *Buteo*s, European sparrowhawks, *Accipiter nisus*, prairie falcons, *Falco mexicanus*, Newton 1978, 1979, Bortolotti 1986, Holthuijzen 1990) and the protection afforded the brood by attendant adults (Newton 1978, Ward and Kennedy 1996). Shortfalls in food supply may result in lower provisioning rates and increased provisioning effort, including greater participation by the female (Newton 1978, 1979, e.g., great horned owl, Rohner and Smith 1996), at the expense of nesting and adult condition (e.g., European kestrel (*Falco tinnunculus*), Dijkstra et al. 1990, Daan et al. 1996) and nest security (e.g., northern goshawk, Ward and Kennedy 1996). Hence, levels of parental care are dependent on local environmental conditions and are sensitive to fluctuations in prey availability (Newton 1979, Bortolotti 1986). Behavior changes at the nest may be an indicator of potential competition and can be detected by direct observations by humans from blinds and by using video cameras.

The Use of Blinds

Blinds can be used to observe northern goshawk and red-tailed hawk foraging ecology and nest behavior during the breeding season. Blinds have been used to observe wildlife for decades (LeCroy 1975). Direct observations have been used to assess the frequency and biomass of prey delivered to nests (Collopy 1983). This technique, however has weaknesses including: (1) it requires considerable time; (2) the probability of identifying different prey types is not always equal because the prey often are plucked, decapitated, or skinned prior to delivery to the nest; and (3) no information can be collected about the items consumed by adults away from the nest (Boal and Mannan 1994). Red-tailed hawks do not use plucking posts, although northern goshawks do (Squires and Reynolds 1997), which can increase the difficulty in identifying prey items delivered. Early in the nesting stage, the male red-tailed hawk brings the prey to the female and she tears the prey into smaller pieces for the nestlings. Later in the nesting period, as the young grow older, the prey is delivered intact to the nestlings (Preston and Beane 1993).

The Use of Video

Although direct observations are most accurate, they are also time consuming and expensive. Small compact weatherproof video cameras can be used to reduce human hours at blinds. Ouchley et al. (1994) used micro-video on an extendible pole to monitor nests and found that the video image provided accurate information about the contents of the nest. Video also provided an efficient, non-invasive protocol to quantify the diet of nestling red-cockaded woodpeckers (*Picoides borealis*) (Franzreb and Hanula 1995). The method posed no potential hazard to either the adults or young, and afforded nearly constant monitoring of prey brought to nestlings. Successful video monitoring was also used by Delaney et al. (1998) to monitor disturbance to nesting Mexican spotted owls (*Strix occidentalis lucida*). Problems of video monitoring include poor visibility of some prey, insufficient contrast to identify prey, and inability to identify partial items (Franzreb and Hanula 1995). Viewing and interpreting the data from video tapes also can take considerable time.

Identification of Pellet and Prey Remains

Diet analysis from direct and video observations can be augmented by identifying pellets and prey remains collected from the nest site. The remains most frequently present in the pellet, feathers and hair, (bones are entirely digested by *Buteo*s and

*Accipiter*s (Culp 1996) do not allow estimation of prey abundance. Real (1996) however, concluded that pellet analysis was the most efficient method of monitoring the overall diet of species, and the presence of species in the diet. Pellets and prey remains were necessary to create an accurate species list of prey items because prey remains alone tended to be biased toward large species (large fragments such as bones and feathers were easily identified) and overlooked difficult to detect smaller species (Culp 1996). Identification of prey using hair in pellets, although time consuming, is quite accurate. External (scale patterns and color bands) and internal (medulla) characteristics of the hair can be used to identify order, family, genus or even species (Moore et al. 1974).

Hypothesis and objectives

There is little diet information for red-tailed hawks in northern Arizona. My study describes the food habits of red-tailed hawks on the Kaibab Plateau for comparison with research conducted in the past ten years on northern goshawks (unpublished data, R. T. Reynolds, Rocky Mountain Research Station). This study also describes differences in parental behavior during the nesting period of red-tailed hawks and northern goshawks. Because of the changes in forest structure and density on the Kaibab Plateau, I hypothesized that red-tailed hawks and northern goshawks were utilizing the same prey species. If red-tailed hawks and northern goshawks occupied the same habitat, and had dietary overlap, then I hypothesized that red-tailed hawk and northern goshawk behaviors would show lower provisioning rates, such as the amount of time spent feeding the chicks.

Chapters 2 and 3 of this thesis are formatted for submission to peer reviewed scientific journals.

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CHAPTER 2

A COMPARISON OF PREY SPECIES USED BY RED-TAILED HAWKS (*BUTEO JAMAICENSIS*) WITH NORTHERN GOSHAWKS (*ACCIPITER GENTILIS*) ON THE KAIBAB PLATEAU, ARIZONA

Abstract: To compare prey species selected by two raptors, the red-tailed hawk (*Buteo jamaicensis*) and the northern goshawk (*Accipiter gentiles*, designated as a U.S.D.A. Forest Service sensitive species), I collected prey remains and pellets from 42 red-tailed hawk nests on the Kaibab Plateau, Arizona and compared their prey remains to known prey used by northern goshawks. Nest trees of red-tailed hawks were climbed at the end of the breeding season between August and October 1998 – 2001. I also collected prey remains from the base of nest trees during site visits, May – July 2000 - 2001. I determined food habits of red-tailed hawks for comparison with known information on northern goshawks to evaluate potential competition. I used Levin's equation to calculate niche breadth for prey that I identified in red-tailed hawk nests. I compare red-tailed hawk niche breadth with calculated niche breadth from previous studies of northern goshawk diets in Arizona. Annual food niche breadth for red-tailed hawks averaged 0.57 per year. Average niche breadth for northern goshawks was 0.32, suggesting that red-tailed hawks were feeding generalists and northern goshawks were specialists. However, 48% of red-tailed hawk diet was composed of species that were also found in the diet of northern goshawks, including Nuttall's cottontail (*Sylvilagus nuttallii*), golden-mantled ground squirrel (*Spermophilus lateralis lateralis*), rock squirrel (*Spermophilyus variegates grammurus*), and northern flicker (*Colaptes auratus*).

Because raptor communities with high dietary overlap and lack of prey partitioning show food-limiting breeding success, greater agonistic behavior, and territoriality, red-tailed hawks have the potential to inhibit foraging success of northern goshawks on the Kaibab Plateau.

INTRODUCTION

Red-tailed hawks (*Buteo jamaicensis*) breed from the boreal forests of Alaska and northern Canada to the tropical forests of Central America and the West Indies. They are typically associated with open areas interspersed with woodland, and are generally absent from dense forests (Fitch et al. 1946, Preston and Beane 1993). The genus *Buteo* is characterized by heavy-bodied, broad-winged raptors with short tails adapted for soaring in openings and above the canopy (Ballam 1984). Red-tailed hawks are considered feeding generalists (Preston and Beane 1993).

Northern goshawks (*Accipiter gentilis*) occur from northeastern Canada to Alaska and southward through the forests of western United States to northern Mexico. They are typically associated with dense mature trees in coniferous, deciduous, and mixed coniferous-deciduous forest stands that have open understories (Reynolds et al. 1994). The northern goshawk is a powerful hunter well adapted for maneuvering through trees (Squires and Reynolds 1997).

On the Kaibab Plateau, red-tailed hawks and northern goshawks frequently occupy similar habitat. They both tend to nest in larger (>41 cm dbh) trees, mid-slope in a drainage in close proximity (<2000 m apart, LaSorte 2001).

On the Kaibab Plateau, the red-tailed hawk and the northern goshawk are two high trophic level raptors that may be partitioning prey and foraging habitat through their morphological differences. Fire suppression, timber harvesting, and livestock grazing over the past 100 years have caused changes in southwestern forests, including the Kaibab Plateau (Weaver 1951, Cooper 1960, Covington and Moore 1994). These changes are believed to have had negative impacts on the northern goshawk. In 1982, the Southwestern Region of the USDA Forest Service listed the northern goshawk as a sensitive species (USDA Forest Service 1991). The Forest Service developed management recommendations for the northern goshawk in the southwestern United States, and recommended an 8 to10 ha buffer zone excluding tree harvesting around active nests (Reynolds et al. 1992). Crocker-Bedford (1990) suggested that large (>10 ha) or small (<10 ha) nest buffers did not sustain northern goshawk reproduction. He observed that despite northern goshawks being provided with nest buffers, red-tailed hawks nested in abandoned northern goshawk nests after timber harvesting. On the Kaibab Plateau red-tailed hawks nested in former northern goshawk nests (Melissa Siders, North Kaibab Ranger District, personal communication), however data have not been analyzed to determine if these occurrences are the result of timber harvesting.

Carey (1984) suggested that decreasing the quality and quantity of old-growth habitat could cause early successional species, such as red-tailed hawks, to dominate the landscape and out-compete old-growth dependent species, such as northern goshawks, even in the remaining old-growth stands. The management practice of creating buffer zones, although maintaining the quality of old growth for nesting sites, did not insure sufficient quantity or quality of old growth outside the buffer zone (Crocker-Bedford

1990). Beyond old growth buffer zones, open areas may favor the foraging habitat of red-tailed hawks more than northern goshawks. Exploring the potential relationship between these two species is one step towards a better understanding of how upper level avian predators have adjusted to human-caused alterations in southwestern forest ecosystems. Further, this understanding could benefit the ability of resource managers to address the viability of the northern goshawk population and maintain ecosystem function.

Competition occurs when use or defense of a resource by one individual reduces the availability of that resource to other individuals (Gill 1990). Interspecific competition occurs when individuals of coexisting species require a resource that is in limited supply relative to their needs such that survival or reproduction of at least one species is decreased when species are sympatric (Ricklefs and Schluter 1994). On the Kaibab Plateau, red-tailed hawks and northern goshawks by their proximity and common habitat could be competing for nest sites and/or prey species. Because reproductive impacts and survival were beyond the scope of this study, my research question focused on determining the food habits of red-tailed hawks on the Kaibab Plateau for comparison with known information on northern goshawks to evaluate potential competition from red-tailed hawks. Because of the creation of openings and the loss of mature dense forests I hypothesized that red-tailed hawks and northern goshawks were using the same prey species, creating the potential for competition.

METHODS

Study Area

The Kaibab Plateau is located in northern Arizona and is part of the Kaibab National Forest. The plateau is oval in shape with dimensions of 55 x 95 km at its broadest points and a total surface area of 2,980 km^2 above 1,830 m elevation. The surface of the plateau is composed primarily of Kaibab limestone. The study area was located within the North Kaibab Ranger District boundaries and confined to elevations above 2,075 m to be consistent with concurrent long-term northern goshawk research (R. Reynolds, Rocky Mountain Research Station, personal communication). Vegetation on the plateau consists of ponderosa pine (*Pinus ponderosa*) between 2,075-2,500 m, and mixed-conifer forest (ponderosa pine; Douglas-fir, *Pseudotsuga menziesii*; white fir, *Abies concolor*; blue spruce, *Picea pungens*; and quaking aspen, *Populus tremuloides*) between 2,500-2,650 m, and Engelmann spruce (*Picea engelmannii*)-subalpine fir (*Abies lasiocarpa*) forest between 2,650-2,800 m (Rasmussen 1941, White and Vankat 1993).

The climate of the Kaibab Plateau is decidedly moist in relation to the surrounding region. Annual precipitation averages 60 to 70 cm, snows are heavy in winter averaging 3 m and the greatest rain occurs in late summer during the monsoonal season (National Oceanic and Atmospheric Administration, 2001).

Prey Remains and Pellet Identification

To determine the diet of red-tailed hawks, prey remains and pellets from 42 active red-tailed hawk nests were collected by climbing trees and sifting through nest materials at the end of the breeding season (after the young had fledged), August – October 1998, 1999, 2000, and 2001 (n = 80 samples) (Table 1). Prey remains and pellets also were collected opportunistically by gathering material under some nest trees during the breeding season, May - July 2000 and 2001 (n = 60 samples). Some nests were visited more frequently than others (Table 1). I considered each collection of pellets and prey remains from a visit to be a discreet sample (140 total samples, n = 1 to 10 samples for each nest, average 3.3). Samples from each nest were collected >3 days apart, and end-of-season samples were collected >30 days after previous collections, so I assumed prey species identified per sample had been consumed since the last sample and represented new prey (e.g., I visited Nest #1 three times at the end of the nesting season and once during nesting over a 3 year period; this counted as 4 visits and each collection was considered an independent sample, Table 1).

