# Grassland bats and land management in the Southwest

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**Abstract.—**Of the bat research that has been conducted in the Southwestern states, few studies have addressed species inhabiting grasslands and the potential effects of management activities on these populations. Up to 17 bat species may be found regularly or occasionally in Southwestern grasslands or short-grass prairie. Main habitat requirements of grassland-dwelling bats are suitable roosts, water, and food. Livestock grazing, fire suppression, mining, bridge construction, agriculture, and urbanization affect the quality, quantity, and distribution of these resources. Effects of activities may not always be negative. Management activities and the natural distribution of roost, water, and food resources ultimately influence the distribution, abundance, and species composition of bats in grasslands. Research is needed to further identify resource requirements and use by grassland-dwelling bats and to confirm specific effects of human activities on local populations.

## INTRODUCTION

Among the many objectives of ecosystem management are the preservation of viable populations of species native to the ecosystem, and the protection and maintenance of ecological processes and species interrelationships (Grumbine 1994; Thomas 1994). Nonetheless, much of the information needed to achieve these objectives is unknown. In this paper, Southwestern grasslands refers to the plains-mesa and desert grasslands of New Mexico and Arizona (Lowe and Brown 1973; Dick-Peddie 1993; McClaran 1995). To balance human use and conservation of these arid grasslands, knowledge of the life history, habitat requirements, interrelationships of animals, and the effects of management practices on different species is necessary.

Bats, the only true volant mammals, are a most unique, but often overlooked, group of animals. Bats feed on nocturnal flying and terrestrial insects, and likely play a role in regulating insect populations (Ross 1967) and insect-related ecological processes. By helping to maintain a balance of relationships within the insect community, and between insects and plants, animals, and other entities, bats are integral to the function and integrity of many ecosystems. The diverse habitats of New Mexico and Arizona support up to 28 species of bats (Findley et al. 1975; Hoffmeister 1986), many of which are found regularly or occasionally in grasslands.

This paper reviews the basic habitat requirements of bats, bat species that use grassland habitats, and the potential effects of historic and current management practices on resources important to grassland-dwelling bats. The information in this review will provide land managers with a better understanding of bats and the potential influence of human activities on bats in Southwestern grasslands.

## HABITAT REQUIREMENTS OF SOUTHWESTERN BATS

Appropriate roosts, available surface water, and food are essential components of suitable bat habitat in the Southwest. Because of their small size, the energetic demands of flight, a limited ability to store fat, and the seasonal abundance of their prey, bats have an annual energy budget that is difficult to balance (McNab 1982). Energy expen-

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ditures are regulated through roost selection (Kunz 1982; Hill and Smith 1984). Consequently, reproductive success and overwinter survival of individuals and populations may largely depend on the availability of suitable roosts (Humphrey 1975). For colonial bats, suitable maternity roosts provide a microclimate that facilitates gestation in pregnant females and rapid growth of the young (Humphrey 1975). Appropriate winter hibernacula (hibernation sites) minimize the potential for disturbance and arousal and maximize efficient use of energy reserves. Therefore, overall distribution and abundance of suitable roost sites (summer and winter) may ultimately determine the distribution and abundance of many bat species (Humphrey 1975). Local distribution and site use may also be influenced by factors unknown to or unstudied by the scientific community such as threat by predators, distance to or availability of local hibernacula, and sensitivity to human disturbance.

Surface water for drinking is another critical component to bat habitat in the Southwest. Due to their high protein diet, insectivorous bats require water to excrete toxic nitrogenous waste products (McNab 1982). In addition, desiccating environments cause high rates of evaporative water loss through wing membranes and respiratory exchange (McNab 1982). California myotis (*Myotis californicus*), western pipistrelle (*Pipistrellus hesperus*), pallid bat (*Antrozous pallidus*), and the Mexican free-tailed bat (*Tadarida brasillensis*) have high urine-concentrating abilities or renal structures that suggest they produce highly concentrated urine (Geluso 1978). As a result, these arid-dwelling bats are more efficient at conserving water. More mesic species with distributions that include or extend into grasslands and deserts (long-legged myotis [*Myotis volans*], fringed myotis [*M. thysanodes*], little brown myotis [*M. lucifugus*], Yuma myotis [*M. yumanensis*], Townsend's big-eared bat [*Piecotus townsendii*]) have low urine-concentrating abilities (Geluso 1978) and probably select habitat with a greater emphasis on water availability.

