Western North American Naturalist 73(4), © 2013, pp. 516–524

INSECT PREY EATEN BY HOARY BATS (*LASIURUS CINEREUS*) PRIOR TO FATAL COLLISIONS WITH WIND TURBINES

Ernest W. Valdez[1] and Paul M. Cryan[2]

ABSTRACT.—Wind turbines are being deployed all across the world to meet the growing demand for energy, and in many areas, these turbines are causing the deaths of insectivorous migratory bats. One of the hypothesized causes of bat susceptibility is that bats are attracted to insects on or near the turbines. We examined insect remains in the stomachs and intestines of hoary bats (*Lasiurus cinereus*) found dead beneath wind turbines in New York and Texas to evaluate the hypothesis that bats die while feeding at turbines. Most of the bats we examined had full stomachs, indicating that they fed in the minutes to hours leading up to their deaths. However, we did not find prey in the mouths or throats of any bats that would indicate the bats died while capturing prey. Hoary bats fed mostly on moths, but we also detected the regular presence of beetles, true bugs, and crickets. Presence of terrestrial insects in stomachs indicates that bats may have gleaned them from the ground or the turbine surfaces, yet aerial capture of winged insect stages cannot be ruled out. Our findings confirm earlier studies that indicate hoary bats feed during migration and eat mostly moths. Future studies on bat behaviors and insect presence at wind turbines could help determine whether feeding at turbines is a major fatality risk for bats.

RESUMEN.—Las turbinas eólicas se están implementando en todo el mundo para cumplir con la creciente demanda de energía y en muchas áreas estas turbinas están provocando la muerte de murciélagos insectívoros migratorios. Una de las posibles causas de la muerte de los murciélagos es que son atraídos por insectos que se encuentran en las turbinas o cerca de ellas. Examinamos los restos de insectos en los estómagos y en los intestinos de los murciélagos grises (*Lasiurus cinereus*) que encontramos muertos debajo de las turbinas eólicas en Nueva York y Texas para evaluar la veracidad de la hipótesis que sostiene que los murciélagos murieron mientras se alimentaban en las turbinas. La mayor parte de los murciélagos que examinamos tenían el estómago lleno, lo cual indicaba que se estaban alimentando cuando murieron. Sin embargo, no encontramos presas en la boca ni en la garganta de ninguno de los murciélagos que indicaran que habían muerto al capturar las presas. Los murciélagos grises se alimentaron principalmente de polillas, detectamos la presencia regular de escarabajos, chinches de campo y grillos. La presencia de insectos terrestres en el estómago indica que es posible que los murciélagos los atraparan en el suelo o en las turbinas, sin embargo no se puede descartar que capturaran a los insectos alados en el aire. Nuestros hallazgos confirman estudios anteriores en los que indican que el murciélago gris se alimenta durante la migración y que consume principalmente polillas. Se necesitan estudios que se enfoquen en la conducta de los murciélagos y en la presencia de insectos en las turbinas eólicas para determinar si los murciélagos que se alimentan en las turbinas corren un mayor riesgo de morir.

Certain insectivorous bats frequently die after encounters with industrial-scale wind turbines. Most of the documented fatalities of bats at turbines involve migratory species that rely on trees as roosts, and the majority of carcasses are found during late summer through autumn (Cryan and Brown 2007, Kunz et al. 2007, Arnett et al. 2008). The hoary bat (*Lasiurus cinereus*) is the most commonly encountered species among turbine fatalities, currently composing about 40% of documented fatalities at wind sites in North America (Kunz et al. 2007, Arnett et al. 2008). Fatality rates of hoary bats at wind turbines are unprecedented, and estimates of total hoary bat fatality at certain wind energy facilities exceed 1000 individuals per year (Arnett et al. 2008, Cryan 2011). The cause or causes of such consistent and high fatality rates of hoary bats at wind turbines remain unknown (Kunz et al. 2007, Cryan and Barclay 2009). One of the hypothesized causes of bat susceptibility to turbines is that bats are attracted to insect prey that might concentrate around or on turbines (Kunz et al. 2007, Cryan and Barclay 2009, Long et al. 2010, Reimer et al. 2010, Rydell et al. 2010a).

Visual observations of bats foraging for insects near operating wind turbines in both Europe and North America lend credence to the plausibility of a link between feeding and bat fatality at turbines (Horn et al. 2008, Ahlén

[1]U.S. Geological Survey, Fort Collins Science Center, Arid Lands Field Station, Department of Biology, MSC03 2020, University of New Mexico, Albuquerque, NM 87131. E-mail: ernie@usgs.gov
[2]U.S. Geological Survey, Fort Collins Science Center, 2150 Centre Ave., Bldg. C, Fort Collins, CO 80526.