Because I had unequal numbers of collections from nests, I examined the relationship between number of collections at each nest and number of prey species and individuals identified (Figure 1). Number of individuals increased as the number of collections increased, as did the number of species (Figure 1). I also examined this relationship on a yearly basis, I did not include 1998 and 1999 since they only had a single collection (Figure 1). Number of species was equal to the number of individuals when there were 1 or 2 collections, but as collection number increased so did the number of individuals and the number of species, however numbers of species increased less (Figure 1). This would be expected since more collections would increase sample size and therefore provide for the identification of more individuals. It is possible that more collections would also provide for the identification of more species, however, I found that an average of 3 collections represented species that were common in many of the nests. Rare species were found in nests that had only one collection, identification of rare species does not seem to be dependent on sample size.

Samples were collected in individual brown paper bags and stored until analysis at the end of the field season. Samples were composed of bone fragments, feathers, and hairs; I used these to identify prey species in each sample. To identify prey, I separated bone, feather, and hair samples and identified all feather and bone samples to species when possible, using bone fragments and feathers stored at the Rocky Mountain Research Station, Fort Collins, Colorado, for comparison.

Because of the large amount of hair (up to 90g per sample) obtained from each sample, I sub-sampled hairs. For each sample collected, I selected 10 hairs for every 1 g of hair (e.g., I selected 300 hairs from a 30-g sample). I spread each sample on a 100-point grid (10x10 points on 0.25 cm spacing). I used a random numbers table to select hairs from the grid. I rinsed hairs through cheesecloth with a 70% ethanol solution, mounted each on a slide with mineral oil, and then viewed them through a compound microscope to identify the characteristics of each hair. If a hair sample was not identifiable (<5 % of time), I randomly selected a replacement hair from the same sample.

I identified hairs using keys (Williams 1938, Stains 1958, Moore et al. 1974) and by comparing hairs directly with hair samples form the Northern Arizona University, Department of Biological Sciences collection and the private collection of H. E. Graham (retiree, Department of Biological Sciences, Northern Arizona University). For animal species not well described by Williams (1938), Stains (1958), or Moore et al. (1974), I used a second technique to identify species. I made a scale cast using 5% gelatin spread on a slide with the hair placed on top. I dried the sample for 2 to 5 minutes, then removed the hair and viewed the cast through a microscope (Moore et al. 1974) and compared it to samples from the NAU Department of Biological Sciences collection and H. E. Graham's collection (retiree, Department of Biological Sciences, Northern Arizona University). Hairs were identified using intact, identifiable characteristics including the presence or absence of color bands, round or flat shape, presence or absence of a hair shield, presence and configuration or absence of medulla (Figure 2). For example, golden-mantled ground squirrel (*Spermophilus lateralis lateralis*) was identified by a basal medulla - beginning absent becoming uniserial ladder then unbroken with cortical intrusions, shield medulla - unbroken with small indistinct central cortical intrusions, basal scales - irregular mosaic with margins smooth and intermediate to distant, and shield scales - irregular-waved mosaic with margins smooth and intermediate becoming irregular wave with margins rippled-crenate and close to intermediate (Moore et al. 1974). Identification of a prey species in each pellet and prey remain sample (including feathers, bones, and hair) only provided information to determine presence of a prey species and was not used to indicate number of individuals of each prey species encountered in a sample. Therefore, if a species occurred in any of the samples, it was counted as 1 individual for that sample. To determine relative importance of a prey species to each red-tailed hawk, I pooled samples across years for each nest and summed number of individuals by prey species (e.g., for Nest #1, I detected hair of Nuttall's cottontail in 3 of the 4 samples collected during a 3-year period, Appendix B). This provided a conservative estimate of prey species consumed by red-tailed hawks.

I compared data for all nests to determine prey species frequency for the red-tailed hawk population I monitored. I calculated the number of times a species occurred for each nest, its frequency, total number and percent of nests in which a prey species occurred (Table 2). Because of my collection method, I may have missed identifying prey species that were not randomly selected for hair analysis (e.g., I may not have detected red squirrel in a sample if I did not select a hair sample from the pellet and prey remain sample for a nest). I also may have undercounted number of individuals delivered to nests because I assumed presence of hair indicated 1 individual only. However, my data represent conservative estimates of prey consumed by red-tailed hawks on the Kaibab Plateau.

Statistical analysis

Prey Species Similarity

Dyer (1978) developed a linear statistical analysis for comparing species dissimilarity. The analysis can be used in conjunction with any species dissimilarity index, and is designed for data sets that involve both multiple species and multiple environmental variables. The total species dissimilarity is divided into components with one component being assigned to each environmental variable or interaction of environmental variables:

$$D_{ij} = ß_0 + ß_1 d_{ij}^{(1)} + ß_2 d_{ij}^{(2)} + \ldots + ß_{ij}^{(m)} + e_{ij}$$

where D_{ij} is the (dis)similarity between observations *i* and *j*, $d_{ij}^{(1)}$ is a known function of *i* and *j* which corresponds to the i^{th} environmental variable or interaction, $ß_1$ is an unknown parameter which represents the contribution of the i^{th} environmental variable or interaction to the total dissimilarity, e_{ij} is an error term with an expected value of 0.

I used this linear model with the Jaccard dissimilarity index (Krebs 1999) to determine whether the species identified in prey remains and pellets of red-tailed hawks were affected by year (1998, 1999, 2000, 2001), vegetation type (ponderosa pine only, mixed conifer with pine dominant, or mixed conifer only), or collection technique (end of the season samples from the nest, opportunistic samples collected from below nest trees during breeding season nest site visits). Jaccard's index is specifically designed for presence-absence data, and because by definition rare species are typically absent, rare species have little influence on the value of the index (Krebs 1999). I used this index since the data obtained were based on species presence with few rare species. The Jaccard dissimilarity index (D_{ij}) is calculated by:

$$D_{ij} = a / (a+b+c)$$

where a is the number of binary characters present in species i and species j, b is the number present only in i, and c is the number present only in j. I simultaneously calculated Dyer's (1978) equation and the Jaccard index and generated an exact P-value (R. King, USDA Forest Service, Rocky Mountain Research Station Biometrics Unit, personal communication). I set alpha level at 0.05 and considered statistical tests significant if $P \leq 0.05$.

Niche Breadth

Niche breadth and niche overlap are widely applied to analysis of foraging and community ecology, where they can be used to estimate competition (Greene and Jaksic 1983). Niche breadths were calculated according to Levins' (1968) equation:

$$ß = 1/Sp_i^2$$

where p_i is the proportion of red-tailed hawk nests with the i^{th} taxon present. The value of ß varies from 1 to n, where n is the number of taxa. If prey taxa occur equally among all nests, then ß = n. Niche-breadth values were standardized and converted to a fraction ranging from 0 to 1 by the equation:

$$ß_{standard} = (ß-1)/(n-1).$$

To calculate niche breadth I created a prey species list based on pooled prey species present across red-tailed hawk nests by year (Table 2). To determine if there was a difference in niche breadth per year, I calculated a chi square ($?^2$) one-sample test for goodness of fit (Ambrose and Ambrose 1995) where:

$$?^2 = S \frac{(\text{Observed frequency} - \text{Expected frequency})^2}{\text{Expected frequency}}$$

The observed frequency was food niche breadth per year and the expected frequency was the mean of food niche breadth for four years. I also calculated a 95% confidence interval for niche breadth.

$$X \pm t_{a/2,\, n-1}\, s/vn$$

where t was an identified score with n - 1 degrees of freedom such that a area was greater than or less than the t-score value. This confidence interval indicated that the true mean of food niche breadth for the red-tailed hawks will occur within some limit unless a one-in-twenty chance has occurred (Freese 1980). The niche breadth for red-tailed hawks on the Kaibab Plateau was compared with known niche breadths calculated for northern goshawks from other studies (Reynolds and Meslow 1984, Bloom et al. 1986, Kennedy 1991, Boal and Mannan 1994. I also measured prey species similarity of red-tailed hawks with northern goshawk prey remain data from Boal (1993), using Jaccard species similarity index (see above equation).

RESULTS

Pellet and Prey Remain Analysis

I identified 478 prey items from 42 red-tailed hawk nests over the four-year study period. Prey included at least 17 species of mammals, 7 species of birds, and 2 species of reptiles (Table 2, Appendices A and B). I did not detect a difference in the frequency of occurrence for each prey species and the percent of time that any prey item occurred in a nest regardless of collection technique, opportunistic (Table 3, Appendix C) or end of the season (Table 4, Appendix D) (P = 0.4). For all four years combined, mammals represented 72% of red-tailed hawk diet and birds represented 27% (Table 2, Appendix B). Only 2 species of reptiles were identified and did not contribute greatly to the overall diet (< 1% of red-tailed hawk diet). Six species accounted for 67% of prey by frequency for all four years combined: Nuttall's cottontail (17.6%), Kaibab squirrel (*Sciurus aberti kaibabensis*) (7.7%), rock squirrel (10.0%), golden-mantled ground squirrel (10.3%), northern flicker (10.7%), and Steller’s jay (*Cyanocitta stelleri*) (10.3%) (Table 2, Appendix B). Rare occurrences of porcupine (*Erethizon dorsatum*), coyote (*Canis latrans*), and mule deer (*Odocoileus hemionus*) comprised <2% of the overall red-tailed hawk diet.

Dissimilarity Measures and Niche Breadth

I did not detect a difference in dissimilarity analysis of prey species frequency identified from pellet and prey remains among years (*P* = 0.3), across habitat types (*P* = 0.8), or by combined collection technique (*P* = 0.4). I calculated diet niche breadth for red-tailed hawks for each year (0.58 in 1998, 0.52 in 1999, 0.51 in 2000, 0.65 in 2001).

I did not detect a difference in niche breadth between years ($?^2$ = 17.3, *P* = 0.5). The mean and 95% confidence interval for red-tailed hawks for all four years combined was 0.57 $\pm$ 0.11. I used this confidence interval to compare food niche breadth of red-tailed hawks with northern goshawks. Values of food niche breadth for northern goshawks were calculated by Reynolds and Meslow (1984), Bloom et al. (1986), Kennedy (1991), Boal and Mannan (1994). Their calculated food niche breadth values (0.42, 0.41, 0.36, and 0.29, respectively, Table 5) did not overlap the confidence intervals of food niche breadth that I found for red-tailed hawks. Species similarity overlap based on Jaccard species similarity index was 55% direct species overlap.

DISCUSSION

The prey species that I identified from pellet and prey remains were comparable to previous prey studies for red-tailed hawks. Red-tailed hawks were feeding generalists, but preyed primarily upon rabbits (*Sylvilagus* spp.), black-tailed jack rabbit (*Lepus californicus*), and ground squirrels (*Spermophilus* spp., Preston and Beane 1993). I found that red-tailed hawks on the Kaibab Plateau primarily preyed upon rabbits, tree and ground squirrels, northern flickers, and Steller's jays. Previous observation and prey remain analysis on the Kaibab Plateau indicated that northern goshawks also preyed primarily upon rabbits and hares, tree and ground squirrels, Steller's jays, and northern flickers (Boal and Mannan 1994, Kaufmann et al. 1994, and Reynolds et al. 1994)

Bosakowski and Smith (1992) found that competition between *Accipiter*s and *Buteo*s was reduced by a difference in prey selection. *Buteo*s selected a higher number of mammals in their diet; *Accipiter*s selected more avian prey. This finding was widely accepted, however my study showed that avian prey was common in red-tailed hawk diet and (Boal and Mannan 1994) have shown that mammals were common in northern goshawk diet on the Kaibab Plateau.

