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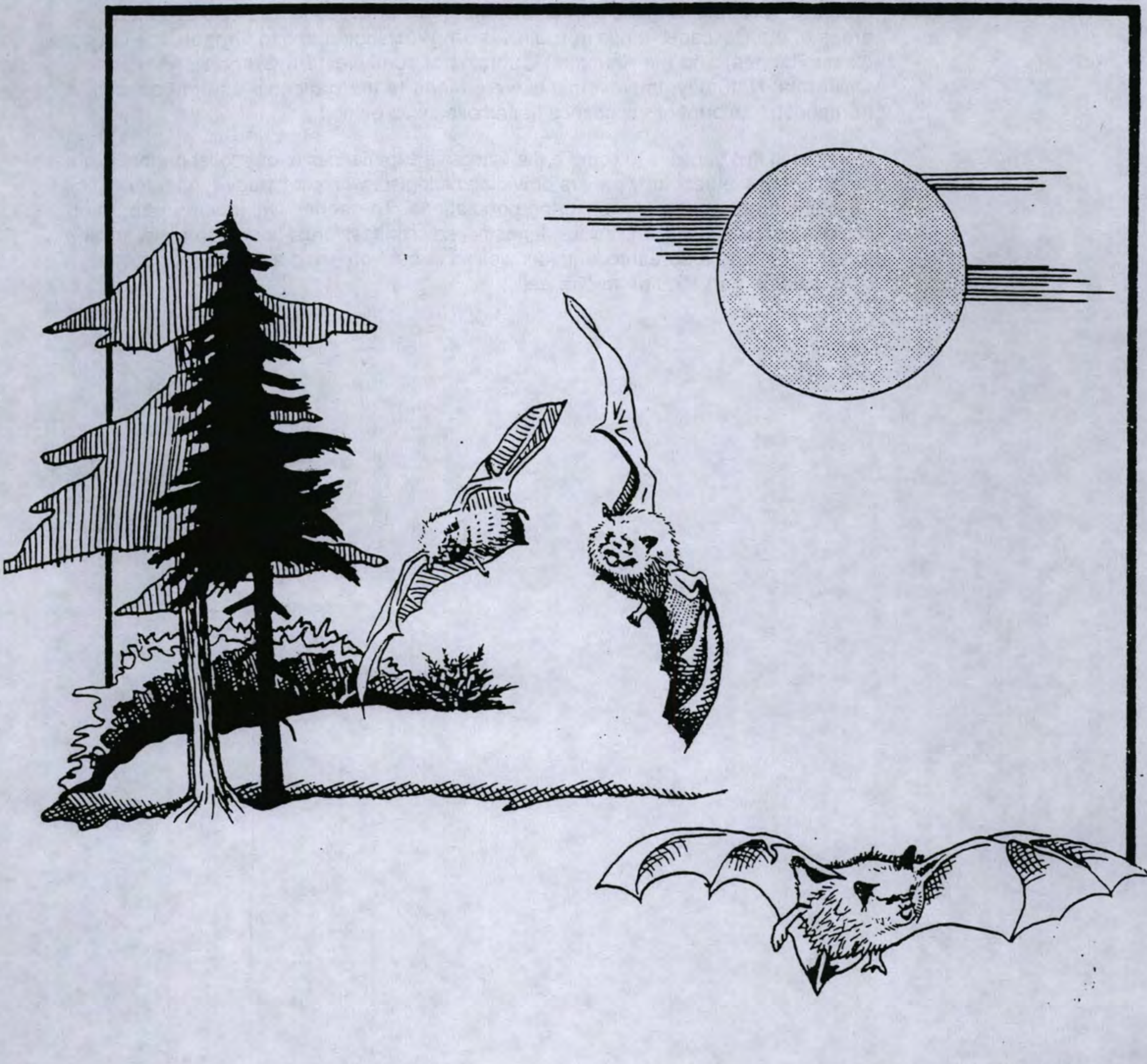
Sampling Methods for Bats

