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Information on diets is fundamental to ecological studies. Prey use by the solitary, tree-roosting hoary bat (*Lasiurus cinereus)* in agricultural landscapes is not known. We examined the stomach contents and fecal material from carcasses of hoary bats collected during a mortality study at wind turbine sites in southwestern Minnesota. We compared diet of hoary bats to availability of prey to determine whether bats were opportunistic or selective. Food of the hoary bats primarily consisted of lepidopterans (moths; 49-50 %) and coleopterans (beetles; 28-40 %). The abundance of insects in the diet of hoary bats was not proportional to the estimated availability of prey. Hoary bats selected large, soft-bodied insects (e.g., lepidopterans and neuropterans) and avoided small or hard-bodied insects (e.g., coleopterans, dipterans, and hemipterans). We suggest that hoary bats do not select prey based on availability, but rather, select prey that are large and soft-bodied.
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INTRODUCTION

Bats of the genus *Lasiurus* are typically solitary and tree-roosting and considered aerial hawking insectivores[1]. Hoary bats (*L. cinereus*) fly at high speeds, prefer open foraging areas, and capture insect prey in flight[2-4]. Their vocalizations, consisting of a single harmonic and a relatively constant, low frequency, are used to locate relatively large prey at long distances in habitats free of obstacles[3]. The apparently high energetic costs of open-air foraging may be mitigated by foraging in areas where insects are concentrated[5].

Previously, prey use by the hoary bat has been investigated from fecal pellets[6-9], stomach contents[10-12], and complete digestive tracts[13, 14]. Hoary bats primarily feed on moths, beetles, flies, grasshoppers, termites, dragonflies, and wasps. Several authors have described hoary bats as moth specialists[6, 8-10, 11, 13, 15, 16], while others have suggested that hoary bats may be opportunistic, especially when other species of bats are absent[14]. Although the hoary bat is a common resident and migrant visitor to the agricultural region of Northern Great Plains[17], no information exists on prey use by the hoary bat in Minnesota or throughout the tallgrass prairie region of the midwestern U.S. Because these grasslands have been largely converted from tallgrass prairie to row-crop agriculture, it is likely that the prey base has changed and the resulting diet of hoary bats reflects the local prey base.

The objective of this study was to determine prey use of the hoary bat in the agriculturally dominated areas of southwestern Minnesota. Given the extensive geographic range of this species, ecotypic variation in diet likely exists because of differences in prey availability and other ecological factors. Specifically, we sought to determine if prey selection existed by comparing prey use to prey availability. If hoary bats are non-selective opportunists, prey abundance in their diet should be proportional to availability. In contrast, non-proportional use of prey would indicate food preference and diet selection.

STUDY AREA

This study was conducted in an agricultural landscape along Buffalo Ridge of Southwestern Minnesota (extending from 44º 25' N, 96º 27' W in the northwest to 44º 04' N, 96º 07' W in the southeast). Buffalo Ridge is formed by the 100-km Bemis Moraine that traverses Pipestone and Lincoln Counties of southwestern Minnesota and extends into eastern South Dakota. Elevation on the ridge ranges from 546 to 610 m and the ridge separates the Missouri River and Mississippi River watersheds. The area is dominated by cultivated cropland comprised mostly of corn (*Zea maize*), soybeans (*Glycine max*), and small grains. Old fields, wildlife management areas, wooded homesteads, and small stock ponds are scattered throughout the area.

METHODS

Bats were collected and stored at -80 °C as part of a larger study examining bat mortality caused by wind turbines[18]. Prey use was determined by examining the contents of the gastrointestinal tract of collected bats. Analyses of stomach contents and feces are both common methods of estimating food habits for small mammals including bats[19-21]. The large intestine and stomach were excised from each bat through an incision in the ventral surface. Bats were considered suitable if they had been killed within 24 hours (i.e., they were neither partially eaten by scavengers nor desiccated[18]).

The contents of individual stomachs were sorted in warm water. Fecal material recovered from the large intestine was loosened with warm water or 90% ethanol and separated under a dissecting microscope at 10 to 30x magnification[22]. Samples primarily consisting of insect viscera were placed first in 50 ml of 2M NaOH for 12 hrs[23]. Preparation in NaOH aided the sorting of stomach contents as the bulk of the non-chitinous material, insect viscera and muscle dissolved. The stomach and intestinal contents of each bat were examined separately. Food items separated from stomachs and intestines were placed on glass microscope slides and preserved in glycerinated gelatin. We placed a cover slip over the sample and the edges sealed with clear varnish[22]. Prepared slides were examined under a compound light microscope at 30 to 400x magnification. When possible, insect fragments were identified to order and family using entomological reference materials[22], and by comparing insect components found in the sample to whole insects collected with adhesive traps (see below). We estimated volume of insects in both stomach and intestine using the grid method[19].