et al. 2009, Rydell et al. 2010b). Dissection of bats found beneath turbines in Germany revealed insect food in their stomachs (reviewed by Rydell et al. 2010a). In North America, Reimer et al. (2010) examined the stomach contents of hoary bats and silver-haired bats (*Lasionycteris noctivagans*) found dead beneath turbines at a wind energy site in Alberta, Canada, and found remains of various insects in the stomachs of most individuals, indicating they fed prior to encountering turbine blades. However, the details of exactly where and when the bats fed were unknown. At the Alberta site, adult and juvenile hoary bats fed mostly on moths (lepidopterans), although several other prey types, including flies (dipterans) and true bugs (hemipterans), were consumed by both age classes. Aside from the study by Reimer et al. (2010), very little is known about the feeding habits of hoary bats during the period of late summer and autumn when they are most often found dead beneath wind turbines (approximately mid-July through late October). Gaining additional information on the feeding habits of hoary bats during this season will help assess whether feeding at turbines is a plausible cause of their high fatality rates. Further study will also help identify which insect taxa are likely candidates for attracting bats to turbines, should such a phenomenon exist.

In general, the hoary bat is considered a moth specialist but is also known to feed on a variety of other insects (Black 1974, Whitaker and Tomich 1983, Rolseth et al. 1994, Jacobs 1999, Carter et al. 2003, Valdez and Cryan 2009, Reimer et al. 2010). Some of these other types of insect prey might be consumed opportunistically (as indicated from study of the Hawaiian subspecies *Lasiurus cinereus semotus;* Whitaker and Tomich 1983) or because of factors associated with age or reproductive status (Rolseth et al. 1994, Reimer et al. 2010). Earlier stomach-content and fecal-sample analyses of presumably migrating hoary bats revealed that they consume large quantities of moths during spring as they move through the southwestern United States (Ross 1967, Black 1974, Valdez and Cryan 2009). Migration movements of hoary bats might coincide with high seasonal abundance of prey, such as moths, in migration corridors (Valdez and Cryan 2009), and bats preying on migrating insects during autumn is a leading hypothesis for susceptibility of bats to turbines (Rydell et al. 2010a). If bats are attracted to turbines by insect prey, then gastrointestinal tracts of bats that die at wind turbines should consistently contain evidence of the same types of insects that are most likely to concentrate at turbines or similar landscape structures.

In this paper, we describe results from examination of entire gastrointestinal tracts of hoary bat carcasses found at wind energy facilities in 2 different regions of North America. Our objectives were to determine whether hoary bats were feeding during or prior to fatal encounters with wind turbines and, if so, identify consistent types of insect prey exploited among regions in order to narrow the list of possible attractor taxa, should bats be attracted to insects present around turbines.

METHODS

Carcasses of adult and juvenile male and female hoary bats were collected for analysis from beneath wind turbines at 5 different wind energy facilities in western New York ($n = 4$) and central Texas ($n = 1$) between 10 July and 22 September 2008. Sex and age of each individual was determined using standard methods (Brunet-Rossinni and Wilkinson 2009, Racey 2009). After retrieval of carcasses from wind facility sites, mouths and throats of bats were examined for insect material under a dissecting microscope at 4X magnification (Model MX5200L, Meiji Techno Co., Japan). Examination was followed by the dissection of carcasses and removal of intact esophagi, stomachs, and intestines. These organ structures were subsequently stored in 100% ethyl alcohol. Digesta were dissected from preserved stomachs and intestines, independent of each other, and then placed in 1.5-mL vials to provide an estimate of food volume in each organ. Volumes <0.1 mL were scored as 0 for analyses. Digesta were then placed in a petri dish and examined under a dissecting microscope, following techniques described by Whitaker et al. (2009) and Valdez and Cryan (2009). All insect prey items were identified to lowest taxonomic level, usually to family, using pertinent literature (Borror and White 1970, White 1983, Whitaker 1988, Borror et al. 1989, Arnett 2000, Arnett and Thomas 2001, Arnett et al. 2002, Triplehorn and Johnson 2008). We also used reference material in the arthropod

collection at the Museum of Southwestern Biology, University of New Mexico, Albuquerque, and we sought assistance in identification from entomology experts. In general, taxonomy of insects followed Triplehorn and Johnson (2008), who included both hemipterans and homopterans within the order Hemiptera. We retained the traditional use of Lygaeidae (Borror et al. 1989).

We followed techniques described by Valdez and Cryan (2009) for calculating percent volume and frequency of occurrence of prey items consumed by hoary bats. These included visual estimation of 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). The frequency of occurrence of prey items (% frequency) was calculated by the sum of samples within each representative insect taxon encountered/total number of samples × 100. Contents of stomachs and intestines from each sample were analyzed independently of each other to provide information on the overall feeding habits of individuals, as well as to give insight on the feeding behavior, digestion, and activity of bats before their deaths at wind turbines. Additionally, general comparisons of food habits could be made with other studies that examined contents from stomachs or intestines only. However, to provide a general overview, we present pooled percent volumes and frequencies of occurrence of all food items from stomachs and intestines of hoary bats, grouped by state.

