FORAGING HABITS OF NORTH AMERICAN INSECTIVOROUS BATS

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This paper presents an historical overview of efforts to characterize and quantify the foraging habits of selected North American insectivorous bats. Where appropriate, it also highlights methods that have been used to explore the foraging habits of other insectivorous species. What we currently know about the foraging habits of insectivorous bats in North America, and elsewhere, has largely been inferred from dietary analyses, captures of bats using mist nets and harp traps, observations of bats in night roosts, temperature recordings in day and night roosts, recordings of echolocation calls with ultrasonic detectors (bat passes and feeding buzzes), assessment of nightly activity using radiotelemetry, and observations enhanced by light tags, night-viewing devices, and infrared video. Recent advances in the study of foraging habits of insectivorous bats have been enriched by the availability of new technologies and approaches, including advanced ultrasonic detection and analysis, Doppler radar imaging, infrared thermal imaging, and passive integrated transponders (PIT) tags. In addition, ecomorphological analyses and computerized models of wing structure, skull, and dentition have contributed greatly to our understanding of foraging habits of bats. Each method has its own biases, advantages, and disadvantages and may yield different results depending on the species being observed or recorded, the local species richness, density and distribution, body size, age, sex, reproductive condition, type of habitat being monitored, and the sensitivity of the bats to the method(s) being used.

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INTRODUCTION

Foraging habits of bats have largely been inferred from the analysis of diet (based on examination of stomach contents and feces and parts of discarded prey), observations of nightly emergence and return times, capture times of commuting, feeding, and drinking bats, temperature recordings in roosts, ultrasonic recordings of commuting and foraging bats, observations of lighted bats, and the activity of radio-tagged and PIT-tagged individuals. Information derived by using one or more of these approaches has provided valuable insight into the foraging habitats of North American insectivorous species. Emerging technologies, such as Doppler radar imaging, infrared thermal imaging, 3-dimensional photography and videography, and computer modeling offer exciting new opportunities to characterize the feeding habits of insectivorous bats. When traditional methods are complemented with advanced technologies, new insight into the behavior and ecology of foraging bats is certain to emerge.

Many early studies that attempted to assess the foraging habits of free-ranging insectivorous bats were based on direct observations during periods when ambient light was sufficient to detect flying/feeding, usually during a brief period following sunset. Early naturalists often recorded bats drinking or foraging over water or near the edges of forests, where their silhouettes could be observed against an unobstructed sky. In some cases, bats were shot while they foraged. Fortuitous captures and shooting provided information on diet (stomach contents), and the places and times that some species fed. The availability of Japanese mist nets after World War II made it possible to readily capture bats as they commuted and foraged or sought water to drink (Dalquest 1954, Handley 1967). The development of the double-frame harp trap in the late 1960s (Tuttle 1974), and more recently the 4-frame harp trap (Francis 1989), has opened new opportunities to capture large numbers of bats, especially at caves and buildings (Kunz and Kurtz 1988), and in forested regions (Kingston et al. 2000), that would not have been possible using mist nets alone.

Ultrasonic detectors were first developed to evaluate the structure of echolocation calls as bats navigated or fed on insects in the laboratory (Griffin 1958, Pye 1983). Bat detectors became available for field use in the 1960s (Griffin this volume, Pye 1983), but many were not widely available or ideally suitable for field studies. From the mid-1970s until present, field-friendly bat detectors have become increasingly available. In the 1980s several commercial developments made it possible for these devices to be deployed for a variety of purposes, ranging from assessing general activity levels to monitoring activity of certain species in different habitats (Fenton 2000, Fenton 2001). In the 1990s, advances in circuit design, microphones with increased sensitivity to ultrasound, and
advanced computer software made it possible to record and store the full range of echolocation-call structures in the field and, in many situations, to identify bats to species (Ahlén this volume; Limpens this volume, Petersson this volume).

Bat detectors offer alternatives to more traditional methods to assess the presence of insectivorous bats, especially in environments and situations where it is not possible to make direct observations or to capture them. Notwithstanding, bat detectors are only one of a number of tools available for investigating the foraging habits of insectivorous bats. As with most devices, biases associated with their limits of detection, uncertainty of discriminating species-specific call signatures, and inability to discriminate individuals by sex, age, and reproductive condition, place limits on the general applicability of bat detection for assessing the full extent of foraging habits of echolocating bats (Hayes 2000). Live captures and other methods (Kunz and Kurtz 1988, Kunz et al. 1996) are needed to gain a full understanding of the foraging habits of insectivorous bats.

