2016

Technique for: Determination of Insect Prey Selection by Insectivorous Bats

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Determination of Insect Prey Selection by Insectivorous Bats

Entomology 888:
Masters Degree Project Proposal
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Abstract: Masters Degree Project Utilizing Fecal Pellet Analysis to Determine Prey Selection by Insectivorous Bats: For my Graduate Project I examined culled exoskeleton parts from bat fecal pellets (guano) to determine identifications of the insects preyed upon by a group of bats to their order and often family levels. Culled insect parts were permanently fixed on microscope slides and viewed under a dissection microscope to determine identifications and to quantify the percentage composition that they represented in the bat's diet. Comparisons were made of prey selected by the different bat species that were foraging at the same location and at the same time. Comparisons were also made of the insect species being predated upon bat species foraging at different times and locations. This project evaluated the fecal pellet technique for it effectiveness as a tool in determining prey selection by insectivorous bats as well as an indicator of the flighted nocturnal insects within a habitat. In part the project evaluates if it can be used effectively to compare different species of bats foraging in similar habitats at similar times to see if they are selecting for different insect prey types or rather if they are choosing what is most available. The results can then show if there are differential prey selection pressures being placed on flighted nocturnal insects by different species of bats.

INTRODUCTION

Insects are the most diverse organisms in terms of speciation (75% of all animals), in their shear numbers and in their combined biomass. It also makes them extremely important in any of the ecosystems they inhabit. This makes them extremely important as an energy source for many other organisms within that system. "Considering the nutritional value of insects; it is not surprising that a vast number of animals depend on them as a source of food energy." (Evans, 1984) The ability to fly sets insects, Hexapods, apart from the other invertebrates, an ability that they share only with a few of the higher vertebrates namely birds and bats. The success of the members of Class Hexapoda, according to Daly, Doyen and Purcell in their Introduction to Insect Biology and Diversity, (1998) book, is also in part due to a highly adaptable exoskeleton, an ability to colonize the terrestrial environments, small body sizes, high birthrates, short generation times and the fact that some have a life history with complete metamorphosis. This last one, combined with flighted adults permits them as a species the ability to exploit different habitats at different life stages.

As an important food or source of energy to so many other organisms, including other insects, we find them playing a major role in the flow of energy in many ecosystems. With such an insect diversity we also find many entomophagus (insectivorous) organisms. Through selective processes, insects have many defenses to reduce the pressure of predation. These range from cryptic coloration to aposematism where they, through color or patterns, advertise unpleasant or dangerous attributes of the animal. Many insects have detachable body parts like scales, legs, etc. that aid them in avoiding predation. We find many with deflection marks that lead the attacker towards false eyespots, some insects possess startle displays or flight patterns that reduce the success of the would be predators. Spines, hair that sting and other chemical defensive organs help reduce the level of predation.

The non-cellular cuticle covering secreted by an insect's epidermal layer forms one of their best defenses in the form of an armor-like covering, their exoskeleton. To be successful, a predator needs to be able to break through it or predate (feed) at a time when

this covering is not as structurally hard, such as when the insect is undergoing molting. Many insects also reduce predation successfully with their forms of movement, such as jumping or flying. When insect adults become flighted it allows them to travel greater distances, fly at greater speeds to escape predators, seek food, or assist in the locating of a mate.

The diurnal flighted insects are predated upon by birds and other flighted insects, like the dragonflies (Odonata). The pressure of this heavy predation has resulted in many insects conducting their flights at night under the cover of darkness. Typically the diurnal, flighted insects are stronger and faster fliers than what nocturnal insects are. Predation on the nocturnal flighted insects in many regions is restricted exclusively to mammals in the order Chiroptera; the bats. Within this diverse order of mammals, we have two sub-divisions- the Megachiropterans and the Microchiropterans. They differ in their sensory abilities. The Megachiropterans are predominantly plant based feeders and use vision and olfactory means to navigate and locate food. The Microchiropterans have the ability to echolocate. Echolocation, also referred to as biosonar, allows them to navigate without the need for visual orientation so they can function just as well in no or low light situations. They can, therefore, effectively take advantage of the nocturnal flighted insects with little or no outside competition.

Echolocation is a navigational process in which a bat emits a high frequency sound and then "listens" for its returning echo. It echoes back only if it strikes an object in its pathway, the lack of an echo signifies the lack of any objects ahead. The form the returning echo takes allows the bat to gain information about the object ahead related to its size, shape and texture. This is done with the deciphering of the returning echo. By sending out a series of these high frequency calls, the bat can detect the movement of an object or the speed at which the bat is approaching it. By matching the wavelength of their call to the size of the prey or target item they are seeking, the bat can get better results with its echolocation. The higher the frequency the sound is, the shorter its wavelength will be. Smaller bats tend to predate upon smaller sizes of insects so they tend to emit echolocation calls that are of a higher frequency than what larger insectivorous bats emit.

The use of high frequency calls is somewhat expensive energy wise in that high frequency sounds do not carry through the environment as far as lower frequency sounds. So bats need to emit calls that are of extremely high decibel levels and even then their effective range for returning echoes is not much beyond a meter in distance. Microchiropteran bats, as a group, have mastered this form of perceiving their environment and become a major predator of night flying insects. " As one indication of the affect that bats have on insects is that many kinds of insects have ears for alerting them to the echolocation calls which herald an approaching bat." (Fenton, 1992)

This information leakage is then available to anyone who can hear them. Many families of moths, some crickets, katydids, mantids, and lacewings have members that are able to perceive the echolocating calls from bats. With several of these groups they do not possess any noise making abilities so their ears are probably solely for the function of alerting them to a foraging bat. When the bat's call is able to be detected, different insect species perform one of a number of evasive actions; from changing flight direction,

dropping out of the air, beginning an erratic flight or, in the case of some Tiger Moths, emitting a call back. The last behavior, by the Tiger Moths, is thought to alert the predating bats, through a learned association, of their "bad taste".

Do bats select specific insects as prey or do they simply eat what ever is available to them? Do some insects have a greater predation pressure on them than others? "Knowledge of the diet can provide fundamental insights into the ecology and behavior of an animal, and dietary information is essential for the proper management of any species." (Kutra and Whitaker, 1998) By knowing what an animal eats we can begin to understand the various aspects of its and its prey ecology. "For example dietary information aids in examining energetics, predator prey interactions and partitioning of feeding resources, both within and between species" (Kutra, A. and S. W. Murray, 2000) "The speed of a flying bat and the short detection range inherent in the use of echolocation make discrimination among different types of prey difficult" (Barclay and Brigham, 1991). Season and habitat and which insect species are flighted, therefore available for foraging bats, strongly determine prey selection.

Being flighted, bats have the ability to congregate in areas of insect outbreaks such as the synchronized emergence of some of the aquatic insects. Bats eat 50% of their body weight per day and lactating females may consume more than their body weight per day. This equates to a lot of insects being eaten. The number or total mass of insects that any one bat eats in its lifetime is very high. Eating large amounts of food makes flight expensive for bats. Some bats will begin to process the insect before they ingest it. They may clip off wings or legs that are lower in nutritive value. Bats, to reduce the burden of carrying the weight too long, have teeth (molars) that are "W" shaped for quickly slicing and crunching the insect ensuring the food is well macerated before swallowing. This is followed by a rapid chemical breakdown of the food. In some species of insectivorous bats the remains are eliminated within 35-170 minutes after ingestion, *Myotis lucifugus* (Buchler, 1975). This allows them to process a vast amount of food each night, but to minimize the amount of extra weight they are carrying at any one time.

For most species of insectivorous bats we know little or nothing about their food habits. To what extent do bats predate on non-flighted insects, or on other Arthropods? What are some morphological adaptations of insects to reduce the predation by bats? What are some of the behavioral adaptations and to what level do they successfully reduce predation?

Questions also arise about the predator-prey interactions within an ecosystem between the insects and the various bat species. "Resource portioning is important in community ecology" (Cater et al, 2003). There is an advantage to reducing direct competition amongst species in the same area. But there is also an advantage to not being too specialized in food preferences. This is especially true if you are feeding on a food source such as adult flighted insects, since the succession of insects being at this stage varies from week to week and even from night to night. A balance between reducing competition between predator species and being adaptable to feed on what is available needs to be met.

We cannot directly observe the insects being consumed by these insectivorous bats, so to ascertain their diet we can either examine their stomach or digestive tract

contents or their feces. With the stomach content analysis the bat needs to be captured and killed immediately. "This raises ethical and legal questions with respect to sampling large numbers of bats, especially where endangered or threatened species are involved." (Whitaker, 1988) Another technique is to examine the animal's feces to acquire information about their food habits. This technique does not require the killing of the subject and can even be accomplished without having to directly catch the animal. With this non-destructive sampling method one can collect the fecal pellets that are regularly cast off by bats while foraging and also collect them from their roost sites.

"Although it is valuable for getting food habits information without harming the animal fecal analysis gives a poor indication of diet in most kinds of animals because of differential digestion. However, it gives a good assessment in insectivorous bats because all flying insects contain much chitin, which is nearly indigestible" (Whitaker and Barnard, 2005) " While it is true that most bats thoroughly chew their food, it is usually possible to identify most of the prey remains to a reasonable level, at least to order and often to family." (Whitaker, 1988) It has been found that most bats do not eat many different kinds of insects at any one time so a single fecal pellet may contain the remains of from one to four insects.

METHODS

In this study I determined what insects were predated upon by four different species of bats. My samples were taken from bats foraging at three different locations in Ohio and on five different nights. I used the fecal pellet analysis technique to determine the animals eaten to order, and in many cases to family level. The first study site, the Ohio American Energy Inc. Red Bird West Site in Jefferson County, Ohio (**Map 1**) is located along the east central edge of Ohio. This 3000-acre site was a former strip mining area and is now used as dumping site for the sludge from a coal burning power plant. It also contains large lakes that serve to cool the heated water that circulates the multi-storied concrete cooling tower located one half mile east on the shores of the Ohio River. Sampling was conducted on this site the night of August 11, 2005. Fecal samples from three species of bats, the Red Bat (*Lasiurus borealis*) (**Photo 1**), Little Brown Bat (*Myotis lucifugus*) (**Photo 2**) and the Big Brown Bat (*Eptesicus fuscus*) (**Photo 3**) were obtained. The sampled bats were all captured while they were foraging. They were captured in a mist net stretched perpendicular to a small stream corridor (**Photo 4**) on this site.