Donald W. Thomas and Stephen D. West



Preface

Concern about the value of old-growth Douglas-fir forests to wildlife in the Pacific Northwest began escalating in the late 1970's. The available information on wildlife-habitat relationships suggested that as many as 75 species including amphibians, birds, and mammals, could be dependent on old-growth forests. The USDA Forest Service chartered the Old-Growth Forest Wildlife Habitat Program to investigate the role old growth plays in maintaining viable populations of wildlife. It was apparent that broad surveys of vertebrate communities would be necessary to determine which species were truly closely associated with old-growth forests. Insufficient guidance on techniques, procedures, and sample sizes was available in the existing literature. We assembled a team of researchers from universities and Federal agencies to conduct pilot studies to develop sampling protocols and to test the basic experimental design for contrasting the wildlife values of young, mature, and old-growth forests. The sampling protocols resulting from the pilot studies were implemented in 1984-86 across broad areas of the Cascade Range in southwestern Washington and in Oregon, the Oregon Coast Ranges, and the Klamath Mountains of southwestern Oregon and northern California. Naturally, improvements were made to the protocols as time passed. A tremendous amount of experience in sampling was gained.

Our goal in this series is to compile the extensive experiences of our collaborators into a collection of methodology papers providing biologists with pilot study-type information for planning research or monitoring populations. The series will include papers on sampling bats, aquatic amphibians, terrestrial amphibians, forest-floor mammals, small forest birds, and arboreal rodents, as well as papers on using telemetry for spotted owls studies and a guide to bird calls.

Andrew B. Carey

Leonard F. Ruggiero

Introduction

As land development and exploitation become more widespread and severe, the concurrent changes in vegetation cannot help but affect animal populations. It becomes increasingly important to know what specific habitats or biotic and structural features in habitats are important for maintaining particular animal populations. One group of animals that may be sensitive to environmental modifications is the bats. In North America, two species of bats are currently on the Federal list of endangered species (*Myotis griscecens* and *M. sodalis*), and at least two other species have already suffered severe population declines *Leptonycteris sanborni* and *Plecotus townsendii*) (Howell and Roth 1981, Perkins 1985).

In the Pacific Northwest, 12 species of bats (including *P. townsendii*) occur on the western slopes of the Cascade Range and in the Klamath and Siskiyou Mountains (table 1), making this group second only to the rodents in importance as measured by species diversity. If previous population declines indicate that bats may be sensitive to habitat destruction, it is important to examine how current large-scale land use patterns, such as forest harvesting, may affect their populations. Forest exploitation may drastically or subtly alter habitat features important to bats. Clearcut logging practices, for instance, may entirely remove certain forest types locally or regionally (for example, old-growth stands of Douglas-fir, *Pseudotsuga menziesii* (Mirb.) Franco). High-grading (removing specific sizes and species) may alter the species composition or structure of the live communities in relatively intact stands. Intensive stand management may alter age composition and snag abundance, thus affecting the live tree communities or the standing dead (snags), or both. To assess the impact of land use practices on bat populations and moderate any observed effects, techniques must be available to monitor these populations. Such techniques might allow us to pose questions at four levels of complexity:

(1) Are any species affected by habitat changes and, if so, which species? (2) What is the degree of impact on a given species—extirpation or population reduction? (3) What changes in the environment are correlated with the observed changes in bat populations? (4) What steps will reverse the population trends or minimize future impacts?

In this paper, we provide an overview of the techniques available for monitoring bat populations in specified habitats or vegetation types (for example, forest blocks of a specified age and species composition). We also provide a detailed description of the techniques and equipment selected and applied in the USDA Forest Service Old-Growth Wildlife Habitat Program in Washington and Oregon. A separate review of bat survey and census methods (Thomas and LaVal 1988) may prove complementary, but it approaches the topic from a different perspective. It focuses on methods appropriate to monitoring bats where they are known to occur in abundance rather than in habitats where there may be no prior knowledge of bat abundance.