The purpose of this paper is to review research methods that offer information useful for evaluating and quantifying the foraging habits of insectivorous bats. In this review, I consider how research on the foraging habits of insectivorous bats (e.g., diet, commuting and foraging behavior, night-roosting, energy budgets, etc.) should employ a number of complementary techniques. Use of complementary techniques, including live capture, identification of species in the hand, fecal analysis, radio-telemetry, temperature telemetry, and the like, when used together, can contribute most towards our understanding. However, each capture device or observational method comes with its own limitations and biases.

**Dietary Analyses**

Most early efforts to characterize feeding habits were secondary to studies designed to document geographic distributions (i.e., dietary data were based largely on specimens destined for museum collections). Additionally, food-habit data were collected only in the first few hours after sunset (e.g., Cockrum and Cross 1964, Jones 1965, O’Farrell and Bradley 1970). In the 1950s and 1960s, it was common to set mist nets over bodies of water, only to dismantle them shortly thereafter. Some studies that at that time were specifically designed to evaluate food habits (e.g., Ross, 1967), and because these and similar efforts were frequently conducted by museum personnel, the animals were often prepared as museum specimens, which provided important information for ecomorphological studies.

During the past 20 years, stomach-content analysis has been replaced by fecal analysis as the preferred method for assessing diets of insectivorous bats (Kunz and Whitaker 1983; Rabinowitz and Tuttle 1982; Robertson and Stebbings 1993, Whitaker 1988). Analysis of cealed parts is also a proven method, especially for gleaners that discard wings and head parts of prey at their feeding roosts (e.g., Bell 1982, Poulton 1929), but these studies were often biased toward large prey that bats carry to feeding roosts. The shift from stomach content to fecal analysis occurred largely in response to declining bat populations and restrictions imposed by state and federal laws protecting threatened and endangered species (Mohr 1972, Jones 1976) and for ethical reasons (Rudran and Kunz 1996). Identification of insect parts based on fecal analysis usually eliminates the need to sacrifice bats (Kunz and Whitaker 1983), although potential biases exist, especially if soft-bodied insects are digested and thus fail to show up in feces (Rabinowitz and Tuttle 1982; Robinson and Stebbings 1993).

Most published studies on diet, based on either stomach-content or fecal analysis, have ignored observations that many species have two or more feeding periods during the night (Lee and McCracken 2002, Whitaker et al., 1996). For example, a comparison of insect prey eaten by Tadarida brasiliensis in the pre-midnight period (mostly coleopterans) exhibited marked differences in composition as compared to insect prey taken in the pre-dawn period (mostly lepidopterans, Fig. 1). These observed differences by a single species within one night may be as great as or greater than differences reported for an entire assemblage of bats (e.g., Ross 1967, Whitaker 1972). Thus, failure to consider insect species consumed by bats at different times of the night may severely bias conclusions about foraging behavior and dietary habits of a particular species. Moreover, failure to consider seasonal patterns of food intake can similarly bias conclusions about diets of insectivorous bats (Lee and McCracken 2002).

Variation in dietary habits can also be evaluated using stable isotope ratios of carbon (12C : 13C) and nitrogen (15N : 14N) (Hatch et al. 2002). Des Marais et al. (1980) compared stable isotope ratios of carbon and nitrogen in Tadarida brasiliensis and concluded that the
diet of this species at Carlsbad Caverns in New Mexico included insects that had fed both on native vegetation (C3 plants) and on agricultural crops (e.g., maize, a C4 plant) in the region. This method also has been used to assess geographic variation in the diet Leptonycteris curasoae (Flemming 1995; Herrera et al. 1993).

The quantity of food that a bat consumes on a given night is of fundamental interest to ecologists, but few efforts have been made to quantify how much insectivorous bats actually eat. Such data have important implications for assessing ecological and economic impacts of bats on both natural and altered ecosystems. Estimates of dietary intake of selected North American insectivorous species have been based largely on gravimetric methods derived from field samples, estimates of feeding rates based on laboratory analyses, and from allometric equations (Nagy 2001; Speakman and Thomas 2003). For example, Gould's (1955) estimate of the amount of food eaten by Eptesicus fuscus was based on the mass of the stomach content of a single individual that was shot after it had foraged for an estimated 45 min. By extrapolating this mass to a one-hour feeding period, Gould calculated that the individual consumed 2.5 g of insects per hour.