Steenhof and Kochert (1988) found that red-tailed hawks showed evidence of switching behavior, preying on a species that was most abundant at the time. Predators that are generalists often have weak and variable prey preferences; they will exhibit switching behavior while specialists with strong or consistent preferences do not (Murdoch 1969). The wider niche breadth of red-tailed hawks indicated a weak preference compared to the narrower niche breadth of northern goshawks. Thus, switching behavior in red-tailed hawks could lead to potential competition with northern goshawks.

Although my study indicated that northern goshawks and red-tailed hawks fed on similar prey items, feather and hair remains most frequently present in the pellet did not permit the quantification of prey species. Even though analysis of pellet and prey remains provided an accurate species list, prey remains provided no insight into spatial or temporal variation, which may be critical components of potential competition. Prey composition and abundances vary geographically and seasonally; I could not determine whether the differences in diet between red-tailed hawks and northern goshawks were due to seasonal or regional differences in prey availability or to different patterns of selection from similar distributions of available prey.

I found that red-tailed hawks and northern goshawks showed high dietary overlap. If red-tailed hawks and northern goshawks foraged in the same areas at the same times, red-tailed hawks could affect northern goshawk foraging.

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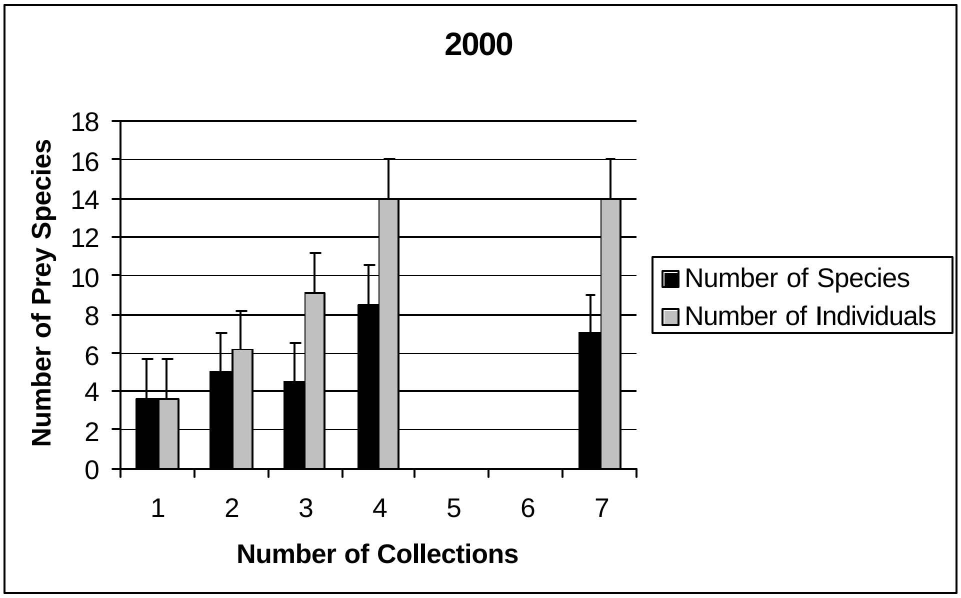
(A)



(B)

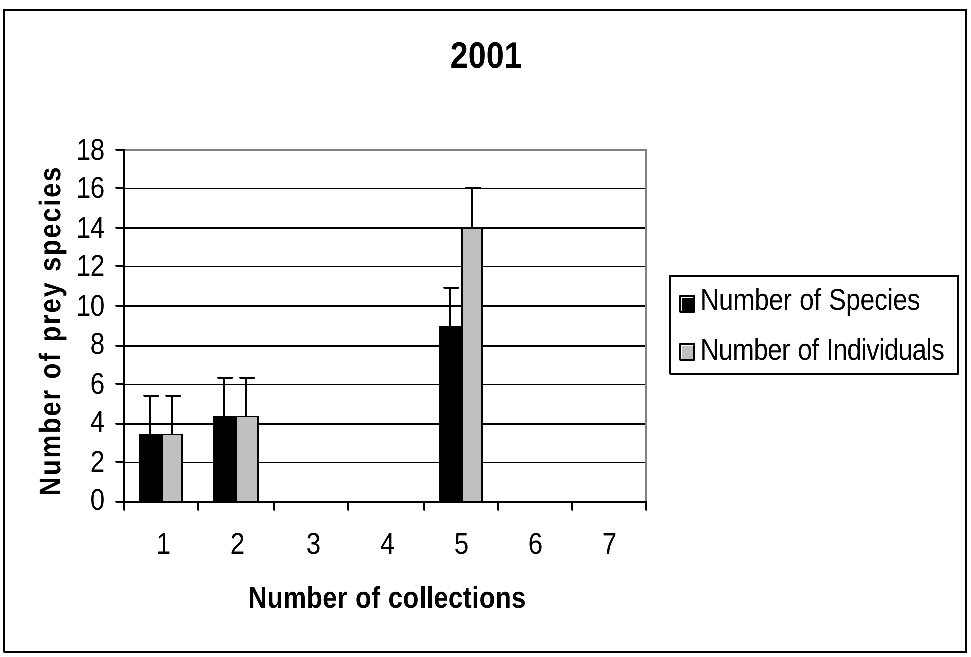


Figure 1. Comparison of number of prey species identified from 42 red-tailed hawk nests as a function of number of collections from nests, May - October 2000 (A) and 2001(B), Kaibab Plateau, Arizona.

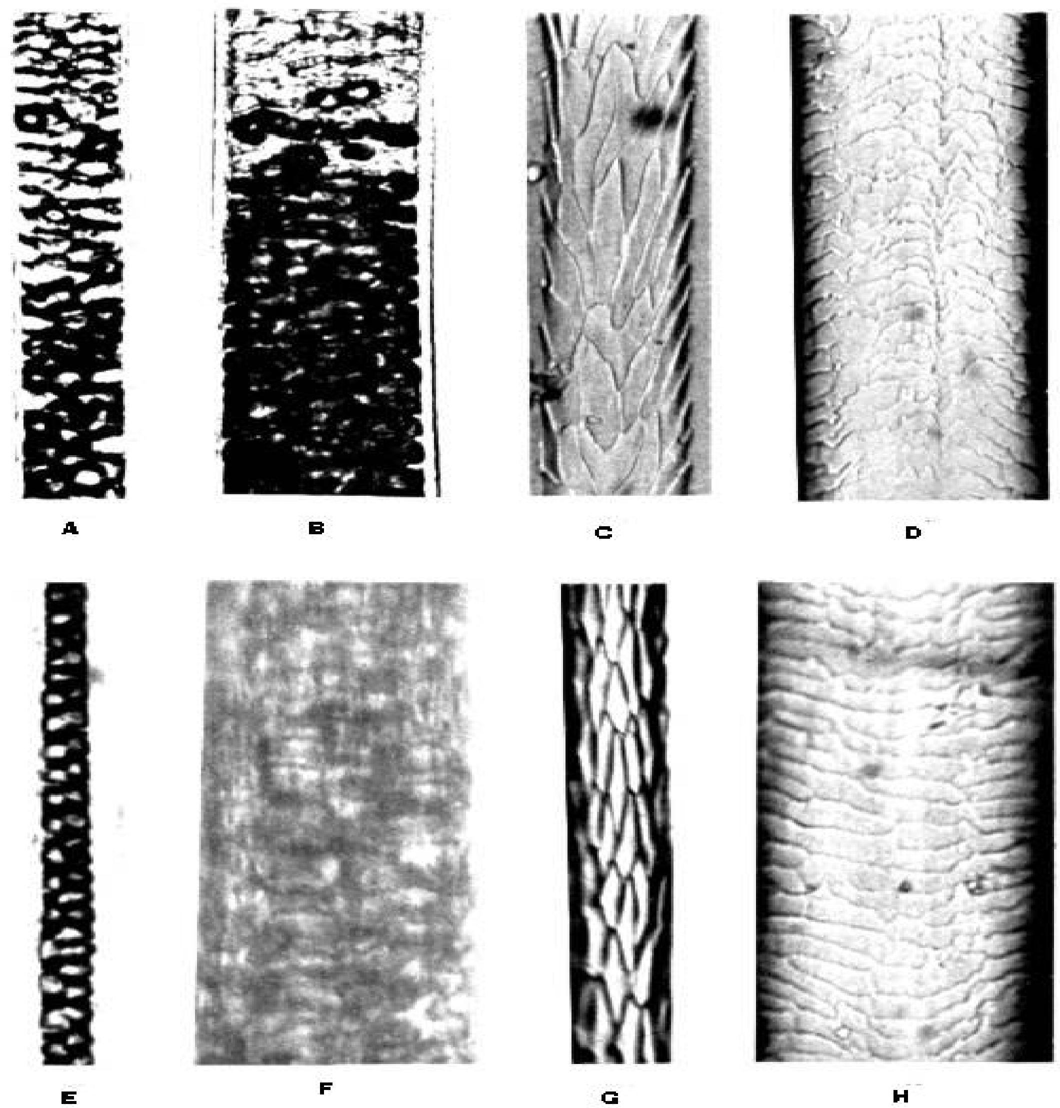


Figure 2. Example of hair internal infrastructure used to identify prey species from pellet and prey remains from red-tailed hawk nests, May through October, 1998-2001, Kaibab Plateau, Arizona. This is an example from an Abert's Squirrel (*Sciurus aberti*) hair. Banded hair medulla: A = basal, B = shield. Banded hair scale casts: C = basal; D = shield and tip. Unbanded hair medulla: E = basal, F = shield. Unbanded hair scale casts: G = basal, H = shield and tip (from Moore et al. 1997).

Table 1. Red-tailed hawk prey remain and pellet sample collections on the Kaibab Plateau, Arizona. End of the season collections, from the nest, are noted by “X”; opportunistic collections during the nest season, from the base of the nest tree, are noted by the date those collections occurred.

Nest number	1998	1999	2000	2001	Total number of collections
1	x	x	x, 7/19		4
2	x	x	7/10, 7/19		4
3	x	x	x, 7/10, 7/18		5
4	x	x	x, 7/3, 7/17	x, 6/10, 6/13, 7/1, 7/16	10
5	x	x	x, 7/7, 7/24		5
6	x		7/24		2
7	x				1
8		x	6/27		2
9	x	x	x, 7/19		4
10	x	x	x, 5/22, 7/20	x, 7/13	7
11	x	x			2
12	x	x	x, 7/1, 7/20		5
13	x	x			2
14	x	x			2
15	x	x	x, 5/24, 6/2, 6/28, 7/4, 7/12, 7/18		9
16	x	x	x, 7/24	x, 6/28	6
17	x		7/12, 7/21	x	4
18		x	x, 7/4, 7/12, 7/18		5
19	x	x			2
20			x, 6/28, 7/24		3

Table 1. continued

Nest number	1998[a]	1999[a]	2000	2001	
21			x, 7/12, 7/17	x	4
22	x				1
23	x			x	2
24	x	x	7/26		3
26			x	x	2
28	x	x	x, 7/24		4
31			x, 7/21	x, 6/5	4
32		x	x, 5/22, 7/20	x	5
34		x	7/20	x	3
35		x	x, 7/1		3
36			6/28		1
37			7/31		1
38		x			1
39			x, 7/18		2
40			x, 7/25		2
41		x			1
44		x	x, 6/28, 7/26, 7/32		5
45			x, 6/29, 7/2, 7/14		4
46			x, 7/11, 7/23		3
49			x, 7/6, 7/31		3
52			x		1
60				x	1

Table 2. Prey species present at red-tailed hawk nests assessed from pellets and prey remains collected May-October 1998, 1999, 2000, and 2001, on the Kaibab Plateau, Arizona.[1]

Prey Species[2]	Total number of each species	Percent frequency	Total number of nests species occurred	Percent of nests species occurred
Nuttall's Cottontail	84	17.6%	36	85.7%
Golden-mantled Ground Squirrel	49	10.3%	26	61.9%
Rock Squirrel	48	10.0%	29	69.0%
Kaibab Squirrel	37	7.7%	21	50.0%
Chipmunk	27	5.6%	20	47.6%
Northern Pocket Gopher	22	4.6%	21	50.0%
Long-tailed Vole	17	3.6%	17	40.5%
Red Squirrel	15	3.1%	13	31.0%
Mouse	13	2.7%	9	21.4%
Shrew	11	2.3%	10	23.8%
Black-tailed Jack Rabbit	8	1.7%	8	19.0%
Long-tailed Weasel	5	1.0%	5	11.9%
Mule Deer	5	1.0%	5	11.9%
Plains Pocket Mouse	3	0.6%	2	4.8%
Porcupine	2	0.4%	2	4.8%
Ringtail	1	0.2%	1	2.4%
Coyote	1	0.2%	1	2.4%
Northern Flicker	51	10.7%	28	66.7%
Steller's Jay	49	10.3%	26	61.9%
Clark's Nutcracker	13	2.7%	10	23.8%
Unknown Avian	8	1.7%	7	16.7%
Common Raven	3	0.6%	3	7.1%
Western Bluebird	1	0.2%	1	2.4%
Hairy Woodpecker	1	0.2%	1	2.4%
Common Nighthawk	1	0.2%	1	2.4%
Snake	3	0.6%	2	4.8%
Mountain Short Horned Lizard[3]	0	0.0%	0	0.0%

[1]From 42 nests, 1,491 prey items were identified out of 140 collections, species identified in individual nests are listed Appendix B.

