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Wind turbines cause mortality in some species of bats, primarily lasiurines, but it is unclear if mortality occurs in proportion to relative abundance. Reports indicate that the hoary bat (*Lasiurus cinereus*) was the most commonly found bat during searches for carcasses at a wind power facility in south-central Wyoming. The goals of my study were twofold: to examine the community structure of bats and to quantify roosting habitat for the hoary bat proximate to the wind power facility. Community structure data were used to determine if mortalities were proportionate to relative abundance. A better understanding of roosting habitat for the hoary bat can inform mitigation strategies at wind farms. Bats were surveyed with mist-nets and ultrasonic detectors in 2000 and 2001. The long-legged (*Myotis volans*) and little-brown (*M. lucifugus*) bats were the most commonly encountered species. The hoary bat was the fourth most abundant species, but may be transient in the study area. The number of hoary bat carcasses was more than four times as great as the number captured, indicating that wind turbines kill this species more frequently than other species in the study area. Most day roosts for the hoary bat were in lodgepole pine trees and were located nearly 7 km from the wind farm. Bats preferred trees that were taller and had greater canopy cover, and those that were located nearer to an edge and nearer to water than randomly selected trees.

ASSESSMENT OF BAT COMMUNITY STRUCTURE AND ROOSTING HABITAT PREFERENCES FOR THE HOARY BAT (*LASIURUS CINEREUS*) NEAR FOOTE CREEK RIM, WYOMING

by

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If I have seen further than others, it is because I have stood
on the shoulders of those who came before me.
– Isaac Newton (1642-1727)

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INTRODUCTION

The results of the work presented in this thesis represent a first step in understanding the effects of large industrial wind turbines on bats as a group and the hoary bat (*Lasiurus cinereus*) specifically. Over the past five years it has become clear that wind turbine-associated mortality of bats occurs in some locations and that bats in the genus *Lasiurus* comprise the bulk of these deaths. Because surveys for bats tend to occur sporadically and to focus on specific species and/or locations, detailed knowledge of bat assemblages is not available for many areas. Lacking this type of information, our ability to place observed mortality in context has been hampered. Turbine-related bat mortality at the Foote Creek Rim Wind Power Facility, located in south-central Wyoming, has been composed chiefly of hoary bats since the facility's inception in 1999. Because successful mitigation strategies must rely on knowledge about species of interest, this study was initiated in 2000. The main goals of the study were to assess the bat community proximate to the Foote Creek Rim Wind Power Facility, compare those data to the proportional mortality of bats at the facility, and to quantify roosting habitat for the hoary bat.

This thesis is organized into four chapters. Chapter 1 provides an overview of the natural history of the hoary bat. In Chapter 2, I present results of surveys designed to assess the relative abundance of different species of bats in the local area, and how the bat community compares to the relative abundance of species found during searches for dead bats at the wind farm. Chapter 3 summarizes roosting habitat preferences for the hoary bat, and Chapter 4 summarizes the current state of knowledge about bat mortality at wind turbines and explores potential reasons that certain species appear to be more susceptible to wind turbine mortality than other species. Appendix 1 at the end of Chapter 4 provides a general guide to designing studies of bat communities with an eye toward reliability of results and discussion of the limitations and biases associated with survey methods for bats.

CHAPTER 1

A REVIEW OF THE NATURAL HISTORY OF THE HOARY BAT (*LASIURUS CINEREUS)*

Introduction

Bats (Chiroptera) are an extremely successful group of mammals. They account for nearly one-quarter of all extant mammal species. In terms of diversity and distribution, they trail only the rodents (Vaughan 1986), and have adapted to a wide variety of habitats, occurring on all landmasses except the poles and a few remote oceanic islands (Vaughan 1986). Bats occupy unique and important niches, and have realized a degree of trophic radiation unparalleled among mammals, to include insectivory, frugivory, nectivory, sanguinivory, piscivory, and carnivory.

The Order Chiroptera is divided into two suborders: Megachiroptera (one extant family: Pteropodidae) and Microchiroptera (about 17 extant families). The Megachiroptera are restricted to the Old World tropics and subtropics, while the microchiroptera enjoy a widespread global distribution. Within the microchiroptera, bats of the family Vespertilionidae are among the most numerous and widespread. The lasiurines (Tribe Lasiurini) are a geographically dispersed group of vespertilionids found in the Americas from the treeline in Canada to the southern tip of South America. Generally foliage-roosting and solitary, the range of the hoary bat (*Lasiurus cinereus*) reaches to the Canadian treeline and into southern South America. The hoary bat has also succeeded in colonizing the Lesser Antilles, the Galapagos, and the Hawaiian islands (Shump and Shump 1982*a*).

Etymology

Lasiurines are called the “hairy-tailed bats” (*Lasi* [Gr.]: hairy; *ur(a)* [Gr.]: tail). The specific epithet *cinereus* refers to the hoary bat’s physical appearance (*cinere* [L.]: ashy). Thus, the hoary bat is the hairy-tailed, ashy-colored bat.

The North American hoary bat (*Vespertilio* [= *Lasiurus*] *cinereus*) was described in 1796 by Ambroise Marie Francois Joseph Palisot de Beauvois (Type specimen: Philadelphia, Pennsylvania). The first usage of the modern name *Lasiurus cinereus* is attributed to Allen (1864).

Phylogeny

The evolutionary origins of Chiroptera are cloudy, owing largely to an incomplete fossil record. The earliest known microchiropteran and megachiropteran fossils are from the Eocene (54-38 mya) and Oligocene (38-23 mya) epochs, respectively. Because well-preserved Eocene specimens show most of the unique adaptations of recent extant microchiroptera (e.g., specialized forelimbs for flight, and auditory regions of the skull that appear specialized for, and suggest the use of, echolocation), it seems that diversification was well underway some 50 million years ago. It is plausible that Chiropteran origins can be traced to the Mesozoic era (245-65 mya): most mammals of this time were small, nocturnal insectivores (Vaughan 1986), and rapid mammalian radiation is thought to have occurred during this era (Vaughan 1986).

The recent evolutionary origin of the hoary bat has been traced to the early Blancan (~2 mya) species *L. fossilis* (now extinct) known from Kansas (Hibbard 1963). Fossil remains from multiple locations in the midwestern and southwestern United States proffer evidence of *L. cinereus* from the late Pleistocene (1.8 mya-11,000 yrs) (Martin 1972). Three subspecies of *L. cinereus* are currently recognized: *Lasiurus cinereus cinereus* in North America*, L. c. villosissimus* (St. Hillaire, 1806) in South America*,* and *L. c. semotus* (Allen, 1890) on the Hawaiian archipelago. Morales and Bickham (1995) used mitochondrial DNA analysis to demonstrate that the Hawaiian hoary bat was most likely derived from the North American *L. c. cinereus* rather than the South American *L. c. villosissimus*, and based on low observed levels of divergence between *L. c. cinereus* and *L. c. semotus*, hypothesized that colonization of the Hawaiian archipelago by the hoary bat happened "relatively recently." Although Morales and Bickham (1995) give no indication of what "relatively recently" might mean, it is known that the bat was present when Polynesians first arrived in Hawaii about 1700 years ago.

The Chiroptera were long considered monophyletic (i.e., derived from a unique ancestor). However, beginning in the early 1970's several workers (e.g., Jones and Genoways 1970, Smith 1976, Smith and Madkour 1980, Hill and Smith 1984) began to challenge this notion, suggesting instead that the group is diphyletic (i.e., derived from separate ancestors). The ensuing "bat monophyly controversy" continues to be the subject of debate among evolutionary biologists. In essence, advocates of the monophyletic hypothesis argue that the megachiroptera and microchiroptera form a clade that is derived from a common ancestor that was capable of powered flight and laryngeal echolocation (Springer et al. 2001); whereas diphyly proponents hold that these two suborders do not share a common ancestor, and thus believe that powered flight evolved independently in the two groups. Most recent investigations support the monophyletic hypothesis (e.g., Van Den Bussche et al. 1998, Porter et al. 1996, Simmons 1994 & 1995, Stanhope et al. 1992, Wible and Novacek 1988). It is thought, therefore, that the ancestral forerunner of modern Chiroptera was capable of powered flight and laryngeal echolocation and that laryngeal echolocation was subsequently lost in megachiroptera.

Taxonomy

Lasiurus (Order Chiroptera, Suborder Microchiroptera, Family Vespertilionidae, Subfamily Vespertilioninae) is the sole genus in the Tribe Lasiurini. The Vespertilionidae comprises nearly 33% of all extant species of bats, and 180 (57%) of these species belong to Vespertilioninae (Koopman 1993).

During the early part of the 20th century the usage *Nycteris* (= *Lasiurus*) was common (e.g., Howell 1919, Hall 1923). To avoid confusion with the already established Old World nomenclature (*Nycteris*), the International Committee on Zoological Nomenclature (1929) endorsed the use of *Lasiurus* for New World species. Later, Hall (1981) suggested that the use of *Nycteris* (Borkhausen, 1797) rather than *Lasiurus* (Gray, 1831) was proper based on priority, but his suggestion has fallen on deaf ears, and the use of *Lasiurus* for New World bats in this genus persists.

Nowak (1994) recognizes 13 species in the genus *Lasiurus*: *L. blossevillii*, *L. borealis*, *L. brachyotis*, *L. castaneus*, *L. cinereus*, *L. degelidus*, *L. ega*, *L. egregius*, *L. intermedius*, *L. minor*, *L. pfeifferi*, *L. seminolus*, and *L. xanthinus*. The number of species attributed to this genus remains in flux, and ranges from seven (Honacki et al. 1982) to 13 (Nowak 1994). Differences in number of species of *Lasiurus* among authorities are, of course, due to taxonomic uncertainty. For instance, Honacki et al. (1982) considered three endemic Caribbean species (*L. degelidus* known from Jamaica, *L. minor* known from the Bahamas, Hispaniola, and Puerto Rico, and *L. pfeifferi* known from Cuba), and one endemic Galapagos species (*L. brachyotis*) to be forms of *L. borealis* (Bickham 1987). Several authors (Shump and Shump 1982*a*, Hall and Jones 1961) recognized 11 species. Recently, the western red bat (*L. blossevillii*) and western yellow bat (*L. xanthinus*) have been recognized as species distinct from the eastern red bat (*L. borealis*) and the southern yellow bat (*L. ega*) on the basis of molecular data (Morales and Bickham 1995).

Ecology

The hoary bat is known to roost in both deciduous and coniferous trees (Shump and Shump 1982*a*), and has been noted in such unusual roosts as a woodpecker hole (Cowan and Guiguet 1965), a squirrel nest (Neill 1952), under a driftwood plank (Connor 1971), on the sides of buildings (Bowers et al. 1968, Whitaker 1967), and in caves (Myers 1960, Mumford 1953). Although caves do not appear to be roosts from which hoary bats often emerge in North America (Myers 1960), they may represent typical roosting structures for the Hawaiian subspecies (Fujioka and Gonn 1988).

The echolocation strategy of the hoary bat is well-meshed with its flight style. The hoary bat uses low-frequency, high-intensity calls, which allows detection of insects over relatively long-range, because low-frequency signals do not attenuate in the atmosphere as rapidly as do high-frequency signals. The hoary bat has high wing loading (mass per unit area of wing) and high aspect ratio (relatively pointed wingtips), and as a result, tends toward relatively fast, straight, unmaneuverable flight (Norberg and Rayner 1987). The hoary bat's flight, combined with its echolocation style, probably limits its prey to moths and other large-bodied insects because of the bat's inability to detect smaller insects, or lack of sufficient maneuverability to capture small prey once detected (Barclay 1986).

Morphology

Because of its relatively large size and distinctive appearance, the hoary bat is not easily confused in hand with other temperate zone bats. It weighs 25-35 g, has an overall body length of 130-145 mm, and achieves a wingspan of 380-410 mm (Clark and Stromberg 1987). There is sexual dimorphism in size: females are roughly 4% larger than males (Clark and Stromberg 1987). The pelage is a reddish-brown with distinctive frosty (hoary) tips, which provides cryptic coloration during diurnal roosting.

Also in contrast to most other temperate zone bats, the uropatagium and undersides of the wings of the hoary bat are well-furred; apparent adaptations to the bat's foliage-roosting habits. The insulative ability of the pelage of the hoary bat is significantly higher than that of red bats (another foliage-roosting species), which is in turn higher than that of the crevice roosting *Myotis* and *Eptesicus* species (Shump and Shump 1980). The advantage of pelage with high insulation values and cryptic coloration is clear for a species that spends the day suspended in the open from a branch rather than hidden in crevices or cavities.

Distribution

The hoary bat is a widely distributed, but often relatively rare species, throughout the Americas. It occurs throughout North America to the treeline in Canada, and as far south as Brazil, Chile, and Argentina (Shump and Shump 1982*a*). Ecological observations (Maunder 1988, Zinn and Baker 1979, Mumford 1963, Provost and Kirkpatrick 1952, Dalquest 1943, Hall 1923) and reconstruction of museum and capture records (Findley and Jones 1964) indicate that sexes segregate during the summer months, with females being more common in the eastern and central United States. In California, it appears that females are more concentrated in the lowlands, and that males occupy the foothills and mountains (Vaughan and Krutzsch 1954).

Reproduction

Like all temperate insectivorous bats, the hoary bat is seasonally monoestrous (Racey and Entwhistle 2000). Typically, parturition occurs during the summer months during peak food availability. Copulation is thought to occur during fall migration (Shump and Shump 1982*a*). Because the sexes appear to be segregated across much of the species range during the summer (Findley and Jones 1964), it has been hypothesized that there are probably established migration routes where the sexes mix. Copulation on the wintering grounds is also a possibility. In species that hibernate (e.g., *Eptesicus, Myotis, Pipistrellus*), some copulation occurs during brief bouts of activity throughout the winter (Thomas 1995). But because sexes segregate during the spring migration (Cryan, in press, Zinn and Baker 1979), with females preceding males, spring mating probably does not occur in the hoary bat.

Many species of bats, and all neartic species of bats, exhibit a discontinuous reproductive cycle, defined by suspension of normal progression of the reproductive cycle between copulation and parturition (Neuweiller 2000). Three general categories of reproductive delay are recognized in bats: delayed fertilization, delayed implantation, and delayed development (Racey and Entwhistle 2000). Reproductive delays are hypothesized to synchronize parturition to periods of optimal food resources and developmental conditions for the young.

Among the strategies of reproductive delay employed by bats, delayed fertilization is the most common and the most physiologically enigmatic. Delayed fertilization is characterized by the long-term storage and viability of intrauterine spermatozoa (Crichton 2000). Because the introduction of spermatozoa into the reproductive tract of the mammalian female is tantamount to an invasion of foreign cells (Hogarth 1982), the ability of intrauterine spermatozoa in Chiroptera to remain viable through extended periods of hibernation (up to 10 months) (Racey and Entwhistle 2000) is unprecedented in mammals (Krutsch et al. 1982). Despite this, the mechanisms responsible for this prolonged viability are still largely unknown (Crichton and Krutzsch 2000). Once thought to be restricted to vespertilionids of temperate regions (which hibernate), delayed fertilization has been identified in a number of tropical species which do not hibernate, although in some of these species the storage time and fertilizing capacity of the sperm is much reduced (Racey and Entwistle 2000).

Although detailed data about reproductive cycles are lacking for most lasiurines, Shump and Shump (1982*a*) stated that the hoary bat employs delayed implantation. However, they provided no corroboration. Under delayed implantation, fertilization occurs immediately following copulation, but the blastocyst remains free-floating. Later, implantation of the blastocyst occurs, and the reproductive cycle continues normally. Inasmuch as other lasiurines exhibit delayed ovulation/fertilization (Kurta and Lehr 1995, Nowak 1994, Shump and Shump 1982*b*), it seems likely that the hoary bat does as well. Indeed, Druecker (1972) suggested that hoary bats ovulate in the spring, which would preclude the use of delayed implantation and implies overwinter sperm storage. Because delayed fertilization is known to occur in species that do not engage in bouts of deep torpor, and the capacity for sperm storage is independent of hibernation (Crichton 2000), delayed fertilization remains a viable, though unverified, strategy for the hoary bat.

Migration

Among North American insectivorous bats, only four species are considered to be migratory over long distances: the hoary bat, the red bat (*L. borealis*), the silver-haired bat (*Lasionycteris noctivagans*) and the Mexican free-tailed bat (*Tadarida brasiliensis*) (Wilkins 1989, Findley and Jones 1964, Allen 1939). These species may complete journeys of 1000 km or more (Norberg and Rayner 1987, Hill and Smith 1984) that can be both latitudinal and elevational (Constantine 1967, Findley and Jones 1964). Although the hoary bat is thought to remain active throughout the winter (Barclay 1995 & 1984), the extent to which it remains active is not known. Several authors have suggested that the hoary bat may hibernate in the mid-western United States (Whitaker and Mumford 1972, Mumford 1969, Whitaker 1967), and Davis (1970) stated that the hoary, red, and silver-haired bats migrate to warmer temperate regions where they hibernate.

The occurrence of migration in hoary bats and other species of bats has been suspected since at least the late 19th century when Linsley (1842) opined that hoary bats migrated south through New England in the fall. Later, Merriam (1888) pondered the apparent lack of three otherwise common North American species of bats from winter hibernacula, and provided evidence that the hoary, red, and silver-haired bats were present in Canada only during the warm months. The literature in the following decades are peppered with anecdotal observations of presumed bat migration (Maunder 1988, Zinn and Baker 1979, Tenaza 1966, Findley and Jones 1964, Hibbard 1963, Mumford 1963, Iwen 1958, Beer 1954, Cooley 1954, Tromba 1954, Provost and Kirkpatrick 1952, Dalquest 1943, Allen 1939, Saunders 1930, Hall 1923, Howell 1908), the cumulative weight of which suggests that some degree of migration does occur in some species. However, full-fledged studies to document the exact nature and extent of the putative migrations have been slow to come and detailed data on seasonal movements by bats are scanty (Blem 1980).

Much of the deficit in information about migration of lasiurines can be explained by inherent difficulties and ethical concerns associated with fall/winter telemetry, and banding studies. Established methods for assessing movements, such as radio-telemetry and wing bands, present significant challenges to both researchers and bats (Fenton and Thomas 1985). For instance, the relatively short range over which a telemetry signal can be detected (< 1 to 5 or 6 km depending on topography and the height of the bat), short battery life (2-4 weeks), and logistical difficulties with tracking bats over long distances all but preclude the use of radio-transmitters for following migrating bats. As well, the added weight of the transmitter or addition of a wing band may impair normal flight, leading to increased stress in the bat (Aldridge and Brigham 1988, Barclay and Bell 1988). Banding provides useful information only if the bands are recovered (or re-sighted) (Barclay and Bell 1988), and has been implicated in scarring of wing tissue.

Griffin (1970), recounting Howell and Little (1924), reported "injury to bats and chewing of the numbers that rendered the bands illegible" when they banded big-brown (*Eptesicus fuscus*) and Mexican free-tailed (*Tadarida brasiliensis*) bats. These concerns notwithstanding, much of what we know about movement patterns has come from studies of banded bats (e.g., Thomas and LaVal 1988, Hill and Smith 1984, Constantine 1967, Davis and Hitchcock 1965, Beer 1955), most of which occurred from the 1930s to the 1970s. Griffin (1970) summarized the results of some of the more successful studies of bat migration. However, banding or other marking techniques may not be effective for studying the migration patterns of the hoary bat or other lasiurines because they do not aggregate in hibernacula, resulting in low resight or recapture rates.

Findley and Jones (1964) attempted to elucidate patterns of hoary bat migration based on their own capture records from New Mexico and a compilation of museum and literature records from across North America. They noted waves of hoary bats in May, August, and September, and an apparent spatial segregation in the summer by the sexes across the species' range, with females tending toward an eastern summering ground and males more common in the west. Presumed migratory "waves" of *L. cinereus* have been noted during spring in California (Vaughan 1953), New Mexico (Findley and Jones 1964), and during autumn in Florida (Zinn and Baker 1979). Hill and Smith (1984) reported that most species of *Lasiurus* follow "relatively precise migration routes each autumn", but sadly, the authors offer no substantiation.

Available evidence suggests that spring migration of hoary bats begins in May and autumn migration begins in August (Koehler and Barclay 2000, Shump and Shump 1982*a*, Zinn and Baker 1979, Findley and Jones 1964). The hoary bat appears to winter in southern California, the southeastern United States, and Mexico (Barbour and Davis 1969). Because the hoary bat roosts in foliage, fully exposed to ambient temperatures and the elements, they may overwinter in areas that remain above freezing and do not receive significant amounts of precipitation. However, because red bats (*L. borealis*) sometimes hibernate in areas where temperatures periodically drop below freezing (Davis and Lidicker 1956) and seem capable of supercooling, at least for short periods, with no apparent adverse effects (Davis and Reite 1967), the hoary bat may be capable of similar feats.

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CHAPTER 2

ASSESSMENT OF BAT COMMUNITY STRUCTURE NEAR FOOTE CREEK RIM (CARBON COUNTY, WYOMING) AND COMPARISON TO WIND TURBINE-RELATED BAT MORTALITY

Abstract

Turbine-related deaths of bats at the Foote Creek Rim Wind Power Facility have been composed chiefly of hoary bats (Lasiurus cinereus) since the facility's inception in 1999. Lacking baseline data on the relative abundance of bats in the area, it has been difficult to place this mortality in context. I used mist-nets and bat-detectors to determine bat community structure in proximity to the wind farm in 2000 and 2001. Based on mist-net surveys, the little-brown bat (Myotis lucifugus) and long-legged myotis (M. volans) were the most abundant species in the study area, followed by the silver-haired bat (Lasionycteris noctivagans), the hoary bat, the long-eared myotis (M. evotis) and the big-brown bat (Eptesicus fuscus). Bat-detector data were congruous with capture results, though calls attributed to the four least abundant species were more evenly distributed than number of captures for those species.

These data on community structure were compared to mortality from wind turbines from 2000 to 2001. The hoary bat was the most common species found dead and experienced turbine-related mortality disproportionate to its relative abundance. Mortality to big-brown, silver-haired, and little-brown bats, and other (unknown) Myotis species also occurred, but to a lesser extent. Like the hoary bat, the silver-haired and little-brown bats experienced mortality apparently associated with migratory movements.