The second study site was at the state Killbuck Wildlife Area in Holmes and Wayne Counties in Ohio. The actual sampling site in this project is located in Wayne County, Ohio (**Map 2)**. This study site is in an extensive Wildlife Area and Marsh (**Map 4**). Sample collections were obtained from bats captured in a mist net spanning Jennings Ditch in the northern part of the Wildlife Area (**Photo 5**). Samplings were done on the nights of August 21, 26 and September 9, 2005. Fecal pellets were obtained from two species, the Little Brown Bat and the Big Brown Bat on August 21. Fecal Pellets were obtained from four species, the Little Brown Bat, the Big Brown Bat, the Red Bat and the Northern Long-eared Bat (*Myotis septentrionalis*) (**Photo 6**) on August 26, 2005. Fecal

Pellets were also collected on September 9, 2005 from three species, the Red Bat, Big Brown Bat and the Little Brown Bat.

The third study site was in Mohican State Park in Ashland County, Ohio. (**Map 3**). Mist nets were stretched across the Clearfork of the Mohican River under a Covered Bridge in the Sate Park. (**Photo 7**) At this site the temperatures cooled off quickly and the bat activity was greatly reduced. Fecal pellets were collected on September 10 from Little Brown Bats. Due to possible contamination of the samples collected there was only one fecal sample that could be used in this analysis. It has been included to add some breadth to the evaluation of this as a technique for comparative studies.

At each study site very fine mist nets (36 mesh, 2 ply, 50 denier, 4 shelf, 12 meter long and 2.6 meter high nets from AFO Banding Supplies of Manomet MA) were set. These were set in double canopy form. A double canopy set-up consists of two, stacked, 12 X 2.6 meter nets stretched between telescoping metal poles with pulley systems for raising and lowering the nets. These were positioned across potential bat corridors (flyways) during each of the survey nights (each lasting at least five hours). The nets were placed at sites with a closed canopy and lateral borders approximating the net's length (12 m). Nets were checked ever 20 minutes and while wearing leather gloves attendees removed the captured bats.

Bats captured were quickly removed from the mist nets (**Photo 8**) and placed in muslin holding bags (**Photo 9**) for 30 to 60 minutes. The bats placed in a holding bag were all of the same species of bat and only those bats captured at the specific study net site. Pellets were removed from the holding bags (**Photo 10**) after the bats had been removed, weighted, aged, sexed, banded and released. The pellets were placed in re-sealable sandwich bags (**Photo 11**) for later analysis. Each bag was marked for date, location and bat species. The total number of fecal pellets in each sample obtained ranged from 1 to 47.

Fecal Pellet Analysis Steps:

1. A randomly selected pellet from a sample is placed in a small container, ie. Petri dish. (**Photo 12**)
2. A drop of water is added. ** (**Photo 13**) This softens the pellet and allows it to be broken up and releases the fragments of the insect's exoskeleton.
3. The container is placed under a dissection scope to perform the following steps. I used a "Reichert-Jung Series 40 (40X) Dissection Scope". Viewing of the sample was accomplished with both top and bottom illumination. (**Photo 14**)
4. With dissection tweezers or probes the pellet is teased apart and spread out in the shallow water. (**Photo 15**) Note; too much water resulted in the material being spread out too far for ease in viewing and also for ease in later picking out insect exoskeleton fragments for placing on the microscope slides.
5. Selected, diagnostic insect parts are removed with fine tipped tweezers and placed on a previously numbered microscope slide. For ease of placement a small drop of water is first placed on the glass slide and the tip of the tweezers inserted into this. This helps to remove the insect parts from the tweezers and

allows the spreading out of thin membranous wings. To insure that all the culled materials would all fit later under a cover slip, a template boundary was marked on a paper and placed under the slide. (**Photo 16**) The culled insect parts placed on the slides should include any antenna, scales from Lepidopterans, membranous wings, elytra sections, eyes, eggs, sections of exoskeletons with diagnostic structures such as toothed edges that might be found in the fecal sample.

6. With all materials removed from the sample and placed on the glass slide it is then set aside to dry. Records need to be kept pertaining to the glass slide's number, the location and date of where the sample was collected and the species of bat that the fecal sample was from.
7. When thoroughly dry a small drop of slide mounting medium (glue) is applied to the center of the culled parts. I used a product by Bio-Quip with 60% resin in Xlene. A cover slip is then laid upon it, starting at one corner and laying it down so as not to trap in any air bubbles. With fine tip tweezers the cover slip can be maneuvered and pressed down gently to secure the sample material. With practice, the right amount of the mounting glue can be applied so as not to have excess squeezing out from under the edges but enough material to completely secure the cover slip. In a couple of situations the amount of culled insect material obtained from one pellet exceeded the area of one cover slip so a second one was placed adjacent to the first.
8. After several days the mounting glue is secure enough so the slides can be worked with. The small size of the culled parts necessitates the use of magnification in the identification process. Both compound and dissection microscopes work for viewing the insect fragments. Compound microscopes using low powers of 40X to 50X are adequate for the identifications. With some of the thicker, impenetrable exoskeleton parts from Coleoptera the top illumination of a dissection scope is necessary to view surface grooves and other diagnostic structures. Identifications were made using a variety of insect keys and field guides. (These are included in the literature citation at the end.) Records of the animal parts identified to order and possibly family level needs to be recorded for each slide. At times individual markings (i.e. Spotted Cucumber Beetle elytra) allow for genus or species level identification.
9. Percentage volume estimates were calculated visually for each insect group by dividing the slide up into to quadrants and determining the areas of coverage each represented insect covered.
10. Permanent labels affixed to the microscope slides should include; slide number, bat species fecal pellet is from, location of sample collection, date of collection.

**Some authors use other wetting agents, when teasing apart the fecal pellets, such as Photo-flo or isopropyl alcohol. I did not find the need to use these, as the water did not cloud up when teasing apart the pellets and water does not have the fumes associated with it.

Note: Some resources useful in identifying the insects from their culled fragments are listed in Appendix C. It includes field guides; pictorial keys and materials for slide preparation.

FECAL PELLET INSECT IDENTIFICATION RESULTS

A total of 45 fecal pellets were examined that were from three sites and collected from four species of bats (**Table 1**). The identified culled parts represented nine orders of insects (**Coleoptera, Lepidoptera, Diptera, Hemiptera, Homoptera, Ephemeroptera, Trichoptera, Odonata,** and **Orthoptera**) plus two other arthropod orders (**Araneida** and **Acarina**) (**Table 2**). Fourteen families were identified (**Scarabaeidae, Carabidae, Cerambycidae, Histeridae, Elateridae, Chrysomelidae, Dytiscidae, Chironomidae, Tipulidae, Culicidae, Lygaeidae, Cicadellidae, Zygoptera {Calopterygidae}, Gryllidae**) from the nine insect orders.

Results showed that collectively the 16 samples from Big Brown Bats (**Table 3**) predated predominately upon Coleopterans, with them representing 70.62% of their diet. Members of the Scarabaeidae (36.28%) and Carabidae (33.63%) families made up the bulk of their food. Hemiptera followed with 16.87%, lesser amounts from the order Lepidoptera with 8.12%, Diptera and Odonata both with 1.25%. Other orders represented in only incidental amounts were Trichoptera, Orthoptera, and a few mites.

Beetles made up a slight majority, overall of the Little Brown Bats (17 samples) diet at 43.62% very closely followed by members of the Lepidopterans at 43.32% (**Table 4**). Little Brown Bats fed more on Diptera (6.23%) than what was evident with Big Brown Bats and they were the only one to feed on members of the Ephemeroptera at 3.57%. Small amounts of spider, mite, Hemiptera and caddisflies (Trichoptera) showed up in their fecal samples.

With the 9 samples (**Table 5**) of Red Bats, Coleoptera comprised the largest portion of their diet as well at 50.11%. Lepidoptera made up the other large portion of their intake at 44.44%. Flies, spiders and mites each showed up in very small amounts in their diet.

The fourth bat species the Northern Long-eared Bat (**Table 6**) comprised of only 3 samples and collected at one location and on one night, had Coleoptera making up the vast majority of its diet at 80% and of this it was exclusively members of the Scarabaeidae family. Lepidoptera at 11.67% and Diptera at 8.33 % of which were in the Crane Flies.

Changes in composition percentages of diet occurred with each of the three bats that were caught at multiple times and places. Big Brown Bats fed primarily on insects in

the order Hemiptera (67.5%) in Steubenville (**Table 7**) but at Killbuck Wildlife Area members of Coleoptera comprised the highest percentages ranging from 70.0% to 96.0% for the three sampling periods there (**Tables 8,9, 10**). Red Bats were sampled at three of the four times and in one of the cases Coleoptera made up the highest percentages of their diet with 65.67%. It equaled Lepidopterans at 50.0% in one sample and on the August 26 sample at Killbuck Wildlife Area Lepidoptera made up 52.4% and Coleoptera following at 40.8% (**Tables 7, 9, 10**).

Little Brown Bats did show the most variation in the species composition of insects that it predated upon. In three of the four sampling efforts Coleoptera made up the majority with 45%, 76.67% and 53%, but on August 26 at Killbuck Wildlife Area it made up only 8.75% of the four samples taken. Lepidopterans made up the rest at 91.25%.

The most extensive samples were obtained on the August 26 at Killbuck Wildlife Area. The total number of bats captured that night exceeded 100 animals and was comprised of four different species. Examining the insects predated by bats based on the size of the bat, clumps the Little Brown And Northern Long-eared Bats together and the Big Brown and Red Bats together. There were not any significant patterns with the larger insects, the moths and beetles but there was with the smaller insect prey items. The smaller bats fed more diversely and they included higher numbers of insects in the orders Diptera, Ephemeroptera.

Incidental or non-insect material showed up in some of the samples (**Table 1**). The presence of spider legs in the fecal pellet analysis occurred in three samples from Red Bats and one sample from the Little Brown Bat. In all four cases these were from the Steubenville site on August 11. Mites were found in the fecal material from four bats and all from the Killbuck sampling site. These included one Big Brown Bat from August 21 with two mites, two different Red Bat pellets from August 26 each having one mite and also one Little Brown Bat from September 9 that contained three mites.

Eggs that are assumed to be from ingested insects were found in 11 of the 45 samples (**Table 1**). They were found in Little Brown, Big Brown and Northern Long-eared Bats. Two came from the August 11 sampling in Steubenville, one from the August 21 sampling in Killbuck, four from the August 26 sampling in Killbuck and four from the September 9 sampling at Killbuck.

Table 1. Major orders and families of insects and arachnids eaten by 4 species of bats at 3 locations in Ohio.

