FOOD HABITS OF THE HOARY BAT (*LASIURUS CINEREUS*) DURING SPRING MIGRATION THROUGH NEW MEXICO

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ABSTRACT—Hoary bats (*Lasiurus cinereus*) exhibit continental patterns of migration that are unique to bats, but details about their behaviors during migration are lacking. We captured 177 hoary bats in spring and early summer 2002 as individuals migrated through the Sandia Mountains of north-central New Mexico. Our results support earlier observations of asynchronous timing of migration between sexes of *L. cinereus* during spring, with females preceding males by ca. 1 month. We provide the first evidence that hoary bats may travel in dispersed groups, fly below the tree canopy along streams, and feed while migrating during spring. Analysis of guano revealed that diet of *L. cinereus* consisted mostly of moths, with more than one-half of samples identified as Noctuidae and Geometridae. We observed a late-spring decline in consumption of moths that might be related to seasonal changes in abundance of prey, differential selection of prey by bats, or sampling bias. We suspect that spring migration of *L. cinereus* through New Mexico temporally coincides with the seasonal abundance of moths.

RESUMEN—Murciélagos cola peluda canosos (*Lasiurus cinereus*) presentan patrones continentales migratorios que son únicos en los murciélagos, pero faltan detalles sobre su comportamiento migratorio. Capturamos a 177 murciélagos cola peluda canosos en la primavera y principios de verano del 2002 cuando los individuos emigraron por las Sandia Mountains del norte-centro de Nuevo México. Nuestros resultados respaldan las previas observaciones de la asincronización migratoria entre los sexos de *L. cinereus* durante la primavera, con las hembras procediendo a los machos aproximadamente un mes. Proveemos la primera evidencia de que los murciélagos cola peluda canosos quizás viajan en grupos dispersados, vuelan debajo del dosel forestal a lo largo de los riachuelos, y comen durante su actividad migratoria primaveral. El análisis de guano reveló que la dieta de *L. cinereus* constaba principalmente de polillas, con más de la mitad de las muestras identificadas como Noctuidae y Geometridae. Observamos una disminución a fines de la primavera en el consumo de polillas que puede estar relacionada con los cambios estacionales en la abundancia de presas, la selección diferencial de presas por murciélagos, o sesgo muestral. Sospechamos que el paso migratorio primaveral de *L. cinereus* por Nuevo México coincide con la abundancia estacional de polillas.

Hoary bats (*Lasiurus cinereus*) are among the most wide-ranging mammals in North America, and their seasonal movements illustrate the unique migration strategies of bats (Findley and Jones, 1964; Cryan, 2003). Behaviors and distributions of male and female bats often are decoupled during spring and summer (Fleming and Eby, 2003). For example, female hoary bats leave wintering grounds in California and Mexico earlier than males during spring, and tend to migrate farther into northern and eastern regions of the continent than males (Findley and Jones, 1964; Cryan, 2003). In New Mexico, female hoary bats captured during spring usually are pregnant (Bogan, 1972; Druecker, 1972) and less likely than males to use energy-saving torpor when faced with cold temperatures (Cryan and Wolf, 2003). This energetically demanding combination of pregnancy and defense of normothermic body temperatures likely imposes additional challenges to the already risky behavior of long-distance migration. How do hoary bats, especially pregnant females, minimize the risk of starvation or energy deficits that impede gestation while migrating through areas subject to inclement

weather? Do hoary bats actively feed during spring migration to offset such energy demands? If so, do they exploit specific sources of food or use a more generalized feeding strategy? We captured hoary bats as they migrated through New Mexico during spring 2002 and collected guano to try and better characterize the food resources they exploit during this critical period. We also report the first anecdotal observations on flight behavior and possible group travel of hoary bats during spring migration.