Introduction

Results of surveys conducted between 1999 and 2001 at the Foote Creek Rim Wind Power Facility located near Arlington, WY (41°35′N, 106°12′W) indicated that the hoary bat (Lasiurus cinereus) represented 88% of the bat carcasses recovered (Young 2001, this study). A recent review of wind turbine-associated bat mortality revealed that lasiurine bats (Lasiurus borealis and L. cinereus) comprised 85% of all dead bats collected at three wind farms in the United States (Keeley et al. 2001). The wind power industry has grown tremendously over the past two decades (AWEA 2002a) and shows no indications of abating (AWEAb). Thus, baseline data on turbine-related mortalities contextualized with the adjacent bat community may prove informative as wind power assumes a more important role in electricity generation.

Compared to avian mortality at wind farms, deaths of bats caused by wind turbines have only recently been reported (Keeley et al. 2001). Although there is an extant and growing literature on avian interactions with wind turbines (e.g., Sinclair 2001, Johnson, et al. 2000, Morrison and Pollock 2000, Anderson et al. 1999), there are few studies addressing the influence of turbines on bats (but see Johnson et al. 2002, Nicholson 2001, Erickson et al. 2000), and even fewer published works on the subject (but see Osborn et al. 1996, Hall and Richardson 1972). In addition to the lack of information about bat-turbine interactions, knowledge of the bat fauna in Wyoming is sparse. The handful of studies of the occurrence and distribution of bats in Wyoming tend to be geographically narrow (Turner 1974) or restricted to assessment of museum records (Bogan and Cryan 2000), hampering the ability to contextualize current levels of turbine-associated bat mortality at Foote Creek Rim. Distribution maps suggest that nine species of bats are present near Foote Creek Rim (Clark and Stromberg 1987). However, because of the paucity of records, delineation of these distribution maps relied heavily on the authors' best guesses (Clark and Stromberg 1987:15).

A successful conservation strategy for bats must include an understanding of how humans influences. Therefore, the current study was initiated in 2000 to quantify the bat community structure on and around Foote Creek Rim. The main goals of this research were to 1) assess the relative abundance of bat species in the local area, and 2) to compare the relative species composition of the local bat community to that of carcasses found near turbines on the Foote Creek Rim.

Study Area

The study area is located in south-central Wyoming (41°35′N, 106°12′W) approximately 72 km WNW of Laramie, WY, and includes the northern portions of the Medicine Bow National Forest and surrounding areas to the north (Fig. 2-1). The study area encompasses 52,578 ha, of which approximately 35% contained suitable roosting habitat (i.e., forested stands or riparian overstory cover) for the hoary bat (Shump and Shump 1982). Elevation ranged from 2133 m to 2896 m. Mean annual temperature and precipitation are 5.5°C and 29.8 cm, respectively. Summer (June-August) temperature and precipitation averages are 16.6°C and 2.6 cm. Summer temperatures range from an average high of 25.7°C to an average low of 7.5°C (Wyoming State Climate Office 2002).

The Foote Creek Rim Wind Power Facility, located within the study area, is at the northern tip of the Medicine Bow National Forest (Fig. 2-1). Foote Creek Rim (the rim) is oriented on a north-south axis, sits about 125 m higher than the surrounding basin, and covers approximately 536 hectares. Elevation at the southern tip of the rim is 2438 m and falls gradually over its 8.8 km length to 2347 m at its northern tip. Habitat on the rim-top consists of low-growing graminoid/forbs with clumped distributions of sagebrush (*Artemisia* spp.) and common rabbitbrush (*Chrysothamnus nauseosus*). There is no open water on the rim-top. There are long, narrow stringers of quaking aspen (*Populus tremuloides*) encompassing about 50 ha on the east slope of the rim.

Habitat outside the forest boundaries is typical sagebrush steppe characterized by a mixture of sage (*Artemisia* spp.) and short grasses (Knight 1994). Overstory tree canopy is restricted to riparian areas (i.e., beaver ponds and stream banks), and consists primarily of eastern cottonwood (*Populus deltoides*) and narrowleaf cottonwood (*Populus angustifolia*), with assorted willows (*Salix* spp.) and mountain alder (*Alnus tenuifolia*). Habitat on the national forest ranges from clumped distributions of lodgepole pine (*Pinus contorta*) and quaking aspen, interspersed with open sage and grasslands at its northern foothills, to more continuous lodgepole pine stands and finally spruce/fir (*Picea engelmannii* and *Abies lasciocarpa*) communities as elevation increases to the south (Knight 1994).

Methods

Mist-Net Surveys

Selection of locations to conduct surveys with mist-nets on any given night was dictated by the need to maximize captures of hoary bats and was not random (see Appendix 2-2 for summary of survey sites and dates). Other selection criteria included availability of personnel and the length of time since a particular site was last surveyed. Bats were netted using standard nylon-mesh nets (mesh size = 2.5 cm) in areas of suspected bat concentration (i.e., over streams and ponds). Nets were approximately 3 m tall when expanded and varied in length from 6-12 m. Mist-net stations were continuously monitored for four hours beginning at civil sunset (U.S. Naval Observatory 2002). No mist-net surveys were conducted on the rim-top due to low expected success and as per my agreement with SeaWest Wyoming, Inc. (on-site managers). I assessed relative age as adult or juvenile (Anthony 1988) and reproductive status (Racey 1988), and collected morphometric data (i.e., forearm length, and mass) of captured bats.

Bat-Detector Surveys

Surveys using bat detectors were conducted on the rim-top, over ponds surrounding the rim (less than 1 km from rim-top), and over streams and ponds on the Medicine Bow National Forest. Assignment of detectors to the rim or away from the rim was based on logistics, weather, and length of time since the previous survey. Although assignment of detectors to a particular habitat was not random, I made every attempt to achieve similar survey effort between the rim and National Forest habitats (Fig. 2-2). When detectors were assigned to the rim, the turbine near which the detector was placed was randomly selected. I avoided sampling with detectors where I was mist-netting over water to avoid bias.

I used Anabat II bat detectors in conjunction with Anabat II delay switches (Titley Electronics Ltd., Ballina, NSW, Australia) and Optimus portable cassette tape recorders (Models CTR-107 and CTR-112, Radio Shack Corp., Fort Worth, TX, USA). Detectors were placed in weather-resistant containers and patched into portable tape recorders, which recorded all bat calls detected by the unit. Units were placed on the ground and tilted upward to maximize the airspace sampled. Units were activated at or before dusk, left on through the night, and collected the next morning. Tapes were downloaded to an IBM-compatible desktop computer using Anabat *V* software (Titley Electronics Ltd.). To determine if I was missing bat activity on the rim by using ground-based sampling, in 2001 I mounted a small platform approximately 15 m above the ground on a metal tower. The platform was used to support a detector unit. The detector was secured to the platform, parallel to the ground, and faced away from the prevailing wind direction, which was generally out of the west. Because the meteorological tower was situated west of the turbines, the detector usually faced the turbines.

Analysis of Bat-Detector Data

I subjectively categorized calls from both years based on their quality. Three categories were created and calls were categorized as follows: Quality 3 (Q3) calls were those that were most complete and/or had a sufficient number of pulses to be reasonably confident of species or species group status. To minimize ambiguity regarding species identification (Barclay 1999), only Q3 calls were classified to species level. Quality 1 (Q1) and Quality 2 (Q2) calls were highly fragmented and as a result species identification and assessment of group status of these calls was problematic.

Quality 3 calls were subjected to linear discriminant function analysis (DFA) using five pulse parameters (entered together) as predictors of membership in one of six species groups. To derive the discriminant functions that characterized each species, I obtained a set of 100 known calls for the six species encountered during the study (Table 2-2) from the Acoustic Call Library at the University of New Mexico (http://talpa.unm.edu/batcall/html/batlinks.html). The known calls were used as a "training data set." The estimated discriminant functions for the known calls were then used to categorize the unknown Q3 calls.

Call parameters were extracted with the Analook computer program (Analook v4.8f, March 24, 2000, Chris Corben). Parameter extraction produces data on each pulse for a given call. To avoid pseudoreplication, pulse parameters were averaged for each call before being analyzed. Although Analook provides 17 parameters for each pulse, many of them are highly correlated to one another and/or unreliably characterize the stated parameter(s). In this analysis I used only the five parameters (Table 2-3) that I deemed to be most reliable based on the algorithms used to derive them (Corben and O'Farrell 1999). All parameter values were standardized to ensure that measurement units were comparable.

Carcass Searches

Searches for carcass were conducted on transects within 30 x 30 m plots centered on selected (non-random) turbines on Foote Creek Rim. Plot size was based on past carcass recovery data from Foote Creek Rim (1999 and 2000) which indicated that 90% of carcasses were found within a 30 x 30 m area around a turbine. Johnson et al. (2000) also noted that over 99% of bat carcasses were found within 30 m of turbines during their study in Minnesota. Plots were square rather than circular to facilitate ease of searching. Searches were conducted weekly from July 16 to September 3 by walking parallel transects 6-8 m wide x 30 m long and visually searching the ground over the entire plot. When carcasses were encountered, distance and bearing to the nearest turbine (and turbine number) were recorded. Sex, age, and time since death were also estimated (when possible) for carcasses.

Western EcoSystems Technology, Inc. (WEST) conducted carcass searches on roughly half of turbines located at the southern end of Foote Creek Rim (turbines 1-69) as part of an ongoing study. They searched 11 strings of 3-4 turbines once every 28 days. WEST searched 63 x 63 m plots centered on a turbine. I searched the 35 adjacent (non-overlapping) turbines. WEST searched turbines 1-134 once every 28 days in 1999 and 2000.

Analysis of Carcass Data

A Chi-square test was performed to test the hypothesis that the proportions of species recovered during carcass searches in 2000 and 2001 were the same as those captured in mist-nets during the same period. The number of carcasses of each species expected (under the null hypothesis that mortality occurred in proportion to relative abundance) was calculated by multiplying its relative abundance (expressed as a proportion) as determined by mist-net surveys by the total number of carcasses collected. The test statistic was calculated by $\sum_i \frac{(Observed_i - Expected_i)^2}{Expected_i}$, where *i* represented a species. The test statistic was compared to a Chi-square distribution with appropriate degrees of freedom. The null hypothesis was rejected if the *P*-value was ≤ 0.05.

Results

Mist-Net Surveys

Mist-net surveys were conducted on 21 nights (averaging twice a week) in 2000 between 29 June and 2 September, resulting in the capture of 67 bats in three genera and five species (Table 2-4). In 2001, surveys were conducted on 37 nights (averaging three times a week) between 5 June and 14 August, yielding 193 bats representing four genera and six species (Table 2-5). A total of 260 bats was captured during the study.

Bats in the genus *Myotis* represented approximately 81% of all bats captured. The long-legged myotis (*Myotis volans*) and little-brown bat (*M. lucifugu.*) were the most commonly encountered bats during mist-net surveys (Table 2-6). The hoary bat was the fourth most abundant species captured. The earliest date on which a hoary bat was captured was 28 June (2001) and the latest date in the season was 17 August (2000). Only two big-brown bats were encountered during the study; one (a male) was captured in a mist-net and the other (unknown sex) was found during searches for carcasses. Combined with a carcass recovery in 1999, only three big-brown bats have been encountered in the study area, suggesting that this species may not be a resident in the area, but does occasionally pass through.

Surveys conducted on the forest were more productive, in terms of absolute numbers of captures and captures per unit effort, than were surveys conducted off the forest (Table 2-7). This difference was driven primarily by the large number of captures of the long-legged myotis at one survey site. If captures from this one site are excluded from calculations, then the difference between coniferous forest sites (on-forest) and cottonwood riparian sites (off-forest) are slight, but still roughly an order of magnitude greater than the other habitat-types.

For both years and all species combined, 100 of the 246 bats that were positively identified were adult males, and 86 were adult females. Juvenile males outnumbered juvenile females by a factor of 2: 34 to 17, and most of these (46/51) were *M. lucifugus* and *M. volans*. The earliest date in the season that a juvenile was captured was 10 August in 2000 and 6 August in 2001.

Bat-Detector Surveys

Bat-detector surveys were conducted on 27 nights in 2000 between 26 June and 21 August, and 23 nights in 2001 between 11 June and 13 August. A total of 80 survey-nights yielded 4315 calls (Table 2-8). Surveys were conducted 3 nights per week in 2000 (mean = 3.0, range 1-4) using 1-2 detectors per night (mean = 1.44) and twice a week in 2001 (mean = 2.2, range 1-3) using 1-3 detectors per night (mean = 1.78).

In general, bat activity on the rim was exceedingly low compared to sites off the rim (Table 2-9). To evaluate if bats were foraging on the rim out of range of the ground-based detectors, I conducted bat-detector surveys at 15 m above the ground on 10 occasions between 27 June and 6 August 2001. On four of those occasions I sampled concurrently at the base of the tower. Six calls were recorded at the ground stations but only three calls were logged at the station on the tower, suggesting that I was not missing bat activity on the rim using ground-based sampling.

Although five discriminant functions were generated during the analysis (since the number of discriminant functions is equal to the smaller of either *g*-1, where *g* is the number of groups, or the number of samples), only the first four were significant (Table 2-10). Based on these functions, DFA correctly classified 73 % of known calls using equal prior probabilities (Table 2-11). The reduction in misclassifications based on the DFA was 42.2%, calculated by (no. correct – chance) ÷ (total – chance), where chance was calculated by (no. correct ÷ no. possible) x (no. correct).

Of the 740 Q3 calls included in the analysis, 20.8% were non-myotis species and 79.2% belonged to species in the genus *Myotis*. These results are similar to the relative proportions of each group observed from mist-net captures, indicating that the assemblage of bats in the study area was comprised primarily of *Myotis* species, which in turn was comprised mostly of *M. lucifugus* and *M. volans* (Fig. 2-3).

An assumption of DFA is that the variance-covariance matrices are equal. Based on Box's M, this assumption was not met. However, Box's M is a "notoriously sensitive test" of this assumption, and DFA is robust to departures from this assumption if sample sizes are large and sample sizes are similar (Tabachnick and Fidell 1996). Therefore, not meeting this assumption probably did not significantly affect the classification results. Another assumption of DFA is that each case belongs to one group. It is possible that one or more of the unknown calls came from a species not encountered during mist-net surveys or carcass searches, and therefore not included in the training data set. If this were the case, then some calls would have been "forced" into species categories to which they did not belong. However, unless there were a great many calls from species not encountered during mist-net surveys, any effect on the outcome was probably minimal.

Carcass Searches

The carcass searches I conducted in 2001 yielded 22 hoary bats and one big-brown bat. Over three years of searches, hoary bats represented the overwhelming majority of recovered bats (Table 2-12). This result stands in contrast to what would be expected if hoary bats were being killed in proportion to their relative abundance (Fig. 2-4). The Chi-square test with 3 df was highly significant ($\chi^2 = 718.8$; $P < 0.001$), indicating that bat mortality by species were disproportionate to relative abundance as determined by mist-net captures. Of the four species found during carcass searches, only the big-brown bat may have experienced mortality in proportion to its relative abundance, whereas all other species exhibited disproportionate mortality (Fig. 2-4).

The bulk of hoary bat mortality occurred between mid-July and mid-September (Fig. 2-5), coinciding with putative migration periods (Koehler and Barclay 2000, Cryan, in press). The silver-haired bat, another migratory species, experienced low levels of mortality in the late summer and early fall. Mortality of the little-brown bat were more spread out, but generally occurred in the spring and fall, when they may have been moving between winter hibernacula and summering grounds.

Discussion

I used mist-nets and bat-detectors to determine bat community structure in the study area in 2000 and 2001. As with all sampling methods, these are not without biases. Highly maneuverable species and slow-flying species seem to be adept at avoiding mist-nets and may be under-represented in capture results. Similarly, because mist-nets are generally placed near or at ground level and usually erected over water, species that forage low over water are more likely to be captured than those that do not.

Bat-detectors record the ultrasonic calls of echolocating bats that pass within range of the detector's microphone. Bats that echolocate loudly are more likely to be detected than those that do not. As well, detectors are often deployed near the ground, so high-flying species may not be detected at a location even if they are present. These biases cannot currently be quantified (O'Shea and Bogan 2000), and may have influenced the depiction of community structure. Although most of the species encountered may have been more detectable by one method than the other, or almost equally detectable by either method, the long-eared myotis (*M. evotis*), a slow-flying, maneuverable bat, is quite capable of detecting and avoiding mist-nets, and echolocates at high frequencies (which attenuate quickly) and at low intensity. Thus, *M. evotis* may have been more abundant than my results indicated. Nonetheless, the combination of both mist-net and bat-detector surveys probably provided the most accurate assessment of community structure possible (O'Farrell and Gannon 1999, Kuenzi and Morrison 1998).

The little brown bat was the most commonly captured bat in 2000, whereas the long-legged myotis was the most commonly captured bat in 2001. This difference in the most commonly captured species between 2000 and 2001 (little brown bat, *n*=43, and long-legged myotis, *n*=96, respectively) probably does not represent a shift in community structure between years. Rather, it is likely a reflection of differential trapping effort (Table 2-7). During 2000, I surveyed primarily beaver ponds and streams at off-forest sites. However, during 2001 I surveyed mostly in the forest at beaver ponds. The bulk (95%) of the captures of long-legged myotis in 2001 were from one coniferous forest site, which apparently was used heavily by one or more maternity colonies, and which was not surveyed in 2000.

Although results from the bat-detector data are congruous with those from mist-net surveys (Fig. 2-6), they should be interpreted with caution, because bat-detector data represent the relative number of bat calls detected, not the relative number of bats present, and thus are only an index of species activity. Also, species identification based on Anabat data can be thorny (Barclay 1999). Although the DFA increased the probability of correct classification for the known set of calls over chance by 42%, there may be considerable geographic variation in species calls (Thomas et al. 1987), and the set of known calls (from which the unknown calls were classified) were collected primarily in the southwestern United States. However, I think that my results are valid and more reliable than subjective classification methods that are not repeatable, and vary with researcher and experience level.

The hoary and the silver-haired bats are reported to engage in long-distance seasonal migrations (Shump and Shump 1982, Kunz 1982). Results from carcass searches at Foote Creek Rim (Young et al. 2001, this study) and other wind farms in the United States (Nicholson 2001, Osborn et al. 1996) reveal that most of the mortalities of these species at wind turbines occur in the late summer and early fall. During a 3-year study of bird and bat mortality at Foote Creek Rim, the little-brown bat and other *Myotis* species experience mortality in the spring and the fall (Young et al. 2001), when they may be commuting between hibernacula and summering grounds. Collectively, these data suggest that most fatalities are associated with movements by bats between summer and winter areas.

Despite the hoary bat's wide distribution in North America, it appears to be a relatively uncommon bat throughout its range (Shump and Shump 1982). This is a curious attribute of a bat that is easily captured in mist-nets (Barbour and Davis 1969), does not require specialized roosting structures, and whose annual reproductive output is typically double that of other temperate zone insectivorous bats (Shump and Shump 1982). It has been hypothesized that low densities of hoary bats may result from food availability and energetic constraints (Fenton and Merriam 1983). If so, the density of hoary bats in an area may be limited by the establishment of territories. Several authors have noted aggressive behavior in foraging hoary bats, which were interpreted to be defense of feeding territories (Hickey 1993, Belwood and Fullard 1984, Barclay 1984 & 1985). However, a non-reproductive hoary bat weighing 30 g would require approximately 38 kJ day^{-1} (Brisbin 1966) to meet normal metabolic requirements. Hickey (1993) noted that lactating hoary bats consumed roughly 73.7 kJ night^{-1}, which suggests that minimum caloric intake for non-reproductive individuals could be easily met. Assuming an average mass of 0.044 g moth^{-1} (Hickey 1993) and 6.48 kJ g^{-1} moth^{-1} (Barclay et al. 1991), a non-reproductive hoary bat would require only 11 moths per night. If considered only from an energetics standpoint, limited food resources do not seem to explain low observed densities.

Alternatively, hoary bat densities may be limited not by conditions on their summer range, but by those on their winter range, as in some bird species (Wuethrich 1998). Data on winter range and habitat for the hoary bat are lacking, but evidence suggests that most spend the winter in southern California, the southeastern United States, and Mexico (Findley and Jones 1964, Cryan, in press). There, hoary bats may coexist not only with other migratory species (e.g., *L. borealis*, *Lasionycteris noctivagans*, *Tadarida brasiliensis*) but also with resident species that may not hibernate. If so, resources may be limiting and inter- and intraspecific competition may occur. On the other hand, reports suggest that the hoary bat and other lasiurine bats are particularly prone to accidents which result in death of the bat, including collisions with buildings and other tall structures (Timm 1989, Crawford and Baker 1981, Saunders 1930), entrapment on barbed wire (Iwen 1958, Hibbard 1963, Wisely 1978) and burdock plants (Johnson 1933), and strangulation (Dunaway 1960). Perhaps, unlike other temperate species, hoary bats and other lasiurines tend more towards life histories with *r*-selected traits. If so, this could explain the above-average reproductive output observed in lasiurines (Barbour and Davis 1969).

Based on observation of marked bats, Hickey (1993) suggested that there were at least 50 *L. cinereus* in his 2352 ha study area. Assuming the entire study area contained suitable roosting habitat, this equates to roughly 0.02 hoary bats ha^{-1}. My study area contained about 17190 ha of suitable roosting habitat for the hoary bat. Therefore, although I captured only 17 hoary bats, the study area may have contained as many as 344 hoary bats. However, Hickey's study area, located near the shore of Lake Huron, probably contained higher densities of flying insects than mine due to its lower elevation and proximity to water, so it is likely that there were far fewer than 344 hoary bats in my study area.

Nonetheless, it is possible that the duration of my mist-net surveys was insufficient to capture more hoary bats. Consistent with some author's suggestion that hoary bats fly later in the evening than other bats (e.g., Barbour and Davis 1969, Shump and Shump

1982), hoary bats were caught, on average, 177 min after civil sunset during this study, whereas other species were caught 132 min, on average, after civil sunset (Table 2-13). Inspection of the distribution of hoary bat captures during 4-hour surveys indicated that surveying for more than four hours might have yielded more hoary bats (Table 2-14). However, surveying all night (i.e., dawn to dusk) would have reduced both the total number of surveys possible and the availability of personnel for daytime radio-telemetry.

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Figure 2-1. Schematic of study area.