Bat Ecology

A detailed review of bat ecology is beyond the scope of this paper, and we direct readers to several review books and their references for details (Barbour and Davis 1969; Fenton 1985; Kunz 1982b; Wimsatt 1970, 1977). A brief overview of certain features of bat ecology is necessary, however, to understand the arguments for, and problems with, bat-monitoring methods.

In the Pacific Northwest, as in most of temperate North America, all bat species are insectivorous. They may be grouped into two general types: cavity-roosting colonial species and foliage-roosting solitary species.

Cavity-roosting colonial species make use of a wide variety of natural and artificial cavities including spaces behind exfoliated bark, natural or excavated cavities in trees, spaces in buildings and other structures, and caves and mines. These species may be only mildly colonial (forming groups of two to tens of individuals) or highly gregarious (forming groups of hundreds to thousands of individuals) (Barbour and Davis 1969, Kunz 1982b). During pregnancy and lactation, females maintain body temperatures well above ambient during the day to maximize fetal growth rates (Racey 1982). For this reason, reproductive females generally group together during the summer months to benefit from the thermoregulatory savings of clustering (Kunz 1982b, Racey 1982). These groups are called maternity colonies. In contrast with the female pattern, males apparently do not maintain high body temperatures during the day, but rather undergo 24-hour cycles of daily torpor and nightly activity.[1] Because they do not maintain a large gradient between body and ambient temperatures, males cannot benefit from clustering and so are typically solitary and possibly vagrant. Little is know about their summer ecology. In fall when the young are weaned, many cavity-roosting colonial species migrate locally or regionally to caves and mines in search of microclimates of high humidity and low temperatures (above freezing) for hibernation (Davis 1970, Fenton 1970). Some species (for example, *Eptesicus fuscus*; Brigham 1987) use buildings for hibernation in some areas, and it is quite possible, at lower elevations in the Pacific Northwest where winter temperatures are not usually severe, that some species use tree cavities for hibernation.

Foliage-roosting solitary species (*Lasiurus cinereus* and *Lasionycteris noctivagans*) generally do not exploit cavities but roost in fixed or shifting locations in tree foliage (Barclay 1984). Females give birth and rear their young at these sites, but little is known about their summer ecology. Both *Lasiurus cinereus* and *Lasionycteris noctivagans* seem to migrate south in winter, but the locations of wintering populations are poorly known (Findley and Jones 1964, Kunz 1982a).

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[1] Since writing this paper, new data are available on the metabolic rates and body temperatures of male little brown bats (*Myotis lucifugus*; Kurta, A.; Kunz, T.H.; 1988. Journal of Mammalogy. 69: 645-651) that suggest males may not be as thermolabile as we indicated. The effect of male thermoregulatory strategies on their choice of roosts has yet to be clarified.

Visual Strip Counts or Equivalents

Strip and variable circular plot counts have commonly been applied to bird studies, but in only one case have they been used with bats (Gaisler 1979). In Gaisler's study, visual identification of three bat species was based on size in an open-sky (city) habitat. Observers moving along fixed routes recorded bat sightings during the first 30 minutes after dusk. Gaisler (1979) applied these counts to population density estimates, but acknowledged that one size was more easily detected than the others. To make final density estimates, he adjusted sightings by an undescribed method. In visual counts, the detection distance is likely dependent on bat size, flight levels, and light intensity, so effective strip widths must differ between species, over time within a sample, and among samples. Accurate measurements of the distance from the observer to bat are required for the subsequent calculation of effective sampling volumes. Without these, no meaningful density estimates can be made (see Ralph and Scott 1981). This approach is unlikely to be of value in closed-canopy, high tree-density environments.