MATERIALS AND METHODS—We captured *L. cinereus* at three proximate sites in the Sandia Mountains east of Albuquerque, Bernalillo Co., New Mexico, during 8 May–25 June 2002. These sites included San Pedro Wash (35°12′N, 106°18′W), upper Tijeras Canyon (35°4′N, 106°23′W), and lower Tijeras Canyon (35°4′N, 106°25′W); sites were netted for 16, 5, and 9 nights, respectively. All capture sites were within 18 km of each other, 1,830–1,970 m in elevation, and situated in riparian areas associated with small streams (1–3 m wide) running through piñon-juniper (*Pinus-Juniperus*) woodlands and mixed-conifer forests. Riparian vegetation along stream banks was dominated by narrow-leaf cottonwood (*Populus angustifolia*), Siberian elm (*Ulmus pulmia*), and willow (*Salix*). We captured bats in mist nets set over pools in flowing or intermittent streams. Nets were monitored continuously, and we recorded the time that each bat was captured, as well as noted when multiple bats were captured together (±10 s). Bats were promptly removed from nets, and we determined sex, age, and reproductive condition using standard methods (Anthony, 1988; Racey, 1988). Bats were placed in clean, individual cloth bags and held for ≥15 min for collection of guano. Mist nets typically were opened 2–4 h/night of sampling. Tissue biopsies were taken from plagiopatagia of most (86%) bats as part of another study, thus providing marks that allowed us to determine if recaptures were common. All bats were released at the initial site of capture.

We examined guano following techniques described by Whitaker (1988). This involved dissecting guano pellets and observing small fragments with a stereo microscope and identifying insect prey items to their lowest taxonomic level, usually family. Number of pellets obtained per individual was 1–5. All guano collected from an individual was regarded as a single sample. After identification of insect fragments, we visually estimated the proportional volume of each insect taxon in samples from individuals (% volume) and across groups of individuals (total proportional volume; sum of individual volumes/total volume × 100). We also calculated frequency of occurrence of each type of prey in samples (% frequency). Two-sample *t*-tests were used to compare diet between sexes on nights when both males and females were captured. To examine temporal trends in diet we averaged volume data across individuals by day of collection.

RESULTS—We captured 177 hoary bats (63 males, 114 females) in 30 nights of netting during our study. Mist nets were deployed for a total of 66 h. We captured significantly more females in May (82%; $\chi^2 = 31.4$, $df = 1$, $P < 0.001$) and significantly more males in June (83%; $\chi^2 = 12.0$, $df = 1$, $P < 0.001$). Analysis of times of capture showed that shorter periods elapsed between captures of females (8.3–13.1 min; 95% C.I.) than between captures of males (16.3–30.1 min). On five occasions, pairs of bats were observed entering nets simultaneously, and on three occasions, three bats were captured in nets together at the same time. Most bats were captured above the center of the watercourse, within 2 m of the surface, and hoary bats could sometimes be seen moving in direct flight beneath the canopy of trees lining stream banks. None of the 153 marked bats was recaptured. Of our total sample, we collected and analyzed guano from 133 individuals throughout our sampling period (44 males, 89 females).

Our analyses revealed that *L. cinereus* consumed 12 families of insects, belonging to 6 orders (Table 1). No significant difference in diet was detected between males and females. Overall, lepidopterans (moths) composed the greatest proportion (percentage volume 93.1%) of insects consumed. Lepidopterans also were the most frequently consumed prey item yielding 99.2% frequency of occurrence across all samples. Coleoptera (beetles), Hemiptera (bugs), and Hymenoptera (ants and wasps) also were discovered in samples, with proportional volumes of 2.2, 2.1, and 2.2%, respectively (Table 1). However, dipterans (flies; 14.3% frequency) were encountered more frequently than coleopterans (11.3%), hemipterans (11.3%), and hymenopterans (6.8%). All other prey items in the diet were represented at <1% of sample volumes (Table 1).

When diet of *L. cinereus* was examined based on date of capture, there was a slight trend toward a lower proportion of moths in the diet after mid-June. This mid-June increase in other non-moth prey mostly was attributed to insects of the orders Hemiptera, Hymenoptera, and Coleoptera. Another exception to the predominance of moths in guano occurred on 29 May when 47% of the total sample volume consisted of beetles (Coleoptera).

DISCUSSION—Our observations support the findings of earlier researchers that showed

TABLE 1—Families and orders of insects identified in guano of 133 hoary bats (*Lasiurus cinereus*) sampled in New Mexico during spring 2002. Values given are of each taxon across all samples. Values of total proportional volume for each order in parentheses equals the sum of all values for each order, whereas frequency of occurrence in parentheses are values for each taxonomic order in samples. Sexual difference in diet was not observed.