We made certain inferences about the timing and foraging habitats of hoary bats found dead at turbines by examining the frequency and proportional volumes of prey items in their gastrointestinal tracts. For example, greater volumes of certain insects found only in the intestine would suggest that prey was eaten earlier in the night, whereas a greater proportion of a certain prey type in the stomach relative to the intestine would indicate that prey was eaten more recently. We assumed that remains of prey might be present in the mouths or esophagi of bats, if the bats had been struck by a blade or exposed to lethal pressure changes while eating.

Our sampling was opportunistic and did not account for potential differences in site locations, habitat types, timing of sampling, and potential insect prey communities. Statistical comparisons between locations, age, or sex groups were therefore not justified because of potential biases caused by temporal and spatial differences in the co-occurrence of bats and the bats' prey at the different sites and time periods sampled. However, gross comparisons between regions were made to provide general information on feeding behaviors of the hoary bat.

RESULTS

We examined gastrointestinal contents of 57 hoary bats from New York (n = 37) and Texas (n = 20). Whole or partially eaten insects were not found in the mouths, throats, or esophagi of any bats examined, although masticated insect fragments were seen among the cusps of teeth in a few (<4) individuals. For the purpose of comparison with other studies, separate values for stomach and intestinal contents are presented in the Appendix.

Moths (Lepidoptera) represented the greatest proportion of insect prey found in samples from New York (76%) and Texas (66%) and were the most frequently detected insect order, occurring in 96% of the bats from New York and 90% of the samples from Texas (Table 1). Insect groups detected at both sites were of the orders Orthoptera (grasshoppers, crickets, katydids), Coleoptera (beetles), Hemiptera (true bugs), and Diptera (flies), whereas Trichoptera (caddisflies), Neuroptera (antlions, lacewings, and allies), and Hymenoptera (ants, bees, wasps) were detected only in bat carcasses from New York.

We were able to identify remains of certain insect families, including members of the Lepidoptera, such as the Noctuidae (noctuid moths) and Geometridae (geometer moths). These families of moths were identified from characteristic body parts and eggs found in the stomachs and intestines of hoary bats. Noctuid moths were found in samples from both regions, but geometrid moths were identified only from New York samples. Orthopterans, which were prey in both regions, were identified mostly as members of the family Gryllidae (crickets and grasshoppers). Crickets consumed by hoary bats from Texas belonged to the subfamily Gryllinae (field crickets), whereas those from New York belonged to subfamily Nemobiinae (ground crickets). Coleopterans identified to family included terrestrial forms

TABLE 1. Combined contents of stomachs and intestines dissected from carcasses of hoary bats (*Lasiurus cinereus*) found dead beneath wind turbines in New York (n = 37) and Texas (n = 20) in 2010. Percent volume (% Vol; percentage of the total sample that each prey type composed) and frequency of occurrence (% Freq; percentage of samples containing the prey type) were calculated for each type of insect prey. Insect prey types are grouped by taxonomic order and/or family when known, as well as by other presumably non-prey items, such as hair, sand, and plants.

	New York		Texas	
Prey items	% Vol	% Freq	% Vol	% Freq
Lepidoptera	76	96	66	90
Unknown	68	87	39	68
Noctuidae	3	3	27	28
Geometridae	5	5	—	—
Coleoptera	8	37	3	25
Unknown	1	14	2	15
Carabidae	4	16	—	—
Scarabaeidae	1	1	—	—
Cerambycidae	1	1	—	—
Heteroceridae	<1	1	—	—
Alleculinae	<1	5	—	—
Hydrophilidae	1	10	<1	3
Thermonectus	—	—	1	10
Diptera	4	27	<1	10
Unknown	1	24	—	—
Calliphoridae	1	4	—	—
Chironomidae	2	4	—	—
Muscoidea	<1	1	—	—
Hymenoptera	2	15	—	—
Unknown	2	15	—	—
Neuroptera	1	26	—	—
Hemerobiidae	1	26	—	—
Hemiptera	1	19	2	35
Unknown	<1	3	—	—
Lygaeidae	<1	4	<1	13
Delphacidae	<1	1	2	20
Corixidae	<1	3	—	—
Pentatomidae	1	10	<1	5
Orthoptera	2	19	28	65
Unknown	<1	10	11	43
Gryllinae	—	—	17	23
Nemobiinae	2	10	—	—
Trichoptera				
Unknown	<1	4		
Unknown insect	2	28	<1	20
Hair	2	7	—	—
Sand	3	3	—	—
Plant	1	4	—	—

(e.g., Carabidae, ground beetles), aquatic forms (e.g., Hydrophilidae, water scavenger beetles), or both, although not in large volumes. Dipterans consumed by bats from New York included the families Chironomidae (midges) and Calliphoridae (blow flies), although fragments of midges were also detected in a few samples from Texas. Additional insects identified from New York samples were members of the neuropteran family Hemerobiidae (brown lacewings). A small number of carcasses found in New York samples had hair, sand, and plant material in their stomachs. A paraesophageal hiatal hernia (stomach protruding into thoracic cavity through diaphragm) was observed in a male bat from New York; insect prey items were present in the part of the stomach that had moved into the thoracic cavity, indicating rapid and recent herniation.