We obtained a reference insect collection and estimated relative abundances of prey populations by collecting flying insects at 48 sites on multiple nights between June and September of 2002. We located sampling sites using a stratified random design so that each dominant vegetation type in the study area was included during each sampling night. Dominant vegetation types included corn field (*Zea maize*), soybean field (*Glycine max*), and grassland. Prey populations were surveyed using adhesive traps made of PVC pipe (40 cm x 10.5 cm) coated with Tangle-Trap Insect Trap Coating (The Tanglefoot Company, Grand Rapids, MI[24]). Although weak-flying insects are more susceptible to capture with adhesive traps, this method allows for the easy monitoring of several sites within a single night[24]. We mounted the adhesive traps 3 m above the ground on metal conduit. Traps were set at dusk and retrieved at dawn the following morning. We measured the body lengths of trapped insects and identified them to order and family when possible. Insect mass (mg) for each individual was estimated using a length-to-weight ratio[25].

To determine if diet estimated from stomach contents and intestine contents provided similar information, we compared the relative proportion of each insect order in diet estimated from the two methods (% volume and % frequency) using contingency table analysis and the G-test[26]. To determine whether bats were using prey proportional to prey availability, we compared the proportion of each order of insect in the diet of bats to availability or relative mass of insects at the study site derived from the adhesive traps using contingency table analyses and the G-test. Where significant differences between diet and availability were detected (P ≤ 0.05), we partitioned the contingency table to determine which groups of insects were selected or avoided (observed abundance in diet being significantly greater or less than expected based on availability).

RESULTS

Of the 140 hoary bats collected, 17 were in suitable condition for diet analysis. Of these 17 suitable bats, 3 were not usable (e.g., stomach was empty and large intestine was missing or empty due to impact with the wind turbine). Of the remaining 14 bats, 11 were used for the stomach content analyses and 12 were used for intestine content analyses.

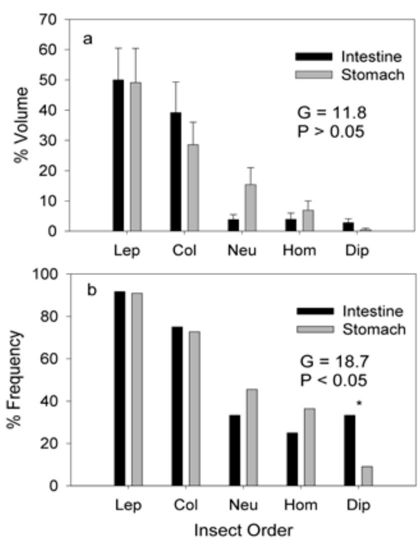

Figure 1. Diet of the hoary bat (*Lasiurus cinereus*) in southwestern Minnesota estimated from the contents of both intestine and stomach. Orders of insects found in the diet of hoary bats included Lepidoptera, Coleoptera, Neuroptera, Homoptera, and Diptera. Comparisons of diet based on stomach and intestinal contents were made using both (a) estimated mean (± SE) percent volume and (b) percent frequency (proportion of all bats that contained that food item. Partitioning of the contingency table allowed the determination of which orders significantly contributed to proportional differences (* indicates P < 0.05).

Five orders of insects were identified in the stomach and intestine samples. In decreasing order of abundance, mean volumetric contents (± SE) of stomachs included Lepidoptera (49.0 ± 11.3%), Coleoptera (28.5 ± 7.4%), Neuroptera (15.3 ± 5.6%), Homoptera (6.8 ± 3.1%), and Diptera (0.5 ± 0.5%). There was no difference between stomach and intestine contents in the proportional representation of orders of insects in diet based on volumetric contents (G = 11.9, P > 0.05; Figure 1a).

Percent frequency of insects in diet provided similar results. In decreasing order of abundance, percent frequency of insect orders in stomachs included Lepidoptera (90.6%), Coleoptera (72.7%), Neuroptera (45.5%), Homoptera (36.4%) and Diptera (9.1%). Based on percent frequency, there was a difference between stomachs and intestines in diet (G = 18.7, P < 0.05; Figure 1b) and partitioning of the contingency table demonstrated that the significance was due to the proportional difference in the least common order of prey, Diptera.

Using adhesive traps, we collected eight orders of insects on the study site. In decreasing order of relative abundance (mean mass ± SE per trap per night), insects sampled on the study site included coleopterans (34.6 ± 19.3 mg), dipterans (4.4 ± 0.8 mg), lepidopterans (4.3 ± 2.3 mg), homopterans (1.8 ± 0.4 mg), hemipterans (1.7 ± 0.6 mg), hymenopterans (0.8 ± 0.4 mg), trichopterans (0.5 ± 0.5 mg), and neuropterans (0.3 ± 0.3 mg). Insect orders in the diet of hoary bats, based on both stomach and intestinal contents, were not proportional to availability of insects on the study site (stomach: G = 55.5, P < 0.01; intestine: G = 33.2, P < 0.01). In particular, relatively large, soft-bodied insects such as lepidopterans and neuropterans were more common in the diet of hoary bats than expected, while relatively small, hard-bodied insects such as coleopterans, dipterans, and hemipterans were less common in the diet than expected (Figure 2).