Griffin (1958) assumed that Myotis lucifugus consumed 2 g of insects per hour, based on Gould's (1955) estimate of the mass of the stomach content from M. lucifugus. Kunz (1974) used a gravimetric approach to estimate nightly consumption in M. velifer, by weighing and comparing different cohorts of bats captured at hourly inter-

vals, during the pre- and post-feeding periods. While these data were not used to estimate total nightly consumption, seasonal changes in estimated consumption from pregnancy through lactation suggested increasing levels of food intake as pregnancy and lactation progressed. Similarly, Anthony and Kunz (1977) and Kunz et al. (1995) used this method to evaluate patterns of nightly food intake during pregnancy and lactation in M. lucifugus and Tadarida brasiliensis, respectively (Fig. 2). Davis et al. (1962) used a gravimetric method to estimate nightly food intake in T. brasiliensis (1 g per night), but their estimate was considerably less than the nightly consumption estimated gravimetrically for the same species by Kunz et al. (1995). Kunz (1980) published two equations for estimating nightly food consumption of insectivorous bats, one based on gravimetric changes in body mass and the other on the amount of feces produced. Estimates of digestive efficiency in insectivorous bats ranging from 75-78% (Barclay et al. 1992; Barclay and Brigham 1991) to 88% (Kunz, 1980) were then used to estimate consumption from fecal production.

Turnover of doubly labeled water (DLW) has been used to estimate nightly food intake in Macrotois californicus during the non-breeding season (Bell et al. 1986). Kurta et al. (1989) used this technique and estimated that lactating female M. lucifugus ingested the equivalent of 100% of a female's body mass (ca. 8 g) during peak lactation. As a first-order approach, estimates of nightly food intake can also be derived from allometric equations (Nagy 2001; Speakman and Thomas 2003), although these equations do not account for variation in season, sex, or reproductive condition.

Figure 2: Variation in the quantity of food consumed by female Brazilian free-tailed bats (Tadarida brasiliensis) during the first feeding period during pregnancy and lactation (from Kunz et al. 1995).

Figure 3: Temporal activity of selected species of bats captured in mist nets set over a small stream in central Iowa (from Kunz 1973). Mist nets were deployed from before sunset until after sunrise.
COMMUTING AND FORAGING BEHAVIOR

It has long been known that bats emerge from their roosts near dusk and return near sunrise. However, not until the 1960s were efforts made to document the activity of bats following the first foraging bout (e.g., Jones 1965). Few early studies sampled bats from dusk until dawn. In one of the first published studies in which netting was conducted throughout the night, Kunz (1973) demonstrated that several syntopic species showed peaks of activity at different times during the night (Fig. 3). Kunz (1993) recorded the number of bats captured at 15-min. intervals from dusk until dawn, over the course of three summers. These data provided the first convincing evidence that bats were active well past the first few hours after sunset, and that some species exhibit different patterns of activity. Direct captures not only make it possible to characterize the activity of each species, but also to determine sex, age, and reproductive condition (Kunz 1973).

One of the primary limitations of capture devices to assess commuting or foraging activity by bats is that capture success at a given location often decreases on subse-

![Figure 4: Activity of bats recorded over a small pond in the flight path of little brown myotis (Myotis lucifugus) in southern New Hampshire. The activity of bats is based on captures with mist nets and bat passes recorded with a bat detector (from Kunz and Brock 1975).](image)

quent nights following initial captures. Kunz and Brock (1975) reported that fewer M. lucifugus were captured in mist nets when they were deployed in the same location along a forest trail and over a small pond on subsequent nights (Fig 4). When nightly activity was monitored simultaneously with mist nets and heterodyne bat detectors (Holgate, Ltd) tuned to 45 kHz, the patterns of activity were similar (Kunz and Brock, 1975). Other studies, however, have reported contrasting patterns of activity based on mist nets and bat detectors (O’Farrell et al. 2000). In part, these observed differences in activity may reflect the fact that some species may be active above the height that mist nets can be deployed or, as noted above, bats may learn to avoid nets.