Slide	**Species**	**Location**	**Date**	**Contents; Order**	**Family**	**(% comp.)**	**Misc.**
1	Red Bat	Steuben-ville	Aug 11	Coleoptera Coleoptera Lepidoptera	Scarabaeidae Carabidae ?	34 33 33	
2	Red Bat	Steuben-ville	Aug 11	Coleoptera Lepidoptera	Scarabaeidae ?	60 35	

				Araneida	Spider leg**	5	
3	Red Bat	Steuben-ville	Aug 11	Coleoptera Coleoptera Lepidoptera Araneida	Carabidae Scarabaeidae ? Spider legs**	50 20 20 10	
4	Big Brown Bat	Steuben-ville	Aug 11	Coleoptera Hemiptera	Scarabaeidae Lygaeidae	60 40	
5	Big Brown Bat	Steuben-ville	Aug 11	Hemiptera Coleoptera	Lygaeidae Scarabaeidae	90 10	
6	Bat Brown Bat	Steuben-ville	Aug 11	Hemiptera Coleoptera Coleoptera	Lygaeidae Carabidae Scarabaeidae	60 25 15	
7	Big Brown Bat	Steuben-ville	Aug 11	Hemiptera Coleoptera	Lygaeidae Scarabaeidae	80 20	
8	Little Brown Bat	Steuben-ville	Aug 11	Coleoptera Araneida	Scarabaeidae Spider legs**	70 30	5 eggs
9	Little Brown Bat	Steuben-ville	Aug 11	Ephemeroptera Lepidoptera Diptera	Mayflies? ? Chironomidae	60 30 10	
10	Little Brown Bat	Steuben-ville	Aug 11	Lepidoptera Coleoptera Coleoptera	? Carabidae Scarabaeidae	60 30 10	6 eggs
11	Little Brown Bat	Steuben-ville	Aug 11	Coleoptera Lepidoptera Coleoptera	Scarabaeidae ? Carabidae	60 30 10	
12	Little Brown Bat	Killbuck	Aug 21	Coleoptera Lepidoptera Diptera	Carabidae ? Chironomidae	60 25 15	
13	Little Brown Bat	Killbuck	Aug 21	Coleoptera Coleoptera Lepidoptera Trichoptera	Carabidae Scarabaeidae ? ?	35 35 15 15	
14	Little Brown Bat	Killbuck	Aug 21	Coleoptera	Scarabaeidae	100	
15	Big Brown Bat	Killbuck	Aug 21	Coleoptera Coleoptera Coleoptera Coleoptera	Cerambycidae Chrysomelidae-(Diabrotica) Carabidae Scarabaeidae	50 20 20 10	
16	Big Brown Bat	Killbuck	Aug 21	Coleoptera Coleoptera Diptera Homoptera	Elateridae Chrysomelidae Tipulidae Cicadellidae	35 35 10 10	1 egg

				Lepidoptera Acarina	? (2 mites)**	5 5	**
17	Big Brown Bat	Killbuck	Aug 21	Coleoptera Coleoptera Odonata Trichoptera Coleoptera	Chrysomelidae Scarabaeidae Zygoptera ? (caddis fly) Carabidae	30 30 20 10 10	
18	Red Bat	Killbuck	Aug 26	Lepidoptera Coleoptera Diptera Acarina	? Scarabaeidae Tipulidae (mite)*	40 30 25 5	**
19	Red Bat	Killbuck	Aug 26	Coleoptera Lepidoptera	Dytiscidae ?	90 10	
20	Red Bat	Killbuck	Aug 26	Lepidoptera Coleoptera	? Carabidae	80 20	
21	Red. Bat	Killbuck	Aug 26	Lepidoptera	?	100	
22	Red Bat	Killbuck	Aug 26	Lepidoptera Coleoptera Coleoptera Acarina	? Scarabaeidae ? (1 mite)*	32 32 32 4	**
23	Northern Long-eared Bat	Killbuck	Aug 26	Coleoptera	Scarabaeidae	100	5 eggs Net fiber
24	Northern Long-eared Bat	Killbuck	Aug 26	Coleoptera	Scarabaeidae	100	3 eggs
25	Northern Long-eared Bat	Killbuck	Aug 26	Coleoptera Lepidoptera Diptera	Scarabaeidae ? Tipulidae	40 35 25	
26	Little Brown Bat	Killbuck	Aug 26	Lepidoptera Coleoptera	? Scarabaeidae	75 25	1 egg fibers
27	Little Brown Bat	Killbuck	Aug 26	Lepidoptera Coleoptera	? Scarabaeidae	90 10	
28	Little Brown Bat	Killbuck	Aug 26	Lepidoptera	?	100	2 eggs
29	Little Brown Bat	Killbuck	Aug 26	Lepidoptera	?	100	
30	Big Brown Bat	Killbuck	Aug 26	Coleoptera Coleoptera	Scarabaeidae Carabidae	80 20	
31	Big Brown Bat	Killbuck	Aug 26	Lepidoptera Coleoptera	? Scarabaeidae	70 30	
32	Big Brown Bat	Killbuck	Aug 26	Coleoptera Coleoptera Lepidoptera	Scarabaeidae Elateridae ?	40 30 30	

33	Big Brown Bat	Killbuck	Aug 26	Coleoptera Coleoptera Lepidoptera	Scarabaeidae Carabidae ?	50 30 20	
34	Red Bat	Killbuck	Sept 9	Lepidoptera Coleoptera	? Scarabaeidae	50 50	
35	Little Brown Bat	Killbuck	Sept. 9	Lepidoptera Coleoptera Coleoptera Diptera	? Carabidae Scarabaeidae Tipulidae	50 25 20 5	
36	Little Brown Bat	Killbuck	Sept. 9	Coleoptera Coleoptera Lepidoptera Acarina	Carabidae Scarabaeidae ? (3 mites)*	70 10 5 15	**
37	Little Brown Bat	Killbuck	Sept. 9	Coleoptera Lepidoptera	Scarabaeidae ?	90 10	
38	Little Brown Bat	Killbuck	Sept 9	Diptera Coleoptera Lepidoptera Diptera	Tipulidae Scarabaeidae ? Chironomidae	50 20 20 10	
39	Little Brown Bat	Killbuck	Sept 9	Lepidoptera Coleoptera Coleoptera Diptera	? Carabidae Histeridae Chironomidae	60 20 10 10	
40	Big Brown Bat	Killbuck	Sept 9	Coleoptera Coleoptera	Cerambycidae Carabidae	70 30	4 eggs
41	Big Brown Bat	Killbuck	Sept 9	Coleoptera Coleoptera Lepidoptera	Cerambycidae Carabidae ?	70 30 Trace	
42	Big Brown Bat	Killbuck	Sept 9	Coleoptera Coleoptera Lepidoptera	Carabidae Scarabaeidae ?	70 25 5	3 eggs
43	Big Brown Bat	Killbuck	Sept 9	Coleoptera Coleoptera	Carabidae Scarabaeidae	60 40	6 eggs
44	Big Brown Bat	Killbuck	Sept 9	Coleoptera Diptera Orthoptera	Carabidae Culicidae Gryllidae	85 5 10	8 eggs
45	Little Brown Bat	Mohican	Sept 10	Lepidoptera Coleoptera Hemiptera Diptera	? Cerambycidae Lygaeidae ?	60 25 10 5	

Table 2; Arthropods by Order and Family (when available) preyed upon by bats:

Order/Family	% Comp. Order	% Comp. Family	#of samples present	Bat species
Coleoptera	**56.70**		**41**	**4 of 4**
Scarabaeidae		29.47		
Carabidae		15.84		
Cerambycidae		4.78		
Histeridae		0.22		
Elateridae		1.44		
Chrysomelidae		1.89		
Dytiscidae		2.00		
Unknown		1.06		
Lepidoptera	**28.78**	--	**31**	**4 of 4**
Diptera	**3.89**		**10**	**4 of 4**
Chironomidae		1.00		
Tipulidae		2.67		
Culicidae		0.11		
unknown		0.11		
Hemiptera	**6.22**		**5**	**2 of 4**
Lygaeidae		6.22		
Homoptera	**0.22**		**1**	**1 of 4**
Cicadellidae		0.22		
Ephemeroptera	**1.33**	--	**1**	**1 of 4**
Trichoptera	**0.56**	--	**2**	**2 of 4**
Odonata	**0.44**		**1**	**1 of 4**
Zygoptera		0.44		
Orthoptera	**0.22**		**1**	**1 of 4**
Gryllidae		0.22		
Araneida	**1.00**	--	**3**	**2 of 4**
Acarina	**0.64**	--	**4**	**3 of 4**
(eggs)	(44 eggs)		**11**	**3 of 4**

Table 3; Insects Predated upon by Big Brown Bats, *Eptesicus fuscus*: 16 Samples

Order/Family	% Comp. Order	% Comp. Family	#of samples present
Coleoptera	**70.62**		**16**
Scarabaeidae		36.28	
Carabidae		33.63	

Cerambycidae		16.81	
Chrysomelidae		7.52	
Elateridae		5.76	
Hemiptera	**16.87**		**4**
Lepidoptera	**8.12**		**6**
Diptera	**1.25**		**2**
Tipulidae		0.94	
Culicidae		0.31	
Odonata	**1.25**		**1**
Zygoptera		1.25	
Homoptera	**0.63**		**1**
Cicadellidae		0.63	
Trichoptera	**0.63**	--	**1**
Orthoptera	**0.63**		**1**
Gryllidae		0.63	
Acarina		--	**4**
(eggs)	(22 eggs)		**5**

Table 4; Insects Predated upon by Little Brown Bats, *Myotis lucifugus*: 17 Samples

Order/Family	% Comp. Order	% Comp. Family	#of samples present
Coleoptera	**43.62**		**14**
Scarabaeidae		26.70	
Carabidae		14.85	
Cerambycidae		1.48	
Histeridae		.59	
Lepidoptera	**43.32**	--	**15**
Diptera	**6.23**		**7**
Chironomidae		2.67	
Tipulidae		3.26	
unknown		0.30	
Ephemeroptera	**3.57**	--	**1**
Araneida	**1.77**	--	**1**
Trichoptera	**0.87**	--	**2**
Acarina	**0.87**	--	**1**
Hemiptera	**0.59**		**1**
(eggs)	(14 eggs)		**4**

Table 5; Insects Predated upon by Red Bats, *Lasiurus borealis*: 9 Samples

Order/Family	**% Comp. Order**	**% Comp. Family**	**#of samples present**
Coleoptera	**50.11**		**8**
Scarabaeidae		25.11	
Carabidae		11.44	
Dytiscidae		10.00	
??		3.56	
Lepidoptera	**44.44**	--	**9**
Diptera	**2.78**		**1**
Tipulidae		2.78	
Araneida	**1.67**	--	**2**
Acarina	**1.00**	--	**2**

Table 6; Insects Predated upon by Northern Long-eared Bats, *Myotis septentrionalis* : 3 Samples