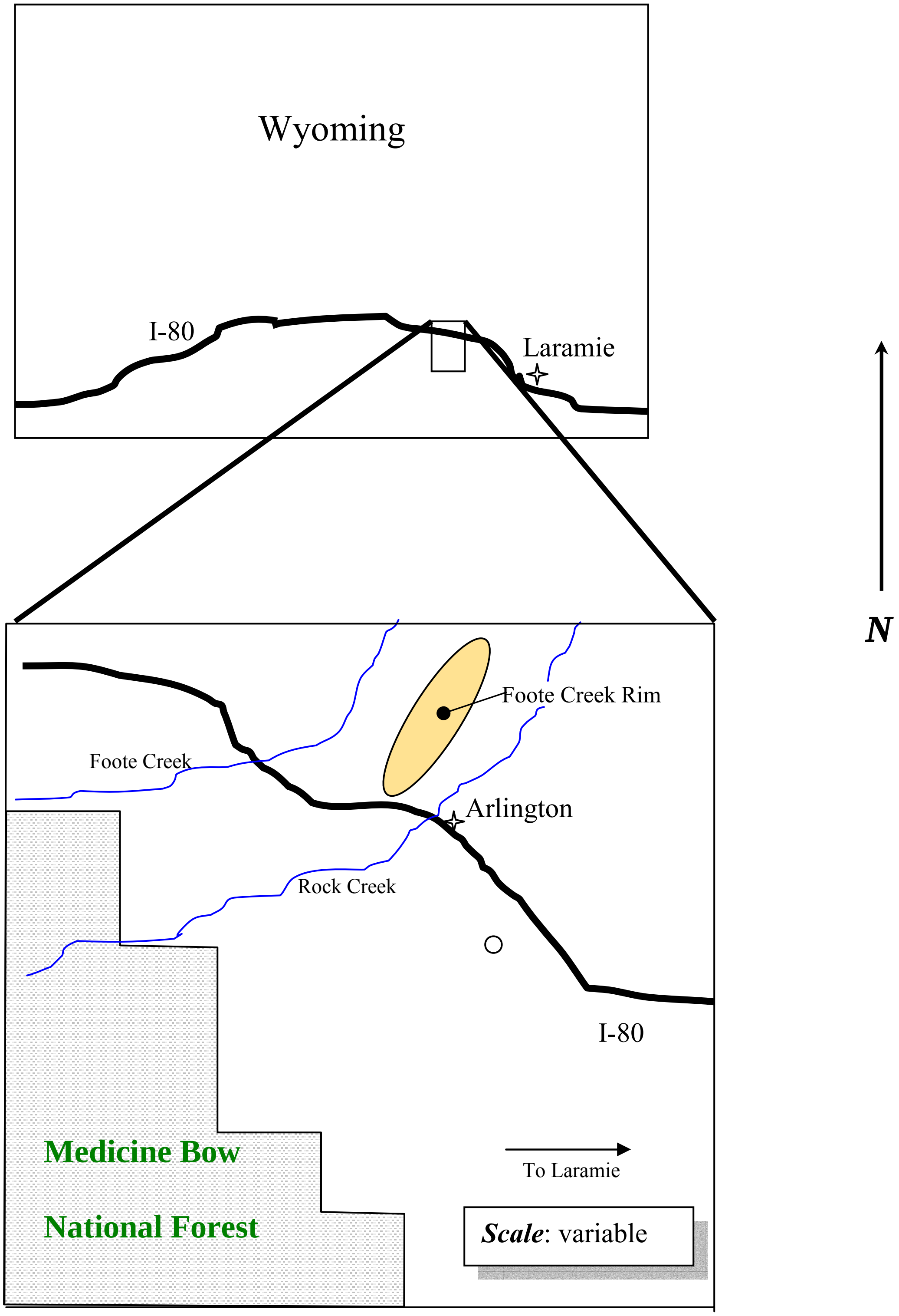

Figure 2-2. Distribution of bat-detector surveys by two-week period conducted on Foote Creek Rim (n = 41 survey-nights) and near water away from the rim (n = 39 survey-nights) 2000-2001.

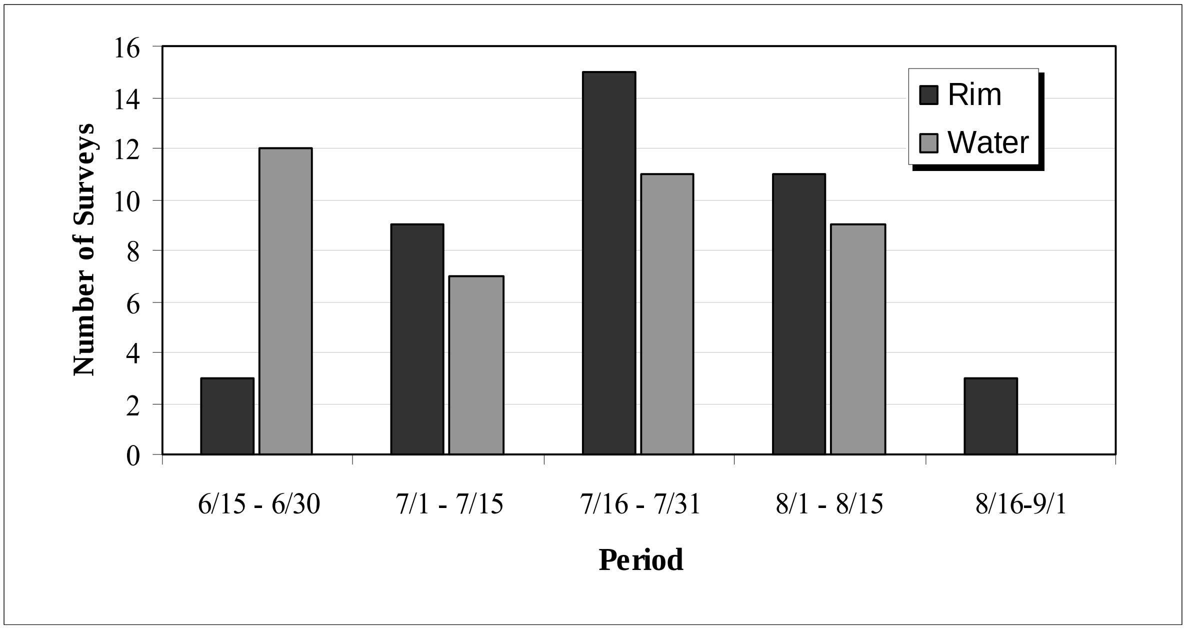

Figure 2-3. Bat calls plotted in discriminant space showing how the unknown calls segregated relative to the known reference calls. Symbols represent individual calls plotted in discriminant space. Numbers represent centroids for associated species. Some of the centroid symbols are hidden behind other symbols, but all centroids are located immediately below their associated number. This plot demonstrates that most unknown calls fell in the region of *Myotis lucifugus* and *M. volans*. See Table 2-1 for explanation of species abbreviations.

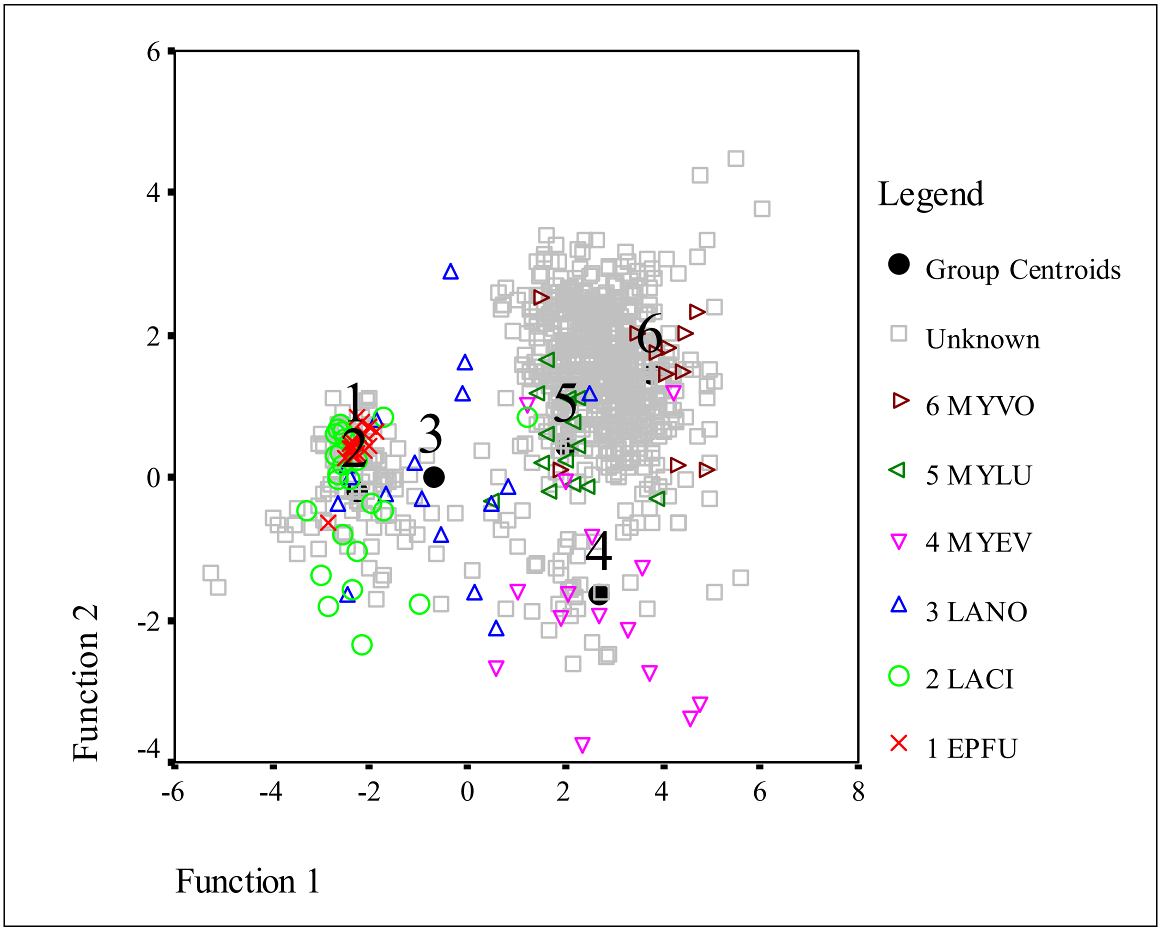

Figure 2-4. Summary of relative species abundance assessed by mist-net surveys and distribution of species recovered during carcass searches near wind turbines. Capture data are from 2000 and 2001. Mortality data are from 1999 (WEST, Inc.), 2000 (WEST, Inc.), and 2001 (WEST, Inc. and this study). See Table 2-1 for explanation of species abbreviations.

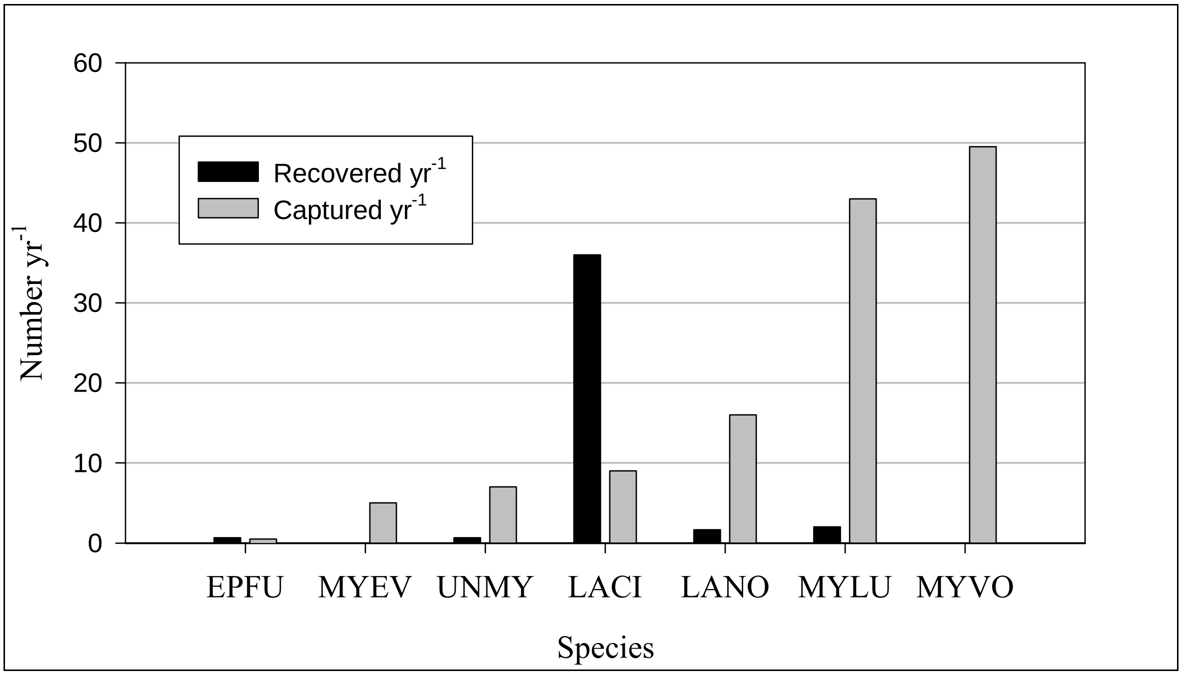

Figure 2-5. Temporal pattern of bat mortality at Foote Creek Rim 1999-2001. Mortality data are from 1999 (WEST, Inc.), 2000 (WEST, Inc.), and 2001 (WEST, Inc., and this study). See Table 2-1 for explanation of species abbreviations. The horizontal axis represents two-week periods and coincides with the search interval used by WEST, Inc. from 1999-2001. Weekly search intervals were used during this study in 2001.

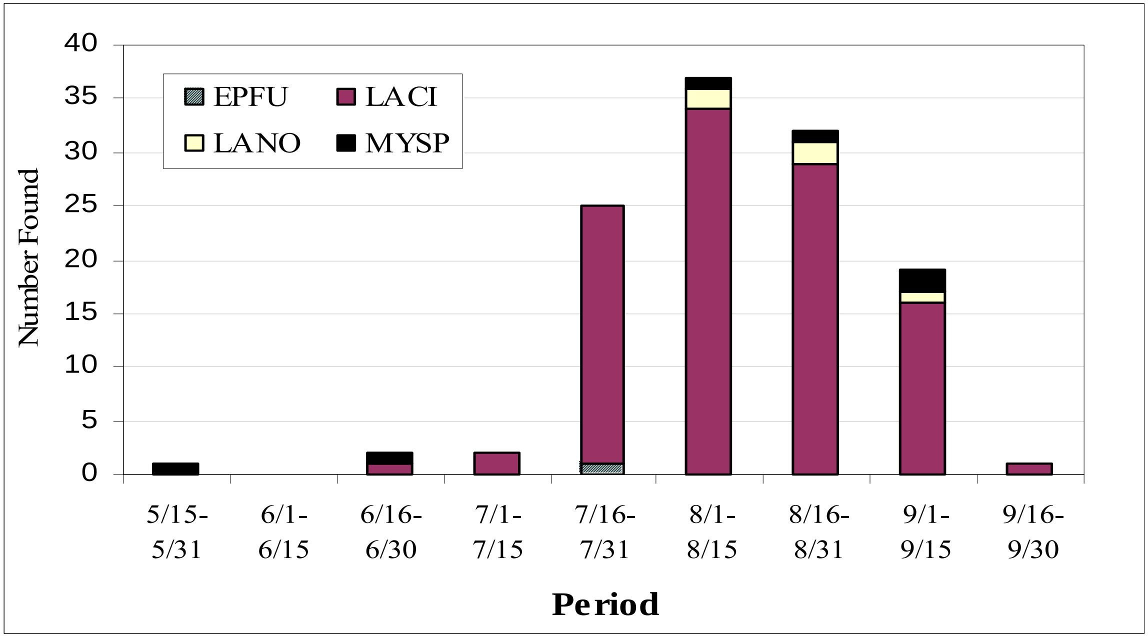

Figure 2-6. Comparison of relative species abundances as determined by bat-detector surveys and mist-net surveys 2000-2001. Bat-detector data are from Q3 calls only.

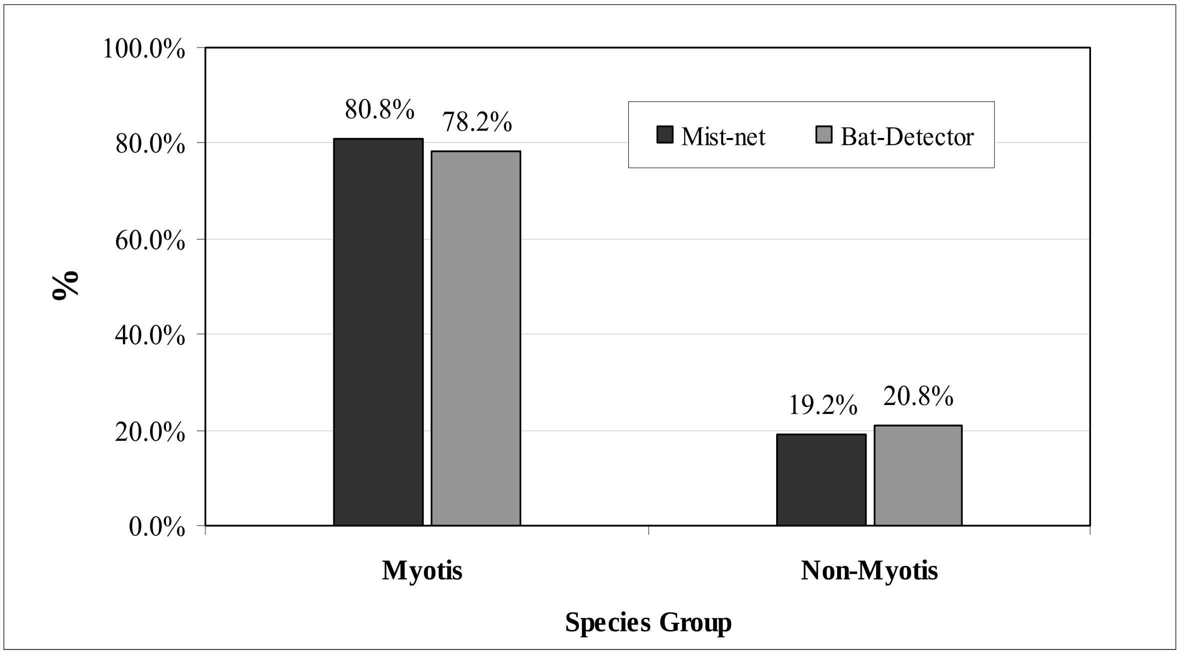

Table 2-1. List of species encountered on the study area and species abbreviations.

Scientific name	**Common name**	**Species abbreviation**
Eptesicus fuscus	Big-brown bat	EPFU
Lasionycteris noctivagans	Silver-haired bat	LANO
Lasiurus cinereus	Hoary bat	LACI
Myotis evotis	Long-eared myotis	MYEV
M. lucifugus	Little-brown bat	MYLU
M. volans	Long-legged myotis	MYVO

Table 2-2. Number of calls for each species used in the discriminant function analysis and classification.

Species	**Number of Calls**
Eptesicus fuscus	17
Lasionycteris noctivagans	17
Lasiurus cinereus	26
Myotis evotis	15
M. lucifugus	14
M. volans	11
TOTAL	**100**

Table 2-3. Summary and description of parameters of bat calls. Parameters were derived from *n* pulses per call.

Parameter	**Description**
Fmax	Maximum frequency (kHz): Highest frequency of a pulse
Fmean	Mean frequency (kHz): area under the curve divided by duration
Fmin	Minimum frequency (kHz): lowest frequency of a pulse
Fc	Characteristic frequency (kHz): frequency at the end of the flattest part of a pulse
S1	Initial slope (OPS [a]): steepest slope during the first five points of a pulse

a: Octaves per second

Table 2-4. Number of bats captured during the 2000 field season by date and species.

See Table 2-1 for explanation of species abbreviations.

Date	LACI	LANO	MYEV	MYLU	MYVO	UNMY	Totals
6/29/2000	0	0	0	0	0	0	0
6/30/2000	0	0	0	1	0	1	2
7/7/2000	0	0	0	0	0	0	0
7/11/2000	0	0	0	0	0	0	0
7/15/2000	0	0	0	5	0	0	5
7/18/2000	0	2	0	1	0	0	3
7/20/2000	0	0	0	1	0	0	1
7/24/2000	0	0	0	0	0	0	0
7/25/2000	2	0	1	1	0	0	4
7/26/2000	0	0	0	0	0	0	0
7/27/2000	1	0	0	0	0	1	2
8/1/2000	0	0	0	0	0	0	0
8/2/2000	0	0	0	1	0	0	1
8/3/2000	0	0	0	0	0	0	0
8/8/2000	0	0	0	1	0	0	1
8/10/2000	0	0	1	2	0	2	5
8/12/2000	1	0	1	2	2	0	6
8/16/2000	0	0	0	8	0	0	8
8/17/2000	2	2	1	17	0	1	23
8/21/2000	0	0	0	2	0	0	2
9/2/2000	0	1	1	1	1	0	4
Totals	**6**	**5**	**5**	**43**	**3**	**5**	**67**

Table 2-5. Number of bats captured during the 2001 field season by date and species.

See Table 2-1 for explanation of species abbreviations.

Date	EPFU	LACI	LANO	MYEV	MYLU	MYVO	UNMY	Totals
6/5/2001	0	0	0	0	0	0	0	0
6/11/2001	0	0	0	0	0	0	0	0
6/15/2001	0	0	0	0	0	0	0	0
6/18/2001	0	0	0	0	0	0	0	0
6/19/2001	0	0	0	0	0	1	0	1
6/21/2001	0	0	0	0	1	1	0	2
6/22/2001	0	0	1	0	1	1	0	3
6/25/2001	0	0	0	0	2	0	0	2
6/26/2001	0	0	1	1	0	0	0	2
6/27/2001	0	0	0	0	2	0	0	2
6/28/2001	0	1	2	0	0	6	0	9
7/2/2001	0	1	1	0	1	1	0	4
7/3/2001	0	1	0	0	1	0	0	2
7/5/2001	0	0	0	0	0	0	0	0
7/9/2001	0	2	0	0	0	0	0	2
7/11/2001	0	1	0	0	0	0	0	1
7/13/2001	0	1	0	0	2	2	0	5
7/16/2001	0	0	1	0	2	0	0	3
7/17/2001	0	1	4	0	2	2	0	9
7/18/2001	0	0	0	0	0	0	0	0
7/19/2001	0	0	0	0	0	0	0	0
7/23/2001	0	0	0	0	2	0	0	2
7/24/2001	1	1	3	0	2	19	3	29
7/25/2001	0	0	0	0	0	2	0	2
7/26/2001	0	0	0	0	0	0	0	0
7/30/2001	0	1	3	1	0	16	1	22
7/31/2001	0	0	0	0	1	0	0	1
8/1/2001	0	1	2	0	1	0	0	4
8/2/2001	0	0	0	0	2	0	0	2
8/6/2001	0	0	2	0	0	4	0	6
8/7/2001	0	0	4	2	1	19	0	26
8/8/2001	0	0	1	0	1	0	0	2
8/9/2001	0	0	0	0	1	0	0	1
8/10/2001	0	0	0	0	14	0	1	15
8/13/2001	0	0	2	1	0	22	2	27
8/14/2001	0	0	0	0	5	0	2	7
Totals	**1**	**11**	**27**	**5**	**44**	**96**	**9**	**193**

Table 2-6. Summary of relative species abundance based on mist-net captures 2000-2001.