[2]Scientific names are listed in Appendix A

[3]Observed but not collected in pellets or prey remains.

Table 3. Prey species present at red-tailed hawk nests assessed from pellets and prey remains collected from the nest at the end of the breeding season August-October 1998, 1999, 2000, and 2001, on the Kaibab Plateau, Arizona.[1]

Prey Species[2]	Total number of each species	Percent frequency	Total number of nests species occurred	Percent of nests species occurred
Nuttall's Cottontail	56	17.7%	31	77.5%
Golden-mantled Ground Squirrel	30	9.5%	23	57.5%
Rock Squirrel	30	9.5%	21	52.5%
Kaibab Squirrel	24	7.6%	16	40.0%
Chipmunk	18	5.7%	15	37.5%
Northern Pocket Gopher	15	4.7%	14	35.0%
Long-tailed Vole	11	3.5%	11	27.5%
Red Squirrel	10	3.2%	8	20.0%
Mouse	9	2.8%	7	17.5%
Shrew	7	2.2%	6	15.0%
Black-tailed Jack Rabbit	5	1.6%	5	12.5%
Long-tailed Weasel	5	1.6%	5	12.5%
Mule Deer	3	0.9%	3	7.5%
Plains Pocket Mouse	2	0.6%	1	2.5%
Porcupine	2	0.6%	2	5.0%
Ringtail	1	0.3%	1	2.5%
Coyote	0	0.0%	0	0.0%
Northern Flicker	36	11.4%	25	62.5%
Steller's Jay	33	10.4%	23	57.5%
Clark's Nutcracker	8	2.5%	7	17.5%
Unkknown Avian	3	0.9%	3	7.5%
Common Raven	3	0.9%	3	7.5%
Western Bluebird	1	0.3%	1	2.5%
Hairy Woodpecker	1	0.3%	1	2.5%
Common Nighthawk	1	0.3%	1	2.5%
Snake	2	0.6%	2	5.0%
Mountain Short Horned Lizard[3]	0	0.0%	0	0.0%

[1]From 40 nests, 316 prey items were identified out of 80 collections, species identified in individual nests are listed Appendix C.

[2]Scientific names are listed in Appendix A

[3]Observed but not collected in pellets or prey remains.

Table 4. Prey species present at red-tailed hawk nests assessed from pellets and prey remains collected opportunistically at the base of the nest tree during the breeding season May-July 2000 and 2001, on the Kaibab Plateau, Arizona[1].

Prey Species[2]	Total number of each species	Percent frequency	Total number of nests species occurred	Percent of nests species occurred
Nuttall's Cottontail	28	17.3%	21	70.0%
Golden-mantled Ground Squirrel	19	11.7%	13	43.3%
Rock Squirrel	18	11.1%	14	46.7%
Kaibab Squirrel	13	8.0%	13	43.3%
Chipmunk	9	5.6%	9	30.0%
Northern Pocket Gopher	7	4.3%	7	23.3%
Long-tailed Vole	6	3.7%	6	20.0%
Red Squirrel	5	3.1%	5	16.7%
Mouse	4	2.5%	4	13.3%
Shrew	4	2.5%	4	13.3%
Black-tailed Jack Rabbit	3	1.9%	3	10.0%
Long-tailed Weasel	0	0.0%	0	0.0%
Mule Deer	2	1.2%	2	6.7%
Plains Pocket Mouse	1	0.6%	1	3.3%
Porcupine	0	0.0%	0	0.0%
Ringtail	0	0.0%	0	0.0%
Coyote	1	0.6%	1	3.3%
Northern Flicker	15	9.3%	13	43.3%
Steller's Jay	16	9.9%	12	40.0%
Clark's Nutcracker	5	3.1%	5	16.7%
Unknown Avian	5	3.1%	5	16.7%
Common Raven	0	0.0%	0	0.0%
Western Bluebird	0	0.0%	0	0.0%
Hairy Woodpecker	0	0.0%	0	0.0%
Common Nighthawk	0	0.0%	0	0.0%
Snake	1	0.6%	1	3.3%
Mountain Short Horned Lizard[3]	0	0.0%	30	0.0%

[1]From 30 nests, 162 prey items were identified out of 60 collections, species identified in individual nests are listed Appendix D.

[2]Scientific names are listed in Appendix A

[3]Observed but not collected in pellets or prey remains.

Table 5. The calculated food niche breadth of breeding northern goshawks based on published data.

Location	**Number of Nests**	**Food niche breadth**	**Source**	**Technique**
Arizona	20	0.29	Boal (1993)	Prey remains
California	114	0.41	Bloom et al. (1986)	Prey remains
New Mexico	8	0.36	Kennedy (1991)	Prey remains
Oregon	4	0.38	Reynolds and Meslow (1984)	Prey remains

CHAPTER 3

PARENTAL CARE BY SYMPATRIC RED-TAILED HAWKS (*BUTEO JAMAICENSIS*) AND NORTHERN GOSHAWKS (*ACCIPITER GENTILIS*) ON THE KAIBAB PLATEAU, ARIZONA

Abstract: To compare parental behavior of two raptors, the red-tailed hawk (*Buteo jamaicensis*) and the northern goshawk (*Accipiter gentilis*, designated as a USDA Forest Service sensitive species), I collected 1258 hours of behavioral information using video surveillance (1028 hours at 9 nests) and observations from blinds (230 hours at 8 nests) for 17 pairs of nesting red-tailed hawks May to July 1999 - 2001. I also conducted 204 hours of video surveillance on 3 pairs of nesting northern goshawks May to July 1999 and 2001 on the Kaibab Plateau, Arizona. I quantified 7 types of parental care: 1) frequency of prey deliveries, 2) frequency of vegetation deliveries, 3) amount of time at the nest, 4) amount of time spent feeding young, 5) amount of time spent interacting with young and 6) loafing by the attending adult. I did not detect a difference in the behavior of red-tailed hawks between years and nests (P = 0.2). Red-tailed hawks averaged 4.5 visits per hour to the nest, 0.25 prey deliveries per hour, and 0.06 vegetation deliveries per hour. Red-tailed hawks spent 9% of their time at the nest. Of that time, 43% of time was spent feeding the chicks, 32% was spent loafing, and 25% was spent interacting with chicks. Northern goshawks made 0.7 visits per hour to the nest, 0.26 prey deliveries per hour, and 0.18 vegetation deliveries per hour. Northern goshawks spent 11% of their time at the nest; of that time, 43% was spent feeding, and 57% was spent loafing. I did not observe any time spent interacting with chicks. I also compared behavior between a

nesting pair of red-tailed hawks and an adjacent northern goshawk pair (nests were <2000 m apart). Each nest had one chick; chicks differed in hatch date by <3 days. I did not detect a difference in adult visits per hour, prey deliveries per hour, vegetation deliveries per hour, percent time spent at the nest, percent time spent feeding the chick, or percent time loafing at the nest. I did detect a difference in the percent of time spent interacting with the chick, red-tailed hawks spend more time interacting with the chick. I found little evidence to indicate a difference between parental care behavior of red-tailed hawks and northern goshawks; however, I had unequal sampling efforts (more time spent sampling in June than other months), and relatively small sample sizes, especially for northern goshawks, which may have contributed to lack of differences.

INTRODUCTION

Some form of parental behavior is present in most living species of birds (Bock and Farrand 1980). Quantifying life history characteristics can help identify the relationships between behavioral patterns and fitness, understand animals' energetic needs under certain ecological conditions, and predict future anthropogenic impacts (Delaney 1997). A bird's behavior during the nesting season is an important determinate of its ultimate reproductive success or failure (Hohman 1986). The primary avian parental behaviors are territory defense, nest building, feeding of the female by the male prior to egg laying and during incubation, incubation of eggs, brooding young, feeding young, escorting young to food sites, and protecting young from predators (Silver et al. 1985).

Enderson et al. (1973), Holhuijzen et al. (1990), and Sovern et al. (1994) described prey delivery and foraging activity during the nesting season. Holthuijzen et al. (1990) described trip frequency and duration for prairie falcons (*Falco mexicanus*) obtaining prey during the nesting season. Enderson et al. (1973), Matray (1974), and Holthuijzen et al. (1990) quantified seasonal change in raptor behavior during nesting. In addition, during times of prey stress, nest behavior by both adults and young are subject to change (Enderson et al. 1973, Laymon 1991).

The food requirements of breeding birds generally peak as young develop from hatchlings to fledglings (Skutch 1976, O'Connor 1984). In socially monogamous species with altricial or semi-altricial young, males usually provision the family for most of the nestling phase of the breeding cycle (Silver et al. 1985), while females remain at the nest to feed and protect the brood. Nestling growth, mortality rates and post-fledging survival are influenced by the frequency of food deliveries to the nest (sparrowhawk, *Accipiter nisus*; *Buteo*s, prairie falcons Newton 1978, 1979, Bortolotti 1986, Holthuijzen 1990) and the protection afforded the brood by attendant adults (northern goshawks, Newton 1978, Ward and Kennedy 1996). These studies have mostly focused on Falconiformes and Strigiformes; few studies have looked at adult *Buteo* nesting behavior throughout the breeding period.

During the nesting season male red-tailed hawks usually provide most of the food, while the female feeds the nestlings, but both parents may deliver food to the nest (Petersen 1979). Aggressive vocalizations are used to defend territories and occasionally in response to human intrusion (Preston and Beane 1993). Female northern goshawks are provisioned exclusively by the male from courtship through early nestling stage, and sometimes throughout the nesting period until fledging (Younk and Bechard 1994). Northern goshawks are extremely aggressive when defending nests from intruders, aggression peaks during early-nestling stage, then wanes as young fledge (Squires and Reynolds 1997). Crannell (1987) observed an aggressive encounter between a northern goshawk and a red-tailed hawk, this encounter occurred outside of the nesting season.

Although much research has been conducted on raptors, there are few studies comparing nesting behavior of red-tailed hawks with northern goshawks. My study described provisioning and nest attendance by breeding red-tailed hawks (*Buteo jamaicensis*) and northern goshawks (*Accipiter gentilis*) to compare the variation in the quality of parental care between these two sympatric species on the Kaibab Plateau, Arizona. I monitored 7 behaviors of 17 pairs of nesting red-tailed hawks and 3 pairs of nesting northern goshawks while birds were attending active nests (1 to 4 young per nest, <5 weeks old) to describe parental behavior of red-tailed hawks and northern goshawks.