Order/Family	**% Comp. Order**	**% Comp. Family**	**#of samples present**
Coleoptera	**80.00**		**3**
Scarabaeidae		80.00	
Lepidoptera	**11.67**	--	**1**
Diptera	**8.33**		**1**
Tipulidae		8.33	
(eggs)	(8 eggs)		**2**

Table 7: Comparison of percentage of insects by order predated upon by different species of bats foraging at same time and site. Steubenville, Ohio. August 11, 2005

Species of bat	*n*	Coleoptera	Lepidoptera	Hemiptera	Diptera	Ephemeroptera	Araneida
Eptesicus fuscus	4	32.5	- -	67.5	- -	- -	- -
Lasiurus borealis	3	65.67	29.33	- -	- -	- -	5.00
Myotis lucifugus	4	45.0	30.0	- -	2.5	15.0	- -

Table 8; Comparison of percentage of insects by order predated upon by different species of bats foraging at same time and site. Killbuck Wildlife Area, Holmes County, Ohio. August 21, 2005

Species of bat	*n*	Coleoptera	Lepidoptera	Homoptera	Diptera	Trichoptera	Odonata	Acarina
Eptesicus fuscus	3	80.0	1.67	3.33	3.33	3.33	6.67	1.67
Myotis lucifugus	3	76.67	13.33	- -	5.0	5.0	- -	- -

Table 9; Comparison of percentage of insects by order predated upon by different species of bats foraging at same time and site. Killbuck Wildlife Area, Holmes County, Ohio. August 26, 2005

Species of bat	*n*	Coleoptera	Lepidoptera	Diptera	Acarina
Eptesicus fuscus	4	70.0	30.0	- -	- -
Myotis lucifugus	4	8.75	91.25	- -	- -
Myotis septentrionalis	3	80.0	11.67	8.33	- -
Lasiurus borealis	5	40.8	52.4	5.0	1.8

Table 10; Comparison of percentage of insects by order predated upon by different species of bats foraging at same time and site. Killbuck Wildlife Area, Holmes County, Ohio. September 9, 2005

Species of bat	*n*	Coleoptera	Lepidoptera	Diptera	Orthoptera	Acarina
Eptesicus fuscus	5	96.0	1.0	1.0	2.0	- -
Myotis lucifugus	5	53.0	29.0	15.0	- -	3.0
Lasiurus borealis	1	50.0	50.0	- -	- -	- -

DISCUSSION

In Whitakers work Prey Selection in a Temperate Zone Insectivorous Bat Community (2004), he tested the null hypothesis " If bats eat what is available, then all bats taken at the same time and place should eat the same foods." He found that there were similarities with the kinds of insects being eaten by bats of similar sizes, but there

were differences in the insects predated upon by larger bats when compared to what the smaller bats were eating. In this study I found that the beetles made up the largest percentage of the diet of all four of the bat species, but the percentage composition ranged from a low of 43.62% to a high of 80%. On the sampling night of August 26 Big Brown Bats, *Eptesicus* fuscus, Coleoptera consumed made up 70%, Red Bats, *Lasiurus borealis* diet comprised of only 40.8% of Coleoptera, Little Brown Bats, *Myotis lucifugus* diet was only 8.75% of Coleoptera and Northern Long-eared Bats, *Myotis septentrionalis*, had 80% of its diet from Coleoptera. Since the bats were being caught within the same feeding or foraging corridor, in the same mist net and within the same relative time frame they were subject to the same insects as potential food sources. This shows that there is some level of differentiation or selection in what insects are present and what are actually being eaten by bat species.

The comparisons of the insects by order the results showed that in all three of the study sample sites a larger sized bat, the Big Brown Bat did not show much variation in its selection of insects. The high presence of culled prey species parts in its fecal pellets from the order Coleoptera demonstrates that this species is showing a level of preference in its prey selection. This is also demonstrated by another larger bat, the Red Bat. This bat's diet was mostly limited to prey items in two orders the Coleopterans and the Lepidopterans and very little variation outside of these orders. According to John Altringham in his book Bats; Biology and Behavior "Moths made up only 10% of the insects caught in traps, but constituted 40% of the bats' diet, and a smaller pattern was seen for dragonflies and beetles." (1998)

Although in this study the smaller bats, the Little Brown and the Northern Long-eared Bats, showed a preference for prey items from the order Coleoptera they showed more variation among other insect orders that were also part of their selection. Their inclusion of significant numbers from the order Diptera and in one site Trichoptera, shows that these insects were present within the foraging corridors being occupied by both the larger and smaller bats, only the smaller bat species were utilizing them. On one hand the "Little Brown Bat (*Myotis*) may have the most diverse diet of any bat in the eastern United States." (Cater et. al., 2003). Many previous studies have noted, "the Big Brown Bat is a beetle specialist" (Black, 1974). The strong jaws of "*Eptesicus fuscus* may lie in its ability to consume large, hard-bodied of Coleopterans." (Agosta et. al., 2003)

The abundance of Coleoptera remains in the fecal samples of all the bats in this study (and many others) brings up some questions as to why. Why are they predated upon more? Is it because they are easier targets, easier to perceive with echolocation or they are slower flyers so easier to catch? Are they a better target nutritionally? Do they occur more often in the fecal pellets because the beetle's harder exoskeletons results in it remaining more intact through the digestive process? Or is it more due to the fact that they are the most diverse and most numerous of the insect orders?

The presence of eggs in the 11 samples indicates that the ingested insects were ready to lay their eggs. Whether or not there was an increased predation on adult females heavy with ova, over those not egg bound, cannot be said. It can only be speculated if there is a reduction in the individual's mobility and therefore a higher vulnerability to

predation. The presence of mites in several of the fecal pellets does not mean that foraging bats were catching them, but probably it is an indication that the bats ingested them while grooming their own fur. Frequently mites can be found crawling on the captured bats. The presence of spider legs does indicate that these were intentional prey species. The most common way that bats capture spiders is with a foraging behavior called gleaning. Instead of picking up flighted or ballooning spiders they pick them directly off the surface of a plant or from a web. This gleaning behavior is mostly attributed to the Northern Long-eared Bat but with this study three Red Bats and one Little Brown Bat samples contained spider fragments.

The fecal pellets collected varied in size both by the species they were from, and by the individual bats. Both the Big Brown and the Red Bats pellets were consistently larger than the pellets from the smaller *Myotis* species. On two occasions the fecal pellets did not result in any distinguishable insect parts that could be collected and used for identification of prey. These may have been the bats' first pellets of the night and comprised of food eaten the previous night. The extended digestive period was therefore adequate enough to break down the chitin as well. "Although chitin was long thought to be indigestible by vertebrates enzymes, some bat species apparently synthesize chitinase in the gastric mucosa" (Jeuniaux, 1961).

There are several things that can lead to a level of bias when using this technique. Insects in the order Trichoptera "are highly desirable but only available intermittently." (Whitaker, 2004) In my results, it occurred in one sample and represented less than 1% of the overall composition. This may not accurately indicate the lack of predation on them but rather more indicative of the sampling period. Like many aquatic, emergent insects there is synchronization with the adult caddisflies in the timing of their flights. The synchronization assures the presence of both sexes, and in high enough densities, to ensure their success in reproducing.

Another area where bias can enter into data collected using this technique is the level to which the more soft tissue insects are concerned. In the order Lepidoptera its level of representation is determined by the presence of scales in the separating of the fecal pellets. In many of these samples there is also, but not always, some unidentifiable material that is probably from the moths exoskeleton. Arriving at a percent composition is therefore more difficult with this order. Questions arise as how to handle the data when there is the presence of scales but nothing that resembles an insect's body. Did the bat feed on a moth? Did the soft exoskeleton get more completely digested? Should we represent it in the sample and to what percentage? Or could the scales be from a previous meal and some got hung up and did not pass through the digestive tract as quickly?

Belwood and Fenton (1976) found "that mayflies fed to Little Brown Bats could not be identified in feces". This can lead to a misrepresentation of this order of insects in fecal pellet analysis studies. I found them in only one sample and that was with a Little Brown Bat from the August 11 sampling time at Steubenville. The site did not have much aquatic habitat conducive for the aquatic phase of this type of insect. Identification was based on the venation of the wing. Is this to say that they may have been otherwise under-represented, or was the lack of insects in this order more a factor of habitats where sampling was done and the timing of the sampling? At one study area (Mohican State

Park) that I have captured and banded several thousand Little Brown Bats over a number of years, we get tremendous numbers of emergent mayflies. Some nights the density of emergent mayflies has been so thick that we had to wear filter masks so we would not inhale the insects while removing bats from the mist nets set over the river. A few nights later and for the rest of the season very few, if any, mayflies are seen in the same locale.

My sampling period did not overlap with any major mayfly emergences. Other insects have been found to be desirable prey, but their occurrence is highly irregular and will not show up with fair representation in this type of analysis unless sampling is done throughout the bats foraging season. These include insects such as termites and flighted ant reproductives.

Adult moths are a major food item of many species of insectivorous bats but are easy to underestimate. The presence of moth scales in the fecal samples indicates the bats are consuming them but it is difficult to arrive at what the actual percentage volume is. According to Whitaker (1988) "Furthermore a few scales could remain in the tract and be detectable for several days". This level of bias coupled with the knowledge that "Lepidopterans are one of the most highly utilized insects by most bats"(Whitaker and Barnard, 2005) makes the arrival of what the accurate picture is for them as a prey item by insectivorous bats.

In one study, Kutra and Whitaker (1998), collected fecal pellets from under a maternity roost at different times in the summer. During the early part of the summer, the roost composition was all pregnant females. The next part, consisted of lactating females and the last part, the roost consisted of both post-lactating females and the recently volant young of the year. They found that there were also changes in the insect species composition, especially with regards to the orders being represented that were showing up in the fecal pellet analysis. Their inference was that as energy needs or demands changed from being pregnant, to lactating and finally to post-lactating her prey selection would also change. The problem is that although any changes in prey selection may be energy related, it might also be the result of other factors including mobility of the foraging pregnant versus non-pregnant female. When carrying her pup/pups the bat's maneuverability is going to be reduced so the insects she captures at that time might be limited to the slower flying ones. Changes in what insects show up in their diet at these different times may also be a factor of what insects are flighted at that specific time and in that area.

Collecting data on the insects preyed upon by a bat species in one area and using it to make decisions about the foraging practices for that same bat species but in another area will not be accurate. In the same manner the insects preyed upon by a bat in one specific area will change from week to week and month to month. To effectively use this technique to arrive at the picture of the predator-prey interactions with insects and insectivorous bats more data needs to be collected. Data needs to be collected from all parts of a species range, as well as at various times in the year.