DISCUSSION

Feeding during migration has been previously demonstrated in hoary bats, and our

results further support the hypothesis that certain insectivorous species of bats supplement energy stores during long-distance migration movements by sometimes feeding en route or during brief stopovers, rather than relying entirely on accumulated body fat (Fleming and Eby 2003, McGuire and Guglielmo 2009, Valdez and Cryan 2009, Reimer et al. 2010, McGuire et al. 2011, Taylor et al. 2011, Šuba et al. 2012, Voigt et al. 2012). If hoary bats depend on the consistent availability of insect prey during migration, and if the airspace around turbines is frequently occupied by insects that can be exploited by migrating hoary bats, it follows that the "feeding hypothesis" for explaining high bat fatality at turbines has great potential as a causal explanation. However, clear evidence linking the insects present around wind turbines to those fed on by bats that died at such structures is still lacking.

Partially eaten insects were not observed in the mouths or esophagi of the hoary bats we examined, as might sometimes be expected if bats were in the act of feeding immediately prior to collision with turbine blades. One possible explanation for the lack of insect prey in the upper gastrointestinal tracts of bat carcasses could be rapid expulsion of esophageal contents associated with thoracic compression during a blade strike or barotrauma event. Grass and sand in the stomachs of some carcasses we examined also indicate that death was delayed in certain bats found beneath turbines, the latter of which has been observed at other wind sites. (Klug and Baerwald 2010). These bats may have had time to swallow or digest the insect prey acquired near turbine blades before dying. However, if foraging success around turbine blades is low and prey capture consequently infrequent, sampling error associated with examination of only 57 carcasses could also account for lack of insect prey in bat mouths and throats. We recommend additional close examination of the mouths and throats of fresh bat carcasses found beneath turbines for evidence that they had food in their mouths during fatal collisions. Considering that tens to hundreds of hoary bats are found at certain wind energy sites each autumn, the approach of closely examining their mouths and throats may be the simplest way of assessing whether bats die at turbines while actively feeding.

Despite the lack of evidence for active feeding at the time of death, most hoary bats examined from the New York and Texas wind energy sites had fed prior to death. Extrapolating what is known about the flight speeds of hoary bats from other studies ($\sim$28 km $\cdot$ h^{-1}; De la Cueva Salcedo et al. 1995) and considering the approximate transit time of insect prey through the gastrointestinal tract of an active bat (30 min in *Myotis lucifugus;* Buchler 1975), we estimate that food items found in the distal intestines of hoary bats we examined could have been consumed in areas as far as 14 km from the wind energy sites where the bats died. Although this is a rough estimate, it illustrates how observation of a full stomach in a bat found dead beneath a wind turbine does not necessarily imply that the bat fed in the immediate vicinity of the turbine prior to death. However, the bat could possibly have fed within the range of the facility, depending on the area occupied by wind turbines.

The overall composition of prey in the stomachs of hoary bats that died at turbines was similar to what has been previously reported for the species during other seasons, with moths eaten more often and in greater abundance than any other prey type (Ross 1967, Black 1972, 1974, Whitaker and Tomich 1983, Valdez and Cryan 2009, Reimer et al. 2010). Similar to the findings of a study of hoary bat carcasses collected beneath turbines from July through September in Alberta, Canada (Reimer et al. 2010), our results indicate that hoary bats fed mostly on moths before dying at wind turbines. The ubiquity of lepidopterans in the diets of hoary bats across wind energy sites and studies reported thus far suggests that if insects are indeed attracting bats to wind turbines, moths are likely involved.

Composition of nonlepidopteran prey types eaten by hoary bats found dead beneath turbines was variable between the New York and Texas sites. For example, hoary bats from New York fed on 7 orders of nonlepidopteran insects, whereas bats from Texas fed on 4 orders of nonlepidopteran insects. However, despite the greater diversity of nonlepidopteran prey types found in New York samples, the proportional volume of the most frequently consumed prey item of this type (i.e., Coleoptera) was only 8%, whereas the most frequently consumed nonlepidopteran prey item from Texas (i.e., Orthoptera) was 28% (Table 1).

In a comparison of food items found in carcasses of hoary bats from wind energy facilities in Alberta (Reimer et al. 2010), prey diversity was similar to our samples from New York. Reimer et al. (2010) documented 7 orders of insects, including Lepidoptera, Diptera, Hemiptera, Homoptera, Coleoptera, Trichoptera, and Neuroptera, consumed by adult and juvenile hoary bats. The proportional volumes reported by Reimer et al. (2010) were greatest for lepidopterans, followed by hemipterans, dipterans, coleopterans, trichopterans, and homopterans. The less consistent presence of nonlepidopteran prey types in hoary bat carcasses among wind energy sites could indicate opportunistic feeding at sites away from turbines rather than feeding on insects that might regularly concentrate on or in the airspace around turbines. Although insects have been studied on the ground near turbines (Long et al. 2010) and are also known to foul turbine blades (Corten and Veldkamp 2001), we are not aware of any published research on the composition and prevalence of insects around the nacelles, towers, and blades of wind turbines. Thus, there is no comparative reference for our findings of multiple prey items in stomachs of hoary bats.