Species Group	**Species**	**Number Caught**	**Percent of Total Captures**	**Percent of Total by Group**
Non-Myotis	*Eptesicus fuscus*	1	0.4%	Non-myotis **19.2%**
	Lasionycteris noctivagans	32	12.3%	
	Lasiurus cinereus	17	6.5%	
Myotis	*Myotis evotis*	10	3.8%	Myotis **80.8%**
	M. lucifugus	87	33.5%	
	M. volans	99	38.1%	
	Unknown *Myotis* spp.	14	5.4%	
	Total	**260**	**100.0%**	**100.0%**

Table 2-7. Number of bat captures by species and habitat 2000-2001. Habitat abbreviations: CFR: coniferous forest, CWR: cottonwood riparian, SG: sagebrush/grass, WLR: willow riparian. Mean number of captures represents total captures divided by number of surveys. Captures per survey effort represents total captures divided by average net-feet-hours.

	Habitat Type (Number of Surveys)				
Species	CFR (28)	CWR (19)	SG (3)	WLR (8)	**Total** (58)
Eptesicus fuscus	1	0	0	0	1
Lasionycteris noctivagans	26	6	0	0	32
Lasiurus cinereus	11	6	0	0	17
Myotis evotis	8	2	0	0	10
M. lucifugus	23	55	5	4	87
M. volans	98	1	0	0	99
Unknown *Myotis*	8	5	0	1	14
Species Totals	175	75	5	5	260
Mean number of captures	6.25	3.95	1.67	0.625	4.5
Captures per survey effort	0.35	0.14	0.017	0.013	0.53

Table 2-8. Number of bat calls collected with bat-detectors by call type and year. Call type represents call quality as defined above.

	Number of Calls			**Call Totals as a**
Call Type	2000	2001	**Call Totals**	**Percent of Total**
Q1	1275	421	1696	39.3%
Q2	1132	747	1879	43.5%
Q3	557	183	740	17.1%
Year Totals	**2964**	**1351**	**4315**	**100.0%**

Table 2-9. Number of detections of each species recorded at Foote Creek Rim (n = 39 survey-nights) or away from the rim at water sources (n = 41 survey-nights) 2000-2001. Data are from Q3 calls only.

Species	**Detections by Location (% of Total)**		**Total**
	Rim	Water	
Eptesicus fuscus	1 (2.0%)	45 (98.0%)	46 (6.2%)
Lasionycteris noctivagans	7 (14.0%)	43 (86.0%)	50 (6.7%)
Lasiurus cinereus	1 (1.7%)	57 (97.8%)	58 (7.8%)
Myotis evotis	0 (0%)	36 (100.0%)	36 (4.9%)
M. lucifugus	9 (3.5%)	247 (96.5%)	256 (34.6%)
M. volans	2 (0.7%)	292 (99.3%)	294 (39.7%)
Total	20 (2.7%)	720 (97.3%)	740 (100.0%)

Table 2-10. Test statistics for the discriminant functions of bat call data.

Test of Function(s)	Wilks' Lambda	Chi-square	df	Significance
1	.054	273.089	25	.000
2	.371	92.651	16	.000
3	.648	40.558	9	.000
4	.854	14.738	4	.005
5	.980	1.845	1	.174

Table 2-11. Classification results for Q3 calls. The discriminant function analysis correctly classified 73.0% of known cases. The number and percentage of correct classifications for each species is found on the diagonal (bold). The unknown group in this table represents calls collected in the field and categorized on the basis of discriminant functions derived from known calls (known calls listed by species). See Table 2-1 for explanation of species abbreviations

		Predicted Group Membership						
	Species	EPFU	LACI	LANO	MYEV	MYLU	MYVO	**Total**
Count	EPFU	**15**	2	0	0	0	0	17
	LACI	7	**15**	3	0	1	0	26
	LANO	2	3	**9**	1	2	0	17
	MYEV	0	0	0	**11**	2	2	15
	MYLU	0	0	0	0	**14**	0	14
	MYVO	0	0	0	0	2	**9**	11
	Unknown	46	58	50	36	256	294	740
%	EPFU	**88.2**	11.8	.0	.0	.0	.0	100.0
	LACI	26.9	**57.7**	11.5	.0	3.8	.0	100.0
	LANO	11.8	17.6	**52.9**	5.9	11.8	.0	100.0
	MYEV	.0	.0	.0	**73.3**	13.3	13.3	100.0
	MYLU	.0	.0	.0	.0	**100.0**	.0	100.0
	MYVO	.0	.0	.0	.0	18.2	**81.8**	100.0
	Unknown	6.2	7.8	6.8	4.9	34.6	39.7	100.0

Table 2-12. Number of carcass recoveries at Foote Creek Rim by species and year. Mortality data were collected by WEST, Inc. (1999-2001) and this study (2001).

	Number of Recoveries				**Species Totals (% of Total)**
Year	1999	2000	2001		
Collector	WEST, Inc.	WEST, Inc.	WEST, Inc.	This Study	
Eptesicus fuscus	1	0	0	1	2 (1.6)
Lasionycteris noctivagans	0	3	2	0	5 (4.1)
Lasiurus cinereus	47	19	20	22	108 (87.8)
Myotis lucifugus	4	2	0	0	6 (4.9)
Unknown	0	2	0	0	2 (1.6)
Year Totals	**52**	**26**	**45**		**123 (100.0)**

Table 2-13 Comparison of capture times by species. Capture times are expressed as minutes after civil sunset.

Species (number of captures)	Mean Capture Time (range)	Median Capture Time
Eptesicus fuscus (1)	152 (n/a)	152
Lasionycteris noctivagans (32)	125 (23-234)	112
Lasiurus cinereus (17)	177 (60-235)	192
Myotis evotis (10)	125 (40-283)	123
M. lucifugus (87)	110 (17-326)	97
M. volans (99)	153 (0-309)	179
Unknown *Myotis*[a] (14)	142 (11-240)	162

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a. Species that escaped before positive identification.

Table 2-14. Distribution of time of capture for the hoary bat. Time categories represent minutes after civil sunset.

Time Category	Number of Captures	Average Time (Range)
0-60 minutes	3	50.0 (33-60)
61-120 minutes	1	66.0 (n/a)
121-180 minutes	2	144.5 (133-156)
181-240 minutes	6	206.0 (191-235)
> 241 minutes	5	253.0 (241-261)

Appendix 2-1. Geographic coordinates in UTM (Zone 13) for sites surveyed with mist-nets in 2000 and 2001. Coordinates were rounded to the nearest meter.

Survey Site	Easting	Northing
5-Ton	390609	4606828
Arlington Bridge	399291	4605193
Black Bear Ponds	391427	4599829
Broken Stick	399518	4605292
Cassiopeia	402938	4610892
Eureka	393931	4602986
Guest Pond	398669	4605039
Hack Creek	400447	4603888
Leech Pond	398671	4609064
Ridge Pond	391030	4601072
Rock Bottom	401101	4608962
Rock Creek Access	402076	4608459
Rock Creek Brokaw	400268	4605893
Rock Creek Trail	398374	4604715
Sandpiper	401279	4607595
Ten Turbine	401706	4611794
White Rock	392464	4602823

Appendix 2-2. Summary of captures by mist-nets by date, location, sex and age, and of species of bat. A=adult, J=juvenile, M=male, F=female, U=unknown sex and age. See Table 2-1 for explanation of species abbreviations.

	Species/Age/Sex	**EPFU**				**MYEV**				**MYLU**				
		A		J		A		J		A		J		U
Date	**Location**	M	F	M	F	M	F	M	F	M	F	M	F	
06/29/2000	Ten Turbine	0	0	0	0	0	0	0	0	0	0	0	0	0
06/30/2000	Leech Pond	0	0	0	0	0	0	0	0	0	1	0	0	0
07/07/2000	Leech Pond	0	0	0	0	0	0	0	0	0	0	0	0	0
07/11/2000	Cassiopeia	0	0	0	0	0	0	0	0	0	0	0	0	0
07/15/2000	Sandpiper	0	0	0	0	0	0	0	0	4	1	0	0	0
07/18/2000	Broken Stick	0	0	0	0	0	0	0	0	1	0	0	0	0
07/20/2000	Rock Creek Trail	0	0	0	0	0	0	0	0	1	0	0	0	0
07/24/2000	Rock Bottom	0	0	0	0	0	0	0	0	0	0	0	0	0
07/25/2000	Broken Stick	0	0	0	0	1	0	0	0	1	0	0	0	0
07/26/2000	Rock Creek Trail	0	0	0	0	0	0	0	0	0	0	0	0	0
07/27/2000	Broken Stick	0	0	0	0	0	0	0	0	0	0	0	0	0
08/01/2000	Guest Pond	0	0	0	0	0	0	0	0	0	0	0	0	0
08/02/2000	Broken Stick	0	0	0	0	0	0	0	0	1	0	0	0	0
08/03/2000	Leech Pond	0	0	0	0	0	0	0	0	0	0	0	0	0
08/08/2000	Ridge Pond	0	0	0	0	0	0	0	0	1	0	0	0	0
08/10/2000	Eureka	0	0	0	0	1	0	0	0	1	0	1	0	0
08/12/2000	Eureka	0	0	0	0	1	0	0	0	1	0	1	0	0
08/16/2000	Rock Creek Brokaw	0	0	0	0	0	0	0	0	1	0	4	3	0
08/17/2000	Arlington Bridge	0	0	0	0	1	0	0	0	6	0	7	1	3
08/21/2000	Eureka	0	0	0	0	0	0	0	0	1	0	1	0	0
09/02/2000	Eureka	0	0	0	0	1	0	0	0	1	0	0	0	0
2000 Totals		0	0	0	0	5	0	0	0	20	2	14	4	3

Appendix 2-2. Continued

	Species/Age/Sex	MYVO				LANO					LACI				
		A		J		A		J		U	A		J		U
Date	**Location**	M	F	M	F	M	F	M	F		M	F	M	F	
06/29/2000	Ten Turbine	0	0	0	0	0	0	0	0	0	0	0	0	0	0
06/30/2000	Leech Pond	0	0	0	0	0	0	0	0	0	0	0	0	0	0
07/07/2000	Leech Pond	0	0	0	0	0	0	0	0	0	0	0	0	0	0
07/11/2000	Cassiopeia	0	0	0	0	0	0	0	0	0	0	0	0	0	0
07/15/2000	Sandpiper	0	0	0	0	0	0	0	0	0	0	0	0	0	0
07/18/2000	Broken Stick	0	0	0	0	1	0	0	0	0	0	0	0	0	0
07/20/2000	Rock Creek Trail	0	0	0	0	0	0	0	0	0	0	0	0	0	0
07/24/2000	Rock Bottom	0	0	0	0	0	0	0	0	0	0	0	0	0	0
07/25/2000	Broken Stick	0	0	0	0	0	0	0	0	0	2	0	0	0	0
07/26/2000	Rock Creek Trail	0	0	0	0	0	0	0	0	0	0	0	0	0	0
07/27/2000	Broken Stick	0	0	0	0	0	0	0	0	0	1	0	0	0	0
08/01/2000	Guest Pond	0	0	0	0	0	0	0	0	0	0	0	0	0	0
08/02/2000	Broken Stick	0	0	0	0	0	0	0	0	0	0	0	0	0	0
08/03/2000	Leech Pond	0	0	0	0	0	0	0	0	0	0	0	0	0	0
08/08/2000	Ridge Pond	0	0	0	0	0	0	0	0	0	0	0	0	0	0
08/10/2000	Eureka	0	0	0	0	0	0	0	0	0	0	0	0	0	0
08/12/2000	Eureka	0	2	0	0	0	0	0	0	0	1	0	0	0	0
08/16/2000	Rock Creek Brokaw	0	0	0	0	0	0	0	0	0	0	0	0	0	0
08/17/2000	Arlington Bridge	0	0	0	0	0	0	0	2	1	0	0	0	1	1
08/21/2000	Eureka	0	0	0	0	0	0	0	0	0	0	0	0	0	0
09/02/2000	Eureka	0	0	1	0	0	0	1	0	0	0	0	0	0	0
2000 Totals		0	2	1	0	1	0	1	2	1	4	0	0	1	1

Appendix 2-2. Continued

	Species/Age/Sex	EPFU				MYEV				MYLU				
		A		J		A		J		A		J		U
Date	**Location**	M	F	M	F	M	F	M	F	M	F	M	F	0
5-Jun-01	Eureka	0	0	0	0	0	0	0	0	0	0	0	0	0
11-Jun-01	Eureka	0	0	0	0	0	0	0	0	0	0	0	0	0
15-Jun-01	Hack Creek	0	0	0	0	0	0	0	0	0	0	0	0	0
18-Jun-01	Leech Pond	0	0	0	0	0	0	0	0	0	0	0	0	0
19-Jun-01	Broken Stick	0	0	0	0	0	0	0	0	0	0	0	0	0
21-Jun-01	Eureka	0	0	0	0	0	0	0	0	1	0	0	0	0
22-Jun-01	Eureka	0	0	0	0	0	0	0	0	1	0	0	0	0
25-Jun-01	Leech Pond	0	0	0	0	0	0	0	0	2	0	0	0	0
26-Jun-01	White Rock Pond	0	0	0	0	1	0	0	0	0	0	0	0	0
27-Jun-01	Eureka	0	0	0	0	0	0	0	0	2	0	0	0	0
28-Jun-01	White Rock Pond	0	0	0	0	0	0	0	0	0	0	0	0	0
2-Jul-01	White Rock Pond	0	0	0	0	0	0	0	0	1	0	0	0	0
3-Jul-01	Eureka	0	0	0	0	0	0	0	0	1	0	0	0	0
5-Jul-01	Broken Stick	0	0	0	0	0	0	0	0	0	0	0	0	0
9-Jul-01	Eureka	0	0	0	0	0	0	0	0	0	0	0	0	0
11-Jul-01	Broken Stick	0	0	0	0	0	0	0	0	0	0	0	0	0
13-Jul-01	White Rock Pond	0	0	0	0	0	0	0	0	1	0	0	0	1
16-Jul-01	Broken Stick	0	0	0	0	0	0	0	0	1	1	0	0	0
17-Jul-01	White Rock Pond	0	0	0	0	0	0	0	0	1	0	0	0	1
18-Jul-01	5-ton	0	0	0	0	0	0	0	0	0	0	0	0	0
19-Jul-01	Eureka	0	0	0	0	0	0	0	0	0	0	0	0	0
23-Jul-01	Broken Stick	0	0	0	0	0	0	0	0	2	0	0	0	0
24-Jul-01	White Rock Pond	1	0	0	0	0	0	0	0	2	0	0	0	0
25-Jul-01	Black Bear Ponds	0	0	0	0	0	0	0	0	0	0	0	0	0
26-Jul-01	Eureka	0	0	0	0	0	0	0	0	0	0	0	0	0
30-Jul-01	White Rock Pond	0	0	0	0	1	0	0	0	0	0	0	0	0
31-Jul-01	Arlington Bridge	0	0	0	0	0	0	0	0	1	0	0	0	0
1-Aug-01	Eureka	0	0	0	0	0	0	0	0	1	0	0	0	0
2-Aug-01	Rock Creek Access	0	0	0	0	0	0	0	0	1	1	0	0	0
6-Aug-01	White Rock Pond	0	0	0	0	0	0	0	0	0	0	0	0	0
7-Aug-01	White Rock Pond	0	0	0	0	2	0	0	0	1	0	0	0	0
8-Aug-01	Broken Stick	0	0	0	0	0	0	0	0	0	0	1	0	0
9-Aug-01	Eureka	0	0	0	0	0	0	0	0	1	0	0	0	0
10-Aug-01	Rock Creek Brokaw	0	0	0	0	0	0	0	0	6	4	3	1	0
13-Aug-01	White Rock Pond	0	0	0	0	0	0	1	0	0	0	0	0	0
14-Aug-01	Arlington Bridge	0	0	0	0	0	0	0	0	3	1	0	0	0
14-Aug-01	Broken Stick	0	0	0	0	0	0	0	0	1	0	0	0	0
2001 Totals		1	0	0	0	4	0	1	0	30	7	4	1	2

Appendix 2-2. Continued.

	Species/Age/Sex	**MYVO**					**LANO**				**LACI**			
		A		J		U	A		J		A		J	
Date	**Location**	M	F	M	F		M	F	M	F	M	F	M	F
5-Jun-01	Eureka	0	0	0	0	0	0	0	0	0	0	0	0	0
11-Jun-01	Eureka	0	0	0	0	0	0	0	0	0	0	0	0	0
15-Jun-01	Hack Creek	0	0	0	0	0	0	0	0	0	0	0	0	0
18-Jun-01	Leech Pond	0	0	0	0	0	0	0	0	0	0	0	0	0
19-Jun-01	Broken Stick	0	1	0	0	0	0	0	0	0	0	0	0	0
21-Jun-01	Eureka	1	0	0	0	0	0	0	0	0	0	0	0	0
22-Jun-01	Eureka	0	1	0	0	0	1	0	0	0	0	0	0	0
25-Jun-01	Leech Pond	0	0	0	0	0	0	0	0	0	0	0	0	0
26-Jun-01	White Rock Pond	0	0	0	0	0	1	0	0	0	0	0	0	0
27-Jun-01	Eureka	0	0	0	0	0	0	0	0	0	0	0	0	0
28-Jun-01	White Rock Pond	0	6	0	0	0	2	0	0	0	1	0	0	0
2-Jul-01	White Rock Pond	0	1	0	0	0	1	0	0	0	1	0	0	0
3-Jul-01	Eureka	0	0	0	0	0	0	0	0	0	1	0	0	0
5-Jul-01	Broken Stick	0	0	0	0	0	0	0	0	0	0	0	0	0
9-Jul-01	Eureka	0	0	0	0	0	0	0	0	0	2	0	0	0
11-Jul-01	Broken Stick	0	0	0	0	0	0	0	0	0	1	0	0	0
13-Jul-01	White Rock Pond	0	2	0	0	0	0	0	0	0	0	1	0	0
16-Jul-01	Broken Stick	0	0	0	0	0	1	0	0	0	0	0	0	0
17-Jul-01	White Rock Pond	1	1	0	0	0	4	0	0	0	0	1	0	0
18-Jul-01	5-ton	0	0	0	0	0	0	0	0	0	0	0	0	0
19-Jul-01	Eureka	0	0	0	0	0	0	0	0	0	0	0	0	0
23-Jul-01	Broken Stick	0	0	0	0	0	0	0	0	0	0	0	0	0
24-Jul-01	White Rock Pond	0	18	0	0	1	3	0	0	0	1	0	0	0
25-Jul-01	Black Bear Ponds	0	2	0	0	0	0	0	0	0	0	0	0	0
26-Jul-01	Eureka	0	0	0	0	0	0	0	0	0	0	0	0	0
30-Jul-01	White Rock Pond	0	16	0	0	0	3	0	0	0	1	0	0	0
31-Jul-01	Arlington Bridge	0	0	0	0	0	0	0	0	0	0	0	0	0
1-Aug-01	Eureka	0	0	0	0	0	2	0	0	0	0	1	0	0
2-Aug-01	Rock Creek Access	0	0	0	0	0	0	0	0	0	0	0	0	0
6-Aug-01	White Rock Pond	0	3	1	0	0	2	0	0	0	0	0	0	0
7-Aug-01	White Rock Pond	0	11	6	1	1	2	2	0	0	0	0	0	0
8-Aug-01	Broken Stick	0	0	0	0	0	0	1	0	0	0	0	0	0
9-Aug-01	Eureka	0	0	0	0	0	0	0	0	0	0	0	0	0
10-Aug-01	Rock Creek Brokaw	0	0	0	0	0	0	0	0	0	0	0	0	0
13-Aug-01	White Rock Pond	1	7	6	8	0	2	0	0	0	0	0	0	0
14-Aug-01	Arlington Bridge	0	0	0	0	0	0	0	0	0	0	0	0	0
14-Aug-01	Broken Stick	0	0	0	0	0	0	0	0	0	0	0	0	0
2001 Totals		3	69	13	9	2	24	3	0	0	8	3	0	0

CHAPTER 3

ROOSTING HABITAT PREFERENCES FOR THE HOARY BAT (*LASIURUS CINEREUS)* IN A CONIFEROUS FOREST IN SOUTH-CENTRAL WYOMING

Abstract

Because hoary bats suffer disproportionate mortality at wind power facilities across the United States, a more thorough understanding of its roosting ecology is needed. Hoary bats were captured over water sources in south-central Wyoming during the summers of 2000 and 2001. Small (< 1 g) radio-transmitters were attached to 14 adults (12M, 2F), but six of these individuals were never located. The remaining individuals were tracked to 17 different day-roosts, nearly all of which were in lodgepole pine (*Pinus contorta*) trees. Odds of structure being used as a roost increased as tree height and % canopy cover at the tree increased, and as distance to nearest water and distance to nearest edge decreased. These results are congruent with anecdotal accounts of roosting habits for the hoary bat that suggest that the bat prefers edge habitat and adequate overhead cover. The importance of tree height and proximity to water to roosting hoary bats may relate to preferred structural characteristics of the stand and proximity to foraging or drinking sites. On average, bats were tracked for about 2 days before apparently leaving the study area. They may have been engaged in exploratory or removal migration, or may have been only transient in the study area.

Introduction

The North American hoary bat (*Lasiurus cinereus cinereus*, Beauvois 1796) is a solitary, foliage roosting bat with a continent-wide distribution ranging from the treeline in Canada to southern Mexico (Shump and Shump 1982). It is a relatively large (20–35 g) bat with high wing loading and high wing aspect ratio, resulting in fast, comparatively unmaneuverable flight (Norberg and Rayner 1987). The hoary bat is thought to be highly migratory (Findley and Jones 1964), although the extent of its migrations and winter ranges remain largely unknown. Due in part to its solitary and migratory behaviors, the hoary bat is one of North America's least studied species.