METHODS

Study Area

The Kaibab Plateau is located in northern Arizona and is part of the Kaibab National Forest. The plateau is oval in shape with dimensions of 55 x 95 km at its broadest points and a total surface area of 2,980 km^2 above 1,830 m elevation. The surface of the plateau is composed primarily of Kaibab limestone. The study area was located within the North Kaibab Ranger District boundaries and confined to elevations above 2,075 m to be consistent with concurrent long-term northern goshawk research (R. Reynolds, Rocky Mountain Research Station). Vegetation on the plateau consists of ponderosa pine (*Pinus ponderosa*) between 2,075-2,500 m, and mixed-conifer forest (ponderosa pine; Douglas-fir, *Pseudotsuga menziesii*; white fir, *Abies concolor*; blue spruce, *Picea pungens*; and quaking aspen, *Populus tremuloides*) between 2,500-2,650 m, and Engelmann spruce (*Picea engelmannii*)-subalpine fir (*Abies lasiocarpa*) forest between 2,650-2,800 m (Rasmussen 1941, White and Vankat 1993).

The climate of the Kaibab Plateau is decidedly moist in relation to the surrounding region. Annual precipitation averages 60 to 70 cm, snows are heavy in winter averaging 3 m and the greatest rain occurs in late summer during the monsoonal season (National Oceanic and Atmospheric Administration, 2001).

Observations of Parental Care Using Blinds and Video Cameras

I observed parental care at 8 red-tailed hawk nests during the nesting season (May to July 2000) using blinds. Blinds were located at ground level 10 to 20 m from the nest tree. Blinds were 4'x4'x4' Coleman children's tents. I used a Bushnell 15 x 40 spotting scope to make observations. I initially conducted observations from blinds for 4 hours at a time, and divided 4-hour time periods into daylight hour blocks (05:00-09:00, 09:00-13:00, 13:00-17:00, and 17:00-21:00). Nests were visited during a randomly selected 4-hour time block. However, after visiting all nests once, I increased observation time from 4- to either 6-, 8-, 10- or 12-hour blocks because 4 hours was inadequate to observe behavior (e.g., few or no recorded behavioral observations during this time period). As the summer progressed, I reduced observation time at inactive nests (chicks fledged) and increased observation time at nests where young remained (Table 1).

I also used video cameras to observe red-tailed hawk nests (3 nests in 1999, 2 nests in 2000, 4 nests in 2001) and northern goshawk nests (2 nests in 1999, no nests in 2000, 3 nest in 2001). Video surveillance occurred during the nesting season (May to July). Cameras were small, waterproof and cylindrical, 2.5 cm x 5.0 cm, and manufactured by Provideo (Model No. CVC-130R). They were mounted laterally to the trunk of the tree at an oblique angle to the nest (Figure 1a). I used Panasonic industrial-grade video recorders (Model AG-1070DPC) to provide 16-hour video coverage, starting at sunrise (05:00) and ending at sunset (21:00) Mountain Standard Time (Figure 1b). I used a 15 m power-line-and-coaxial-cable down line and a 60 m trunk line to minimize potential disturbance from noise from the recorder and from changing out of tapes by offsetting the recorder and batteries to an out-of-sight tarpaulin blind.

Because of time constraints and logistical problems, video observations for red-tailed hawks and northern goshawks were unequal (approximately 1028 hours for red-tailed hawks and 204 hours for northern goshawks, Table 1), and most observations occurred during June. These observations, however, occurred during the most active phases of nesting (chick ages 1 to 4 weeks), and thus provided an adequate sample to describe nesting behavior.

Behavior Parameters

To describe parental care of red-tailed hawks and northern goshawks, I observed and quantified 7 parameters: 1) adult visits to the nest, 2) prey delivery rate, 3) vegetation delivery rate, 4) percent of time an adult was present at the nest, 5) percent of time adult(s) spent feeding chicks, 6) percent of time adult(s) interacted with chicks, and 7) percent of time adult spent loafing at nest. I defined prey delivery rate and vegetation delivery rate as the average number of items delivered per hour; adult visits also were calculated on a per hour basis. I determined the percent of time an adult was present, including the time spent feeding chicks, interacting with chicks, and loafing. I calculated feeding time, interacting time, and loafing time as an average time spent conducting these behaviors over the total amount of time that the adult was at the nest.

I also measured brood size (number of young) and estimated chick age (days since hatching) to determine their effect on adult behavioral patterns. To estimate chick age, I averaged nestling ages for each brood using age descriptions for red-tailed hawks (Moritsch 1983) and northern goshawks (Boal 1994). I did not distinguish between genders for adult red-tailed hawks and northern goshawks, because of the difficulty of establishing gender for red-tailed hawks.

To determine the overall behavior of red-tailed hawks I compared the behavior of red-tailed hawks between nests and years. I assumed that adult behavior toward chicks was consistent between years but might vary over season as chick aged. I also assumed that an adult would perform the same behaviors for one chick as it would for two or three. To justify pooling data for observation techniques (video surveillance vs. use of blinds) for red-tailed hawks, I used a one-way ANOVA (Freese 1980) and compared observation technique across years and chick age. I also used a one-way ANOVA to examine the variation of behavioral parameters between nests (Freese 1980). If I did not detect a significant difference with a test, I tested for power using Least Significant Number (LSN) (Dwass 1955, Snedecor and Cochran 1967). LSN estimated the sample size needed to discern a significant difference. The power of the effect test when the sample size is equal to the LSN is always greater or equal to 50% (Wright and O'Brien 1988). If I detected a significant difference in behavior between nests, I used an ANOVA with interaction to test for differences across nests based on brood size (Freese 1980).

I compared one pair of red-tailed hawks and northern goshawks that were considered "nearest neighbors" (nests were $\leq$2000 m apart, occurred in the same vegetation type, and each nest had one chick). I compared the same seven behavior patterns using a one-way ANOVA.

Except for the nearest neighbor pair I did not feel that I could statistically compare red-tail hawk and northern goshawk behaviors, since I did not have observation data in 2000 for northern goshawks, and I had fewer video observation hours (Table 1). I averaged the 7 behavior parameters over all observations, to compare the behavior of red-tail hawks and northern goshawks.

RESULTS

Red-tailed hawk behavior parameters

From blinds, I recorded a total of 230 hours of observations for 8 different nests May – July 2000. For time-lapse video coverage, I recorded 166 hours for 3 nests in 1999, 259 hours for 2 nests in 2000, and 603 hours for 4 nests in 2001.

Red-tailed hawks averaged 4.5 visits per hour to the nest, 0.25 prey deliveries per hour, and 0.06 vegetation deliveries per hour. Red-tailed hawks spent 9% of their time at the nest. Of that time, 43% of time was spent feeding the chicks, 32% was spent loafing, and 25% was spent interacting with chicks. Time spent at the nest declined over time as chicks aged (Figure 2a). There was a peak in visits by adults at chick age 18-22 days, prey deliveries and vegetation deliveries also peaked at this age, compared to visits and deliveries at other age groups (Figure 3a).

I did not detect a difference regardless of observation technique or year between nests in (1) the number of prey deliveries per hour (n = 240 prey deliveries, $\bar{x}$ = 0.25 prey deliveries per hour, P = 0.3, LSN = 150), (2) the number of vegetation deliveries per hour (n = 60 vegetation deliveries, $\bar{x}$ = 0.06 vegetation deliveries per hour, P = 0.5, LSN = 271), (3) the percent of total time that the adult spent on the nest (n = 116 total hours at nest, $\bar{x}$ = 12% of viewing time, P = 0.5, LSN = 111), (4) the percent time of loafing (n = 36.7 hours loafing, $\bar{x}$ = 32 % of total time at nest, P = 0.8, LSN = 290), or (5) the percent time the adult spent feeding the chicks (n = 48.5 hours feeding chicks, $\bar{x}$ = 43% of total time at nest, P = 0.1, LSN = 90). I did detect a difference in the percent time of adult interaction with the chicks (n = 27.8 hours interacting with chicks, $\bar{x}$ = 25% of total time at nest, P = 0.02), and a difference when the parameter number of chicks was added (P = 0.03).

Northern goshawk behavior parameters

Time-lapse video coverage included 118 hours for 2 nests in 1999, and 86 hours for 1 nest in 2001. Because of small sample sizes I did not statistically analyze behavior patterns for northern goshawks but I did calculate average behavior parameters. Northern goshawks made 0.7 visits per hour to the nest, 0.26 prey deliveries per hour, and 0.18 vegetation deliveries per hour. Northern goshawks spent 11% of their time at the nest; of that time, 43% was spent feeding, and 57% was spent loafing. I did not observe any time spent interacting with chicks. Northern goshawk activity budget decreased as chick age increased (Figure 2). Adult visits per hour and vegetation deliveries per hour also decreased as chicks aged; however, prey deliveries per hour remained relatively constant (Figure 3).

Red-tailed hawk compared to northern goshawk behavior parameters

Red-tailed hawks appeared to make more visits per hour (4.5 for red-tailed hawks compared to 0.7 for northern goshawks) and more vegetation deliveries per hour (0.06) than northern goshawks (0.18), but both made similar numbers of prey deliveries (red-tailed hawks 0.25, northern goshawks 0.26) (Figure 3). The primary difference between red-tailed hawks and northern goshawks was the amount of time each species spent interacting with chicks. Northern goshawks spent no time interacting with chicks (0% for northern goshawks, 25% for red-tailed hawks). However, northern goshawks appeared to spend more time loafing at the nest, especially when chicks were young (57% of time loafing for northern goshawks, 32% for red-tailed hawks) (Figure 2).

Nearest neighbor nest comparison

For nearest neighbor nest comparison (one red-tailed hawk nest compared with one northern goshawk nest located <2000m apart), I did not detect a difference in (1) adult visits per hour (P = 0.78, LSN = 719), (2) prey deliveries per hour (P = 0.59, LSN =175) (3) vegetation deliveries per hour (P = 0.62, LSN = 178), (4) percent time spent at the nest (P = 0.60, LSN = 197), (5) percent time feeding the chick (P = 0.48, LSN = 110), or (6) percent time loafing at the nest (P = 0.27, LSN = 273). I did detect a difference in the percent of time spent interacting with the chick (P = 0.03) (Figure 4).

Although differences were not statistically significant, I did observe that red-tailed hawks made more visits per hour to the nest site; northern goshawks made fewer prey deliveries per hour. Towards the end of the nesting season (chicks >27 days) both red-tailed hawks and northern goshawks made the same number of visits to the nest per hour as the number of prey deliveries per hour (Figure 5). Both also make the same number of vegetation deliveries per hour peaking at chick age 18-22 days (Figure 5). The activity budget for the two species was similar.

DISCUSSION

Red-tailed hawk behaviors

My study corroborated some of the general behavior patterns observed for red-tailed hawks in previous studies (e.g., nest attendance, Preston and Bean 1993). In my study, red-tailed hawks brooded and preened chicks until chicks were about 30 days old. Preston and Bean (1993) found similar levels of parental care. As chicks aged, adult activity budgets in all categories decreased. Also as chicks aged, adult visits per hour decreased however, prey deliveries per hour remained fairly consistent.

I did record differences in prey delivery rates that contradicted earlier research. Santana et al. (1986) found that red-tailed hawks delivered prey to the nestling 10 to 15 times a day; this differed greatly with the number of prey deliveries that I observed (approximately 4 per day). Delivery rate and prey biomass can vary among individual birds and are affected by brood size and prey availability (Newton 1979). I did not find a difference in prey delivery rates between nests with different brood sizes. I did not examine prey availability, so it is unknown whether the difference in prey deliveries that

I observed were lower then that which Santana et al. (1986) found. The prey species commonly delivered to nests in my study were large prey (e.g., rabbits and hares, northern flickers and Steller's jays). This may explain the difference in prey delivery rate if prey in Santana et al.'s (1986) study were small.

Some of the parental care that I observed by red-tailed hawks contradicted long-term observations regarding the feeding of nestlings. Petersen (1979) found that the adult preferentially fed the dominant chick and frequently pecked the subordinate. Stinson (1980) witnessed violent sibling aggression. I did not encounter either of these actions. During feeding the adult would come to the nest and the dominant chick would eat during the first prey delivery. During additional prey deliveries the adult would actively feed the subordinate chick. This behavior continued late into the nesting season when the chicks were >25 days old. I found 2 cases where a dead chick in the nest was not removed until the end of the second day and was not consumed. I also observed an unhatched egg that remained in the nest past the date that the hatched sibling fledged. I collected the egg during end of the season nest searches.