Hoary bats in the Hawaiian Islands (*L. c. semotus*) are "highly opportunistic" in their feeding behavior (Whitaker and Tomich 1983). A certain degree of opportunistic feeding behavior was observed in our study, with a variety of prey items supplementing a diet composed mostly of moths. Ground and field crickets were consumed frequently and in large quantities by the hoary bats we examined, especially those from the Texas site. The presence of ground-dwelling insects, such as crickets, in the diet of hoary bats was somewhat surprising. In a food habits study of bats from Big Bend National Park in Texas, Easterla and Whitaker (1972) reported the presence of orthopterans, likely belonging to the families Gryllidae or Tettigionidae, in the diets of pocketed free-tailed bats (*Nyctinomops femorosaccus*), big free-tailed bats (*Nyctinomops macrotis*), and greater mastiff bats (*Eumops perotis*), all migratory species in the family Molossidae. Similar to the diets of hoary bats that we examined from Texas, gryllid-tettigoniid orthopterans were the second-most abundant and frequently consumed prey items after lepidopterans in free-tailed and mastiff bats sampled in Texas (Easterla and Whitaker 1972). Easterla and Whitaker (1972) suggested that these orthopterans were gleaned from canyon walls. It is possible that such insects could be gleaned by bats from surfaces of turbines as well, and video observations indicate that bats sometimes closely approach and touch wind turbines (Horn et al. 2008). However, most long-distance migratory insectivorous bats like hoary bats and molossids do not show the same morphological adaptations typical of bat species that specialize in gleaning prey (e.g., large ears and wings with low loading values and high aspect ratios). Furthermore, there is no prior evidence that hoary bats glean insect prey from foliage or the ground (Whitaker and Tomich 1983). An alternative explanation for the high volume of crickets in the stomachs of hoary bats that died at wind turbines in Texas is that those insects were flying at the time of capture. Studies on polymorphic forms of cricket wings have shown that there are micropterous (small-winged) and macropterous (large-winged) forms, with development of wing length triggered by cues such as reproduction, crowding, or movement to new habitat. For example, Olvido et al. (2003) found that seasonal climate and density of individuals during development increased the abundance of long-winged forms. Determining where hoary bats obtain typically ground-dwelling prey may help determine whether such insects (which often produce loud mating calls) potentially draw bats toward wind turbines.

We found evidence that hoary bats found beneath turbines in New York and Texas sometimes foraged near wetlands or riparian habitats in the minutes leading up to their deaths at turbines. Similar evidence of hoary bats feeding above aquatic habitats was reported from the study at turbines in Canada (Reimer et al. 2010). Aquatic or semiaquatic families of insects we found in stomachs of hoary bats included Dytiscidae (predaceous diving beetles), Hydrophilidae, Corixidae (water boatmen), and Chironomidae. As with the presence of typically ground-dwelling crickets in the diets of bats not known to extensively glean prey from surfaces, the presence of aquatic insects in hoary bat diets likely involves capturing such insects as they fly from their aquatic habitats to disperse (Reimer et al. 2010). Some movement of dytiscids and

hydrophilids may be related to their attraction to lights at night (Triplehorn and Johnson 2008), but they are also known to leave their natal water source in search of new locations, especially during periods of drought or crowding, similar to corixids under extreme heat temperatures (K.B. Miller personal communication, Velasco and Millan 1998). This behavior was also reported in midges, a diverse group of flies, most of which are highly associated with aquatic habitats, especially during reproduction (Triplehorn and Johnson 2008). Therefore, the presence of these insects in the diets of hoary bats from New York provides additional evidence that bats foraged near aquatic habitats prior to dying at turbines.

Analysis of gastrointestinal tracts did not reveal direct evidence that hoary bats frequently die while pursuing and eating prey around the blades of turbines, but the analysis did show that most hoary bats feed within a short period before they are struck down by turbines. The most prevalent and consistent food exploited by hoary bats within the vicinity of turbines was moths, whereas exploitation of other prey types was much more variable. We believe that the feeding hypothesis for explaining bat fatality at turbines deserves additional study, and we agree with Reimer et al. (2010) that additional techniques, such as monitoring echolocation calls for "feeding buzzes" at turbine nacelles, are needed for establishing causality. We also suggest that better characterization of the types and densities of insects occurring around and on wind turbines is needed, as well as use of more accurate methods of determining specific prey in bat stomachs (e.g., genetic analysis; McCracken et al. 2012). Fatality of hoary bats at turbines occurs consistently across most of North America where wind energy facilities have been built. If this fatality is strongly linked to the consistent presence of certain insects at turbines, there may be simple ways to reduce insect and thus bat occurrence at turbines.