Perhaps owing to its solitary, foliage-roosting lifestyle, hoary bat roosting habitat has not been adequately described. In some cases, systematic searches have been used to identify bats roosting in foliage. Constantine (1959 & 1966) searched orchards and wooded areas and located roosting lasiurines in California and Iowa. Barclay (1984) and Koehler and Barclay (2000) searched a "forested dune-ridge" (MacKenzie 1982) and located roosting lasiurines at Delta March, Manitoba, Canada. However, most descriptions in the literature of the hoary bat's roosting preferences are limited to anecdotal observations (e.g., Constantine 1966, Tenaza 1966, McClure 1942). Among the more unusual are reports of hoary bats roosting in a woodpecker hole (Cowan and Guiguet 1965), in a squirrel nest (Neill 1952), under a driftwood plank (Connor 1971), on the sides of buildings (Bowers et al. 1968, Whitaker 1967), and in caves (Myers 1960, Mumford 1953), but reports of hoary bats in caves consisted primarily of dead bats and/or skeletal remains (Myers 1960).

I found only one instance in the literature of radio-telemetric locations of roosts for the hoary bat. In a short note, Kalcounis (1994) reported tracking three female hoary bats to roosts in white spruce (*Picea glauca*) and lodgepole pine (*Pinus contorta*) in Saskatchewan, Canada. These hoary bats roosted 7-10 km from the capture site (M. Kalcounis, UC Berkeley, pers. comm.), demonstrating this species' ability to cover large distances in a short period. Indeed, the hoary bat is thought to engage in the longest migrations of any North American species (Barbour and Davis 1969).

Recently, the hoary bat has garnered attention as the most commonly encountered species during carcass searches near wind turbines (Keeley et al. 2001). Successful conservation strategies for any species must include an understanding of the species ecology. I am unaware of any published works that quantify roosting preferences for the hoary bat. Therefore, this study was initiated in 2000 to assess habitat preferences for roosts of the hoary bat in southeastern Wyoming near a wind farm.

Study Area

The study area is in south-central Wyoming (41°35′N, 106°12′W) approximately 72 km WNW of Laramie, WY, and includes the northern portions of the Medicine Bow National Forest (Fig. 3-1) and surrounding areas to the north. The study area encompassed 52,578 ha. Elevation ranges from 2133-2896 m. Mean annual temperature and precipitation are 5.5°C and 29.8 cm, respectively. Mean summer (June-August) temperature and precipitation are 16.6°C and 2.6 cm. Summer temperatures range from an average high of 25.7°C to an average low of 7.5°C (Wyoming State Climate Office 2002).

Habitat outside the forest boundaries is typical sagebrush steppe characterized by a mixture of sage (*Artemisia* spp.) and short grasses (Knight 1994). Overstory tree canopy is restricted to riparian areas (i.e., beaver ponds) and stream banks, and consists primarily of eastern cottonwood (*Populus deltoides*) and narrowleaf cottonwood (*Populus angustifolia*), with assorted willows (*Salix* spp.) and mountain alder (*Alnus tenuifolia*). Habitat on the national forest ranges from clumped distributions of lodgepole pine (*Pinus contorta*) and quaking aspen (*Populus tremuloides*) interspersed with open sage and grasslands at its northern foothills, to more continuous lodgepole pine stands and finally spruce/fir (*Picea engelmannii* and *Abies lasciocarpa*) communities as elevation increases to the south (Knight 1994).

Methods

Radio-Telemetry

Bats were captured using mist-nets set up over ponds and streams. Surveys began at civil sunset (US Naval Observatory 2002) and generally lasted four hours. I assessed relative age (Anthony 1988), reproductive status (Racey 1988), and collected morphometric data (i.e., forearm length, and mass) of captured bats. Transmitters were attached to the intrascapular region of adult hoary bats using Skin-Bond® brand non-toxic surgical adhesive (Smith and Nephew United, Inc., Largo, FL). Instrumented bats were held for approximately 30 minutes to ensure that the adhesive was set and then released on site. Transmitters weighed < 1 g (Model BD-2, Holohil, Ontario, CA and Model SOM-2011, Wildlife Materials, Carbondale, IL, USA), and the bats to which transmitters were attached weighed 25.2 g on average (range 21-28 g). Thus, the transmitters represented approximately 4% of the bats' mass (range 3.6-4.8%), and probably had negligible effects on bats' flight performance and behavior (Hickey 1992).

The day following instrument attachment, I searched for the instrumented bat using Telonics receivers (Model TR-2) and roof-mounted omni-directional antennas (Model RA-5A). Once the signal was detected, individuals were located using Wildlife Materials (Carbondale, IL, USA) 3-element folding Yagi antennas (Model A10). Individuals were tracked approximately every 24 h or until the signal was lost or the transmitter was shed. Once a roost structure was identified, its location was recorded using a hand-held Global Positioning System unit (Garmin *e*Trex Vista, Olathe, KS, USA) and marked with flagging for future reference. I conducted two aerial telemetry surveys during the summer of 2001 in a fixed-wing aircraft with a 3-element yagi antenna mounted to each wing strut, and a scanning radio-receiver (Telonics Model TR-2, Mesa, AZ, USA). Each 3-hour flight covered approximately 300 km^2.

Habitat Data Collection

Habitat surrounding known roosts was quantified and compared to habitat surrounding randomly selected sites. Habitat variables were chosen based on anecdotal reports of hoary bat roosting preferences (e.g., Barbour and Davis 1969) and variables considered important to bats in general (e.g., Brigham and Barclay 1996) (Table 3-1). Habitat plots (0.5 ha) were defined by a 40 m radius circle centered on the roost or random tree (Fig. 3-2). Species, DBH, height, and % canopy cover were recorded at each roost or random tree. Canopy cover was estimated using a concave spherical densiometer. Forty-meter transects were run from the structure in the four cardinal directions. Flagging was used to demarcate 5, 10, 20, and 40 m stations along transects. Each of the four stations at 5, 10, 20 and 40 m were connected to demarcate four concentric circles or sub-plots. In the center sub-plots, height, DBH, species, and distance from roost were recorded for all trees. Likewise, trees were tallied by species in each of the three larger sub-plots. At the flagged 10, 20 and 40 m stations (12 total), I recorded the species, height and DBH of the tree nearest the station and estimated % canopy cover. Only % canopy cover was recorded if there were no trees within 5 m of a transect station. Because the number of trees in the center sub-plot varied between plots, only tree height, DBH and % canopy cover data collected at the 10, 20, and 40 m stations were used to estimate plot averages. When different roosts for the same individual were within 5 m of one another (3 occasions), plots were not re-sampled, although tree-specific data (i.e., height, DBH, % canopy cover) were collected.

To determine the area from which random locations would be selected, I drew circles with radius of 9.65 km around each known roost on 1:24,000 USGS Quad maps. The perimeter of the resulting polygon was taken to define the sampling area. I used 9.65 km because this was the farthest known distance an instrumented bat had traveled from capture-site to day-roost during the study, and thus provided the best estimate of the area available to instrumented bats during my study.

Within the sampling area, intersections of section lines on the maps were randomly identified. Random locations that fell on private property without access permission or those that fell on unsuitable areas (those without an overstory of trees) were eliminated from consideration. A total of 26 random habitat plots was then sampled following the protocol outlined above.

ArcView GIS 3.2 (ESRI, Redlands, CA) was used to measure landscape-scale variables and assess available habitat in the study area. Roost and capture locations, and locations of random plots were overlayed on vegetation and stream coverages. Forest coverages were obtained from the Medicine Bow National Forest, and off-forest coverages were digitized from USGS Digital Raster Graphics (DRG) topographic maps, (1:24000). Using the GIS maps, I calculated the distance from each roost and random structure to the nearest forest edge (e.g., meadow or clear-cut) and water source (i.e., stream, pond, or lake).

Statistical Analysis

Habitat characteristics at known roosts and random sites were compared using logistic regression. The logistic model is used to predict the relative probability of use based on a binary response variable. Because of the large number of potential models relative to the number of samples, I used Akaike's Information Criteria (AIC), corrected for small samples (AIC_c) to evaluate the relative fit of the models and determine the best model given the model set and the data (Burnham and Anderson 1998). Candidate variables for the final model set were determined using a two-stage process: evaluation of univariate models and correlation between variables. Based on univariate model results, variables with P-values > 0.10 were excluded from further consideration. Other variables were excluded by examining the correlation between variables selected from stage one. When two variables were highly correlated (e.g., tree height and tree dbh), only one of the two was retained. After eliminating habitat variables that were highly correlated and those that had P-values > 0.10 in univariate models, four variables remained, resulting in a set of 39 competing models that included all possible combinations of the four variables plus all two-way interactions (hereafter referred to as the "model set") (Table 3-2). All models were run and the AIC_c values for each were retained. The model with the lowest AIC_c was considered the overall best model. Models were rescaled to a minimum AIC_c value of zero (because AIC_c is on a relative scale) to facilitate comparisons between the best model and other candidates. These AIC_c differences (ΔAIC_c) are interpreted as evidence that a particular model is best. In general, models with ΔAIC_c values < about 2 have considerable support as being plausible given the data (Burnham and Anderson 2000).

After ranking the models based on ΔAIC_c, I computed Akaike weights (w_i) for each model. Akaike weights are interpreted as the normalized relative likelihood that a certain model is best, given the data (Burnham and Anderson 1998). Akaike weights were also used to rank the relative importance of each variable. The importance of a variable (i.e., its "importance value"), is the sum of the Akaike weights for each model in which the variable occurs (Burnham and Anderson 1998). For instance, the intercept will have an importance value of 1.0 since it occurs in every model. High importance values result for variables that consistently occur in models with high Akaike weights, and indicate variables with high predictive value. Likelihood ratios and standardized Pearson residuals plotted against the fitted values were used to assess the adequacy of the model fit.

Results

Radio-Telemetry

I attached radio transmitters to 14 adult hoary bats (12 M, 2 F). Six of these bats were never located. The remaining eight individuals were tracked to 17 different roosts. The mean distance traveled by hoary bats between capture and roost sites was nearly 2.5 km (range: 324-9895 m) (Table 3-3). Bats roosted nearly 7 km from the rim (mean = 6.7 km; range 1.1-9.9 km). On average, bats were tracked for only about 2 days (mean = 2.29 days, range 0-10 days) before bats apparently left the study area. The number of days an instrumented bat remained in the study area was not linearly correlated with time of capture (minutes after civil sunset) ($r = -0.507$, $p = 0.064$, $n=14$), progression of summer (number of days after beginning fieldwork) ($r = -0.074$, $p = 0.080$, $n=14$), or body mass ($r = 0.091$, $p = 0.76$, $n=14$).

Instrumented bats roosted primarily in live lodgepole pine trees, although two individuals roosted in medium-sized (< 5 m) understory deciduous shrubs (*Alnus tenuifolia)*. Both individuals found roosting in shrubs did so on the day following attachment of the transmitter. One spent the second day in a lodgepole pine tree before it apparently left the study area. I was not able to re-locate the other individual after the first day. Because these roosts may have been anomalous, they were excluded from the analysis, resulting in 16 known roosts available for analysis. On two occasions I did see the bat hanging in the tree. In both instances the bat hung by one foot with the other foot curled around its ventral side. Because the dorsal uropatagium is well-furred, the bat appeared to be a compact, homogenous unit, and bore an uncanny resemblance to the lodgepole pine cones amongst which it hung, a phenomenon also noted of *L. seminolus* (Menzel et al. 1999).

Concerned that the inability to locate signals using standard techniques was due to topographical and/or areal coverage constraints, I conducted two aerial telemetry surveys during the summer of 2001. On the first occasion (13 July), I searched for five transmitters that were unaccounted for. I detected (and later recovered) one transmitter that had been shed by the bat and was lying on the ground under patchy canopy approximately 2 km from its last known roost, and another transmitter for a bat whose location was known from the previous day. I searched for three transmitters during the second flight (7 August), but did not detect any signals. Detection distances for transmitters during aerial telemetry flights ranged from > 4 km for the shed transmitter to approximately 7 km for a transmitter on a bat whose location was verified with ground-tracking.

Roosting Habitat Preferences

The best logistic regression model, given the model set and the data, was the 4-variable model with no interactions that included tree height, distance to edge, distance to water, and % canopy cover as covariates (Table 3-4). The likelihood ratio (an estimate of goodness of fit) of the best model indicated that model fit was adequate ($\chi^2 = 33.08$; $p < 0.001$). Likewise, investigation of the standardized Pearson residuals showed that only one of the 42 observations was greater than 3.0 and that 88% (37/42) were less than 1.0, indicating good model fit (Ramsey and Shaeffer 1997).

Parameter estimates indicate that the odds a tree was used increased as tree height and canopy cover at the tree increased, and odds decreased as distance to nearest edge and distance to nearest water increased (Table 3-5). Tree height and distance to nearest water were the most important variables in segregating used versus random sites (Fig. 3-3). The relative odds that a tree was used as a roost, holding other covariates constant, were 7.3 times greater if the tree was 21 m tall (observed mean of used trees) than if the tree was 15.8 m tall (observed mean for randomly selected trees). The relative odds that a tree was used as a roost, holding other covariates constant, were 27.4 times greater if the tree was 105 m from nearest water (observed mean of used trees) than if it was 341 m from nearest water (observed mean for randomly selected trees). These results suggest that mature stands located near a water source are important habitat characteristics for hoary bats.

Distance to nearest edge and % canopy cover were less important in separating used from random sites, but still contributed to overall model efficiency. Holding other covariates constant, the relative odds that a tree was a roost were 3.2 times greater if it was 89 m versus 282 m from the nearest edge, and 1.7 times greater than if % canopy cover at the tree was 73% versus 67% (observed mean values for used and randomly selected trees respectively). None of the interaction terms contributed greatly to predicting use, as indicated by the low importance values (Fig. 3-3).

Discussion

The apparent proclivity for lodgepole pine stands used for roosting may be related to proximity to foraging or watering areas, an associated preferred microclimate or stand structure, or greater protection from predators. Bats selected roosts with greater canopy cover that were located in stands that were both nearer to water and taller than randomly selected sites. The need to drink and a readily available supply of prey at water sites may make roost sites near water attractive to bats (Kunz 1982), while increased canopy cover may have provided a preferred microclimate or greater protection from predators, most of which are avian (Shump and Shump 1982). Bats exhibited a preference for taller trees, which in the nearly monotypic, even-aged stands of lodgepole pine in the study area equates to more mature stands with relatively open understories. Constantine (1966) and Barclay (1984) noted that hoary bats seemed to roost in trees with unobstructed flight paths that allowed the bats to initiate flight after dropping from their perch. Because the hoary bat is a relatively fast, unmaneuverable flyer (Norberg and Rayner 1987) that tends to forage in the open (Shump and Shump 1982), tall trees in stands that provide relatively unobstructed understories should be better suited for hoary bat roosting habitat than shorter trees in stands with cluttered understories. Bats chose roost sites that were nearer to an edge than randomly selected sites. Constantine (1959) noted the hoary bat's apparent tendency to roost in "edge habitat", which minimizes the amount of cluttered space the bat must navigate in route to foraging or drinking areas.

Alternatively, lodgepole pines may simply provide better concealment than other species of trees in my study area. Despite the fact that the hoary bat roosts in the open, hanging from leaf or branch, the individuals that I tracked were exceedingly difficult to find once the roost was identified. However, as noted above, on two occasions I pinpointed the bat. In both instances, the bat appeared to be a compact, homogenous unit, and bore an uncanny resemblance to the lodgepole pine cones amongst which it hung. This posture may aid in thermoregulation and potentially help the bat remain hidden from predators.

The hoary bats in my study area had at their disposal a relatively homogenous matrix of coniferous forest consisting chiefly of lodgepole pine stands at lower elevations and mixed stands of Engelmann spruce and subalpine fir at higher elevations. Despite pockets of aspen, some quite near known roosts, and stringers of mature cottonwood along streams (Table 3-6), hoary bats used lodgepole pine trees in mature stands almost exclusively. Although the hoary bat is known to roost in both deciduous and coniferous trees (Shump and Shump 1982), some reports suggest that where conifers are present, hoary bats prefer them to deciduous trees (Kalcounis 1994, McClure 1942, this study). However, due to logistic constraints, Kalcounis was only able to locate roosts for the hoary bats once (M. Kalcounis, UC Berkley, pers. comm.), and these bats (all females) may have used deciduous trees on other occasions. Interestingly, in a study conducted at the same location, Barclay (1984) noted the exclusive use of deciduous trees by the females he tracked, indicating that the hoary bat may be a generalist with regard to species of tree in which it roosts.

During this study, bats that were tracked for multiple days used different roosts in the same localized area (except for one non-reproductive female that used the same roost 9 out of 10 days). In Hawaii, hoary bats returned to the same area, and possibly the same roost, over a fortnight of tracking (Jacobs 1993). Lewis (1995) suggested an inverse relationship between roost fidelity and roost supply, with bats that use spatially abundant roosts switching more frequently than bats that occupy spatially-rare roosts. She also noted that some roost-switching species exhibit fidelity to a particular area even though they use different structures (e.g., *Thyroptera tricolor*). In foliage roosting bats, fidelity to a particular area rather than a particular roost may be the general rule, but the hoary bats that I tracked apparently tended toward large-scale movements, often moving out of range in the course of a night. For example, six of the bats to which I attached transmitters were never re-located, and most remained in the study area for only a few days (Table 3-7).

The apparent lack of fidelity to the study area exhibited by the bats that I tracked is puzzling, but may have represented classical migratory movement (i.e., *removal migration*; Baker 1978:26) or exploratory migration (Baker 1978:26), movement to or from breeding areas, or roaming behavior. Anecdotal evidence suggests that the hoary bats that I tracked may have engaged in exploratory migrations. Upon returning to a known roost site to collect habitat data, I observed a hoary bat roosting in the exact location where one had last been observed 41 days earlier. Although this individual no longer carried a transmitter, the dime-sized area of fur that had been clipped for transmitter attachment was clearly visible. It seems likely that the bat using the roost on that occasion was the same individual that had used it previously, although it could have been another individual to which I had attached a transmitter. On another occasion I tracked a bat for two days before losing the signal. This bat reappeared five days later in the same roost, used it for two days before going elsewhere for a night, and then used it again for one day.

Alternatively, the bats in my study area may have been initiating movements to find mates. Dalquest (1943) noted the propensity of "male hoary bats [to] wander widely in the months of June and July." This roaming behavior may represent an effort to locate females in breeding condition. Findley and Jones (1964) noted spatial segregation in the summer by the sexes, with females tending toward an eastern summering ground and males more common in the west. Cryan (in press) noted a similar trend in sexual segregation, but also an apparent mixing of the sexes in the northern Rocky Mountains in late summer. He hypothesized that the mixing, undetected during other times of the year, may coincide with breeding activities. The hoary bat, like most other north-temperate species which initiate breeding activities in the fall, is thought to copulate during fall migration, or possibly on the wintering grounds (van Zyll de Jong 1985). Inasmuch as many of the hoary bat females encountered in the spring are pregnant (Koehler and Barclay 2000, Mullican 1999, Barclay 1984, Turner 1974, Bogan 1972, Druecker 1972, Findley and Jones 1964, Poole 1932), and exhibit a discontinuous reproductive cycle (Shump and Shump 1982), it seems likely that they were bred the previous fall.

Alternatively, the bats that I tracked simply may have chosen to roost wherever the brightening sky found them. Unlike males and non-reproductive females, reproductive female hoary bats are responsible for nursing and care of the young from June through July (Shump and Shump 1982). Being free of the constraints of rearing the young, males and non-reproductive females have more latitude than reproductive females to meander about the landscape. Because availability of roosting structures did not appear to be a limiting factor for hoary bats in my study area, the bats that I tracked may have had no reason to remain in a particular area. The distance and direction traveled on any given night may have represented a “random walk” or may have represented more purposeful actions. For instance, bats may have been tracking an ephemeral and patchily distributed prey base.

The bats that I followed may have been transient individuals in the study area. Although I have no data to support this supposition, the fact that I captured only 17 hoary bats during the two years of my study, while greater than four times (on a per annum basis) as many dead hoary bats were recovered over three years (two of which overlapped my study) at a nearby wind power facility (Young et al. 2001, J. Gruver, University of Wyoming, unpub. MS thesis) suggests that hoary bats may not be full-time summer residents in the study area.

Hoary bats in my study area roosted primarily in lodgepole pine trees that were taller and had greater canopy cover than randomly selected trees. The roosts were located in stands that were nearer to water and an edge than randomly selected trees. Also, bats did not appear to remain in the study area very long. These results suggest that although hoary bats select roost trees and roost areas that provide some benefit, they also may wander widely. However, all standard disclaimers regarding scope of inference of my results to other populations or areas apply here. The efficacy of the results of this study to other areas will depend largely on the similarity of habitat, abiotic conditions, and sex ratio and residency status of hoary bats in the area of question. For instance, because reproductive females are subject to high energetic and physiological demands associated with pregnancy and lactation (Racey 1982), they may be constrained to using different types of habitats than males and non-reproductive females (Barclay 1991). I tracked only males and non-reproductive females that seemed to be transient residents during this study. Reproductive females or summer residents may have used different types of habitat.

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Figure 3-1. Schematic of Study Area.