Prey item	Total proportional volume (%)	Frequency of occurrence (%)
Geometridae	0.7	0.8
Noctuidae	50.8	51.1
Unknown Lepidoptera	41.6	47.4
All Lepidoptera	(93.1)	(99.2)
Carabidae	0.3	1.5
Scarabaeidae	1.4	3.8
Unknown Coleoptera	0.5	6.0
All Coleoptera	(2.2)	(11.3)
Cicadellidae (Auchenorhyncha)	0.2	2.3
Lygaeidae (Heteroptera)	1.2	3.8
Pentatomidae (Heteroptera)	(0.7)	5.3
All Hemiptera	(2.1)	(11.3)
Braconidae	0.6	0.8
Ichneumonidae	1.5	2.3
Unknown Hymenoptera	0.2	3.8
All Hymenoptera	(2.2)	(6.8)
Tachinidae	0.1	3.8
Unknown Diptera	0.1	10.5
All Diptera	(0.2)	(14.3)
Hemerobiidae	0.0	0.8
Myrmeleontidae	0.1	1.5
All Neuroptera	(0.1)	(2.3)
Unknown insects	(0.1)	(7.5)
Unknown material	(0.0)	(3.0)

female *L. cinereus* tend to migrate through New Mexico about a month before males in spring (Findley and Jones, 1964; Jones, 1966; Findley et al., 1975). Our lack of recaptures, combined with consistent presence of female hoary bats only during spring in New Mexico (Cryan 2003), suggests that most bats captured were actively migrating. However, some of the males we captured later in June may have been residing in the study area, because male *L. cinereus* regularly occur in the region during summer (Findley et al., 1975). Overall, our general impression was that hoary bats were migrating at low altitudes above water courses where we captured them and that they were feeding as they traveled. We are not aware of any other published information on the flight behavior of hoary bats during spring migration. However, the high proportion of collision incidents (e.g., buildings, aircraft, and wind turbines) reported from autumn (Cryan and Brown, 2007) indicate fundamental differences in flight behavior between migration seasons (Cryan and Veilleux, 2007).

Diet of *L. cinereus* has been described as being composed mostly of moths (Ross, 1967; Black, 1972, 1974; Whitaker and Tomich, 1983; Barclay, 1985), but other prey items such as beetles, flies, grasshoppers, termites, dragonflies, and wasps also have been noted (Poole, 1932; Ross, 1967; Zinn and Baker, 1979; Rolseth et al., 1994). Studies by Ross (1967) and Black (1974) involved comparable samples of hoary bats captured during spring in New Mexico. We examined 124 museum specimens collected by Ross (1967) and housed at the Museum of Southwestern Biology and found that 92% were collected during May and June 1960 and 1961. Females were captured only during May and in greater numbers than males, whereas males were cap-

tured in May through July, with the greatest number being in June (71% of all males). Black (1974) reported capturing 74 hoary bats during 1970 in the San Mateo Mountains, Socorro Co., New Mexico. Of those captures, 56% occurred in May and June, 28% in July, and 18% in September (Black, 1974). Thus, both studies offer comparable data on the spring diet of hoary bats. Overall, our findings were similar to those of Ross (1967) and Black (1974); diet of *L. cinereus* seems to be dominated by lepidopterans during spring in New Mexico.

We observed a trend toward fewer moths in the diet of hoary bats during late spring and early summer. Warner (1985) studied diet of 12 hoary bats collected at a site in northern Arizona during June–August and reported that diet was dominated by moths, but showed greater frequencies of other orders of insects than we observed. Temporal shifts in diet related to availability of prey are common in vespertilionid bats in the southwestern United States. For example, Valdez (2006, in litt.) observed temporal changes in diet of *Myotis occultus* and postulated that seasonal and latitudinal changes in temperature may explain presence or abundance of certain prey items (e.g., beetles) in guano collected during early spring. This hypothesis seems to be supported by seasonal presence (7 March–10 October 1970) and abundance of nocturnal insects collected in the San Mateo Mountains, New Mexico, by Black (1974). During all months of collecting nocturnal insects, moths outnumbered all other orders of insects sampled and only soft-bodied insects (e.g., lepidopterans, dipterans, and hymenopterans) were captured in light traps during March–May (Black, 1974). Although light traps are biased toward certain types of insects, this observed preponderance of moths suggests that hoary bats opportunistically exploit the most abundant food source during spring migration through the region.