Deployment of canopy mist nets is one approach that has been used to assess the activity of bats as they forage or commute in the sub-canopy. These nets have been erected (most often several stacked nets) over streams, along trails, and in forest trails, although they

![Figure 5: The effects of alternate mist net positions on capture success of bats. Net positions (lines) over and adjacent to the pond are designated by the letters (A-D). Short lines represent 6-m nets and long lines represent one 12-m or two 6-m nets. Positions and orientation are given for two ultrasonic detectors (net site and non-net site) at the pond. Letter combinations (with subscripts) denote the initial and subsequent nights that each net position was used (from Kunz and Brock 1975).](image)

![Figure 6: Rigging and position of a stacked canopy mist net extending from ground level to 30 m into the sub-canopy (from Hodgkinson et al. 2002).](image)
require support from above and thus have limited application in open habitats. Handley (1967) was the first to report captures of tropical bats in the sub-canopy by deploying a series of stacked nets. Francis (1989), Ingle (1993), Kalko and Handley, (2001), and Hodgkinson et al. (2002), have successfully used canopy nets to capture insectivorous and plant-visiting species in tropical regions (Fig. 6). Kurtz (1982) used stacked nets positioned over streams to assess how bats used the space from the surface of the water to just beneath the overhanging riparian tree canopy.

Different configurations of canopy nets have been used. Most commonly, several standard 6- or 9-m-long mist nets have been stacked in a series and raised from ropes suspended from overhanging branches (reviewed in Hodgkinson et al. 2002, Kunz 1988, Kunz et al. 1996). Munn (1991) described a method of reconfiguring standard mist nets by rotating the axis of the net 90 degrees and restringing the horizontal cords along the short axis of the net. This type of canopy net is now available commercially, although it requires special handling (Rinehart and Kunz 2001, Fig. 7). Alternatively, a series of up to 10 stacked nets requires specialized rigging to raise nets up to 30 m into the sub-canopy (Hodgkinson et al. 2002). Macro mist nets have been deployed successfully in open areas to capture high-flying bats (Rautenbach, 1998).

**Recording and Observing Bats in Day and Night Roosts**

The timing of emergence, return, and commuting/foraging activity of bats can, in part, be determined by monitoring the day and night roosting activity, using changes in roost temperature or observations with night-vision devices or video recordings. Kunz (1974) used thermister probes coupled to a telemeter to monitor day and night roosting activity of *Myotis velifer* in maternity roosts located in buildings. Thermisters were installed in roost crevices while bats were absent from the roost at night (Fig. 8). When bats occupied these roosts, temperature changes provided a direct measure of roosting activity and an indirect estimate of foraging activity. It was clear from

**Figure 7:** Preparation and deployment of an Avinet canopy mist net. **A:** Attachment of nylon loops to stationary object; **B:** Wire retaining loop holding the lateral, white plastic rings; **C:** Two knots in guidelines, linking topmost plastic ring, with one knot in guideline placed below each subsequent ring; **D:** Frontal view of deployed canopy net; **E:** Coupled S-hook assembly used to attach pulley rope and to balance net (from Rinehart and Kunz 2001).

**Figure 8:** Temperature profile recorded in a maternity colony of cave myotis (*Myotis velifer*) occupying a crevice roost in a barn located in south-central Kansas (from Kunz 1974). The observed decrease in temperature in the maternity roost at sunset depicts the emergence from a roost crevice at the onset of the first foraging period of bats. Subsequent changes show a single night-roosting period and a second foraging period in the predawn period.

**Figure 9:** Seasonal changes in nightly emergence patterns of little brown myotis (*Myotis lucifugus*) from a barn located in southern New Hampshire (from Kunz and Anthony, 1996).
Nightly Activity Based on Capture with Harp Traps

Harp traps are more effective for collecting data on temporal activity than mist nets in many situations, largely because they make it possible to handle large numbers of bats without the necessity of removing individuals from nets. Kunz (1974) used a two-frame harp trap (Tuttle 1974) set in the open doorway of barns and caves that housed maternity colonies of *Myotis velifer* in southwestern Kansas. The nightly activity patterns of captured bats illustrate seasonal changes in female (Fig. 11A) and juvenile activity (Fig. 11B). If traps are monitored at more frequent intervals, high-resolution data on activity is possible. In these situations, harp traps should not be placed so that they cover the entire opening used by bats. Notwithstanding, some bats learn to avoid being captured, bounce off, or sometimes pass through the trap (Kunz and Anthony 1977), thus potentially contributing to biased results.