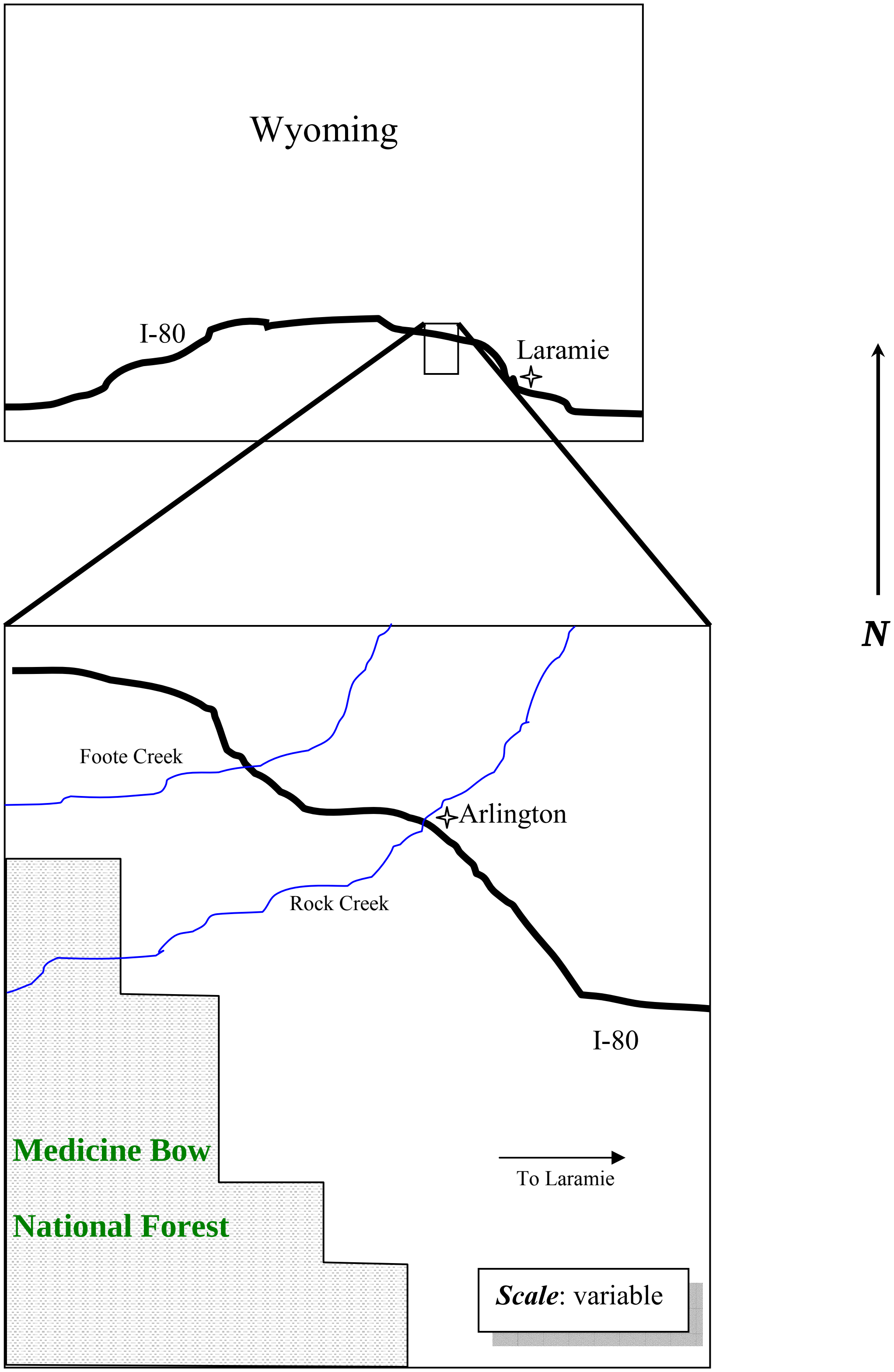

Figure 3-2. Schematic of habitat plot layout. Transects were extended in the cardinal directions from a roost or randomly selected tree. Trees were tallied by species in each sub-plot. Height, DBH, species, and distance from focal tree were recorded for all trees in the 5 m sub-plot. Height, DBH, % canopy cover, and species were recorded for trees within 5 m of intersections of transects and sub-plot boundaries.

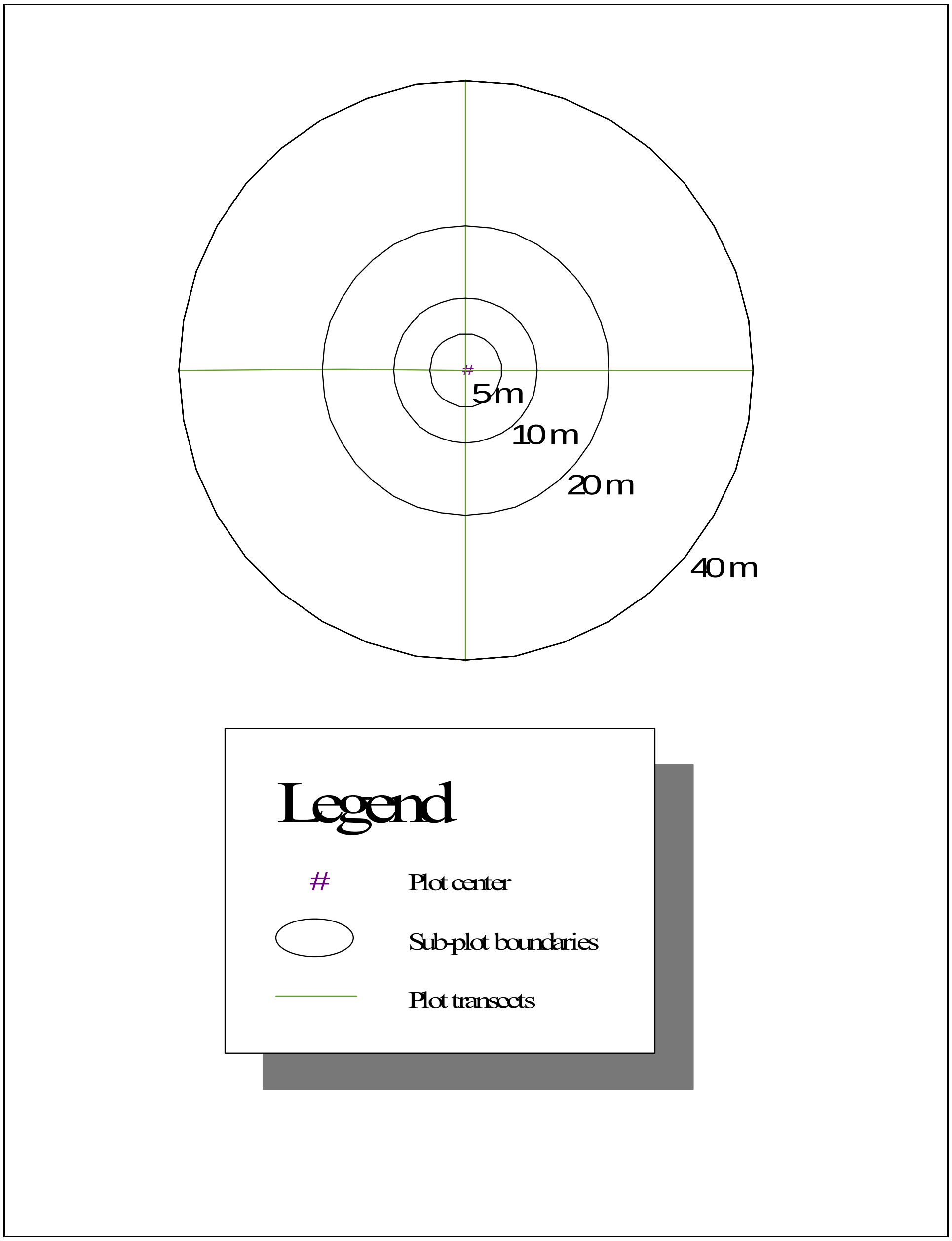

Figure 3-3. Summary of the relative importance of the variables included in the model set. A description of the calculation of importance variables is found in the Methods section. Abbreviations for variables: Intercept = model intercept (importance value = 1.0 by definition); TreeHt = height of roost or random tree (m), To Edge = distance of roost or random tree to edge (m), ToWater = distance of roost or random tree to nearest water (m), TreeCC = % canopy cover of roost or random tree.

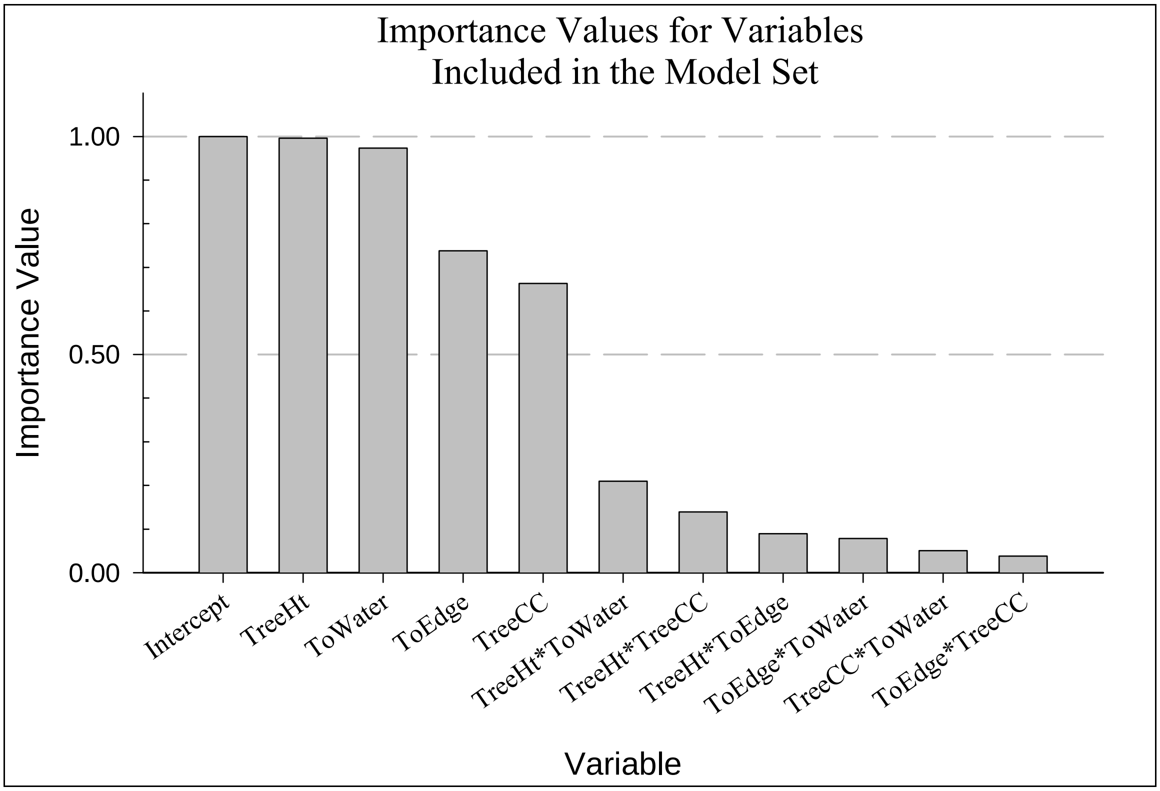

Table 3-1. Habitat variables measured at roost and random sites. A description of how these variables were measured is found in the Methods section.

Spatial Scale	Method	Measurement Units	Variable Type
Roost/Random Tree			
DBH	Diameter tape	Centimeters	Continuous
Height	Clinometer	Meters	Continuous
% canopy closure	Densiometer	Percent	Continuous
Species	Ocular	Taxonomic	Discrete
Habitat Plot			
Aspect	Compass	Degrees	Continuous
Average % canopy closure	Densiometer	Percent	Continuous
Average height of trees	Clinometer	Meters	Continuous
Average DBH of trees	Diameter tape	Centimeters	Continuous
DBH of trees within 5 m	Diameter tape	Centimeters	Continuous
Distance to trees within 5 m	Tape Measure	Meters	Continuous
Height of trees within 5 m	Clinometer	Meters	Continuous
Tree density by species	Count	Ordinal	Continuous
Landscape Level			
Available habitat in study area	GIS	Hectares	Continuous
Distance to capture site (roosts only)	GIS	Meters	Continuous
Distance to edge	Aerial photo/GIS	Meters	Continuous
Distance to nearest water	Tape Measure/GIS	Meters	Continuous
Spatial distribution of roosts	GIS	Meters	Continuous
Spatial distribution of roosts relative to capture sites	GIS	Meters	Continuous

Table 3-2. List of variables used to construct the model set (*n* = 39 models), and the models. Model number 33 was the best model based on AIC$_c$.

Variables	
TreeHt	(Tree Height)
ToEdge	(Distance to nearest edge)
ToWater	(Distance to nearest water)
TreeCC	(% Canopy cover)

Model number and associated model

1) TreeHt
2) ToEdge
3) TreeCC
4) ToStream

5) TreeHt, ToEdge
6) TreeHt, TreeCC
7) TreeHt, ToStream
8) ToEdge, TreeCC
9) ToEdge, ToStream
10) TreeCC, ToStream

11) TreeHt, ToEdge, TreeHt*ToEdge
12) TreeHt, TreeCC, TreeHt*TreeCC
13) TreeHt, ToStream, TreeHt*ToStream
14) ToEdge, TreeCC, ToEdge*TreeCC
15) ToEdge, ToStream, ToEdge*ToStream
16) TreeCC, ToStream, TreeCC*ToStream

17) TreeHt, ToEdge, TreeCC
18) TreeHt, ToEdge, ToStream
19) TreeHt, TreeCC, ToStream
20) ToEdge, TreeCC, ToStream

21) TreeHt, ToEdge, TreeCC, TreeHt*ToEdge
22) TreeHt, ToEdge, TreeCC, TreeHt*TreeCC
23) TreeHt, ToEdge, TreeCC, ToEdge*TreeCC
24) TreeHt, ToEdge, ToStream, TreeHt*ToEdge
25) TreeHt, ToEdge, ToStream, TreeHt*ToStream
26) TreeHt, ToEdge, ToStream, ToEdge*ToStream
27) TreeHt, TreeCC, ToStream, TreeHt*TreeCC
28) TreeHt, TreeCC, ToStream, TreeHt*ToStream
29) TreeHt, TreeCC, ToStream, TreeCC*ToStream
30) ToEdge, TreeCC, ToStream, ToEdge*TreeCC
31) ToEdge, TreeCC, ToStream, ToEdge*ToStream
32) ToEdge, TreeCC, ToStream, TreeCC*ToStream

33) TreeHt, ToEdge, TreeCC, ToStream

34) TreeHt, ToEdge, TreeCC, ToStream, TreeHt*ToEdge
35) TreeHt, ToEdge, TreeCC, ToStream, TreeHt*TreeCC
36) TreeHt, ToEdge, TreeCC, ToStream, TreeHt*ToStream
37) TreeHt, ToEdge, TreeCC, ToStream, ToEdge*TreeCC
38) TreeHt, ToEdge, TreeCC, ToStream, ToEdge*ToStream
39) TreeHt, ToEdge, TreeCC, ToStream, TreeCC*ToStream

Table 3-3. Distance traveled between capture and roost site(s) by hoary bats tracked to a roost at least once as determined by GIS. Distance is expressed in meters.

Bat ID	Roost ID	Capture Site	Distance
227	R1	Eureka Pond	7067
294	R1	White Rock Pond	1271
506	R1	Broken Stick	9895
506	R2		9879
Average for 506			**9887**
574	R1	Eureka Pond	778
574	R2		747
574	R3		725
574	R4		2299
574	R5		726
574	R6		717
574	R7		721
574	R8		747
Average for 574			**932**
604	R1	White Rock Pond	324
869	R1	White Rock Pond	435
909	R1	White Rock Pond	2203
960	R1	White Rock Pond	1402
960	R2		1405
Average for 960			**1403**
Average for all Bats			**2432**

Table 3-4. Summary of the five best logistic regression models predicting relative probability of use by hoary bats. For each model the maximized log-likelihood (Log($\mathcal{L}$)), number of estimable parameters (K), information criterion (AIC$_c$), model differences (ΔAIC$_c$), and the model (Akaike) weights (w_i) are shown. Abbreviations for model parameters: TreeHt = height of roost or random tree (m), To Edge = distance of roost or random tree to edge (m), ToWater = distance of roost or random tree to nearest water (m), TreeCC = % canopy cover of roost or random tree. AIC$_c$ is AIC corrected for small samples (i.e., $n < 10K$ for the largest model) = $(-2\text{Log}\mathcal{L}) + (2k) + [2k(k+1)/(n-k-1)]$

Model	**Log($\mathcal{L}$)**	***K***	**AIC$_c$**	**ΔAIC$_c$**	**w_i**
0.382(TreeHt) – 0.006(ToEdge) – 0.014(ToWater) + 0.081(TreeCC) – 9.82	-11.37	6	37.14	0.00	0.1895
0.350(TreeHt) – 0.005(ToEdge) – 0.011(ToWater) – 4.28	-13.18	5	38.03	0.89	0.1215
1.97(TreeHt) – 0.007(ToEdge) – 0.011(ToWater) + 0.440(TreeCC) – 0.205(TreeHt x TreeCC) – 38.41	-10.43	7	38.16	1.02	0.1139
0.357(TreeHt) – 0.009(ToWater) – 5.46	-10.51	7	38.54	1.40	0.0943
0.321(TreeHt) – 0.015(ToEdge) – 0.133(ToWater) – 0.081(TreeCC) + 0.0005(Ht x ToEdge) – 8.82	-14.73	4	39.48	2.34	0.0589

Table 3-5. Parameter estimates and odds ratios for variables in the AIC$_c$ best logistic regression model. Odds ratios were derived by modeling the probability of use. Odds ratios indicate the change in the odds that a tree will be used as a roost given a one-unit increase in the value of the variable. The sign of the estimate indicates whether the odds of use increases or decreases with a one-unit increase in the value of the variable. See Table 3-4 for explanation of variable abbreviations.

Variable	**Estimate**	**Odds Ratio**	**95% Wald Confidence Interval**	
			Lower	Upper
TreeHt	0.382	1.466	1.125	1.910
ToEdge	−0.006	0.994	0.994	1.001
ToWater	−0.014	0.986	0.976	0.997
TreeCC	0.081	1.085	0.987	1.193

Table 3-6. Summary of available roosting habitat for the hoary bat as determined by GIS. Percent of total area is expressed as the total area (ha) occupied for each tree species divided by the total in the study area (52,578 ha). Area in clearcuts was subtracted from the area available.

Tree Species	**Total Area (ha) Occupied**	**Relative Percent of Area (ha) Occupied**	**Percent of Total Area**
Aspen (*Populus tremuloides*)	189	1.04	0.36
Cottonwood (*P. deltoides/angustifolia*)	6192	34.0	11.74
Douglas fir (*Pseudotsuga menziesii*)	119	0.65	0.23
Limber pine (*Pinus flexilis*)	27	0.15	0.05
Lodgepole pine (*P. contorta*)	9032	49.6	17.12
Spruce/Fir (*Picea engelmannii* and *Abies lasciocarpa*)	2650	14.6	5.02
Subtotal	18209	100.0%	34.52%
Area in clearcuts less than 30 yrs old	1019	0.56%	0.019%
Totals	**17190**	**99.44%**	**34.5%**

Table 3-7. Residence time in the study area of hoary bats carrying radio-transmitters. Number of days tracked to a roost represents the elapsed time between the day following transmitter attachment and the last day a roost was located. If a bat was never located, number of days tracked is zero. Number of days tracked does not necessarily indicate that a roost was located for a bat on each day since some bats were not located on day(s) between positive locations.

Number of days tracked to a roost	Number of individuals (sex)
0	6 (5 M, 1 F)
1	2 (M)
2	3 (M)
7	1 (M)
8	1 (M)
10	1 (F)

CHAPTER 4

A REVIEW OF BAT-WIND TURBINE INTERACTIONS

Abstract

The wind power industry has grown rapidly in the past two decades, and reports documenting turbine-associated bat mortalities suggest that most mortality befalls lasiurine bats and tends to occur in the late summer and early fall. The reasons for bat-turbine interactions are not known, but may relate to reduced use of echolocation by migratory species, higher densities of aerial insects near turbines, or echolocation morphology.

Wind farms clearly contribute to mortality of flying vertebrates, but estimating impacts of wind farms to bat populations is problematic due to difficulties in accurately assessing population densities of bats. Nonetheless, wind farms may represent no greater threat to bats or birds than other methods of generating electricity, whose effects on wild populations are less easily identified. Because mortality at wind farms can be linked directly to turbines or other tall structures, efforts to understand and minimize the causes of mortalities should prove fruitful. Mitigation measures must rely on detailed knowledge of the local bat fauna, and will be most successful when the causes of bat-turbine interactions are better understood.

Introduction

Wind-generated electricity has enjoyed a recent surge in popularity in the United States, as evidenced by the increase in total wind power capacity in the United States from 10 MW to 4261 MW between 1981 and 2001 (AWEA 2002*a*), which is currently enough energy to meet the instantaneous demand for approximately 3.2 million homes simultaneously. Due to increases in production capacity and technological advances in turbine design, the unsubsidized cost of wind-generated electricity (4.0-6.0 cents/kWh) fell to levels comparable to that of traditional coal-generated electricity (4.8-5.5 cents/kWh) by 1996 (AWEA 2002*b*). With existing or proposed facilities in 30 states (AWEA 2002*c*), and over 2000 MW of new wind-generated electricity projected for 2003 (AWEA 2002*d*), wind power has become a cost-effective and stable source of electricity. In light of probable long-term persistence of existing sites, and likely development of new U.S. wind power facilities, turbine-associated bat mortality cannot be considered a fly-by-night issue.

Compared to raptor and songbird turbine-related mortality, deaths of bats at wind farms have only recently been reported and addressed (Keeley et al. 2001). Records of turbine-related bat mortality have steadily increased in the U.S., the cumulative results of which suggest two noteworthy trends: 1) most deaths are detected from late summer to early fall, and 2) bats in the genus *Lasiurus* (specifically *L. borealis* and *L. cinereus*) appear to represent the majority of recovered carcasses. These two trends may be interconnected inasmuch as these two species, along with the silver-haired bat (*Lasionycteris noctivagans*) and Mexican free-tailed bat (*Tadarida brasiliensis*), are thought to be the most highly migratory species in North America.

As has been the case with avian-turbine issues, mitigation plans for bats will likely rely on information about how local species assemblages use the landscape in relation to existing or proposed wind farms. More useful still will be assessments of factors influencing bat-turbine interactions, and studies designed to test hypotheses related to these factors. To that end, this document summarizes the current state of knowledge surrounding bat-wind turbine interactions, and offers guidance for future monitoring and research. Appendix 1 provides a general guide to studying bats in relation to new or proposed wind farms.

Bat-Wind Turbine Interactions

Although generally considered environmentally benign, wind turbines represent potential threats to flying vertebrates. Documented fatalities at wind farms include birds and bats in the United States (Johnson et al. 1999, Osborne et al. 1996), bats in Australia (Hall and Richards 1972), and birds in Europe (Winkelman 1994). A recent review of wind turbine-associated bat mortality revealed that lasiurine bats (*Lasiurus borealis* and *L. cinereus*) comprised 85% of all dead bats collected at three wind farms in the United States (Keeley et al. 2001). The results of three years of monitoring avian and bat mortality (1999-2001) at a wind farm in southern Wyoming indicated that *L. cinereus* represented 88% of the bat carcasses recovered (Young 2001, J. Gruver, University of Wyoming, unpub. MS Thesis).