DISCUSSION

We used two methods to examine diet of hoary bats; 1) contents of the stomachs comprised of mostly undigested material and 2) contents of the large

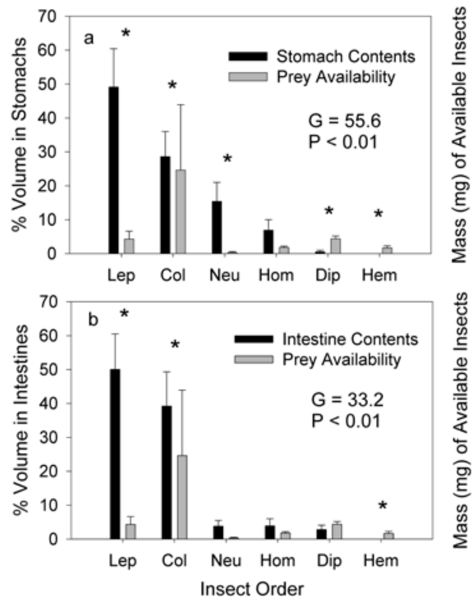

Figure 2. Diet of the hoary bat (*Lasiurus cinereus*) relative to mean prey availability (mg ± SE per trap per night) in southwestern Minnesota. Common orders of insects that were available for consumption induced Lepidoptera, Coleoptera, Neuroptera, Homoptera, Diptera, and Hemiptera. Comparisons of diet to prey availability were made using both mean (± SE) percent volume of prey in stomach contents (a) and intestines (b). Partitioning of the contingency table allowed the determination of which orders significantly contributed to the proportional differences between diet and prey availability (* indicates P < 0.05).

intestine comprised mostly of insect fragments remaining after digestion. Regardless of the data used (i.e., estimated volume or frequency), composition of diet was similar using stomach or intestines. We suggest that both provide accurate information on diet of bats, which is consistent with previous research[11].

Lepidopterans (moths) were the most common prey in the stomachs and intestines by both volume and frequency. This is consistent with previous work that suggests lepidopterans comprise a majority of the diet of hoary bat, which may be a moth specialist[4, 8, 9, 13, 15, 16]. In fact, Whitaker *et al*.[11] noted that hoary bats fed exclusively on lepidopterans in Oregon. However, the idea that hoary bats are moth specialists is not universal. For example, Whitaker and Tomich[14] found that beetles comprised a majority of the hoary bat diet in Hawaii. Similarly, coleopterans, although not preferred, comprised a large proportion of the diet in the bats we examined. In addition, we commonly found insects from order Neuroptera, Homoptera, and Diptera. A diet comprised of a variety of insects in the agricultural landscape of the Northern Great Plains may suggest opportunistic food habits. However, such a statement requires knowledge of the availability of potential prey.

In our study, hoary bats did not forage on prey proportional to their abundance at the study site. Specifically, bats foraged on lepidopterans and neuropterans more than expected, and appeared to avoid coleopterans, hemipterans, and dipterans. Lepidopterans were the most common prey item, but comprised a very small proportion of the prey available at the study site. In contrast, coleopterans were very common in the diet of hoary bats, but were consumed less frequently than expected based on their relative abundance. This result illustrates the importance of collecting data on availability. Data on food habits alone would likely have suggested opportunistic foraging, which has been suggested in the past[6, 13, 14]. However, our data suggest that hoary bats are not opportunistic foragers. Rather, they prefer prey that are relatively large and soft bodied (i.e., Lepidoptera and Neuroptera) and avoid prey that are relatively small or have hard bodies (Coleoptera, Hemiptera, and Diptera).

The small number of Lepidopterans trapped is of interest. Only seven times moths were recorded to have struck the adhesive traps as evidenced by the presence of a smudged area with moth scales or body-part fragments on the adhesive. In fact, data from the adhesive traps indicate that 167 other prey items were available for each Lepidopteran that was available to predators. Compared to beetles, which were in greater abundance and eaten often by bats, moths, although rare, were preferred. It is possible that our method of sampling invertebrates (i.e., sticky traps) in the region was biased, which could influence our conclusions. For example, weak flying or less maneuverable insects may be more susceptible to capture leading to over-representation of such groups in our estimates of availability. However, this method has been used for estimation of prey availability in studies of bat diet[24], and nearly all alternative methods of assessing abundance of invertebrates (e.g., sweep netting, pitfalls, light traps, etc.) have similar potential for bias.

Although we were limited to analysis of only 14 bats, our results provide the first description of prey use by the hoary bat within an agricultural landscape. Patterns of prey selection are strong and are supported. It appears that hoary bats in the agricultural landscape of the Northern Great Plains preferentially foraged on lepidopterans and neuropterans and avoided coleopterans, hemipterans, and dipterans. Land management practices that influence the abundance and distribution of insects, moths in particular, have a strong likelihood of influencing the abundance and distribution of hoary bats. Although specific preferences may vary, it is likely that many species of bats that occupy the Great Plains have diets that are similarly selective. Therefore, composition of the bat community will likely be affected by any practice that alters the local or regional composition of the insect community.

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