Collecting and Direct Captures

Under the right conditions, bats can be collected by using shotguns and dust shot. Such drastic "sampling" techniques have occasionally been used to suggest habitat preferences (see for example, Whitaker and others 1977, 1981). Collecting is feasible, however, only where lighting conditions permit sightings and bat flight levels are relatively low. This necessarily biases the sampling effort towards open habitats, often forest and stream and pond edges: results are therefore impossible to interpret. The question always remains whether the bats were truly less abundant in a given area or merely less visible.

Mist nets and specialized Tuttle traps (Tuttle 1974) can frequently be used to capture large numbers of bats. Because of these large samples, many biologists believe that hands-on methods can provide reliable indices of bat activity or abundance at the netting site. Surprisingly, no one has done an evaluation of the inherent problems associated with using nets and traps to survey or census bats (but see Bell 1980). We are forced to rely on personal experience and discussions to present the following argument.

There are good reasons to believe that captures cannot provide a reliable index of bat activity or abundance at one site or a comparison of relative activity levels or abundances among several sites. Where bats commute down habitual flyways, such as paths, gaps in vegetation, or constrictions imposed by bridges, they seem highly prone to capture if they fly at net height. In these situations, they may be familiar with the obstacles in the flyway and, although echolocating, are paying little attention to the weak echoes off nets or traps. At feeding sites, however, individuals are searching for the weak echoes from insect prey in the airspace before them, and they can readily detect and identify nets and traps as obstacles. Although at times large numbers of bats can be caught where they are clearly feeding, the proportion of individuals present that are caught is certainly low. Anyone netting bats over a pond has experienced the frustration of seeing what appear to be large numbers of feeding individuals while catching only a few or none. At the same time, bats seem to be capture-prone at habitual drinking sites, especially in dry environments. Kunz and Brock (1975) found that nets produce similar results to ultrasonic detectors at a drinking site, but this cannot be used to infer that results would be similar at feeding sites (Bell 1980). Based on this, we feel that capture methods have site biases and capture data cannot provide unequivocal information on the distribution of bats among various sites or habitats.

45 kHz or any other frequency, these detectors function as leak detectors. Any bat species sweeping out of the frequency range of other bats (for example, one incorporating a 25-kHz component when other bats are using higher frequencies) can be detected and identified by tuning to that frequency. A degree of species identification is thus provided, but the separation of all species in a complex community cannot be done.

Divide-by-*n* detectors couple a broad-band microphone with a circuit that divides the input frequencies by n. With a suitable divisor (usually $n = 10$), ultrasonic signals are rendered audible. A sweep of 100-40 kHz becomes 10-4 kHz at the output. These low-frequency outputs can be interpreted by ear or recorded on low-speed (4.8-9.5 centimeters/second) tape recorders for later analysis. Simple divide-by-10 detectors can be built from circuit diagrams (Miller and Andersen 1984, Paige and others 1985). The electronic transformation of the echolocation signal in this design results in the loss of all amplitude and harmonic frequency information. Only the fundamental frequencies and time characteristics are retained. Commercial varieties that retain the amplitude and harmonic structure of the calls and have a variety of extra features are available. Analysis of divided echolocation calls stored on tape can be done by using either a zero-crossing period-meter or a sophisticated sound-spectrum analyzer (Simmons and others 1979b). The period-meter provides a visual display of frequency and time (the shape) of fundamental frequencies of the echolocation calls on an oscilloscope screen, again losing any amplitude or harmonic details. Sound-spectrum analyzers can permit the analysis of these latter features if they are retained in the original recordings. The divide-by-*n* system allows for the monitoring of bat presence, species identity, and feeding activity.

Finally, a broad-band microphone coupled directly to a high-speed tape recorder (76 centimeters/second) can record all the information available in the echolocation signals as they are received at the microphone (fundamental frequencies and harmonics, amplitude, and time). These signals can be analyzed by using a period-meter or sound-spectrum analyzer.

Approximate costs of the systems are as follows:

- Leak and heterodyne detectors—<$200
- Divide-by-*n* detector and period-meter:
  - Commercial—<$3,000
  - Homemade—<$1,000
- Broad-band microphone and high-speed tape recorder and sound-spectrum analyzer—>$20,000.