A variation of this technique has been used successfully with the collection of fecal pellets from the ground under bat roost sites instead of actually capturing the bats as was done in this study. This can be accomplished during the day and without as much effort, but there are some unknown factors inherent in its results;

- You cannot always be sure of the identity of the bat species that the pellet came from.
- You cannot always know when the pellet was produced, although with regular visits and the clearing away of previous pellets you can narrow down the time frame.
- You do not know the location where the bat was foraging when it ingested the insects. With the radio-tracking work that I, and others have done, it has been determined that bats roosting in one area will travel miles away each night to a foraging site. Each lactating female bat that I have radio-tracked that was foraging for insects over the Clearfork River within Mohican State Park had traveled from three to five miles from their day roosts to a specific foraging section. Pellets gathered from the attics of the homes, rafters of the barns or the wall spaces of older homes did not represent the insects found in the vicinity of these rural or urban habitats but rather the insects flying in the pristine forest and rivers of Mohican.

CONCLUSION

This fecal pellet analysis technique is valuable in allowing one to determine some of the insects that are commonly being predated upon by insectivorous bats that otherwise cannot be ascertained. The lack of direct observation requires the use of another technique to accomplish this task and this method works. It allows sampling both in the field and also at roost sites without the sacrifice of the animal as is required with other food analysis techniques. One case in point is with the federally endangered Indiana Bat; *Myotis sodalis* there has been great effort to assure the continued existence of this species "by protecting its wintering hibernaculas but we still see declines in its numbers". (Kutra and Whitaker, 1998) Is it the insects it forages on? There currently is very little known about its food preferences and this technique could be used to acquire that information. In this case, working with and endangered species, stomach content analysis and the sacrificing of the animal would not be acceptable. It could be accomplished with both the collecting fecal pellets from captured individuals or from pellets collected from under roost sites.

"Examination of 30 pellets is sufficient to document all major dietary items in a sample of the feces of insectivorous bats." (Kutra and Whitaker, 1998) Identification takes considerable practice. Insect keys are also beneficial and because most flying insects are adults, keys only need to focus on this age group (the exception being with the mayflies) and not on immatures. Identification is most efficiently done by comparing unknown material with whole insects or a systematic collection of insect parts, (i.e. wings, legs, mouth parts) collected at the same time and place as the bats. To pursue this it would be best to also compare the insects available through the use of various insect traps, such as using suction, light traps or collecting nets and do this at different levels in the study area. These samples should be done so one could compare the results with collections made from month to month.

Literature Cited

Agosta, S.J., D. Morton. 2003. Diet of the big brown bat, *Eptesicus fuscus*, from Pennsylvania and Western Maryland. Northeastern Naturalist 10(1):89-104.

Altringham, J.D. 1998. Bats; Biology and Behavior. First Edition. Oxford, New York University Press. 262 pp.

Barclay, R.M.R. and R. M. Brigham. 1991. Prey detection, dietary niche breadth and body size in bats: why are aerial insectivorous bats so small? American Naturalist. Vol. 137, 693-703.

Belwood, J.J., and M.B. Fenton. 1976. Variation in the diet of *Myotis lucifugus* (Chiroptera: Vespertilionidae). Canadian Journal of Zoology 54:1674-1678.

Black, H.L. 1974. A north temperate bat community: structure and prey populations. Journal of Mammalogy 55:138-157.

Buchler, E.R. 1975. Food transit time in *Myotis lucifugus* (Chiroptera: Vespertilionidae). J. Mammal., 56:252-255.

Cater, 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(1):83-88.

Daly, H.V., J.T. Doyen and A. H. Purcell III. 1998. Introduction to Insect Biology and Diversity. Second Edition. Oxford New York: Oxford University Press. 680 pp.

Evans, H E. 1984. Insect Biology: A Textbook of Entomology. First Edition. Reading Massachusetts: Addison – Wesley Publishing Co. 436 pp.

Fenton M.B. 1992. Bats. New York, New York: Facts On File. 207 pp.

Jeuniaux, C. 1961. Chitinase: An addition to the list of hydrolases in the digestive tract of vertebrates. Nature, 192:135-136.

Kutra, A., and S. W. Murray. 2000. Philopatry and migration of banded Indiana bats (*Myotis sodalis*) and effects of radio transmitters. Journal of Mammalogy 83:585-589.

Kutra, A., J.O. Whitaker. 1998. Diet of the endangered Indiana bat (*Myotis sodalis*) on the northern edge of its range. American Midland Naturalist. Vol. 140:280-286.

Whitaker, J.O. 1988. Food Habits of Insectivorous Bats. Pp. 171-189, *In* T. H. Kunz, (Ed.). Ecological and Behavioral Methods for the Study of Bats. Smithsonian Institution Press. Washington, DC. 533 pp.

Whitaker, J.O. 2004. Prey selection in a temperate zone insectivorous bat community. Journal of Mammalogy. 85(3):460-469.

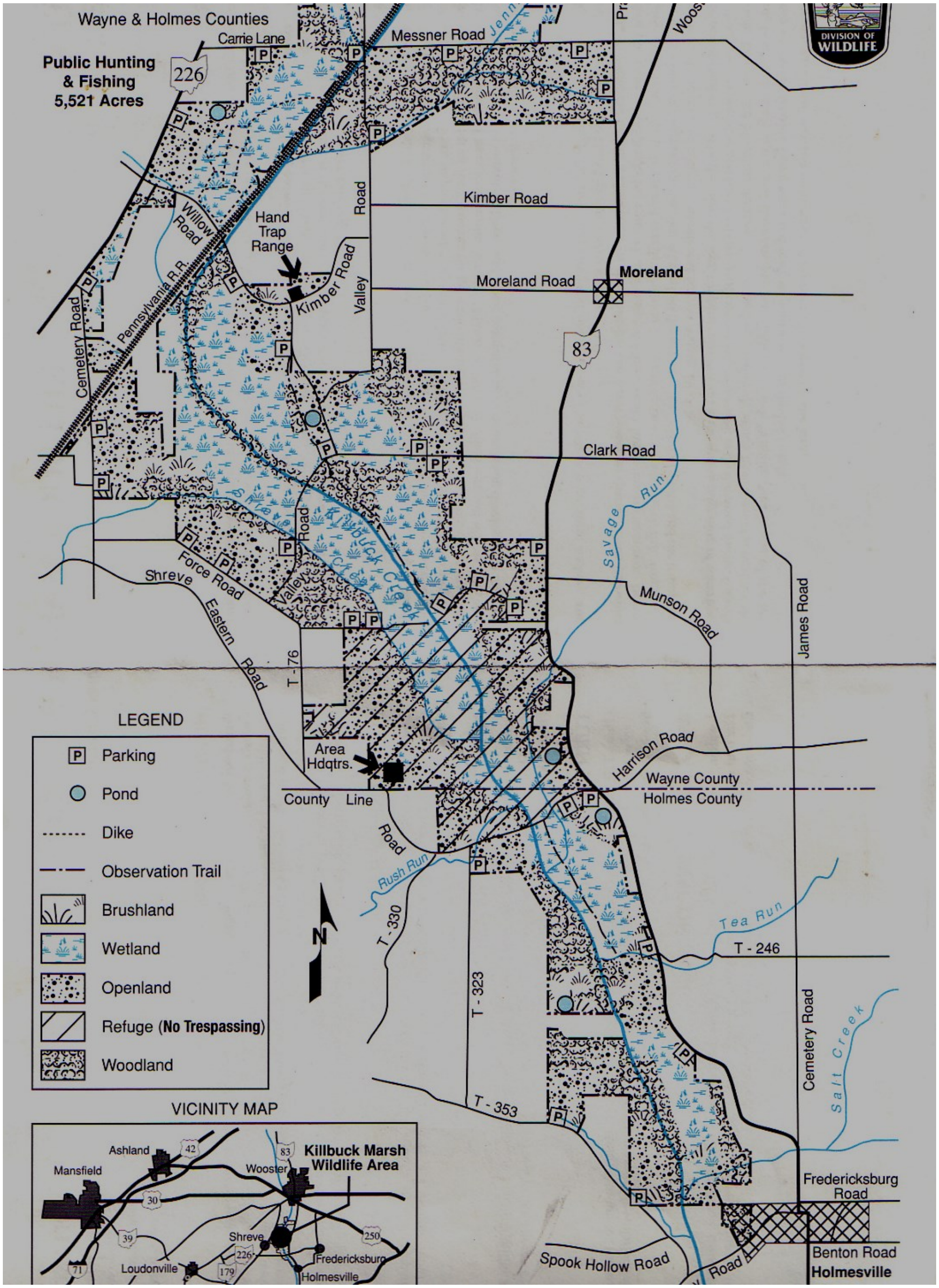
Whitaker, J.O. and S.M. Barnard. 2005. Food of Big Brown bats (*Eptesicus fuscus*) from a colony at Morrow, Georgia. Southeastern Naturalist. 4(1):111-118.

Appendix A: Maps

Map 1. Location of Jefferson County, Ohio.

Map 2. Location of Wayne County, Ohio

Map 3. Location of Ashland County, Ohio



Map 4. Killbuck State Marsh and Wildlife Area. Wayne and Holmes

Counties, Ohio.

Appendix B: Photos

Photo 1. Red Bat captured at Steubenville Ohio.

Photo 2. Little Brown Bat.

Photo 3. Big Brown Bat captured at net site at Steubenville.

Photo 4. Steubenville net site placed across a stream just downstream of beaver impoundment.

Photo 5; Jennings Ditch off Valley Road at Killbuck Wildlife Area.

Photo 6. Northern Long-eared Bat showing long ear tragus.

Photo 7; Clearfork River in Mohican State Park, Ashland County, Ohio.

Photo 8. Little Brown Bat captured at Net Site 4-W

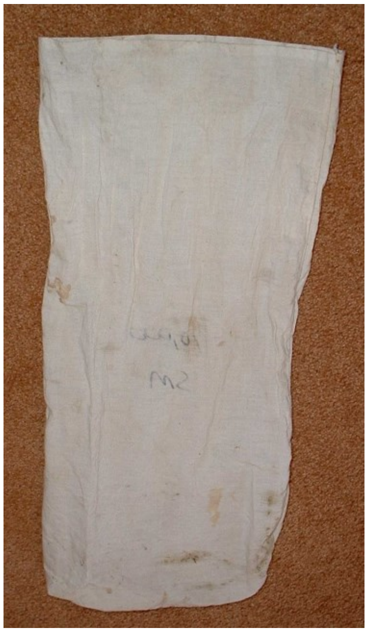


Photo 9. Muslin bat holding bag.

Photo 10. Guano deposits in holding bag.