Red-tail hawk behaviors across nests and years seemed to be consistent. Although I did not detect a difference in prey deliveries per hour or the percent time the adult spent at the nest, I had an adequate sample size to detect such differences. I felt that the behaviors observed for red-tailed hawks adequately reflected the behaviors of nesting red-tailed hawks, and that these behaviors could be compared to those of northern goshawks.

Northern goshawk vs. red-tailed hawk behaviors

Raptors characteristically place green plant material in their nests. This vegetation is not part of the nest structure but is placed haphazardly around the edges or inside the nest. These birds of prey replenish the vegetation, often daily, during incubation and the nestling period (Brown and Amadon 1968, Beebe 1976). Schnell (1958) observed vegetation, usually conifer sprigs, delivered by female northern goshawks throughout nestling stage. Wimberger (1984) suggests that plants are placed in the nests to repel or actually kill avian ectoparasites. Plant material may repel or kill ectoparasites because of the secondary compounds it contains. Secondary compounds often function as insect repellents in plants (Levin 1971). I observed heavy insect infestation within the nest and on the young of both red-tailed hawks and northern goshawks. Red-tailed hawk nestling parasitism by the blood-sucking fly (*Eusimulium clarum*) and blackflies (*Simulium canonicolum*) has been well documented (Fitch et al. 1946, Smith et al. 1998). I did not identify the insects at red-tailed hawk or northern goshawk nests, but insect infestation may be the reason for the high number of vegetation delivery rates for both species.

Feeding rates and time invested in brooding and guarding nestlings are fundamental elements of avian parental care (Skutch 1976, Simmons 1989). Although the sample sizes in my study were small, it appeared that red-tailed hawks and northern goshawks had similar nest visit and feeding rates. In other studies, delivery rate varied either as a function of bird species, prey biomass, brood size and prey availability (Preston and Beane 1993) or adults operated at maximal capacity to supply food to young regardless of brood size (Snyder and Snyder 1973). My findings followed those of Silver and Ball (1985), who observed altricial young must be nourished individually, and the cost of providing this care increased directly as a function of clutch size.

Although I did not detect a difference, possibly due to sample size, in the nearest neighbor comparison of total time that red-tailed hawks and northern goshawks spent at each of their nests, red-tailed hawks spent more time interacting with young than did northern goshawks. I did not observe any chick interaction behavior from northern goshawks, and the parental caring of young has not been reported (Squires and Reynolds 1997). Red-tailed hawks spent almost half of the time at the nest directly interacting with the chicks; most of this interaction was preening chicks. Red-tailed hawk nest attentiveness steadily declined as the chicks aged, except for the time period of chick age 17 - 19 days old. During this period, heavy rain appeared to affect both red-tailed hawk and northern goshawk behavior with an increase in adult visits and prey deliveries to the nest. Red-tailed hawks on the Kaibab Plateau exhibited consistent behavior between nests and years. Their behaviors were similar to the behaviors exhibited by northern goshawks. Red-tailed hawks and northern goshawks are sympatric species on the Kaibab Plateau. My data are useful to describe some aspects of the behavioral similarities and differences between red-tailed hawks and northern goshawks and it may be possible to use these behaviors to further examine whether these species compete for resources.

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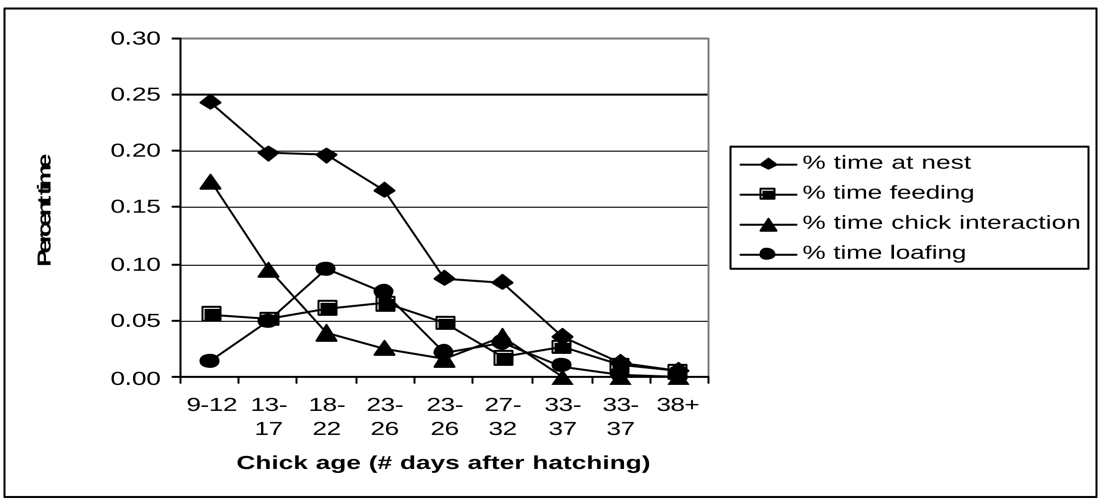
Figure 1. Video surveillance system for monitoring red-tailed hawk and northern goshawks nests on the Kaibab Plateau Arizona.

Figure 2. Average activity budget of adult (a) red-tailed hawks during 230 hours of blind observations from 8 nests May-July 2000 and 1028 hours of video observations from 3, 2, and 4 nests May-July 1999, 2000, and 2001 respectively and (b) northern goshawks from 204 hours of video observation from 2 nests May-July 1999, and 86 hours from 1 nest May-July 2001, on the Kaibab Plateau, Arizona. Chick age was estimated from published age descriptions for red-tailed hawks and northern goshawks (Moritsch 1983, Boal 1994).

(a) red-tailed hawks



(b) northern goshawk

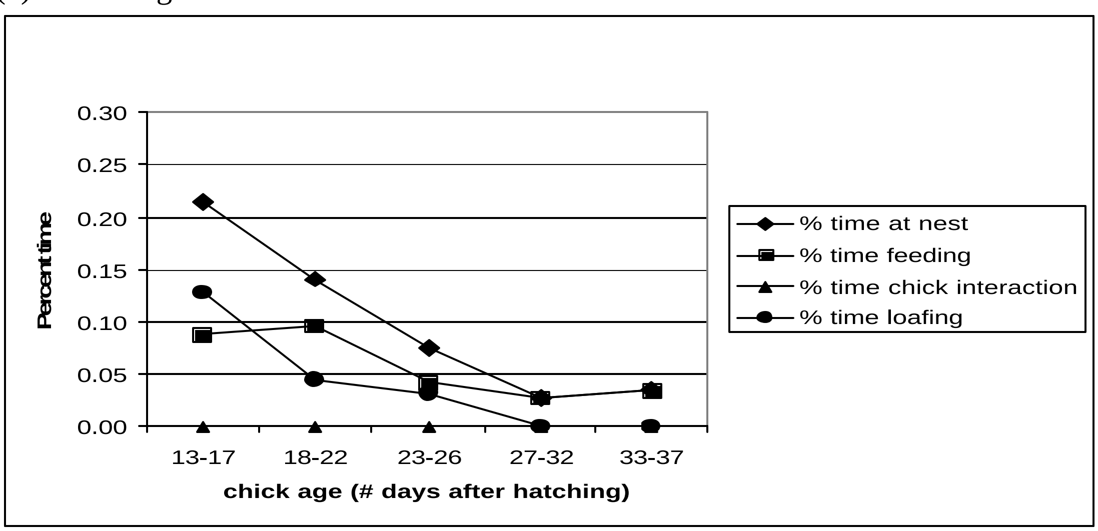
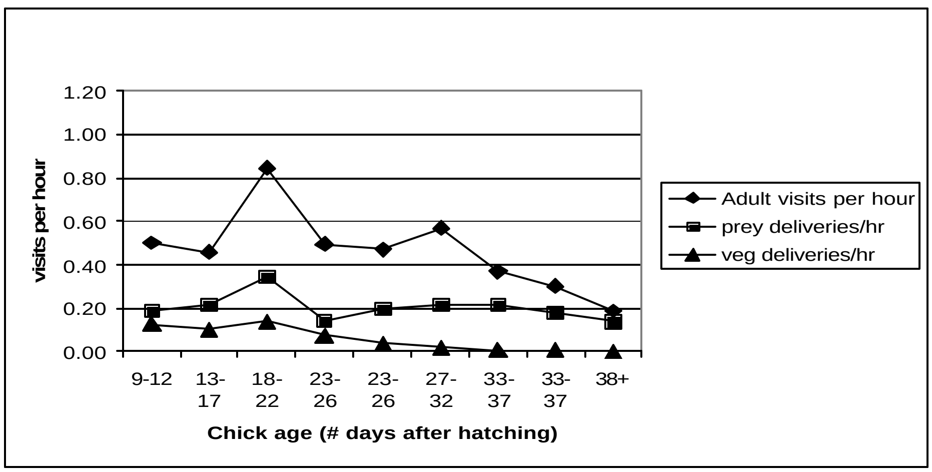


Figure 3. Average adult visits per hour by (a) red-tailed hawks during 230 hours of blind observations from 8 nests May-July 2000 and 1028 hours of video observations from 3, 2, and 4 nests May-July 1999, 2000, and 2001 respectively and (b) northern goshawks from 204 hours of video observation from 2 nests May-July 1999, and 86 hours from 1 nest May-July 2001, on the Kaibab Plateau, Arizona. Chick age was estimated from published age descriptions for red-tailed hawks and northern goshawks (Moritsch 1983, Boal 1994).

(a) red-tailed hawks



(b) northern goshawks

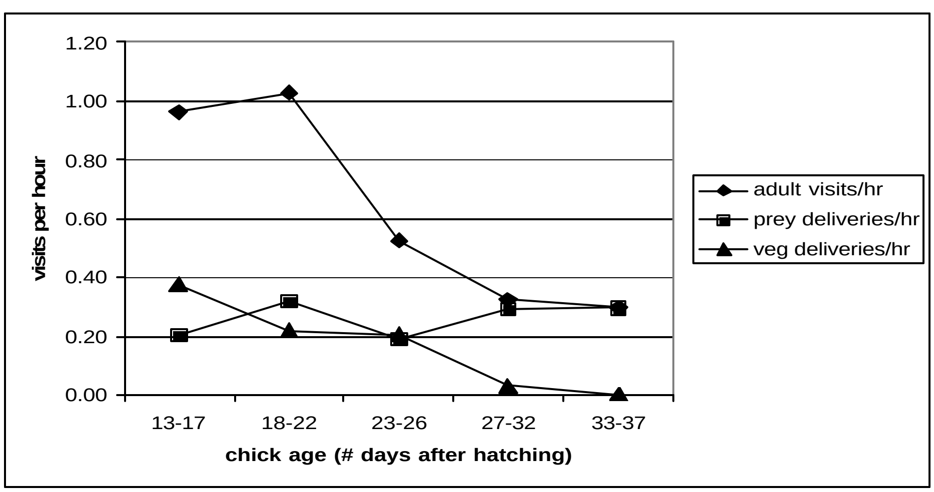
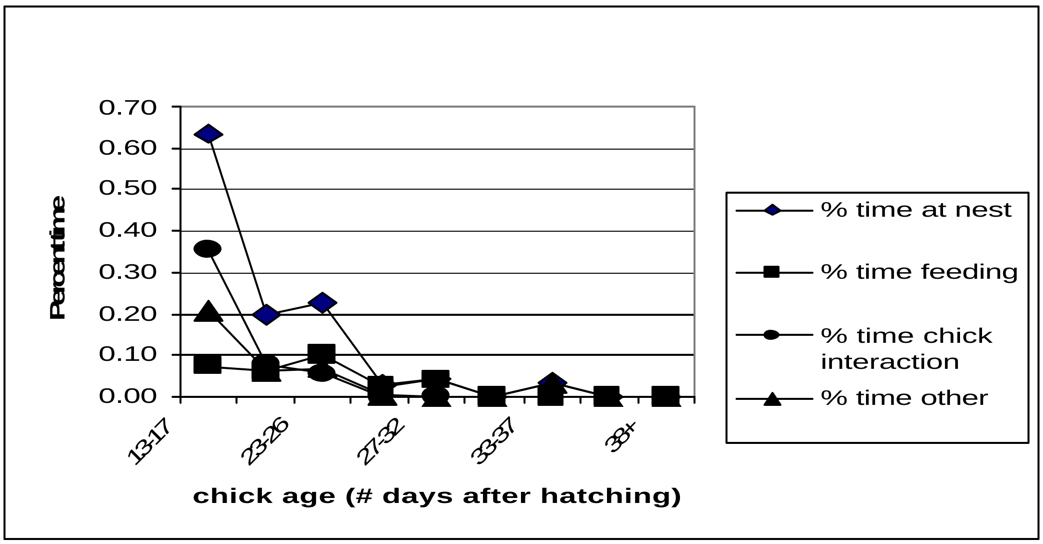


Figure 4. Average activity budget of adult nearest neighbor (a) adult red-tailed hawk during 128 hours of video observations May-July 2001 and (b) adult northern goshawk during 71 hours of video observations May-July 2001, on the Kaibab Plateau, Arizona. Chick age was estimated from published age descriptions for red-tailed hawks and northern goshawks (Moritsch 1983, Boal 1994).