Osborn et al. (1996) reviewed a number of factors that may potentially lead to bat-turbine interactions including interference of bat echolocation systems by turbines, inclement weather during fall migration, reliance on sight rather than echolocation by migrating species, and the possibility that bats attempt to use the turbine structures as temporary roosts.

Two of these factors relate directly to migration, and evidence suggests that timing of mortalities coincides with initiation of fall movements by lasiurines, the species most often involved in turbine collisions. Both *L. cinereus* and *L. borealis* are reported to engage in long-distance migrations, and evidence suggests that most fatalities at wind farms are associated with migrating individuals (Keeley et al. 2001).

The question of why some bats apparently do not detect (or detect but do not avoid) such obvious obstacles as wind turbines remains unresolved. The most plausible explanations based on current knowledge relate to migratory behaviors and/or normal foraging behaviors. Bat mortality near turbines seem to peak in late summer and early fall, and thus may represent migrating individuals that may not detect the turbines. Alternatively, bats may drawn to the movement of turbine blades or concentrations of insects behind turbine blades.

It has been suggested that bats may not use echolocation during migration (Crawford and Baker 1981), and so may not detect large obstacles protruding into open airspace. Although bats incur no additional energetic cost while echolocating during flight (Speakman and Racey 1991), migrating bats may rely more heavily on visual or passive auditory clues than on echolocation during migration because of the relatively short distance (an estimated 15-100 m maximum) over which echolocation is effective (Fenton 1982, Griffin 1970). Indeed, bats observed foraging (and thus actively echolocating) near wind turbines in Europe experienced no detectable mortality (Bach et al. 1999), further suggesting that bat-turbine interactions during migratory periods are the result of bats navigating by means other than echolocation.

If it is primarily migratory individuals falling to wind turbines, the apparent absence of fatalities during spring migration is perplexing. Several authors observed concentrations of hoary bats in the spring (Findley and Jones 1964, Mumford 1963, Vaughan 1953), although these studies occurred in areas thought to harbor wintering individuals (New Mexico, Arizona, and California). Findley and Jones (1964) noted that female hoary bats moved north in the spring before males, which probably reduces the spatial and temporal overlap of individuals. Because wind farms that have reported bat fatalities tend to be in the northern parts of North America (Table 4-1), the lack of spring deaths may be explained by migratory individuals being more dispersed as they enter these areas.

Many of the documented episodes of dead bats found near tall human structures occur in the fall (Young et al. 2001, Timm 1989), suggesting that perhaps the fall migration is more concentrated than the spring migration. Zinn and Baker (1979) noted waves of hoary bats during fall migration in northern Florida, whereas the spring migration appeared to be more scattered. Possibly, migrants make a more temporally discrete southward migration. Or, rather than the apparently segregated northward migration, the sexes may mix for the purpose of breeding during fall migrations (Shump and Shump 1982).

As opposed to hypotheses relating directly to migration, bats may forage near wind turbines to take advantage of concentrations of insects, whether during migration or otherwise. Because turbines capture some of the kinetic energy in wind, wind speed is reduced for some distance in the lee of the turbine. This “wind-shadow” may hold increased densities of aerial insects (Lewis 1970). Barclay (1985) noted that *L. cinereus* and *Lasionycteris noctivagans* took refuge on the leeward side of a ridge in windy conditions, as did *Pipistrellus pipistrellus* (Racey and Swift 1985), presumably to take advantage of higher concentrations of insects (Grindal 1996). Both *L. cinereus* and *L.*

borealis appear to prefer to forage along habitat edges (Mager and Nelson 2001, Furlonger et al. 1986). If this is the case, then relatively unmaneuverable bats (e.g., *L. cinereus*) may not be able to avoid turbine blades if preoccupied with chasing and capturing an insect. It is also possible that bats do not run into turbines or turbine blades directly. Most bats found near turbines appear to have died from blunt-force traumas. Typical injuries include broken wings and necks (pers. obs.), which can be attributed to a bat striking a turbine, or a bat flying too close to the turbine blade and getting knocked to the ground from wind-shear, or both.

Because narrowband constant frequency (CF) calls are associated primarily with flutter detection (Schnitzler 1987), Schnitzler and Kalko (1998) noted that, "an echo from any moving target is a typical food-specific situation and indicates a flying insect." Because hoary and red bats rely on CF signals while hunting (Obrist 1995), a possible explanation for relatively high rates of turbine-associated mortalities for lasiurines is that they mistake rotating turbine blades for an insect (or possibly a swarm of insects) and are enticed into the rotor-swept area in search of a meal. However, this suggestion falls short in explaining why bats collide with buildings, lighthouses, windows, and other large stationary objects.

Lastly, it is possible that bat-turbine interactions are random events with respect to species or migratory habits. If so, then migratory species would be expected to encounter turbines no more often than other species. Yet if migrating bats travel in groups as has been suggested (Howell 1908, Heppenstall 1960), then encounters with turbines may result in greater mortality than for non-migratory species, and as a result species traveling in groups would appear in greater numbers during searches for carcasses. Evidence from a number of studies indicates that the majority of bird-kills at communications towers, wind turbines, and tall buildings occur during seasonal migrations of large flocks (Erickson et al. 2001, Cochran et al. 1958). Whether bats-turbine interactions are random events or not remains unresolved, but migratory bats may take advantage of winds to help save energy while migrating (Davis et al. 1962) as many birds do (Berthold 1993), and so may migrate along corridors that correspond with areas advantageous for wind farms.

Discussion

Although it is clear that wind turbines kill birds and bats, it is important to place this mortality in context. An estimated 150 million birds are killed each year in the U.S. due to collisions with automobiles, tall structures (e.g., communications towers), and plate glass (Erickson et al. 2000), with another 100 million estimated deaths annually from housecats (Fitzgerald 1988). Although these types of estimates are unavailable for bats in the U.S., records of bat mortality from anthropogenic structures or activities include television towers (Avery and Clement 1972, Taylor and Anderson 1973, Zinn and Baker 1979, Crawford and Baker 1981), large glass windows (Timm 1989), high-rise buildings (Terres 1955), lighthouses (Saunders 1930), barbed-wire fences (Johnson 1933, Iwen 1958, Hibbard 1963, Hitchcock 1965, DeBlase and Cope 1967, Wisely 1978), road oil (Koestner 1942) and mortality associated with road, flight, and rail traffic (Kiefer et al. 1995). In addition, reports of dead bats on burdocks (*Arctium* spp.) appear in the literature (Lyon 1925, Johnson 1933, Verts 1988), and Dunaway (1960) reported an individual *L. seminolus* that had apparently become entangled in its roost of Spanish moss (*Tillandsia usneoides*) and was found strangled. The bat was found with several strands of moss twisted tightly around its neck. It is interesting to note that bats in the genus *Lasiurus* were involved in most of the cases above. Why lasiurines seem predisposed to accidents is not clear, but may be an artifact related to greater visibility of lasiurines by human observers.

There are currently no reliable methods for estimating densities for most populations of bats (O'Shea and Bogan 2000), so accurately assessing population-level effects of any source of mortality for most species of bats remains out of reach. Estimates of bat mortality at wind farms range from 0.74-10.0 bats turbine^{-1} year^{-1} (Table 4-1). Although the impacts of wind turbines on bats are readily visible, they may be no more severe than traditional power-production methods (e.g., coal-fired power plants). It is a much more difficult undertaking to quantify effects of the emission of pollutants on bats or other wildlife populations. Nonetheless, the relatively direct nexus between wind turbines and mortality of flying vertebrates provides an opportunity not only to develop sound mitigation strategies, thereby increasing wind power's appeal to environmentally-conscious consumers, but also to provide insight into poorly understood aspects of bat and bird ecology.

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Table 4-1. Bat mortalities documented at wind power facilities. All totals are adjusted for searcher bias and scavenger removal rates, except Nicholson (2001) and Hall and Richards (1972) which represent unadjusted totals.

Location	**Estimated[a] Mortalities turbine^{-1} year^{-1}**	**Survey Period**	**Source**
Buffalo Mountain Wind farm (Anderson Co., TN)	10.0	10/2000-9/2001	Nicholson, (2001).
Buffalo Ridge Wind Resource Area (Lincoln and Pipestone Counties, MN)	3.78	7/2000-10/2000	Krenz, (2000).
Buffalo Ridge Wind Resource Area (Lincoln and Pipestone Counties, MN)	3.89	15 March-15 November 1996 - 1999	Johnson et al., (1999 & 2002).
Foote Creek Rim Wind power Project (Carbon Co., WY)	1.51	11/1998-12/2000	Young et al., (2001).
New South Wales, Australia (3 locations)	5.50	6/1967-6/1971	Hall and Richards, (1972)
Vansycle Wind Project (Umatilla Co., OR)	0.74	1/1999-12/1999	Erickson et al., (2000)

Appendix 4-1. Reference guide to designing and analyzing studies of bats near wind turbines.

Abstract

Assessing impacts of wind farms on bats requires knowledge of the local bat community, how these bats utilize the landscape and whether changes in abundances are attributable to the wind farm.

Information about species presence, relative abundance and absolute abundance can be gathered through capture surveys, acoustic-detection surveys, and visual inspections. Each method has biases which are difficult to quantify, resulting in ambiguity regarding detection rates. Combining methods should allow more accurate assessments of community structure. Population density estimates are not currently attainable for most populations of bats.

Documenting and assessing the impacts of wind farms on bats can be accomplished by conducting visual searches of plots surrounding turbines, meteorological towers, or other tall structures on the wind farm. The presence of dead bats within the plots provides evidence of mortality associated with these structures. Sample designs that include reference or control plots, and/or pre-construction surveys (e.g., Before/After, Control/Impact) can strengthen this association.

Owing largely to the nocturnal habits of bats, we currently have little knowledge regarding how the presence of turbines affects bat behavior. Where bat densities are high, radar studies may shed light on this question. Light-tagging or radio-telemetric studies on individual bats may provide data on movement patterns of bats in relation to wind farm structures.

Introduction

Protocols for monitoring birds (e.g., point-counts, nest surveys) have long been used to determine species presence/absence, population density estimates, and population trends (Thompson 2002). Statistically rigorous methods of accounting for biases, such as differing probabilities of detection, are fairly well developed (Thompson 2002). Unfortunately, bats are not birds. While birds are generally apparent (for instance while singing or in flight) to the perceptive observer, the crepuscular and nocturnal habits of insectivorous bats present a significant hurdle to researchers.

Due to the unique natural history of bats, their temporal and spatial diversity in habitat use, and need for better methods to survey them, realistic questions about most bat populations are currently limited to species presence (inventories), and relative abundance. Assessments of absolute abundance are possible only for colonially roosting species. Capture surveys and acoustic surveys are the two most commonly used methods to investigate bat presence/absence, relative abundance, and habitat use. Capture surveys are conducted with mist-nets and harp (Tuttle) traps, but other methods are available (e.g., hand-nets, and bag and funnel traps). Kunz and Kurta (1988) discuss the use of each of these methods. Ultrasonic detectors are used for acoustic surveys.

Of the 45 species of bats in the U.S., 41 are insectivorous, three are nectarivorous, and one is frugivorous. The non-insectivorous species are geographically restricted and occur only near the southern periphery of the continental U.S.; a distribution that represents the northernmost extent of their ranges. The attention of this work will focus on the insectivorous species that comprise the bulk of the bat fauna in the United States.

Methods for and limitations of surveys for nectarivorous and frugivorous species are discussed in O'Shea and Bogan (2000).

Bats are often generically categorized by their roosting habits. Species that aggregate are said to be "colonial." Those that roost solitarily or in small temporary aggregations are called "dispersed," a term that refers to the dispersed distribution of individual roosts across a landscape. Species that roost in tree or rock crevices (usually singly or in small groups), or in foliage (usually singly) are dispersed, while those that use caves, mines, buildings or similar structures are often colonial. Clearly, survey methods and the type of data that can be gathered will vary depending on these distinctions. The reader will find these terms throughout this section, but should bear in mind that the distinction may not be so clear-cut. There is no formal definition of how many individuals define a colony, and many dispersed species aggregate for hibernation.

This document is intended for researchers who plan to conduct surveys for bats within and around extant or proposed wind farms. I have taken a conservative approach and made the assumption that not all researchers involved in such projects will be familiar with bat sampling techniques and, more importantly, the limitations and biases associated with those techniques. Therefore, the general goals of this section are to describe the methods and limitations of commonly used bat survey methods and to discuss the level of inference afforded by each with the understanding that the methods are applicable to most locations (i.e., within a wind farm or at surrounding locales). The description of methods draws heavily from two existing references (Kunz 1988, OShea and Bogan 2000), and the reader is referred to these and the other references in Appendix A-2 for more detail.

Getting Started

Prior to designing the study and heading to the field, a thorough review of existing literature should be performed to determine how many of the 45 U.S. bat species (Koopman 1993) are present at any time of the year in the area of interest. The review should cover migration and dispersal patterns, food preferences, foraging behavior and timing, roost requirements, and conservation status of those species present. A thorough review can provide direction for survey techniques, species to be considered, extent of the study area, and timing of surveys. The types of questions to be addressed and the level of resolution required from surveys must be established before designing and executing surveys.

Following the literature review, the study site should be reconnoitered. Geographic analysis of the site should include both on-site assessment and examination of geographic data. Important features to note include potential roost sites and foraging areas. Caves, cliffs, large cavity-bearing trees, foliage, rock crevices, bridges, mines, and abandoned buildings are all potential roost sites (Kunz 1982). Potential foraging areas include water bodies, riparian vegetation and forests (Pierson 1998). Because moths and other night-flying insects that are attracted to light provide convenient prey for bats (Hickey and Fenton 1990), brightly lit areas are also potential foraging sites.

Personnel involved in surveys should be familiar with standard capture and holding techniques for bats (Kunz and Kurta 1988) and the use and limitations of all equipment. As with all wild animals, care should be used when handling bats to avoid injury to the animal. To minimize risks to bats and researchers, those handling bats should have pre-exposure rabies vaccinations.

Survey Timing

Most temperate zone species of bats are active in numbers only during the warm months and usually only at night, but there is a high degree of variability in bat activity between nights and locations. In general, the goals of the research and the types of data required will dictate survey methods and intensity (Table 4A-1).

Colonial Species

Sampling bats while they are active (versus while they are roosting or hibernating) may impose the lowest cost to individual bats. When surveys involve physically entering the roosts (e.g., to visually count or photograph clusters of roosting bats), timing of surveys should coincide with periods in which disturbance is least harmful to the bats and when numbers of individuals are likely to be most stable. Near the beginning and end of hibernation, arousals and flights of bats are more frequent than during the middle of hibernation (Eckert 1982). Therefore, surveys during mid-hibernation should yield the most consistent counts.

Some species roost communally throughout the year (e.g., *Tadarida brasiliensis*), whereas others do so either through the pre- and post-partum periods or during winter hibernation (e.g., many species of *Myotis*, *Eptesicus,* and *Pipistrellus*). Colonial species often use caves and abandoned mines, but some have adapted to use manmade structures such as attics, barns, bridges, and abandoned buildings. Human intrusion into colonial roosts can deleteriously impact bats. Disturbance of roosting colonies can lead to roost abandonment or costly energetic expenditures. Minimizing unnecessary energy expenditures is particularly important for overwintering bats, which may lose up to 68 days worth of fat reserves for each arousal (Thomas et al. 1990). Careful consideration of the benefits and costs of disturbing roosting colonies should help to minimize impacts.

Dispersed Species

Dispersed species tend to roost in low densities in roosts scattered across the landscape. Dispersed species may roost singly (e.g., *Lasiurus*), or may aggregate in small colonies. Many temperate-zone species form "maternity colonies" comprised primarily of pre- and post-partum females, and juveniles. Some dispersed species use a variety of structures as roosts (e.g., tree and rock crevices, bridges, buildings, caves, and mines) throughout the year. Location and type of roost sites may depend on social grouping/organization, roost fidelity/lability, and intersexual differences. Roost switching is especially problematic for monitoring populations because of spatial and temporal uncertainty in locating bats (O'Shea and Bogan 2000).

Because bats are least active during daylight hours and during the winter, capture and detection surveys must be performed at night and during the summer months. Caution should be used when interpreting results of surveys near the peripheries of the active season because temporary fluxes of migratory species or species moving to or from hibernacula may distort the picture of local population structure.

Surveying Winter Hibernacula

Nearly all temperate-zone bats, whether they roost colonially or dispersed across a landscape, must seek refuge during the cold winter months when food resources are scarce (or non-existent) and ambient temperatures are too low to allow metabolically efficient thermoregulation. An exception are those species that migrate to warmer regions (i.e., *Lasiurus borealis*, *L. cinereus*, *Lasionycteris noctivagans*, and *Tadarida brasiliensis*), although some populations of these species are known to hibernate.

Although there are notable exceptions, locations of winter hibernacula for most populations are unknown. Even if hibernacula are located within an area of interest (e.g., near a proposed or extant wind farm), the density of bats recorded from these locations is unlikely to reflect the density of bats that will take up residency in the area in the spring. Notwithstanding, identification of hibernacula near proposed or existing wind farms is important because hibernacula represent specialized and, presumably, limiting resources to bats. Furthermore, because the ability to conserve energy stores is absolutely crucial to overwinter survival, suitable hibernacula play a critical role in the year-to-year viability of the populations using them. Existing or proposed wind farms in close proximity to hibernacula may contribute to mortality as bats converge on and disperse from the structure(s) in the fall and spring, or during foraging and watering bouts on mild fall or winter evenings.

Because hibernacula can be relatively permanent and accommodate sizeable numbers of bats (Thomas and LaVal 1988), species and abundance counts within may provide reliable information on long-term population trends. However, because of the sensitivity of hibernating bats to human intrusion, recommendations for survey frequency in hibernacula range from annual to bi-annual. Therefore, the time required to generate useful data with this technique may not coincide with the goals of the study or the study period.

Assessing Species Presence

Species inventories can be conducted at roosts or away from roosts using either capture or detection methods (Table 4A-2). The most commonly used capture methods are mist-nets and harp (Tuttle) traps. Ultrasonic “bat-detectors” are used for detection surveys. Capture methods allow for species identification, assessment of reproductive status (Racey 1988), age (Anthony 1988) and sex, and other measurements of physical condition. Capture methods necessarily require the handling of bats. Care should be taken to avoid injury to the bats, particularly the fragile wing bones. Pre-exposure rabies vaccinations are recommended for those who will handle bats. Lightweight leather gloves worn by handlers will minimize the risk of having to sacrifice a bat because it has bitten a careless or inexperienced worker. Scientific collection permits to capture bats will likely be required by federal and/or state agencies.

In some cases, complete enumeration of individuals and positive species identification is possible when surveying at roosts. Exit counts conducted at inaccessible roosts (e.g., tree roosts) may provide complete enumeration of individuals, but species identification may not be possible. Surveys to document species presence may overlook rare species, or may miss species that are relatively common due to biases in sampling methods used (MELPRIB 1998). Lacking the ability to sample large numbers of bats in a single location, surveys for dispersed species are most productive (in terms of absolute numbers of bats) when conducted at areas known to concentrate bat activity, such as ponds, streams, forest trails, and other known flyways.

Capture Surveys

Originally used for the commercial and scientific collection of birds, mist-nets have been used to capture bats since the 1950s, and remain the most commonly employed capture method for bats. Nets vary in length and mesh size, but tend to be 2-3 m tall when fully expanded. Nets generally are erected over bodies of water (e.g., streams, ponds), across forest trails, or other known flyways. Bats taken over water correspond to those foraging or drinking, while those captured along forest trails represent individuals commuting between foraging areas or between roosts and foraging areas (Findley 1993).

The popularity of mist-nets as capture devices are related to their light weight, ease of deployment, and large areal coverage relative to other capture devices. Among the disadvantages of mist-nets are that they cannot be left unattended, do not capture all bats equally, and are subject to environmental conditions. Bats left too long in mist-nets become quite tangled, resulting in potential injury to the bats and difficulty in their removal. Because nets generally are set at ground level, bats that forage and/or commute above net-height may be underrepresented (or unrepresented) in the sample. High-flying species may be sampled by hoisting nets into the air (see Kunz and Kurta 1988). The height that a net can be hoisted and feasibility of such an operation will vary from site to site, and will require the outlay of additional resources in the form of ropes, pulleys, and labor. Some species, particularly the slower flying and more maneuverable species seem to be more apt at detecting and avoiding mist-nets and may be underrepresented in the sample. Meteorological conditions can also affect capture success. Capture rates on bright moonlit nights and during breezy or rainy conditions tend to be lower. Breezy conditions, which cause the nets to “billow” or bright nights, may make the nets more “visible” to bats. Rainy conditions are generally associated with low foraging activity by bats, and the onset of rain during sampling may simply cause bats to cease foraging and take shelter. The number of nets that can be used will depend on the size and shape of the site. The number of workers needed will depend on the number of nets used, the level of activity at the site, and the experience level of the workers. A minimum of two workers per site is recommended.

Harp traps (Tuttle 1974) consist of a double frame through which fine wires or monofilament is strung. Trap designs vary, but typically are constructed of aluminum tubing and cover an area of about 2 m^2. Bats that fly into the wires drop into a canvas bag suspended from the base of the frames. A sheet of heavy plastic can be hung from the insides of the bag to prevent escape of bats that crawl up the sides of bag. Kunz and Kurta (1988) provide illustrations and recommendations for the placement of harp traps. In general, the use of harp traps is restricted to situations where bat flight is constricted in a small area (e.g., cave or mine exits, building exits). The major advantage of harp traps is that they may be left unattended. It should be noted, however, that predators may key in on the traps, and that lactating females must return to the roost to nurse at least once per night (Racey and Swift 1985). Therefore, traps should not be ignored for long periods.

Acoustic Surveys

Many species of bats, and all insectivorous bats, rely on echolocation while foraging and commuting, although it is hypothesized that commuting and migrating bats may make less use of echolocation (Speakman and Racey 1991). Commercially available ultrasonic "bat detectors," are potentially valuable tools for the study of bat distributions (Gannon and Bogdanowicz 2000). Detectors may be tunable narrow-band, time expansion broadband, or divide-by-*n* broadband models. Narrow-band detectors record only specific frequencies and thus are not appropriate for most investigations of species presence or abundance. Time-expansion detectors record a wide range of frequencies and retain call characteristics important for species discrimination (e.g., harmonics, intensity, etc.), but will not record incoming calls while processing a previously recorded call. Therefore, there is some loss of information about activity levels. Because broadband divide-by-*n* detectors record a wide range of frequencies in real time they are the preferred type for assessing bat activity at different sites. Species identification based on calls from divide-by-*n* detectors can be problematic because they do not retain harmonics and call intensity information for a call. However, frequency and duration of the call are retained, and these two characteristics can be used for species (or species group) discrimination by experienced workers. However, the ability to identify species accurately and consistently based on echolocation data is the subject of considerable debate (e.g., see Barclay 1999, O'Farrell and Gannon 1999, O'Farrell et al. 1999).