Observing Commuting and Foraging Bats

Results Using Light Tags

Buchler (1976, 1980) used light tags to assess dispersal, commuting, and foraging behavior of insectivorous bats. Others (reviewed in Barclay and Bell 1988) have also used this technique, with the greatest success rates recorded in open areas, along flyways, and adjacent to forest edges. Buchler and Childs (1981) used light tags on E. fuscus and concluded that this species dispersed nightly to feeding grounds by following cues produced by calling frogs and stridulating insects. Light tags have also been used successfully, in combination with bat detectors, to follow known individuals while their echolocation calls are monitored. The main limiting factor of using light tags in heavily forested areas is that the bats often quickly disappear from view. They are most successful in open habitats.

Results from Radiotelemetry

Williams and Williams (1967, 1970) were among the first to use radiotelemetry with bats, specifically to assess homing behavior in *Phyllostomus hastatus*, a Neotropical omnivore. Early radiotelemetry studies were limited to relatively large species, because the components and batteries at the time were relatively large and bulky compared to those presently available (<0.4 g). With increased miniaturization of transmitter components and the availability of small, relatively long-lasting batteries, radiotelemetry has become a standard method to assess the foraging habits and roosting behavior of relatively small (>8 g) species (e.g., Barclay 1989, Barclay and
Field Observations and Recordings of Echolocation Calls

Based on field observations, several investigators have classified bats into different foraging strategies (e.g., Kalko and Schnitzler 1998; Neuweiler 1989; Norberg and Rayner 1987). These foraging strategies are based on unique echolocation signals and the relative amount of physical clutter present (Kalko and Schnitzler 1998). Making direct observations of flying bats in concert with recording echolocation calls is essential for a full understanding of foraging (Limpens this volume).
Recordings of echolocation calls synchronized with multi-flash, 3-dimensional photography or videography can provide valuable data on the behavior and echolocation-call structure associated with prey capture (Kalko, this volume). Multi-flash photographic sequences of aerial captures of insects by echolocating bats suggest a shift from a search mode to a target-oriented approach, immediately after bats detect potential prey (Kalko and Schnitzler 1998). Multi-flash recordings in open habitats indicate that bats often approach their prey from behind, moving into optimal positions immediately above the insect being pursued. In contrast, gleaning bats usually fly directly towards their prey, making captures by pounding on the prey (Kalko and Schnitzler 1998).

FROM ECHolocation TO FORAGING

Captive Studies

Much of what has been learned about the foraging habits of insectivorous bats has come from laboratory studies of echolocation and prey capture. In his classic book, *Listening in the Dark*, Griffin (1958) eloquently summarized what had been learned from recordings of echolocation calls in the laboratory during the early period of discovery (reviewed in Griffin, this volume). In the intervening years, enormous progress has been made, especially in the development and use of bat detectors for recording echolocation calls and the refinement of specialized software for analysis (Corben, this volume; Pettersson, this volume; Szewczak, this volume). Some of the most promising research on foraging by insectivorous bats has combined studies of behavior in captivity with observations in the field (see Iones, this volume; Seimers, this volume; Kalko, this volume).

Future studies on foraging habits that combine laboratory and field-based research on echolocation promise to provide revealing insights with respect to how bats actually navigate and forage in different environments.

Habitat Use Based on Bat Detector Surveys

One of the current applications of bat detectors is to assess the composition of local assemblages and characterize nightly activity patterns. To accomplish these goals requires reliable species identification. Unfortunately, many efforts to date have been hampered by inappropriate sample design and uncertainties about species identity (e.g., Hayes 1997; Hayes 2000). Until these uncertainties and protocols can be addressed, bat detectors for general surveys will provide little useful information with respect to how and when insectivorous bats commute and forage in different habitats.

Direct Observations

In some instances, it may be possible to visually observe bats as they forage in open habitats, especially near sunset and at high latitudes with extended period of twilight (e.g., Nyholm 1965, Rydell 1986). At most other times and places, however, opportunities to directly observe and record the foraging behavior of insectivorous bats requires artificial illumination (Racey 1995).