Echolocation signals in air—As echolocation signals radiate out from a bat's mouth, the overall amplitude of the sound declines by the square of the distance. If all frequencies were attenuated equally, all the original information in the signal would be retained at any distance. But humid air causes additional power loss, and higher frequencies are attenuated more than lower frequencies (Griffin 1971). Power loss (attenuation) is an exponential function of frequency; increasing humidity increases the slope of this

Ultrasonic Detection and Bat Surveys in the Pacific Northwest

Based on the considerations outlined above, ultrasonic detection was selected as the only method able to provide a survey of bats in several small- to medium-size forest blocks in the Pacific Northwest (Thomas 1988). The system chosen had to be portable and able to provide species-level identification for all or a major proportion of the bat community. It also had to be sufficiently inexpensive to allow the purchase or construction of enough units to sample 45 study stands in a given region in a short time (ca. 1 month). Given these constraints, we selected a divide-by-10 system based on the Miller and Andersen design (1984). Although this system has been used to recognize bats by ear (Ahlen 1981), we were not confident that interobserver variation was negligible. For this reason, we coupled each divide-by-10 detector with a sound-activated tape recorder (Panasonic RQ-355) that stored the divided echolocation calls on tape after being triggered by the first call of a sequence. These recordings were later analyzed in the laboratory by using a period-meter to display the frequency-time form of the calls on a calibrated oscilloscope screen (Telequipment D32). This formed the basic detector system used throughout the study; however, the peripherals to this system evolved in complexity over two field seasons.

In 1984, six divide-by-10 and recorder systems were used to sample bat activity in 41 stands in the Cascade Range of southern Washington. Because bat activity is not constant throughout the night, each stand was sampled for 75 minutes (15 minutes each at five stations) starting about 30 minutes after sunset. Each stand was sampled three times to measure intrastand variation. This required six field assistants, each equipped with one detector system.

In total, only 277 bat passes were detected, representing a mean detection rate of 1.8 bats of all species per hour. For recognizable species in the genus *Myotis* (the most commonly occurring genus), detection rates ranged from 0.09 to 0.47 passes/hour. These rates were too low to permit any analyses other than presence and absence for grouped categories (for example, cavity- and foliage-roosting species). Bat activity is too low in stands in the Pacific Northwest to permit labor-intensive sampling with hand-held detectors. In addition, this system cannot provide any data on bat activity at the forest canopy level.

The solution to the problem of sampling in areas of low bat activity was sought in automation. We modified the basic divide-by-10 and recorder system so it activated itself at a preset time, stored bat passes as they occurred, recorded voice-synthesized time entries at 32-minute intervals, and turned off at a predetermined time. This detector system recycled to provide data on bat activity over successive nights. This system had an additional benefit of allowing a microphone to be raised to the canopy level to provide a sample for the lower to upper canopy stratum. The only limitations to the duration of sampling were the number of entries (bat passes, time entries, and spurious noise or insect calls) that could be contained on one side of a 90-minute cassette and the life expectancy of the power source. In the appendix and in tables 2 and 3, we provide additional information on this system, but we highly recommend consulting an electronics expert before considering following our schema.

The system used in field surveys of bats in the Pacific Northwest and specifically in the stands selected for study in the Old-Growth Wildlife Habitat Program had to meet three criteria: it had to record echolocation calls and allow data analysis, and the equipment had to be easy to deploy for data collection.