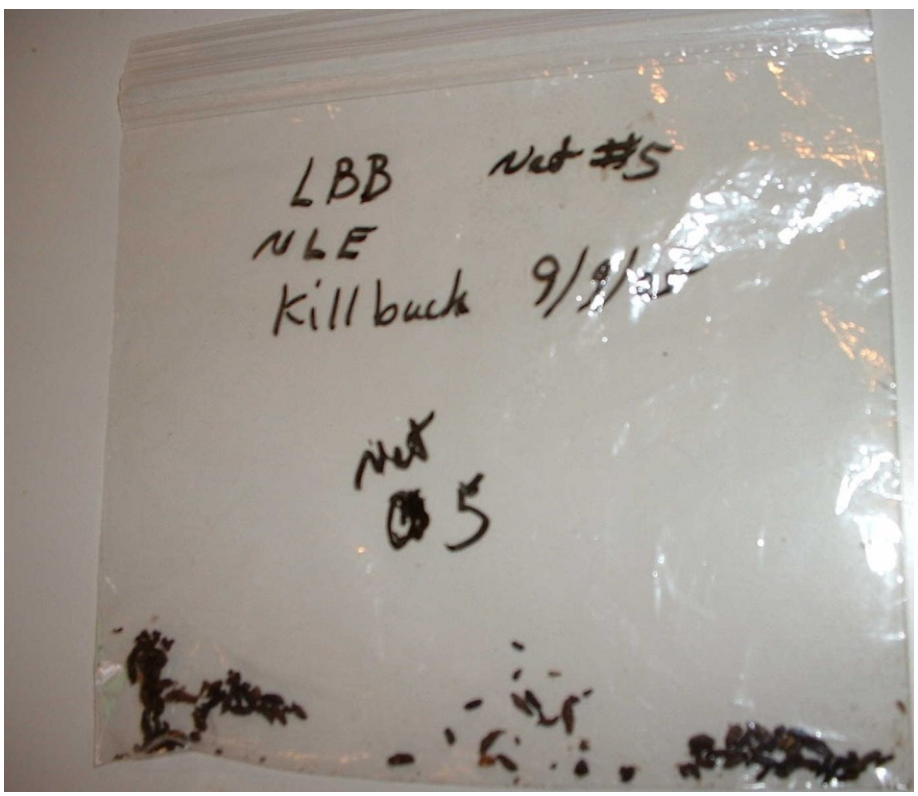


Photo 11. Bagged and labeled guano samples.


Photo 12. Fecal pellet placed in small shallow container. Tweezers and water dropper for later steps.


Photo 13. A drop of water added to loosen up the pellet and release the insect fragments.

Photo 14. Dissection scope with fecal pellet.

Photo 15. Spreading out of the fecal pellet material.

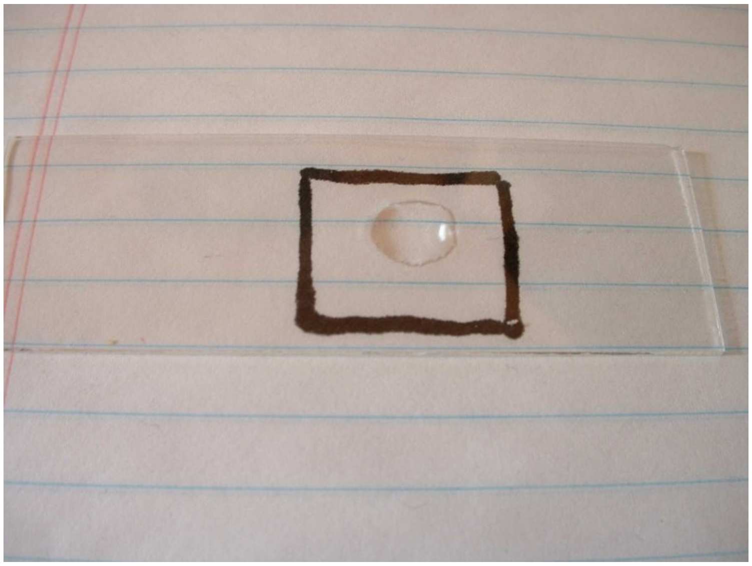


Photo 16. Glass microscope slide with marked template and drop of water.

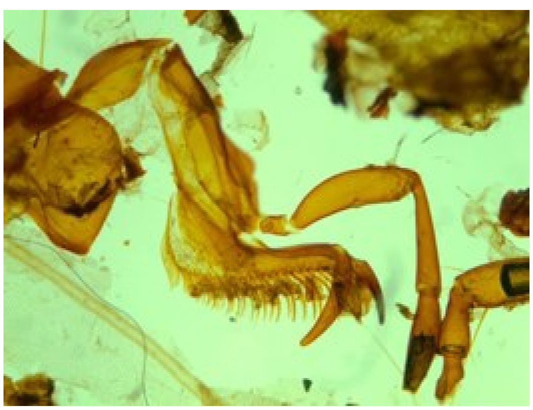


Photo 17. Microscope view of exoskeleton parts from fecal pellet.

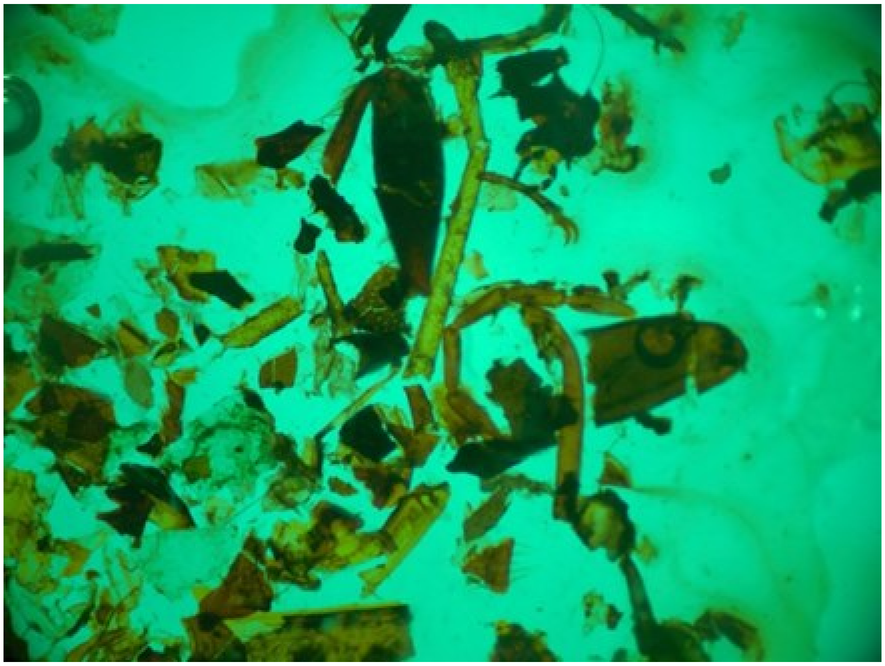


Photo 18. Insect exoskeleton fragments.

Appendix C: Resource Materials

Books: for use in insect identifications.

Audubon Society Field Guide to Insects and Spiders. Lorus and Margery Milne. 1980 or most recent edition. Alfred A. Knopf, New York. 989 pp.

In Ohio's Backyard: Bats. Jacqueline Belwood. 1998. Ohio Biological Survey Backyard Series No. 1. 195 pp.

Dragonflies and Damselflies of Northeast Ohio. Larry Rosche. 2002. Published by Cleveland Museum of Natural History. 94 pp.

Insects of the Great Lakes Region. Gary A. Dunn. 1996. 310 pp.

Peterson Field to Beetles. Richard E. White. 1983 or most recent edition. Houghton Mifflin Company. 368pp.

Peterson Field Guide to Insects. Donald J Borror and Richard E. White. 1970 or most recent edition. Houghton Mifflin Company. 404 pp.

Materials: for use in making the microscope slides of culled insect exoskeleton parts.

Microscope glass slides; 3" X 1" from BioQuip Products Inc. 2321 E. Gladwick St. Rancho Dominquez, Ca. 90220

Microscope Cover Glass; 22 X 22mm. No.1 thickness. From: BioQuip Products Inc. 2321 E. Gladwick St. Rancho Dominquez, Ca. 90220

Slide Mounting Medium. #6370. 2 OZ. . From: BioQuip Products Inc. 2321 E. Gladwick St. Rancho Dominquez, Ca. 90220

Fine-tip Tweezers: From: BioQuip Products Inc. 2321 E. Gladwick St. Rancho Dominquez, Ca. 90220

Pictorial Insect Key: Copied below for aid in insect identification.

From: Ecological and Behavioral Methods for the Study of Bats. Edited by Thomas H. Kunz. 1988. Smithsonian Institution Press. Washington, D.C.

(see sketches following)

Figure 1. Lepidopteran scales.

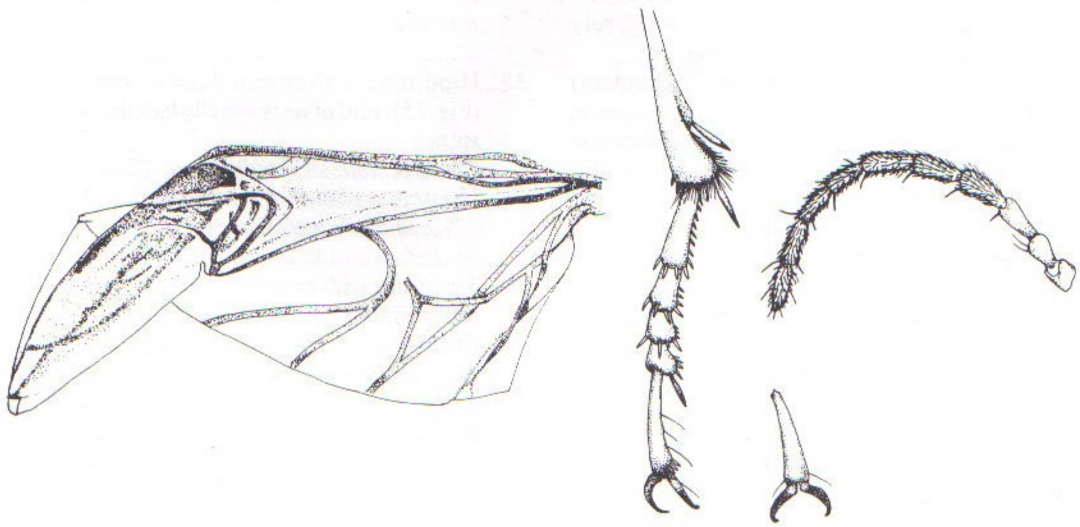


Figure 2. Hind wing, tarsi, and antenna of carabid beetle.