(a) red-tailed hawk



(b) northern goshawk

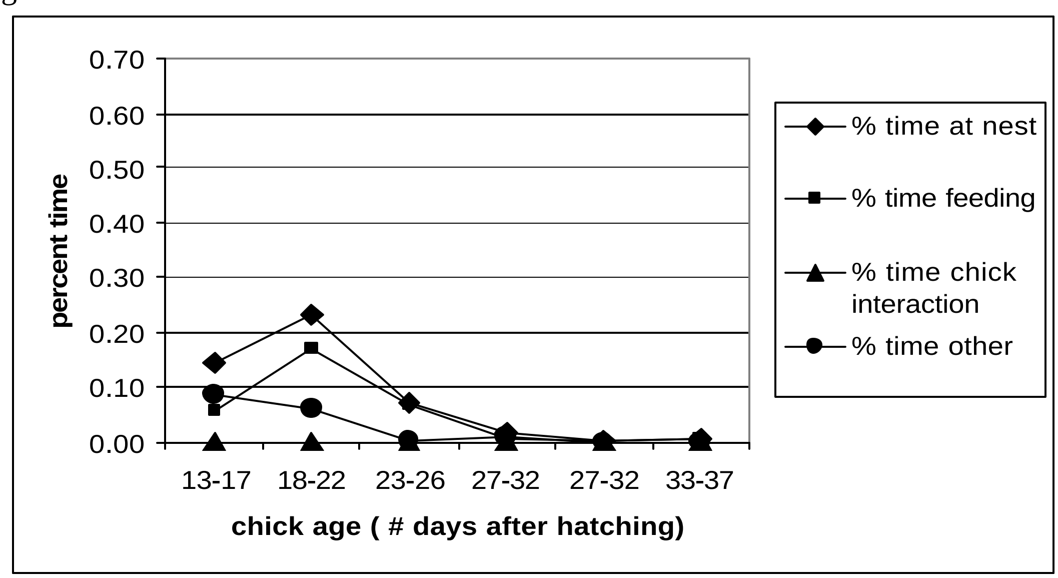
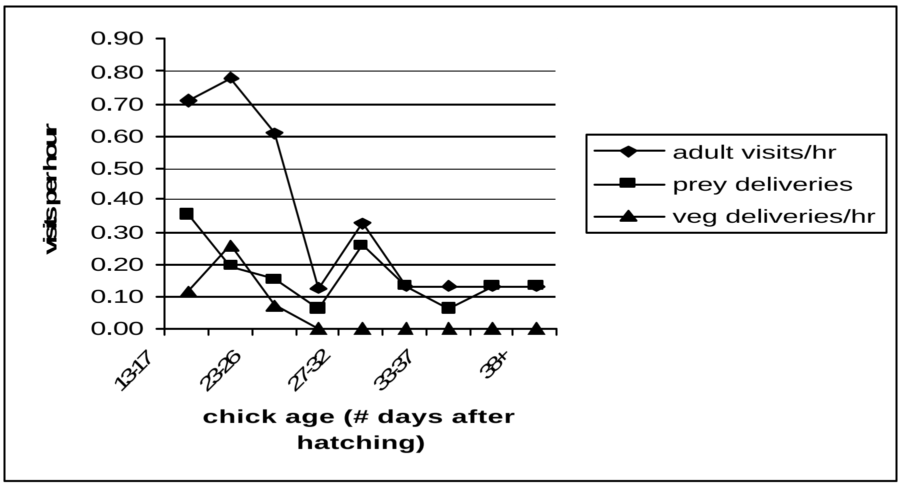


Figure 5. Average adult visits per hour of nearest neighbor (a) adult red-tailed hawk during 128 hours of video observations May-July 2001 and (b) adult northern goshawk during 71 hours of video observations May-July 2001, on the Kaibab Plateau, Arizona. Chick age was estimated from published age descriptions for red-tailed hawks and northern goshawks (Moritsch 1983, Boal 1994).

(a) red-tailed hawk



(b) northern goshawk

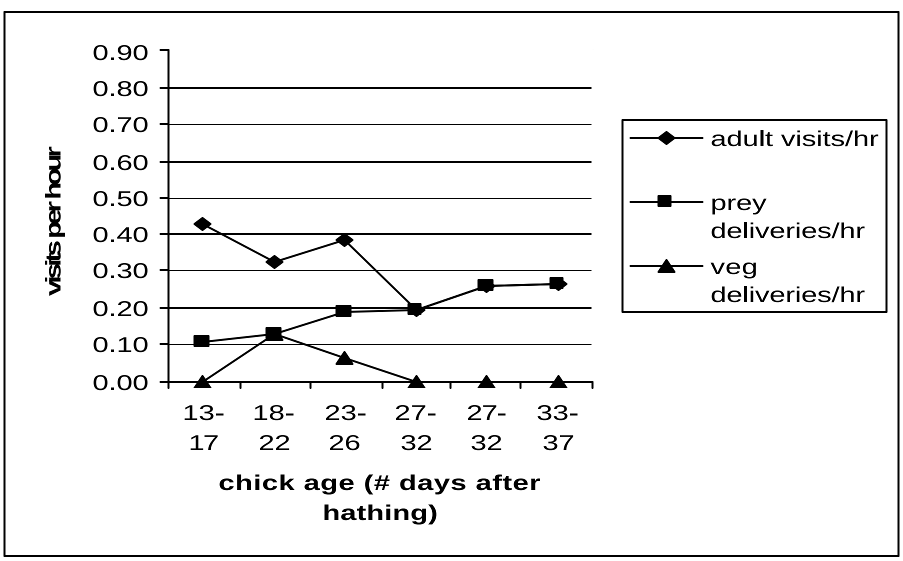


Table 2. Surveillance times and techniques of red-tailed hawks and northern goshawks on the Kaibab Plateau, Arizona.

Species	Nest Number	Technique	Dates observed	Hours observed	Total hours observed	Time of day observed[1]
red-tailed hawk	15	blind	5/25/2000	4	16.75	0900-1300
			5/31/2000	4		0500-0900
			6/9/2000	4.75		1215-1700
			6/14/2000	4		1700-2100
red-tailed hawk	45	blind	5/25/2000	2	66.5	1700-1900
			6/9/2000	4		0500-0900
			6/4/2000	4		0900-1300
			6/23/2000	8		0700-1200,1400-1700
			6/28/2000	10.5		0700-1730
			6/29/2000	7		1030-1730
			6/30/2000	10		0700-1700
			7/1/2000	10.5		0700-1730
			7/2/2000	10.5		0630-1700
red-tailed hawk	4	blind	5/26/2000	4	16.25	0500-0900
			6/4/2000	4		1700-2100
			6/10/2000	4.25		0845-1300
			6/15/2000	4		1300-1700
red-tailed hawk	35	blind	6/4/2000	4	22.5	0900-1300
			6/11/2000	4		1700-2100
			6/15/2000	4		0500-0900
			6/24/2000	10.5		0730-1800
red-tailed hawk	18	blind	5/29/2000	3	12.00	1000-1300
			6/6/2000	4		0500-0900
			6/13/2000	5		1200-1700
red-tailed hawk	3	blind	5/29/2000	4.5	35	1700-2130
			6/6/2000	4		1300-1700
			6/12/2000	4		0500-0900
			6/17/2000	7		0500-1200
			6/19/2000	7		1400-2100
			6/25/2000	8.5		0630-1500

Table 1. Continued

Species	Nest Number	Technique	Dates observed	Hours observed	Total hours observed	Time of day observed
red-tailed hawk	4	video	5/30/2001	16	181	
			6/2/2001	16		
			6/5/2001	16		
			6/8/2001	16		
			6/11/2001	8		
			6/14/2001	16		
			6/17/2001	16		
			6/23/2001	15		
			6/26/2001	15		
			6/29/2001	16		
			7/2/2001	15		
			7/5/2001	16		
red-tailed hawk	16	video	6/15/2001	8	127	
			6/18/2001	15		
			6/21/2001	13		
			6/24/2001	16		
			6/27/2001	15		
			6/30/2001	15		
			7/3/2001	15		
			7/6/2001	15		
			7/9/2001	15		
red-tailed hawk	31	video	6/18/2001	16	136	
			6/21/2001	16		
			6/24/2001	16		
			6/27/2001	16		
			6/30/2001	16		
			7/3/2001	11		
			7/9/2001	15		
			7/12/2001	15		
			7/15/2001	15		

Table 1. Continued

Species	Nest Number	Technique	Dates observed	Hours observed	Total hours observed	Time of day observed
red-tailed hawk	26	video	6/11/2001	15	159	
			6/14/2001	15		
			6/17/2001	15		
			6/20/2001	16		
			6/23/2001	15		
			6/27/2001	14		
			6/29/2001	16		
			7/2/2001	15		
			7/5/2001	8		
			7/8/2001	15		
			7/11/2001	15		
red-tailed hawk	14	video	6/28/1999	16	64	
			6/30/1999	16		
			7/5/1999	16		
			7/8/1999	16		
red-tailed hawk	11	video	6/24/1999	16	32	
			6/28/1999	16		
red-tailed hawk	3	video	7/8/1999	16	86	
			7/11/1999	16		
			7/15/1999	16		
			7/18/1999	16		
			7/22/1999	8		
			7/23/1999	14		
northern goshawk	19	video	6/21/2001	9	88	
			6/24/2001	16		
			6/27/2001	16		
			6/30/2001	16		
			7/301	16		
			7/6/2001	15		

Table 1. Continued

Species	Nest Number	Technique	Dates observed	Hours observed	Total hours observed	Time of day observed
northern goshawk	13	video	6/28/1999	16		
			7/5/1999	4		
			7/6/1999	8		
northern goshawk	37	video	6/24/1999	16		
			6/28/1999	16		
			7/5/1999	16		
			7/6/1999	10		
			7/11/1999	15		
			7/15/1999	15		

[1]All videos were set up to run from 0430-2130, time variation is due to video visibility, visibility is affected by time of day and moisture.

Appendix A. Prey items identified at 42 red-tailed hawk nests May - October 1998, 1999, 2000, and 2001, on the Kaibab Plateau, Arizona.