Table 3—Sources and approximate costs of some equipment required for monitoring bats with automated detector systems

Item	Source	Cost
Electret microphone (BT 1759)	Knowles Electronics Inc 3100 Mannheim Rd Franklin Park, IL	$1000/100
Talking quartz clock	Purchased at Schucks Auto Supply outlets in Washington	$30
Lead acid battery EP1295	ElPower Corp. 2117 South Anne St. Santa Ana, CA 92704	$50
Panasonic tape recorder RQ-355	Local electronics outlets	$50
Period meter	Science Workshop Carleton University Ottawa, ON, Canada	$500
Oscilloscope: Telequipment D-32 Nonlinear Systems MS-15	Local electronics outlets	$400-1000
Recharger/power supply LA250	Lambda Electronics 515 Broad Hollow Road Melville, NH 11747	$185

Recording

To use echolocation frequency-time characteristics for species identification, records must be obtained for known individuals of each species in a given study region (see Thomas and others 1987). We made efforts to capture and record the 12 species of bats in the Pacific Northwest to provide the data base for this study. Table 1 presents the frequency-time characteristics for the species that we captured. A more detailed description of the frequencies and durations of echolocation calls of these species can be found in Thomas and others (1987). In this study, we recognized seven species or species groups: *Myotis lucifugus/M. yumanensis*, *M. volans*, *Eptesicus fuscus/M. thysanodes*, *Lasionycteris noctivagans*, *Lasiurus cinereus*, *Plecotus townsendii*, and a "*Myotis* group." This latter group was comprised of four species (*M. evotis*, *M. ciliolabrum*, *M. septentrionalis*, and *M. californicus*). The similarities in roosting and feeding ecology among the undifferentiable species make these acceptable "ecological" groupings.

- Phenological patterns. Bat activity may differ during the three distinct reproductive periods of the summer: gestation, lactation, and weaning and recruitment. During gestation, females do not return to the day roosts during the night, but rather group together in separate night roosts between foraging bouts (Anthony and Kunz 1977, Barclay 1982). During lactation, however, the nursing schedule causes females to return to the day roosts to feed their young (Swift 1980). This, and the increased energy demands associated with lactation, may result in increased commuting and feeding activity during lactation. After weaning, the juvenile cohort is recruited into the flying population. The concommitant increase in the effective population size may also affect activity levels. These periods may correspond with April-June (gestation), July (lactation), and August-September (weaning and recruitment) in the Pacific Northwest, although insufficient data exist to permit their precise characterization (see Barbour and Davis 1969). All sampling should be completed within each reproductive period until these differences can be assessed.

- Vertical stratification. Little is known about the vertical distribution of activity either among species or within species for different locations and times. Stands should be sampled at ground and canopy levels wherever possible.

- Distribution of stands. The time involved in commuting to stands and setting up detectors is not negligible. Where stands are highly dispersed, as they were in the Cascade Range of southern Washington and the Oregon Coast Range, commuting may amount to >50 percent of the total time required to deploy detectors.

Given the constraints outlined above, the distribution of sampling effort within and among stands is determined primarily by the number of detector systems and field assistants available. In the Old-Growth Wildlife Habitat Program, we distributed our sampling effort as follows: in the Cascade Range of southern Washington and the Oregon Coast Range, two groups of 45 stands were selected for study. These represented five treatment groups (nine replicates each) covering the spread of age classes and moisture conditions found in Douglas-fir stands in the Pacific Northwest (Old-Growth Dry, Old-Growth Mesic, Old-Growth Wet. Mature Mesic, and Young Mesic). Each stand was sampled on two successive nights at both the ground and canopy levels with one detector at each level. To sample the canopy, the detector microphone was raised to the low- or mid-canopy height (>30 m) by shooting a monofilament line over a branch with a bow and weighted arrow. Both detectors were set to begin sampling at dusk (ca. 30 minutes after sunset) and to remain activated for 8 hours. In both regions, each of the 45 stands was sampled in July and again in August.

In this sampling scheme, we collected partial (>3 hours) or complete (16 hours) samples in 68 percent and 77 percent of efforts at ground level and in 48 percent and 39 percent of efforts at canopy level in Washington and Oregon, respectively. Sampling failure was due to equipment malfunction, radio interference, or orthopteran stridulations that caused the cassette to run out (see appendix). With this effort, albeit incomplete, we were able to collect samples totaling 1,599 hours in Washington and 1,500 hours in Oregon during July and August combined. These samples yielded 3,029 bat passes in Washington and 6,211 passes in Oregon (respectively, 10.9 and 22.4 times the sample sizes that we were able to collect with hand-held detectors).