ACKNOWLEDGMENTS

This research was funded in part by the U.S. Fish and Wildlife Service and the USGS Fort Collins Science Center. This work would not have been possible without the help of A. Hicks, L. Slobodnik, and the late A. Linehan. We thank E.A. Snider for her invaluable assistance in the field and A. Englert for help processing bats in the laboratory. The following people and organizations helped us obtain bat carcasses, for which we are grateful: D. Adams, R. Bennett, C. Brown, L. Brown, R. Carnie, D. Crandall, Curry and Kerlinger LLC, A. Fuerst, N. Gill, M. Gilmore, C. Goodman, C. Hansen, A. Harte, B. Hastings, K. Herzog, A. Hicks, J. Histed, Horizon Wind Energy, Iberdrola Renewables, J. Jackson, T. Kidd, J. Kirch, M. Lehman, S. Lehman, J. Lieb, A. Lyndaker, L. Lynn, P. McCarthy, J. Meachum, M. Milholland, T. Nash, Noble Environmental Power, S. Occonor, L. Packer, S. Pageau, D. Pursell, J. Quant, K. Russell, H. Trudell, and L. Vigneault. Thanks to K.B. Miller, S. Brantley, and D. Lightfoot for their insight and assistance in the identification of select insects. We are grateful for the use of reference material housed in the Arthropod Division of the Museum of Southwestern Biology, University of New Mexico. Any use of trade product or firm names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

LITERATURE CITED

AHLÉN, I., H.J. BAAGØE, AND L. BACH. 2009. Behavior of Scandinavian bats during migration and foraging at sea. Journal of Mammalogy 90:1318–1323.

ARNETT, E.B., W.K. BROWN, W.P. ERICKSON, J.K. FIEDLER, B.L. HAMILTON, T.H. HENRY, A. JAIN, G.D. JOHNSON, J. KERNS, R.R. KOFORD, ET AL. 2008. Patterns of bat fatalities at wind energy facilities in North America. Journal of Wildlife Management 71:61–78.

ARNETT, R.H., JR., M.C. THOMAS, P.E. SKELLEY, AND J.H. FRANK. 2002. American beetles, Polyphaga: Scarabaeoidea through Curculionoidea. Volume 2. CRC Press LLC, Boca Raton, FL.

ARNETT, R.H., JR. 2000. American insects: a handbook of insects north of Mexico. 2nd edition. CRC Press, Boca Raton, FL. 1024 pp.

ARNETT, R.H., JR., AND M.C. THOMAS. 2001. American beetles, Archostemata, Myxophaga, Adephaga, Polyphaga: Staphyliniformia. Volume 1. CRC Press LLC, Boca Raton, FL.

BLACK, H.L. 1972. Differential exploitation of moths by the bats *Eptesicus fuscus* and *Lasiurus cinereus*. Journal of Mammalogy 53:598–601.

_____. 1974. A north temperate bat community: structure and prey populations. Journal of Mammalogy 55:138–157.

BORROR, D.J., C.A. TRIPLEHORN, AND N.F. JOHNSON. 1989. An introduction to the study of insects. 6th edition. Saunders College Publishing, Philadelphia, PA.

BORROR, D.J., AND R.E. WHITE. 1970. A field guide to insects: America north of Mexico. Houghton Mifflin Company, Boston, MA.

BRUNET-ROSSINNI, A.K., AND G.S. WILKINSON. 2009. Methods for age estimation and the study of senescence in bats. Pages 315–325 *in* T.H. Kunz and S. Parsons, editors, Ecological and behavioral methods for the study of bats. 2nd edition. Johns Hopkins University Press, Baltimore, MD.

BUCHLER, E.R. 1975. Food transit time in *Myotis lucifugus* (Chiroptera: Vespertilionidae). Journal of Mammalogy 56:252–255.

CARTER, T.C., M.A. MENZEL, S.F. OWEN, J.W. EDWARDS, J.M. MENZEL, AND W.M. FORD. 2003. Food habits of seven species of bats in the Allegheny Plateau and Ridge and Valley of West Virginia. Northeastern Naturalist 10:83–88.

CORTEN, G.P., AND H.F. VELDKAMP. 2001. Insects can halve wind-turbine power. Nature 412:42–43.

CRYAN, P.M. 2011. Wind turbines as landscape impediments to the migratory connectivity of bats. Environmental Law 41:355–370.

CRYAN, P.M., AND R.M.R. BARCLAY. 2009. Causes of bat fatalities at wind turbines: hypotheses and predictions. Journal of Mammalogy 90:1330–1340.

CRYAN, P.M., AND A.C. BROWN. 2007. Migration of bats past a remote island offers clues toward the problem of bat fatalities at wind turbines. Biological Conservation 139:1–11.