Common name	**Scientific name**
Mammals	
Black-tailed Jackrabbit	*Lepus californicus*
Chipmunk	*Eutamias* sp.
Coyote	*Canis latrans*
Golden-mantled Ground Squirrel	*Spermophilus lateralis*
Kaibab Squirrel	*Sciurus alberti kaibabensis*
Long-tailed Vole	*Microtus longicaudus*
Long-tailed Weasel	*Mustela frinata arizonensis*
Mouse	*Peromyscus* sp.
Mule Deer	*Odocoileus hemionus*
Northern Pocket Gopher	*Thomomys talpoides*
Nuttall's Cottontail	*Sylvilagus nuttallii*
Plains Pocket Mouse	*Perognathus flavescens*
Porcupine	*Erethizon dorsatum*
Red Squirrel	*Tamiasciurus hudsonicus*
Ringtail	*Bassariscus astutus*
Rock Squirrel	*Spermophilus variegatus grammurus*
Shrew	*Sorex* sp.
Birds	
Clark's Nutcracker	*Nucifraga columbiana*
Common Nighthawk	*Chordeiles minor*
Common Raven	*Corvus corax*
Hairy Woodpecker	*Picoides villosus*
Northern Flicker	*Colaptes auratus*
Steller's Jay	*Cyanocitta stelleri*
Western Blue Bird	*Sialia mexicana*
Reptiles	
Mountain Short Horned Lizard	*Phrynosoma douglassi*
Snake	*Reptilia* sp.

Appendix B. Prey species present at 40 individual red-tailed hawk nests; assessed from pellets and prey remains collected May-October 1998, 1999, 2000, and 2001, on the Kaibab Plateau, Arizona.

Prey Species[1]	Nest number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Nuttall's Cottontail		3	3	3	6	3	2	1	2	2	4	1	4	1	2	5	3	2	4	2	2	2
Golden-mantled Ground Squirrel			1	3	2	4		1		4	2	1	1	2	1	5		3		1		2
Rock Squirrel		2	4	1	5	2	1		1		1	2	2			1	1		1	1		1
Kaibab Squirrel		2		2	2	1				3	2		1			3	2	2	1		1	2
Chipmunk		2		1		2	1		1	1	2			1		2	3		1		1	1
Northern Pocket Gopher		1	1	1	1		1			1	1				1		2		1	1		1
Long-tailed Vole		1			1			1	1								1	1	1			1
Red Squirrel				1	1		2						1	2				1	1			
Mouse					2	1							2						2	1		
Shrew		2	1		1			1	1		1		1						1			1
Black-tailed Jack Rabbit										1	1					1				1		
Long-tailed Weasel										1	1		1				1	1				
Mule Deer																	1				1	
Plains Pocket Mouse					2																	
Porcupine												1										
Ringtail																						
Coyote																						

Appendix B.
Continued

Prey Species[1]	Nest number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Northern Flicker		3	2	1	5	2	1	1		1	2	1	2			4	5	3		1	1	
Steller's Jay		1	2		5	1		1			2	1	2		1	4	4	1		1	2	1
Clark's Nutcracker					2		1						1				1	2				
Unknown Avian											2							1	1			
Common Raven											1									1		
Western Bluebird				1																		
Hairy Woodpecker				1																		
Common Nighthawk																						
Snake																						1
Mountain Short Horned Lizard[2]																						
Total number of individuals		18	16	18	39	21	15	13	14	23	32	18	30	19	19	40	40	34	32	29	28	34
Numer of collections per nest		4	4	5	10	5	2	1	2	4	7	2	5	2	2	9	6	4	5	2	3	4

[2]Scientific names are listed in Appendix A

[3]Observed but not collected in pellets or prey remains.

Appendix B.

Continued

Prey Species[1]	Nest number	22	23	24	26	28	31	32	34	35	36	37	38	40	41	44	45	46	49	52	60
Nuttall's Cottontail			1	1	2	2	2	2	2	1		1	1	2		4	2	3			
Golden-mantled Ground Squirrel				2		1	2			2						3		2	2		1
Rock Squirrel			1	2	1		1		2	1		1	1		1	4	2	1	2	1	
Kaibab Squirrel				2		1		4	1				1			2	1			1	
Chipmunk				1		1	1	1	1					1		1					
Northern Pocket Gopher		1		1		1	1		1		1				1		1		1		
Long-tailed Vole							1		1	1	1				1		1	1			1
Red Squirrel				1	1		1			1	1						1				
Mouse			2	1			1											1			
Shrew																			1		
Black-tailed Jack Rabbit			1					1							1				1		
Long-tailed Weasel																					
Mule Deer				1	1												1				
Plains Pocket Mouse																		1			
Porcupine						1															
Ringtail																1					
Coyote																	1				

Appendix B.
Continued

Prey Species[1]	Nest number 22	23	24	26	28	31	32	34	35	36	37	38	40	41	44	45	46	49	52	60
Northern Flicker	1	1	1	1	1	1		2						1	2	3	1		1	
Steller's Jay		1	3	1	2		2		1						1	4		2	1	
Clark's Nutcracker					1								1		1	2	1			
Unknown Avian				1		1	1	1												
Common Raven					1															
Western Bluebird																				
Hairy Woodpecker																				
Common Nighthawk		1																		
Snake							2													
Mountain Short Horned Lizard[2]																				
Total number of individuals	24	31	40	34	40	43	45	45	42	39	39	41	44	46	63	64	57	58	56	62
Numer of collections per nest	1	2	3	2	4	4	5	3	3	1	1	1	2	1	5	4	3	3	1	1

[2]Scientific names are listed in Appendix A

[3]Observed but not collected in pellets or prey remains.

Appendix C. Prey species present at 40 individual red-tailed hawk nests; assessed from pellets and prey remains collected from the nest at the end of the breeding season August-October 1998, 1999, 2000, and 2001, on the Kaibab Plateau, Arizona.

Prey Species	Nest number	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Nuttall's Cottontail		3	2	3	4	3	1	1	1	2	4	1	3	1	2
Golden Mantled Ground Squirrel			1	1	1	2		1		3	1	1	1	2	1
Rock Squirrel		1	3	1	3	2			1		1	2			
Kaibab Squirrel		1		1	2					3	2		1		
Chipmunk		1		1		1	1		1		2			1	
Northern Pocket Gopher		1	1		1					1	1				1
Long-tailed Vole		1						1	1						
Red Squirrel				1			2							2	
Mouse					2								1		
Shrew		2	1					1	1		1				
Black-tailed Jack Rabbit										1					
Long-tailed Weasel										1	1		1		
Mule Deer															
Plains Pocket Mouse					2										
Porcupine												1			
Ringtail															
Coyote															
Northern Flicker		2	1	1	3	1		1		1	2	1	2		
Steller's Jay		1	2		3	1		1			1	1	1		1
Clark's Nutcracker					1		1								
Unknown Avian															
Common Raven											1				
Western Bluebird				1											
Hairy Woodpecker				1											
Common Nighthawk															
Snake															
Mountain Short Horned Lizard[2]															
Total number of individuals per nest		13	11	11	22	10	5	6	5	12	17	7	10	6	5
Numer of collections per nest		3	2	3	4	3	1	1	1	3	4	2	3	2	2

[1]Scientific names are listed in Appendix A

[2]Observed not collected in pellets or prey remains

Appendix C.
Continued

Prey Species Nest number	15	16	17	18	19	20	21	22	23	24	26	28	31	32
Nuttall's Cottontail	3	2	2	2	2		1		1		2	1	1	
Golden Mantled Ground Squirrel	2		2		1		1			1		1	1	
Rock Squirrel				1	1				1	2	1			
Kaibab Squirrel	2	1	1			1	2			1				3
Chipmunk	2	2				1	1					1	1	1
Northern Pocket Gopher		2		1	1			1					1	
Long-tailed Vole		1	1	1										
Red Squirrel										1	1	1		
Mouse				1	1				2				1	
Shrew							1							
Black-tailed Jack Rabbit					1				1					
Long-tailed Weasel		1	1											
Mule Deer		1								1	1			
Plains Pocket Mouse														
Porcupine												1		
Ringtail														
Coyote														
Northern Flicker	3	4	2			1		1	1	1		1	1	
Steller's Jay	3	4	1		1	2			1	2	1	1		1
Clark's Nutcracker		1	2									1		
Unknown Avian													1	1
Common Raven					1							1		
Western Bluebird														
Hairy Woodpecker														
Common Nighthawk									1					
Snake							1							1
Mountain Short Horned Lizard[2]														
Total number of individuals per nest	15	19	12	6	9	5	7	2	8	9	6	9	7	7
Numer of collections per nest	3	4	2	2	2	1	2	1	2	2	2	3	2	3

Appendix C.
Continued

Prey Species	Nest number	34	35	36	37	38	39	40	41	44	45	46	49	52	60
Nuttall's Cottontail		1	1			1		1		2	1	1			
Golden Mantled Ground Squirrel			1				1					1	2		1
Rock Squirrel		2				1	1		1	1	2		1	1	
Kaibab Squirrel						1				1				1	
Chipmunk								1							
Northern Pocket Gopher									1		1		1		
Long-tailed Vole		1					1		1			1			1
Red Squirrel		1									1				
Mouse												1			
Shrew															
Black-tailed Jack Rabbit									1				1		
Long-tailed Weasel															
Mule Deer															
Plains Pocket Mouse															
Porcupine															
Ringtail										1					
Coyote															
Northern Flicker		1							1	1	1	1		1	
Steller's Jay							1			1	1			1	
Clark's Nutcracker										1	1				
Unknown Avian		1													
Common Raven															
Western Bluebird															
Hairy Woodpecker															
Common Nighthawk															
Snake															
Mountain Short Horned Lizard[2]															
Total number of individuals per nest		7	2			3	4	2	5	8	8	5	5	4	2
Numer of collections per nest		2	2			1	1	1	1	2	1	1	1	1	1

Appendix D. Prey species present at 30 individual red-tailed hawk nests; assessed from pellets and prey remains collected opportunistically at the base of the nest tree during the breeding season May-July 2000 and 2001, on the Kaibab Plateau, Arizona.

Prey Species[1]	Nest number	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Nuttall's Cottontail			1		2		1		1				1		
Golden-mantled Ground Squirrel				2	1	2				1	1				
Rock Squirrel		1	1		2		1						2		
Kaibab Squirrel		1		1		1									
Chipmunk		1				1				1					
Northern Pocket Gopher				1			1								
Long-tailed Vole					1										
Red Squirrel					1								1		
Mouse						1									
Shrew					1								1		
Black-tailed Jack Rabbit											1				
Long-tailed Weasel															
Mule Deer															
Plains Pocket Mouse															
Porcupine															
Ringtail															
Coyote															
Northern Flicker		1	1		2	1	1								
Steller's Jay					2						1		1		
Clark's Nutcracker					1										
Unknown Avian					1						2				
Common Raven															
Western Bluebird															
Hairy Woodpecker															
Common Nighthawk															
Snake															
Mountain Short Horned															
Total number of individuals		4	3	4	14	6	4		1	2	5		6		
Numer of collections per nest		1	2	2	6	2	1		1	1	3		2		

[1]Scientific names are listed in Appendix A

[2]Observed not collected in pellets or prey remains

Appendix D.
Continued

Prey Species[1] Nest number	15	16	17	18	19	20	21	22	23	24	26	28	31	32	34
Nuttall's Cottontail	2	1		2		2	1			1		1	1	2	1
Golden-mantled Ground Squirrel	3		1							1			1		
Rock Squirrel	1	1					1						1		
Kaibab Squirrel	1	1	1	1						1		1		1	1
Chipmunk		1		1						1					1
Northern Pocket Gopher							1			1		1			1
Long-tailed Vole							1						1		
Red Squirrel			1	1											
Mouse				1			1			1					
Shrew				1											
Black-tailed Jack Rabbit	1													1	
Long-tailed Weasel															
Mule Deer						1									
Plains Pocket															
Mouse															
Porcupine															
Ringtail															
Coyote															
Northern Flicker	1	1	1			1						1			1
Steller's Jay	1					1	1			1		1		1	
Clark's Nutcracker		1													
Unknown Avian				1										1	
Common Raven															
Western Bluebird															
Hairy Woodpecker															
Common Nighthawk															
Snake														1	
Mountain Short Horned															
Total number of	10	6	4	8		5	6			7		5	4	7	5
Numer of collections per	6	2	2	3		2	2			1		1	2	2	1