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"on" time. When the alarm activates, the clock speaker signal is fed through a pulse-stretching circuit (7555) to a flip-flop (4013) that flips to its high ("on") state and pulls in the contacts of relay 1. A manual reset button is provided to ensure that the flip-flop is in its low ("off") state when the equipment is first powered. When pulled in, relay 1 supplies power to the detector amplifier circuits (12V), the dividing circuit (5V), the tape recorder (5V), and a timing circuit (12V). When it receives power, the timing chip (555a) begins pulsing every 3.8 seconds. This pulse rate is adjusted by varying R19. This output is read by a 14-stage binary counter (4060) that divides the pulse rate by a selectable function (2^{1}-2^{14}). The output at stage 14 goes high at the first input pulse from 555a and remains high for 9 hours. After this period, it goes low and resets the flip-flop (4013) to its low ("off") state and turns off relay 1. This interrupts the power supply to the detector, timer, and tape recorder until the alarm restarts the system on the following night. In this way, the alarm-timer combination governs the exact time that the detector system comes on and the duration of the sample on a given night.

Time entries are provided on the tape at 32-minute intervals by feeding an output from stage 9 of the binary counter (4060) to a timer (555b) that briefly pulls in relay 2. Closing the contacts on relay 2 shorts the contacts behind the "talk" button on the clock and causes it to announce the time. The clock has to be opened and wires soldered to three pairs of contacts behind the "talk" button for the relay to control the talk function. The voice signal is taken off the clock speaker and filtered (C16-C18, R16) to remove a spurious 10-mHz signal that disrupts the automatic gain control of the tape recorder. The filtered voice signal is provided at the tape jack.

The system is powered by a 9.5-amp 12-volt sealed lead acid battery. On an 8-hour-on and 16-hour-off cycle, the power supply lasts about 72 hours.

For each 1- to 3-night sample, the cassette contains the power-on (alarm) time and time entries at 32-minute intervals. Bat echolocation calls are entered as they occur.

For canopy samples, the microphone lead is extended to >30 meters in length, allowing only the microphone to be raised. If shielded rather than coaxial cable is used, a following circuit (fig. 1) must be added to the output of the preamplifier in the microphone housing (pin 12 of 3600a-R3 junction) for impedance matching.

Problems

In some areas (about 25 percent of study sites in the Cascade Range of southern Washington and the Oregon Coast Range), we encountered serious AM band radio interference when microphones were raised on long leads into the canopy. Despite copper screen shielding on the circuit itself and the normal cable shield, AM radio signals were picked up and passed into the dividing circuit. These appeared at the headphone and tape recorder jacks as intermittent to continuous static. These signals triggered the tape recorder and caused the tape to run out. A radio-frequency filter at the input to chip 3600b or enhanced shielding may reduce this problem, but we have not explored possible solutions.

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Bats represent the second most diverse group of mammals inhabiting the western slopes of the Cascade Range in southern Washington and the Oregon Coast Range. Bat populations may well be sensitive to changes in forest age, structure, or distribution, but their nocturnal habits and high mobility render the study of the habitat requirements of bats problematical. Unlike most other groups of vertebrates, bats are difficult to either observe or capture, and survey methods are poorly known. This paper reviews techniques for surveying bat populations and presents the methodology used in the Old-Growth Forest Wildlife Habitat Program in the Pacific Northwest.

Keywords: Bats, Chiroptera, distribution, abundance, habitat use, surveys, sampling methods, ultrasonic detection.

Pacific Northwest Research Station
319 S.W. Pine St.
P.O. Box 3890
Portland, Oregon 97208-3890