DE LA CUEVA SALCEDO, H., M.B. FENTON, M.B.C. HICKEY, AND R.W. BLAKE. 1995. Energetic consequences of flight speeds of foraging red and hoary bats (*Lasiurus borealis* and *Lasiurus cinereus;* Chiroptera: Vespertilionidae). Journal of Experimental Biology 198: 2245–2251.

EASTERLA, D.A., AND J.O. WHITAKER, JR. 1972. Food habits of some bats from Big Bend National Park, Texas. Journal of Mammalogy 52:887–890.

FLEMING, T.H., AND P. EBY. 2003. Ecology of bat migration. Pages 156–208 *in* T.H. Kunz and M.B. Fenton, editors, Bat ecology. University of Chicago Press, Chicago, IL.

HORN, J.W., E.B. ARNETT, AND T.H. KUNZ. 2008. Behavioral responses of bats to working wind turbines. Journal of Wildlife Management 72:123–132.

JACOBS, D.S. 1999. The diet of the insectivorous Hawaiian hoary bat (*Lasiurus cinereus semotus*) in an open and a cluttered habitat. Canadian Journal of Zoology 77: 1603–1608.

KLUG, B.J., AND E.F. BAERWALD. 2010. Incidence and management of live and injured bats at wind energy facilities. Journal of Wildlife Rehabilitation 30:11–16.

KUNZ, T.H., E.B. ARNETT, W.P. ERICKSON, A.R. HOAR, G.D. JOHNSON, R.P. LARKIN, M.D. STRICKLAND, R.W. THRESHER, AND M.D. TUTTLE. 2007. Ecological impacts of wind energy development on bats: questions, research needs, and hypotheses. Frontiers in Ecology and the Environment 5:315–324.

LONG, C.V., J.A. FLINT, AND P.A. LEPPER. 2010. Insect attraction to wind turbines: does colour play a role? European Journal of Wildlife Research 57:323–331.

MCCRACKEN, G.F., J.K. WESTBROOK, V.A. BROWN, M. ELDRIDGE, P. FEDERICO, AND T.H. KUNZ. 2012. Bats track and exploit changes in insect pest populations. PLOS ONE 7:e43839.

MCGUIRE, L.P., AND C.G. GUGLIELMO. 2009. What can birds tell us about the migration physiology of bats? Journal of Mammalogy 90:1290–1297.

MCGUIRE, L.P., C.G. GUGLIELMO, S.A. MACKENZIE, AND P.D. TAYLOR. 2011. Migratory bat stopover in the long-distance migrant silver-haired bat, *Lasionycteris noctivagans.* Journal of Animal Ecology 81: 377–385.

OLVIDO, A.E., E.S. ELVINGTON, AND T.A. MOUSSEAU. 2003. Relative effects of climate and crowding on wing polymorphism in the southern ground cricket, *Allonemobius socius* (Orthoptera: Gryllidae). Florida Entomologist 86:158–164.

RACEY, P.A. 2009. Reproductive assessment of bats. Pages 249–264 *in* T.H. Kunz and S. Parsons, editors, Ecological and behavioral methods for the study of bats. 2nd edition. Johns Hopkins University Press, Baltimore, MD.

REIMER, J.P., E.F. BAERWALD, AND R.M.R. BARCLAY. 2010. Diet of hoary (*Lasiurus cinereus*) and silver-haired (*Lasionycteris noctivagans*) bats while migrating through southwestern Alberta in late summer and autumn. American Midland Naturalist 164: 230–237.

ROLSETH, S.L., C.E. KOEHLER, AND R.M.R. BARCLAY. 1994. Differences in the diets of juvenile and adult hoary bats, *Lasiurus cinereus.* Journal of Mammalogy 75:394–398.

ROSS, A. 1967. Ecological aspects of the food habits of insectivorous bats. Proceedings of the Western Foundation of Vertebrate Zoology 1:205–264.

RYDELL, J., L. BACH, M.J. DUBOURG-SAVAGE, M. GREEN, L. RODRIGUES, AND A. HEDENSTRÖM. 2010a. Mortality of bats at wind turbines linked to nocturnal insect migration? European Journal of Wildlife Research 56:823–827.

_____. 2010b. Bat mortality at wind turbines in northwestern Europe. Acta Chiropterologica 12:261–274.

ŠUBA, J., G. PETERSONS, AND J. RYDELL. 2012. Fly-and-forage strategy in the bat *Pipistrellus nathusii* during autumn migration. Acta Chiropterologica 14: 379–385.

TAYLOR, P.D., S.A. MACKENZIE, B.G. THURBER, A.M. CALVERT, A.M. MILLS, L.P. MCGUIRE, AND C.G. GUGLIELMO. 2011. Landscape movements of migratory birds and bats reveal an expanded scale of stopover. PLOS ONE 6:e27054.

TRIPLEHORN, C.A. AND N.F. JOHNSON. 2008. Borror and DeLong's introduction to the study of insects. 7th edition. Thomson Brooks/Cole, Belmont, CA.