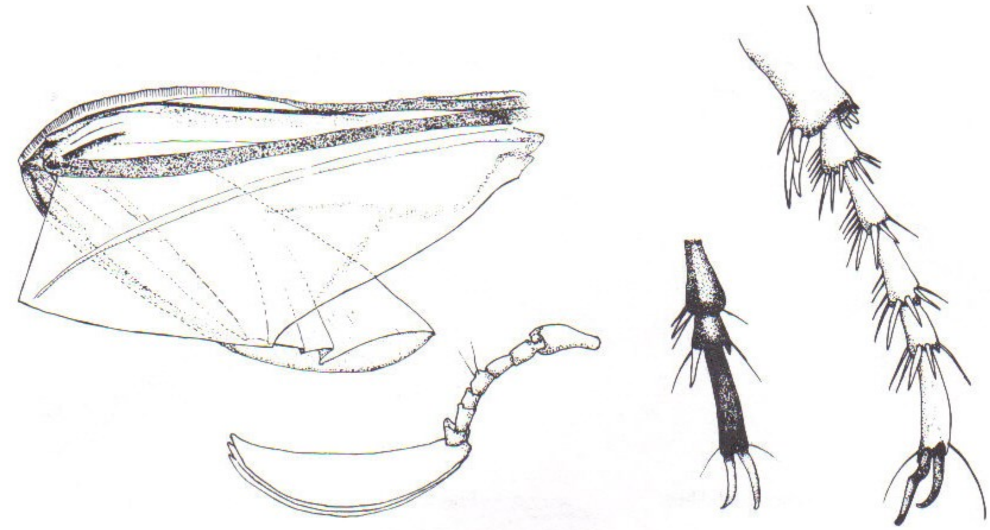


Figure 3. Hind wing, tarsus, and antenna of scarabaeid beetle.

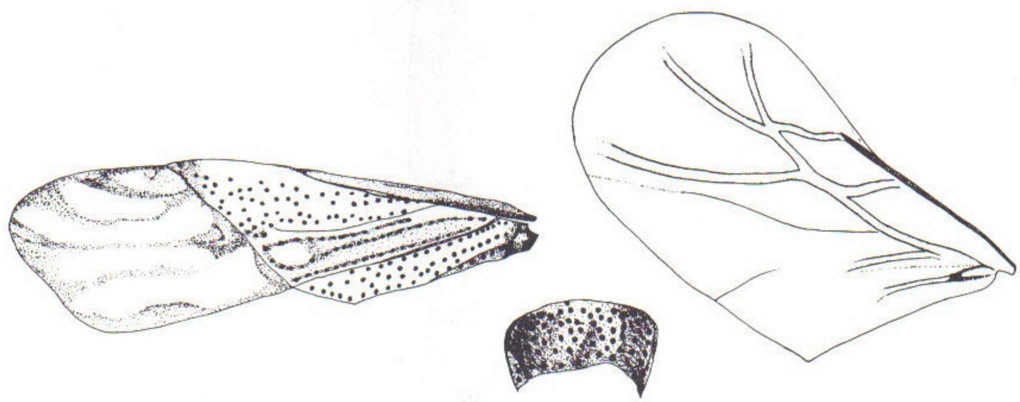


Figure 4. Front wing, portion of body wall, and hind wing of lygaeid bug.

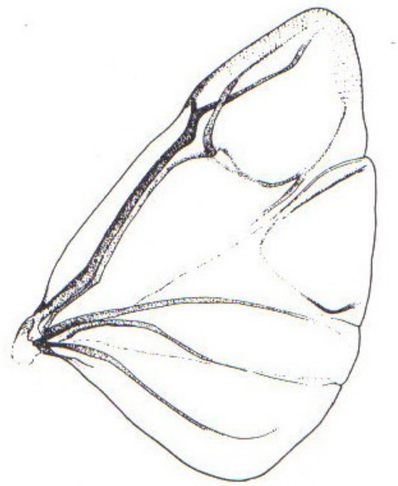


Figure 5. Hind wing of pentatomid bug.

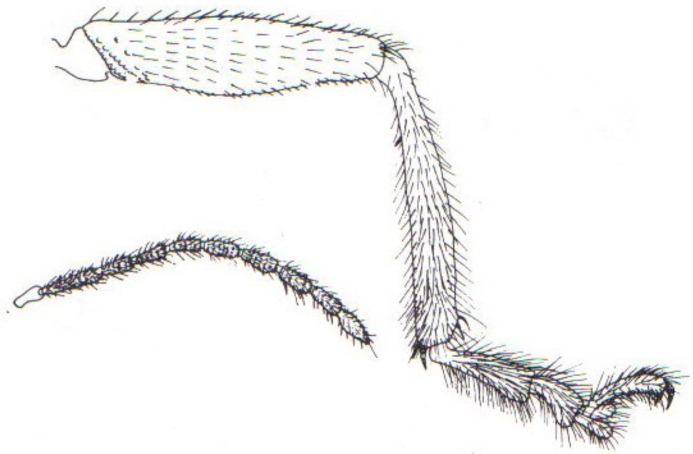


Figure 6. Leg and antennae of Chrysomelidae.

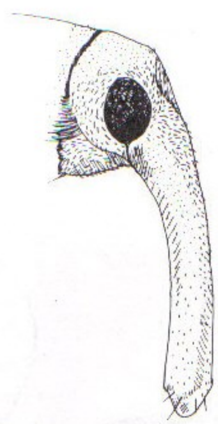


Figure 7. Mouth parts of snout beetle, Curculionidae.

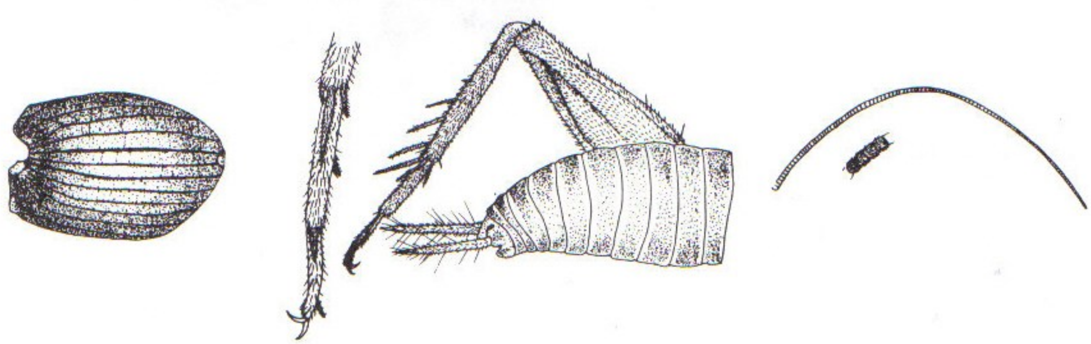


Figure 8. Front wing, tarsus, and abdomen, including cerci, and antenna of cricket, Gryllidae.

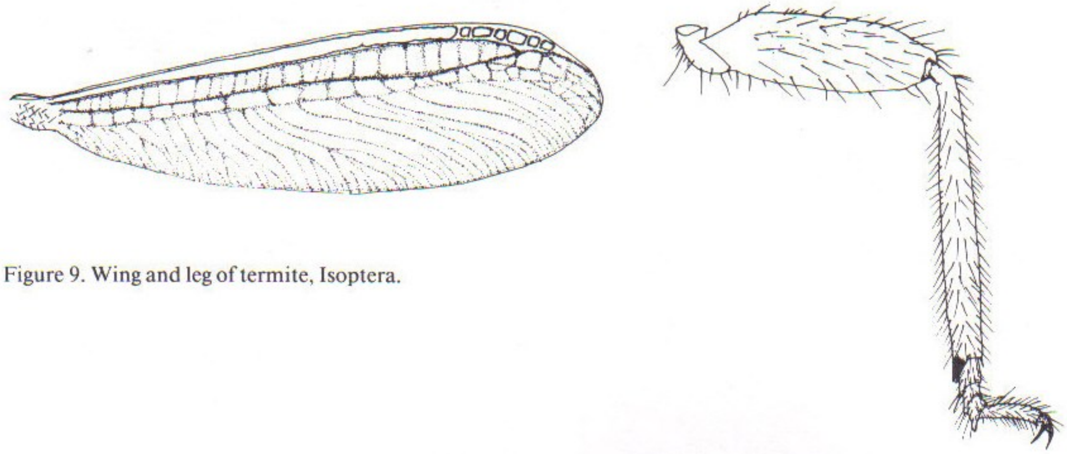


Figure 9. Wing and leg of termite, Isoptera.

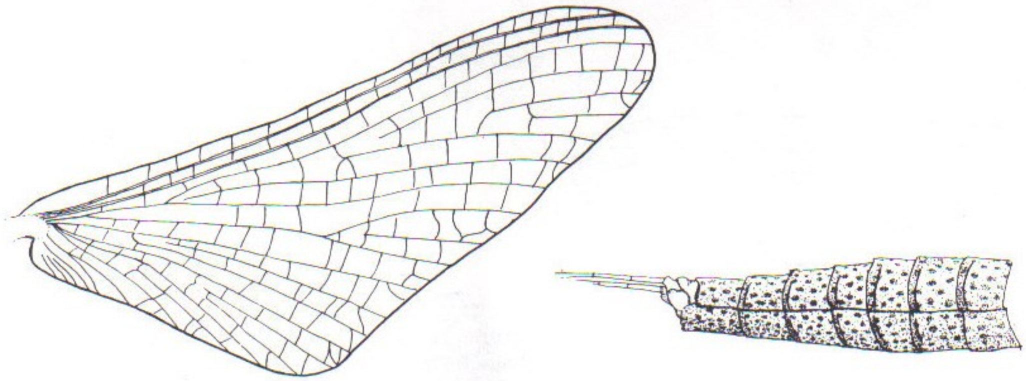


Figure 10. Wing and abdomen, including cerci, of mayfly, Ephemeroptera.

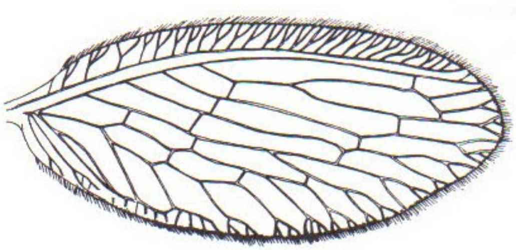


Figure 11. Wing of brown lacewing, Hemerobiidae.

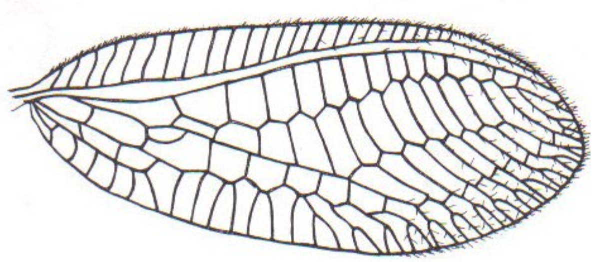


Figure 12. Wing of green lacewing, Chrysopidae.