Probably the most popular divide-by-*n* detector used in the U.S. is the Anabat system (Titley Electronics, Ltd., Ballina, NSW, Australia). These detectors use a zero-crossing period meter to obtain characteristics about a bat call (e.g., minimum and maximum frequency). Anabat detectors may be patched directly into a laptop computer which saves each individual call, or connected to an audiocassette recorder. When used with a tape recorder and a delay switch, incoming calls are recorded onto the cassette tape along with a time signature. Calls on the tape can be downloaded onto a computer for analysis at a later time. Calls recorded directly to a laptop are “cleanest” because there is no conversion from digital to analog and back to digital, but requires a laptop, an external power source (typically a deep-cycle 12-volt battery) and an AC-DC converter. Hayes and Hounihan (1994) describe field use of the Anabat system.

Despite the utility of the Anabat system, it appears to be less sensitive than another (albeit more expensive) detecting system, and as a result may misrepresent both the species present and the levels of activity in an area (Fenton et al. 2001). For example, compared to the time-expansion system, they found that the Anabat system yielded narrower bandwidths and shallower slopes for echolocation calls, and that the Anabat system frequently missed calls. Therefore, Fenton et al. (2001) made two recommendations: 1) Anabat (and other zero-crossing period meter systems) are probably inappropriate to describe echolocation calls of bats, and 2) when used to assess levels of activity and use of habitat, Anabat (and other zero-crossing period meter systems) should be calibrated against more sensitive bat-detectors.

Estimating Relative Abundance

Roosts of colonial species may be censused via visual surveys at roost exits, electronic beam-splitter count devices, photographic counts, mist netting, and harp traps (Thomas & Laval 1988). Potential roosts can be identified using any of these methods, or by direct observation or fecal evidence. However, access and safety in caves and mines make direct observation and presence of feces a less viable option in these types of roosts. Colonial roosts may also be identified via radio-telemetry by tracking instrumented individuals to the roost.

Surveys conducted away from roosts represent a sample of a larger population and will provide only an index of relative abundance or activity of the species using an area, the implications of which are discussed in greater detail below in the section ***Statistical Considerations***. Surveys to assess relative abundance are identical to those used for species inventories. The difference is that the goal is to obtain an additional level of abstraction from the data. That is, given that species A, B, and C exist in the study area, we wish to know the relative abundance of species A, B, and C. If species A is captured or detected twice as often as species B, we would like to be able to conclude that species A is twice as abundant. This conclusion relies heavily on the assumption that species A and B are equally detectable by the survey method, which is almost certainly false. Similarly, conclusions about the relative abundance of species at differing sites will be suspect if different methodologies were used consistently between the two (i.e., if site 1 was always surveyed with detectors, while site 2 was always surveyed with mist-nets.).

Estimating Absolute Abundance

Estimates of absolute abundance are limited to single roosts (Thomas and LaVal 1988). The areal extent of the landscape used by bats counted at these roosts is rarely known, however, so data on absolute abundance are difficult to extrapolate to population densities. Dispersed populations pose even greater difficulties for researchers who wish to assess population densities of bats. Because most of the assumptions upon which mark-resight/recapture models rest are violated with mist-net surveys, this technique is not feasible to estimate population densities for dispersed species. For instance, once captured in mist-nets, recaptures of marked individuals in nets are exceedingly uncommon. Moreover, the area sampled by the nets is rarely known (Findley 1993). To date, methods to estimate population parameters for dispersed species based on mark-resight/recapture techniques have not been developed (O'Shea and Bogan 2000).

When roost locations are known, active bats may be sampled non-intrusively as they leave roosting sites in the evening by stationing observers at roost exits to count numbers of individuals and identify species present, or by placing electronic counting devices near roost exits. The accuracy of counts and species identification using human observers will vary with observer experience, number and types of species present, and amount of vegetative clutter surrounding the exit. The effectiveness of human observers may be increased with night-vision equipment. Electronic devices such as beam-splitter count devices, video recorders, and photographic equipment may be used at accessible roosts with restricted exits, and may improve the accuracy of counts but may not help with species identification. Electronic devices have the advantage of being easily deployed at multiple sites, but require reliable power sources, and may not be feasible in areas of frequent human activity. Ultrasonic detectors may be used to identify bat presence at a roost, but are least preferable for counts and species identification because detectors are unable to distinguish multiple detections of an individual from single detections of many individuals. Issues relating to species identification of recorded bat calls are discussed above.

Estimating Turbine Impacts

Many new and existing wind farms have bird monitoring protocols in place which often include searching plots for carcass to monitor avian mortality. Concurrently searching for bats would require little or no alteration in search protocol or design. As with carcass search protocols for avian mortality, search designs for dead bats should include estimates of scavenger removal rates and searcher efficiency rates (Anderson et al. 1999). Adjusting total numbers of carcasses found for scavenging and observer bias rates will allow more accurate estimates of mortality and facilitate comparisons among wind farms in different regions.

Carcass searches typically are conducted within a predefined area around a turbine, with searchers walking parallel transects spaced 6-8 m apart until the entire plot has been searched. The size of the plot will be dictated by prevailing physical conditions at the site, previous carcass records (if any), and availability of resources, but should be large enough to find, with reasonable certainty, most of the carcasses present.

Young et al. (2001) cite data from Johnson et al. (1999), Higgins et al. (1996), and Orloff and Flannery (1992) to support their use of a 126 x 126 m plot. Plots were centered on the turbine. Therefore, searches were conducted at least 63 m away from the turbine in any direction. They also describe using square rather than circular plots for ease of searching and boundary-marking. Plot boundaries may be demarcated with stakes, flags, or other visual markers, or may be gauged by searchers who have measured the number of paces required to walk a given distance. Permanent plot boundaries are preferable because of consistency and repeatability. Transect width and walking speed, and thus total search time per turbine, will vary with habitat density and complexity.

Johnson et al. (2002) reported an average of 20-25 minutes spent on each 60 x 60 m plot in their study area consisting chiefly of agricultural crops and Conservation Reserve Program (CRP) grasslands. Young et al. (2001) reported an average of 45 minutes per turbine in their study area comprised mostly of short bunchgrasses and shrubs. It is not clear whether these estimates represent person-minutes or total search time.

When carcasses are found, searchers should record distance and bearing to the nearest structure (and structure type), species, sex and age (if possible), condition (e.g., intact, desiccated, scavenged), and other notes or comments pertinent to the mortality. To avoid biasing subsequent surveys, carcasses should be collected, labeled, and stored for future reference. Collections will most likely require permits from appropriate state or federal agencies.

Total numbers of carcasses collected should be adjusted for two primary sources of bias: scavenger removal and searcher efficiency (i.e., probability of detecting a carcass when it is present) (Erickson et al. 2000). When sufficient numbers of bat carcasses are unavailable for use in quantifying removal rates and observer bias, small drably colored passerines may be used as proxies. However, theses proxies may be poor surrogates for bat carcasses due to differences in coloration, posture, and scavenger removal rates. I have noted the remarkable resemblance of dried banana peels to bat carcasses. In terms of color and shape, desiccated peels closely resemble a bat lying on the ground with wings splayed, a pose typical of many recovered bat carcasses. This method is probably not appropriate for estimating scavenger removal rates, however. Keeley et al. (2001) recommended the use of trained dogs to enhance carcass recovery success. Despite potential shortcomings, using surrogates is preferable to not accounting for the aforementioned sources of bias. Appropriate statistical techniques for incorporating scavenger removal and searcher efficiency trials can be found in Erickson et al. (2000).

Turbines should be searched at regular intervals as often as possible. Nicholson (2001), working at a 3-turbine facility in Tennessee, was able to search all the turbines once a week, and sometimes twice a week, over the course of one year. Where the number of turbines precludes a complete search of all turbines in a timely manner, sampling methods may be used. Young et al. (2001) searched half of the 69 turbines in their study area once every two weeks, such that all turbines were searched every 28 days during their 2-year study in Wyoming. Johnson et al. (2002) searched a random sample of turbines (80 of 281) once every two weeks in their study in Minnesota. See Erickson et al. (2000) for a description of extrapolating sample results to the larger population of turbines, accounting for the period of study.

When possible, control or reference plots should be used in conjunction with plots centered on turbines or other tall wind farm structures. Although replication is difficult on a landscape scale, ideally, reference plots should be approximately the same size and shape as turbine plots, be located within a predefined area of interest, consist of similar habitat, and receive similar search effort as turbine plots. Likewise, pre-construction searches in areas where turbines are to be erected will provide baseline data against which to compare results from post-construction searches. These points are discussed in greater detail in ***Statistical Considerations***.

Assessing Turbine Influences on Bat Behavior

By virtue of their nocturnality, direct observation of bats away from the roost is difficult. Where bats are present in huge densities, as with *Tadarida brasiliensis* in the southwestern United States, weather and Doppler radar can track the movements of bats as they exit their roosts and move across the landscape. However, *T. brasiliensis* forms some of the largest aggregations of bats known. The efficacy of this technology for monitoring bats that are present in more modest densities remains to be seen. Additionally, the costs associated with establishing radar sites may be prohibitive.

On a more local scale, individual bats may be monitored either by affixing a small light-tag (Buchler 1976) or by radio-transmitter (Waldien and Hayes 2001) to the bat. Foraging flight of light-tagged bats can be monitored by continuous visual observation (Aldridge and Rautenbach 1987). The foraging patterns of bats carrying transmitters can be determined by direct simultaneous triangulation (Waldien and Hayes 2001). Both of these techniques require multiple observers placed strategically to maximize sightings, and the success of either technique hinges on the bat(s) remaining in a fairly small area and visible to the observers. However, if the bat(s) choose not to fly near the turbines, no relevant data can be gathered unless pre-construction data are also available. Also, transmitter weight should not exceed 5% of the bats mass (Aldridge and Brigham 1988). Because the smallest transmitters currently available weigh about 0.5 g, placing transmitters on the majority of U.S. bats, which weigh less than 10 g (Barbour and Davis 1969) may result in altered flight behavior in those bats and lead to erroneous conclusions.

Statistical Considerations

Estimating Population Size

Where turbine-associated mortality occurs, it is desirable to be able to place the mortality in context. For instance, managers might like to know what proportion of a population the mortality represents. Population size is generally expressed in terms of population density (i.e., the number of animals per unit area). Regrettably, current methods are inadequate to allow rigorous estimations of population size, particularly for dispersed species (O'Shea and Bogan 2000). Results from capture surveys provide counts of bats caught at a specific location, but the size of the area sampled is rarely or never known. Results from detection surveys suffer from the same shortcoming, but have the additional disadvantage of the inability to distinguish individual bats detected multiple times from multiple individuals detected once. Even where complete enumerations of colonially roosting species can be obtained, the area used by the bats is generally unknown.

From the 1940s-1960s banding was a valuable tool for monitoring changes in population size. Using plastic or aluminum-alloy wing bands, mark-recapture methods were used to estimate population sizes, dispersal routes, and home range sizes of hibernating and colonially roosting species. However, with the recognition that bands caused long-term injury to the bats, banding was largely abandoned. Other marking techniques have been developed (e.g., necklaces, dyes, wing-punches, and PIT tags), but their efficacy and long-term effects are unknown.

Estimating Relative Abundance

The results of capture and detection surveys for dispersed species represent indices of abundance or “relative abundances” of species in a localized area. Because indices of abundance do not measure abundance directly, the relationship between the index and the true population parameter of interest (e.g., population size) must be assumed. Often, the relationship is assumed to be direct and linear, and temporally homogenous, but these assumptions may not be valid (O’Shea and Bogan 2000). Furthermore, O’Shea and Bogan (2000) reported that, “We currently have no understanding of detection probabilities (i.e., the probability of detecting an individual with a given technique under specified conditions)…”, and point out that this situation severely hampers our ability to make meaningful inferences about population structure based on mist-net and detector data. Mark-recapture/resight methods could be used to calibrate these indices, but extremely low recapture/resight rates and violation of model assumptions currently render these methods ineffective (O’Shea and Bogan 2000). Despite all this, estimates of relative abundance based on capture and detection surveys abound in the literature. The lack of standardization in techniques among researchers and across studies makes comparing estimates of relative abundance between studies problematic. However, methodological consistency within a study should help to produce more reliable study-specific results.

Capture/Detection Biases

While all sampling methods have biases, those associated with acoustic and capture surveys of bats are such that estimating and accounting for them is often impossible. For instance, some species of bats seem capable of adroitly detecting and avoiding mist-nets, thus lowering their probability of detection and acoustic surveys detect only those individual bats (or species of bats) that fly within range of the detector's microphone. These biases introduce considerable variation in results which cannot be accounted for. In most cases, (possibly excepting counts at roosts), surveys to determine species presence and abundance represent a sample of all bats active in a given area at a given time. Valid statistical inference to the larger population relies heavily on two assumptions: 1) that captures/detections represent random samples of the population of interest, and 2) that capture/detection rates do not vary across species, between sexes, or by age. Assuming that samples are random or that detection rates are equivalent across groups when they are not can lead to erroneous conclusions about the actual composition of the bat fauna.

There is little question that the assumptions listed above do not hold when conducting bat surveys. Capture surveys nearly always violate assumptions regarding randomness of samples because surveys tend to be conducted at sites (e.g., water) that concentrate bat activity. Moreover, water bodies that are difficult to access (either too far from a road, or on private property), too deep to wade, or those with too much surface area to adequately cover with nets tend to be ignored. Capture surveys also do not sample all groups consistently. Species that are adept at avoiding nets and species that tend to forage above the level of the nets may be under-represented in the sample. Females may be over-represented in mist-net captures if the physiological demands of lactation predispose them to spend more time at watering holes than males. Likewise, juveniles, being relatively inexperienced fliers, may be more prone to stumble into the nets. Unfortunately, we currently are unable to quantify with certainty the probability with which these subpopulations are captured.

Similarly, surveys with bat detectors are prone to bias. Bats with low-intensity calls are typically underrepresented in detector surveys and, when detectors are deployed at ground-level, high-flying bats also may be missed. Detectors placed at some height above the ground may record more of the high-flying bats, but then may miss those that forage or commute closer to the ground. The degree to which individual bats or different species vary their use of the vertical space available to them remains largely unknown (but see Hayes and Gruver 2000, Hecker and Brigham 1999, Kalcounis et al. 1999, and McCracken et al. 1997).

Temporal and Spatial Variation in Bat Distribution and Activity

Statistical considerations when designing surveys for bats include spatial and temporal variation in bat activity. Bats are not regularly distributed across a landscape. Rather, they have a patchy distribution that reflects the irregular distribution of resources important to bats. Moreover, the resources that are important to bats tend to be species-, sex-, and age-dependent, and vary seasonally. If survey goals include a comparison of species abundance or activity between habitats, it is advisable to pair surveys at two or more sites on a given night (Hayes 1997). Paired surveys can help control for potential confounding factors associated with detection and capture rates at a particular site (e.g., weather, insect distributions, interspecific competition, distance from roosts, etc.), and allow variance estimates for numbers of detections and captures.

Bat activity at a particular location is often highly variable through time. Results of a study of bat activity on the Oregon coast (Hayes 1997) indicated high levels of temporal variation in numbers of bats detected; a situation probably not unique to that study site. Inherently high levels of temporal variation are likely to increase bias associated with estimates of activity, and reduce statistical power to detect differences at sites across time (Hayes 1997). Erroneous findings are likely to result from poor temporal replication.

The validity of statistical inference will depend greatly on the number of surveys conducted. Therefore, the number of surveys conducted during the active season should be maximized. However, capture surveys typically result in a change of behavior by the bats that use an area. Most researchers recognize that conducting capture surveys on consecutive nights at the same location usually results in reduced capture success. At least one study quantified the decrease at a site in New Hampshire (Kunz and Brock 1975), and the authors noted that the bats seemed to learn to avoid the nets, as changing the position of the nets improved capture success on subsequent nights. Unfortunately, the size, shape, and water depth of many water bodies allow little flexibility in the placement of nets. Therefore, consideration should be given to the number of sites available for capture surveys and the frequency that they may be surveyed. Bat-detectors may be deployed at the same site on consecutive nights with no loss in data quality if it can be assumed that the presence of the detector or the act of deploying the detector does not influence bat activity.

The amount of temporal replication necessary to achieve a given level of statistical power or a given confidence interval will require an estimate of the variability in the parameter of interest. This information is usually unknown. If data are available on the relative use of different habitats by bats in the study area, stratified sampling schemes (Thompson 1992) can be used to maximize statistical rigor while minimizing sampling effort.

Sampling Designs to Assess Impacts of Wind farms on Bats

Statistically rigorous assessments of impact can be accomplished by correlating the presence of the factor causing the impact with observed fluctuations in a variable of interest (e.g., species abundance) of target species. Several sampling methods have been developed to measure this association, each with varying levels of inference and statistical power (Table 4A-3).

Before-After/Control-Impact (BACI) designs are common in the literature (e.g., Stewart-Oaten et al. 1986), and provide a statistically rigorous method of assessing impacts. Typically, pre- and post-construction surveys at impact and control sites are conducted to measure a variable of interest. Post-construction differences in the variable of interest at the impact site, relative to the control site, can be attributable to changes at the impact site since the control site provides an indication of observed changes in the variable of interest due to natural fluctuations. The use of several control sites (ideally, randomly selected) is preferable to a single control (Underwood 1992).

Where pre-construction data are unavailable (e.g., turbines are already operational), Before-After designs, Impact-Reference designs, and Impact-Gradient designs (Anderson 1999) can be used. Before-After designs are less costly than BACI designs because they do not require a reference (control) area, but have less power to detect real changes in the parameter of interest. The reliability of Impact-Reference designs to assess impacts depends on maximizing temporal and spatial replication since observed changes may be related to site-specific differences, or natural fluctuations. Impact-Gradient designs are used to analyze the relationship between some "impact indicator" and distance from the site of alleged impact (Anderson 1999). This design can be used in combination with any of the others.

Summary

The goal of studies to assess the impacts of wind turbines on bats range from assessing the relative abundance and temporal distribution of species of bats in the area near the turbines to addressing how turbines influence the foraging and flight behavior of bats. Another important goal is to quantify the magnitude of deaths of bats that is attributable to the turbines.

Assessing relative abundance and temporal distribution of species of bats requires surveys for bats. A variety of methods exist to survey bat populations, but inferences based on these surveys vary by the method employed and the quality of the data obtained. Establishing how turbines influence the behavior of bats requires careful observation of the activity bats near the turbines, ideally before and after the turbines are erected. However, observing active bats is not easy, and may have to rely on expensive technology. Quantifying the number of dead bats attributable to wind turbines is methodologically straightforward. However, the relative efficiency of different searchers in detecting dead bats, and the length of time a carcass remains after falling to the ground should be estimated. These estimates are used to calibrate the estimate of deaths as determined by searches for carcasses.

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Table A-1. Techniques to assess detected/not detected, relative abundance, and absolute abundance of bats. Table from MELPRIB (1998).

Objective	**Recommended Combination of Techniques**
Detected/Not Detected	Capture Techniques (Mist netting; harp trapping) used simultaneously with Ultrasonic Detection and Listening for *E. maculatum*.
Relative Abundance	Capture Techniques (Mist netting; harp trapping) used simultaneously with Ultrasonic Detection and Listening for *E. maculatum*.
Absolute Abundance	Counts at roosts (emergence or surface area); possibly in conjunction with telemetry (to locate roost).

Table A-2. Sampling methods for 16 common North American species of bats and location of summer roosts. Table from MELPRIB 1998.

Species	**Summer Roost**	**Recommended Sampling Method**
Spotted Bat (*Euderma maculatum)*	Cliffs	Listen with unaided ear
Townsend's Big-eared Bat (*Corynorhinus townsendii)*	Caves, Mines, Buildings	Mist net/Harp trap
Pallid Bat (*Antrozous pallidus)*	Rock Crevices,	Mist net at ground level
Big Brown Bat (*Eptesicus fuscus*)	Buildings, Tree Cavities, Rock Crevices	Mist net (5-10m high) / Bat Detector
Western Red Bat (*Lasiurus blossevilli)*	Foliage	Bat Detector
Hoary Bat (*L. cinereus*)	Foliage	Bat Detector
Silver-haired Bat (*Lasionycteris noctivagans*)	Tree Cavities	Mist net/Harp trap; Bat Detector
California Myotis (*Myotis californicus)*	Buildings, Tree Cavities, Rock Crevices	Mist net (1-3 m high) / Harp trap
Western Small-footed Myotis (*M. ciliolabrum)*	Rock Crevices	Mist net (1-3 m high) / Harp trap
Western Long-eared Myotis (*M. evotis)*	Rock Crevices, Tree Cavities, Buildings	Mist net / Harp trap (roads & cut lines through trees)
Keen's Long-eared Myotis (*M. keenii)*	Rock Crevices	Mist net/Harp trap
Northern Long-eared Myotis (*M. septentrionalis*)	Tree Cavities	Mist net / Harp trap (roads & cut lines through trees)
Little Brown Myotis (*M. lucifugus)*	Buildings, Tree Cavities, Rock Crevices	Mist net (over water at water level) / Harp trap

Table A-2. (Continued).

Species	**Summer Roost**	**Recommended Sampling Method**
Fringed Myotis (*M. thysanodes)*	Buildings, Caves, Rock Crevices	Mist net / Harp trap
Long-legged Myotis (*M. volans*)	Rock Crevices, Tree Cavities	Mist net / Harp trap
Yuma Myotis (*M. yumanensis*)	Buildings, Tree Cavities	Mist net (over water at water level) / Harp trap

Table A-3. Summary of impact assessment designs. Adapted from Anderson et al. (1999).

Study Conditions	Recommended Design
Pre-impact data possible, Reference Area indicated	BACI
Pre-impact data not possible, Reference Area indicated	Impact-Reference
Pre-impact data possible, Reference Area not indicated	Before-After
Small homogenous area of potential impact	Impact-Gradient

Appendix A-1. Bibliography of reports documenting turbine-related bat mortality

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Appendix A-2. Resources for designing bat surveys

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