VALDEZ, E.W., AND P.M. CRYAN. 2009. Food habits of the hoary bat (*Lasiurus cinereus*) during spring migration through New Mexico. Southwestern Naturalist 54:195–200.

VELASCO, J., AND A. MILLAN. 1998. Insect dispersal in a drying desert stream: effects of temperature and water loss. Southwestern Naturalist 43:80–87.

VOIGT, C.C., K. SÖRGEL, J. ŠUBA, O. KEIŠS, AND G. PĒTERSONS. 2012. The insectivorous bat *Pipistrellus nathusii* uses a mixed-fuel strategy to power autumn migration. Proceedings of the Royal Society of London Series B–Biological Sciences 279:3772–3778.

WHITAKER, J.O., JR. 1988. Food habits of insectivorous bats. Pages 171–189 *in* T.H. Kunz, editor, Ecological and behavioral methods for the study of bats. Smithsonian Institution Press, Washington, DC.

WHITAKER, J.O., JR., G.F. MCCRACKEN, AND B.M. SIEMERS. 2009. Food habits analysis of insectivorous bats. Pages 567–592 *in* T.H. Kunz and S. Parsons, editors, Ecological and behavioral methods for the study of bats. 2nd edition. Johns Hopkins University Press, Baltimore, MD.

WHITAKER, J.O., JR., AND P.Q. TOMICH. 1983. Food habits of the hoary bat, *Lasiurus cinereus*, from Hawaii. Journal of Mammalogy 64:151–152.

WHITE, R.E. 1983. A field guide to the beetles of North America. Volume 29. Houghton Mifflin Company, Boston, MA.

Received 23 April 2013
Accepted 19 September 2013

APPENDIX. Contents of stomachs and intestines (in parentheses) dissected from carcasses of hoary bats (*Lasiurus cinereus*) found dead beneath wind turbines in New York (n = 37) and Texas (n = 20) in 2010. Percent volume (% Vol; percentage of the total sample that each prey type composed) and frequency of occurrence (% Freq; percentage of samples containing the prey type) were calculated for each type of insect prey. Insect prey types are grouped by taxonomic order and/or family when known, as well as by other presumably non-prey items, such as hair, sand, and plants. Prey types were identified separately to allow comparison to studies that examined only stomach or intestinal contents.

	New York		Texas	
Prey item	% Vol	% Freq	% Vol	% Freq
Lepidoptera	79 (73)	92 (100)	70 (63)	85 (95)
Unknown	71 (65)	84 (97)	40 (39)	55 (75)
Noctuidae	3 (3)	3 (3)	30 (24)	30 (25)
Geometridae	5 (5)	5 (5)	—	—
Coleoptera	5 (9)	35 (35)	2 (3)	15 (35)
Unknown	1 (2)	16 (11)	<1 (3)	15 (15)
Carabidae	2 (5)	11 (22)	—	—
Alleculinae	<1 (<1)	3 (8)	—	—
Hydrophilidae	2 (<1)	11 (8)	0 (<1)	0 (5)
Dytiscidae: *Thermonectus* sp.	—	—	2 (<1)	10 (10)
Scarabaeidae	0 (1)	0 (3)	—	—
Cerambycidae	0 (1)	0 (3)	—	—
Heteroceridae	0 (<1)	0 (3)	—	—
Diptera	1 (4)	24 (30)	<1 (<1)	10 (10)
Unknown	1 (1)	22 (27)	<1 (<1)	10 (10)
Calliphoridae	<1 (1)	3 (5)	—	—
Chironomidae	<1 (1)	3 (5)	—	—
Muscoidea	0 (1)	0 (3)	—	—
Hymenoptera	2 (2)	11 (19)	—	—
Unknown	2 (2)	11 (19)	—	—
Neuroptera	<1 (2)	16 (35)	—	—
Hemerobiidae	<1 (2)	16 (35)	—	—
Hemiptera	1 (1)	19 (19)	<1 (3)	30 (40)
Unknown	<1 (<1)	3 (3)	—	—
Lygaeidae	<1 (<1)	3 (5)	<1 (<1)	10 (15)
Delphacidae	0 (<1)	0 (3)	<1 (3)	15 (25)
Pentatomidae	<1 (1)	11 (8)	<1 (<1)	5 (5)
Corixidae	<1 (<1)	3 (3)	—	—
Orthoptera	1 (3)	16 (22)	27 (30)	75 (55)
Gryllidae	<1 (<1)	8 (11)	14 (9)	55 (30)
Gryllidae: Gryllinae	—	—	14 (20)	20 (25)
Gryllidae: Nemobiinae	1 (3)	8 (11)	—	—
Trichoptera	<1 (<1)	5 (3)	—	—
Unknown	<1 (<1)	5 (3)	—	—
Unknown insect	2 (2)	35 (22)	0 (1)	0 (40)
Hair	1 (2)	5 (8)	—	—
Sand	2 (3)	3 (3)	—	—
Plant	2 (<1)	5 (3)	—	—