Regional or demographic differences in diet of hoary bats might also exist. In the Delta Marsh of Manitoba, Canada, hoary bats consumed greater proportions of odonates (dragonflies) and coleopterans, with beetles composing a greater proportion of samples than moths during June (Barclay, 1985; Rolseth et al., 1994). Low prevalence of coleopterans in samples from *L. cinereus* in New Mexico may simply reflect inactivity of beetles during early spring in the southwestern United States, but it also could be attributed to regional differences in availability of prey.

Differences in energy needs and foraging abilities of individual bats might also contribute to observed regional differences in foods of hoary bats. Many female hoary bats captured while migrating through New Mexico in spring were in early stages of pregnancy (Findley and Jones, 1964; Druecker, 1972; Cryan and Wolf, 2003), whereas those occurring in Canada are typically in late stages of pregnancy or lactating (Hickey and Fenton, 1996). Female bats may be more likely to feed on less-maneuverable prey such as beetles during late pregnancy and lactation (Anthony and Kunz, 1977), possibly influencing the observed differences in diet between New Mexico and Canada. Inasmuch as beetles were more prevalent than moths in diet of juvenile *L. cinereus* sampled in Manitoba (Rolseth et al., 1994), it seems possible that ease of capture might influence dietary composition of inexperienced bats. However, we cannot discount the possibility that differences in diet observed between this and other studies are due to sampling bias. Additional studies from other regions and different seasons are needed to better assess variation in diet of hoary bats.

In general, fragments of lepidopterans are difficult to identify more precisely than to order when examining guano. However, we were able to identify two families of moths in guano, Noctuidae and Geometridae; noctuids were identified most frequently. Ross (1967) also reported that noctuid moths (=Phalaenidae) were the most common prey consumed by the 131 *L. cinereus* he sampled during spring in New Mexico. In Manitoba, Canada, Hickey et al. (1996) recovered wings of noctuid moths more frequently than any other family of lepidopterans eaten by foraging hoary bats. Like previous researchers, we also saw evidence that hoary bats feed on moths of the family Geometridae, but in smaller quantities than noctuids (Ross, 1967; Hickey et al., 1996). Characteristics of echolocation calls of hoary bats indicate a foraging strategy involving long-range detection of large-bodied prey (Barclay, 1986). Moths may dominate diet samples from hoary bats simply because they are more likely to be detected by echolocation calls (Griffin, 1958; Black, 1974; Barclay and Brigham, 1991). This long-range foraging strategy may be an important component of survival

for migrating bats that are continually moving across a landscape and not stopping to forage in particular areas. Predominance of moths in the spring diet of hoary bats in New Mexico coincides with the general timing of irruptions of cutworm (Noctuidae) and other moths in the region. It is unclear whether these irruptions involve newly hatched or migrating moths. Regardless of origins of these moths, our evidence indicates that hoary bats exploit this abundant food while migrating through the region. The synchronous timing of spring migration by hoary bats and irruptions of cutworm and other moths in the Southwest could potentially help minimize risks associated with long-distance migration, particularly to pregnant females in need of a consistent and readily available food.

Among bats killed by wind turbines, hoary bats have thus far been recovered more frequently than any other species in North America (Kunz et al., 2007; Arnett et al., 2008). Few fatalities of bats at wind turbines occur during spring; most are documented during late summer and autumn (Cryan and Brown, 2007; Arnett et al., 2008). The ultimate reason for susceptibility of bats to wind turbines has not been established, but it is hypothesized that they may be attracted to insects concentrated around turbines and, thus, collide with blades of turbines while foraging (Kunz et al., 2007). Alternative hypotheses also have been proposed that do not involve feeding (e.g., attraction to sounds or magnetic fields around turbines, bats looking for opportunities to roost, aggregate, or mate; Kunz et al., 2007; Arnett et al., 2008; Cryan, 2008). Little is known about food habits of hoary bats during autumn migration. Analysis of gastrointestinal tracts of hoary bats killed by wind turbines during late summer and autumn would not only help us understand seasonal variation in the food habits of the species, but potentially offer important clues into the circumstances leading up to collisions.

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