ADVANCED IMAGING TECHNOLOGIES

Doppler Radar

Where NEXRAD Doppler radar installations exist, this technology can be used to quantify nightly behavior of bats as they disperse and forage. For example, the Brazilian free-tailed bat (*Tadarida brasiliensis*) in the southwestern United States forms enormous colonies that often disperse upwards of 70 km from their daily refuges. These movements can be monitored by recording the reflectivity of the dispersing animals using NEXRAD Doppler radar (Fig. 12). These data are available from the U.S. government and some private organizations and can be downloaded for quantitative analysis of time, direction, and density of dispersing bats (J. Horn and T.H. Kunz, unpublished). This technology offers a powerful tool for quantifying the nightly dispersal and foraging activity of species that form large colonies, which is not otherwise possible.

Infrared Thermal Imaging

Infrared thermal-imaging cameras also offer opportunities to record the nightly emergence and feeding behavior of bats independent of natural or artificial illumination. Infrared thermal cameras are designed to detect heat emitted by objects as long as they are warmer than the background. Coupled to computers, infrared thermal images have been used successfully to census bats as they emerge from roost sites (Frank et al. 2003, Sabol and Hudson 1995) and to document flight trajectories during foraging bouts (Fig. 13).
Pit Tags and GPS Transmitters

Only a few studies have used passive integrated transponders (PIT tags) to investigate the ecology and behavior of bats (Brooke 1997; Kerth 1996). PIT tags offer an excellent opportunity to record roosting habits and by absence, to infer foraging by bats. Recently, PIT tags have been used to investigate the emergence and return times and use of night roosts at a maternity roost of Myotis lucifugus (J. Horn and T.H. Kunz, unpublished). When bats pass through a loop antenna positioned strategically over an opening used for exit and return or through cavities used as night roosts, it is possible to record the activity of individuals. When data for an entire season are plotted, patterns related to season (day length), reproductive condition, and age can be obtained (Fig. 14). From these data, it is possible to quantify time budgets of individuals.

Ecomorphology

The structure of wings, skull, and dentition of bats provides a valuable means to predict foraging habits (e.g., Freeman 1998; Norberg 1998; Norberg and Rayner 1987; Stockwell 2001; Swartz 1988; Swartz et al. 2003). Wing shape, wing loading, and aspect ratio are three important variables used to compare and predict the foraging habits of bats in different environments (e.g., Adams 1998, Aldridge and Rautenbach 1987, Badley and Brigham 1991, McKenzie et al. 1995). Wing structure of bats is often highly correlated with echolocation call design, flight mode, speed, and the amount and type of environmental clutter present (e.g., Aldridge and Rautenbach 1987; Heller and von Helversen 1989, Jones et al. 1993; Kingston et al. 2000).

Wing structure has also been used to evaluate intraspecific differences in foraging behavior (e.g., Adams 1997, Adams 2000). For example, Adams (1996, Adams 1997, Adams 2000) found that young Myotis lucifugus typically forage in less cluttered environments when they first begin to fly, but shift to more cluttered habitats as they perfect foraging skills and wing dimensions reach adult size. Differences in wing structure may also differ geographically within a given species, especially in habitats where the species assemblage may differ. Developments in computer simulation (Stockwell 2001), computer modeling of wing design, and studies that take into consideration the dynamics of wing shape and function during flight promise to provide more realistic interpretations of foraging behavior than is possible using static models (Swartz et al. 2003).

The predictive power of ecomorphological studies can guide field workers evaluating diet, and field-based biologists who study diets of bats can provide research direction to ecomorphologists. The skull and dentition in particular the shape and size of teeth, are important structures that can be used to interpret and predict the diets and trophic status of different species (e.g., Freeman 1979, Freeman 1992, Swartz et al. 2003). The nature of food items and how the teeth of insectivorous bats have evolved has been the subject of considerable research (Freeman 1988; Freeman 1998). For example, consumers of hard-bodied prey can often be distinguished from those who eat soft-bodied prey by their more robust mandibles and canines larger but ever teeth, longer canines, and abbreviated third upper molars.

Conclusions

Biologists interested in studying the foraging habits of insectivorous bats have an increasing array of devices and analytical methods at their disposal. These include traditional tools, such as mist nets and harp traps for capture, and also specialized instrumentation for recording
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