Figure 13. Balancing organ (haltere) of true fly, Diptera.

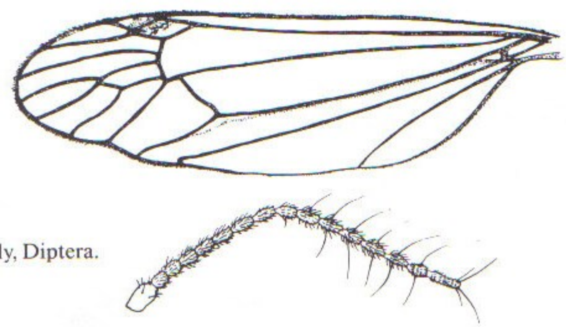


Figure 14. Wing and antenna of crane fly, Tipulidae.

Figure 15. Wing of mosquito, Culicidae.

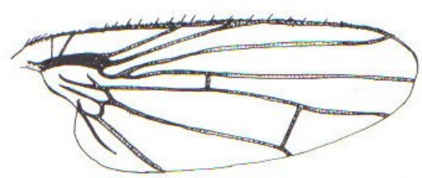


Figure 16. Wing of Muscoidea (group that includes houseflies).

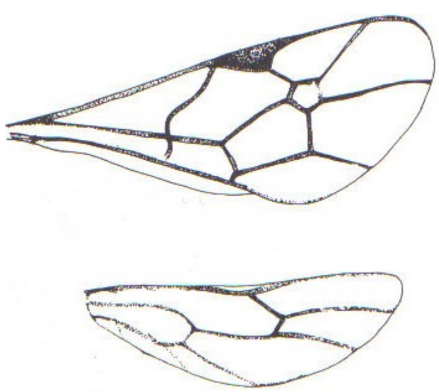


Figure 17. Wings of ichneumon wasp, Ichneumonidae.

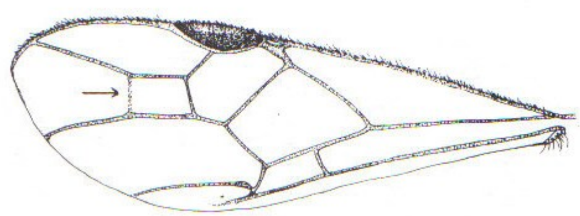


Figure 18. Wing of Braconidae.

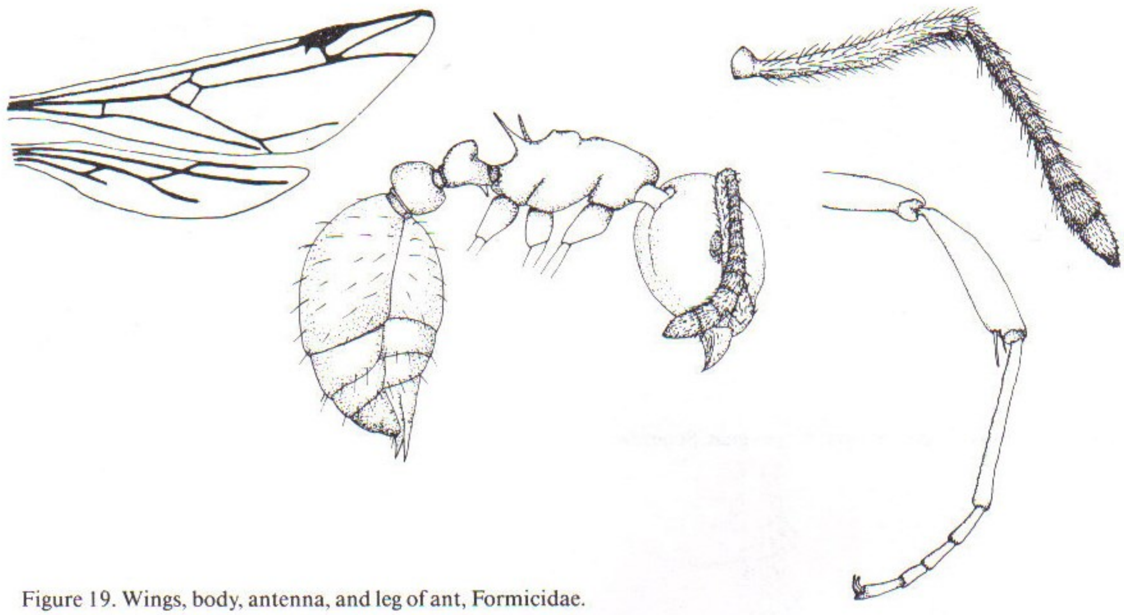


Figure 19. Wings, body, antenna, and leg of ant, Formicidae.

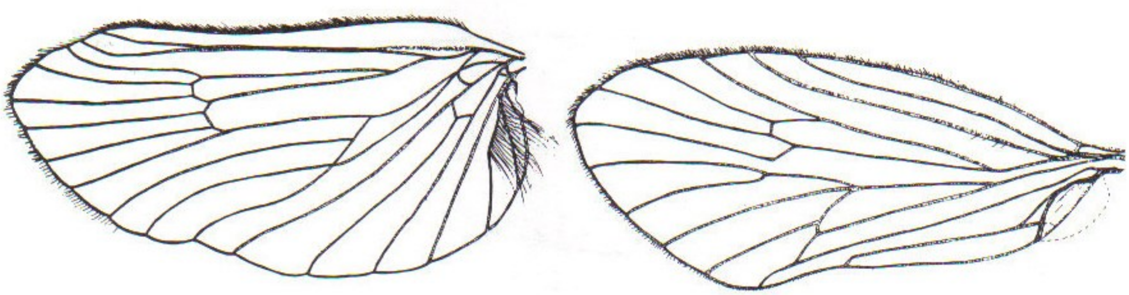


Figure 20. Wings of caddisfly, Trichoptera.

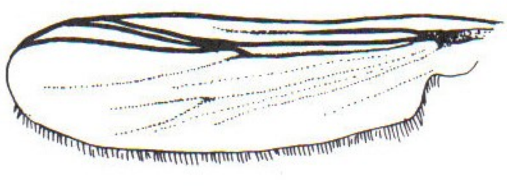


Figure 21. Wing of midge, Chironomidae.

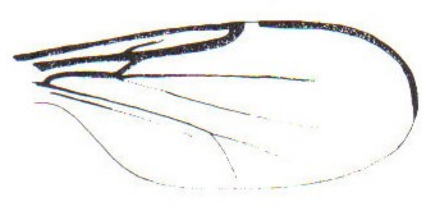


Figure 22. Wing of blackfly, Simuliidae.

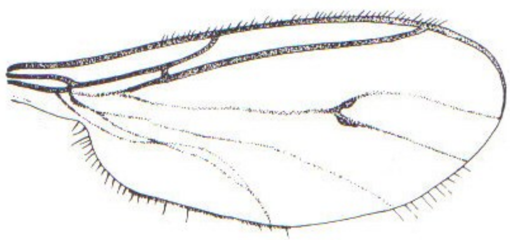


Figure 23. Wing of dark-winged fungus gnat, Sciaridae.

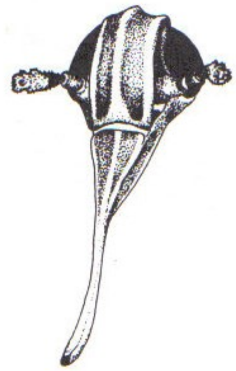


Figure 24. Head capsule of Homoptera.

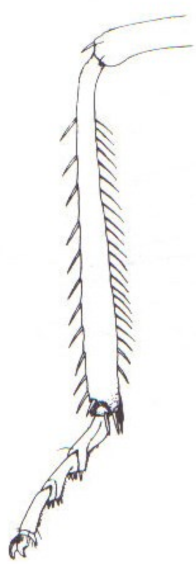


Figure 25. Hind leg of leafhopper, Cicadellidae.

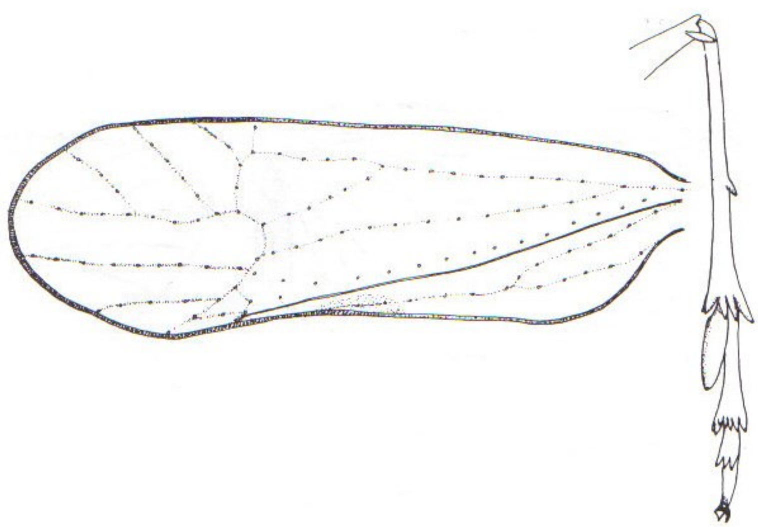


Figure 26. Wing and hind leg of delphacid planthopper, Delphacidae.

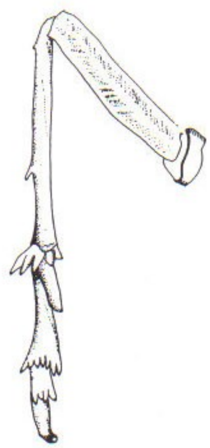


Figure 27. Hind leg of leafhopper, Cercopidae.

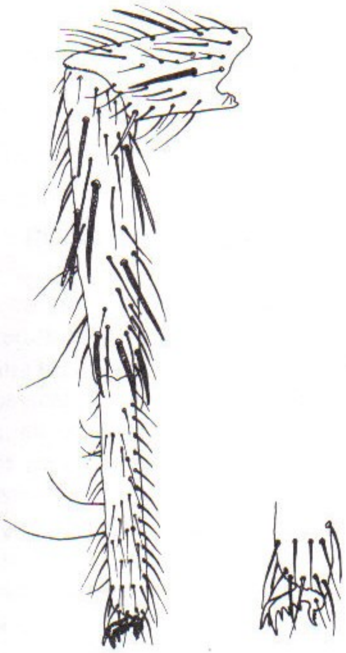


Figure 28. Leg of spider.