Based on physiological adaptations to water conservation or lack thereof, bats must find roosts and foraging areas that have water within an economical flight distance. Bats foraging in grasslands and desert scrub probably seek water at stock- tanks, perennial streams, drainage ditches, or the closest river. Prior to livestock grazing, bats may have relied on sparsely distributed springs, seeps, and permanent water sources. Historically, the geographic distribution of species not adapted for water conservation or for long distance flight may have been limited by water availability. However, construction of water holes and placement of stock tanks in Southwestern grasslands over the last 100- 150 years have increased the quantity and distribution of water available. Areas originally devoid of water may have become viable roosting and foraging habitat to other bat species (Geluso 1978). Because few records document bat distributions prior to livestock grazing in the Southwest, it is impossible to confirm whether ranges of such species (e.g., fringed myotis, long-legged myotis, etc.) have expanded into grasslands and deserts due to the increased number of water holes and stock tanks.

Food availability also determines bat species distribution and habitat use. Although insects appear to be so abundant as to preclude competition between bat species (Ross 1967; Humphrey 1975), dietary partitioning among insectivorous bat species may be evident from their wide range of sizes, flight styles, echolocating abilities, and the partitioning of vertical and horizontal space during foraging (Black 1974). Nonetheless, our understanding of the food habits and dietary preferences of insectivorous bats is extremely limited. Nondestructive methods of studying diet, the difficulty with which arthropod remains are identified and quantified in feces, and the lack of methods to effectively sample species composition and seasonal abundance of arthropods have limited the number of dietary studies conducted. The insect orders *Lepidoptera* (moths) and *Coleoptera* (beetles) are numerous and diverse and probably represent a universally available food source for most bat species (Ross 1967). In New Mexico, California myotis, western pipistrelles, and long-legged myotis are classified as moth strategists, and pallid bats, long-eared myotis (*M. evotis*), and fringed myotis are classified as beetle strategists (Black 1974). However, all of these species consume a diversity of arthropods in addition to moths and beetles, including *Orthoptera* (grasshoppers), *Hymenoptera* (bees/wasps), *Diptera* (flies), *Homoptera* (leafhoppers), *Hemiptera* (true bugs), and *Isoptera* (termites) (Ross 1967; Black 1974; Whitaker et al. 1981). Diet composition also likely reflects seasonal peaks of different arthropod species (Black 1974) and probably varies with habitat type. Consequently, differences in insect fauna between two habitat types may cause grassland-dwelling bats to have different diets than individuals of the same species from adjacent habitats. Further studies of insect availability and dietary preferences and requirements of bats are needed to interpret the effects of human activities on bat populations.

## BATS OF SOUTHWESTERN GRASSLANDS

In the eastern half of New Mexico, plains-mesa grasslands grade into and, depending on the classification scheme, are considered part of the short-grass prairies of the Great Plains (Wright and Bailey 1980; Dick-Peddie 1993). Because these grassland types are similar and animals do not recognize artificial boundaries, bats found in Southwestern grasslands (New Mexico and Arizona) and short-grass prairie (northern Texas, western Oklahoma, southwestern Kansas, and

**Table 1. Federal status and types of summer roosts used by bats in Southwestern grasslands and short-grass prairies.**

| Species | USFWS status | Types of summer roosts |
|---|---|---|
| **Species more commonly associated with grasslands** | | |
| Small-footed myotis (*Myotis ciliolabrum*) | Species of concern | Cracks and crevices of cliffs and rocks, abandoned buildings and barns, under rock slabs and loose bark; possibly in caves and mine tunnels. |
| California myotis (*M. californicus*) | | Cliffs, hillsides, rock outcrops, mine shafts, barns, houses, under tree bark and sign boards, amongst desert shrubs, and on the ground. |
| Cave myotis *(M. velifer)* | Species of concern | Primarily caves and tunnels; occasionally buildings, bridges, and under rocks. |
| Pallid bat (*Antrozous pallidus*) | | Rocky outcrops, crevices, caves, mine tunnels, buildings, and under rocks. |
| Western pipistrelle (*Pipistrellus hesperus*) | | Canyon walls, cliffs, and other rock crevices; under rocks, in burrows and buildings. |
| Mexican free-tailed bat (*Tadarida brasiliensis*) | | Caves, mines, bridges; occasionally in buildings. |
| **Species found in grasslands given appropriate habitat** | | |
| Little brown bat (*M. lucifugus*) | | Buildings, hollow trees, natural crevices, mines. |
| Yuma myotis (*M. yumanensis*) | Species of concern | Crevices, mines, caves, buildings. |
| Fringed myotis (*M. thysanodes*) | Species of concern | Caves, mine tunnels, rock crevices, old buildings. |
| Long-legged myotis (*M. volans*) | Species of concern | Abandoned buildings, cracks in ground, cliff face and other crevices, under loosebark. |
| Long-eared myotis (*M. evotis*) | Species of concern | Tree hollows, loose bark, folds of wood/bark, rock crevices, abandoned buildings, mines. |
| Hoary bat (*Lasiurus cinereus*) | | Foliage of trees and shrubs. |
| Silver-haired bat (*Lasionycteris noctivagans*) | | Hollow trees, woodpecker holes, under loose bark, and in buildings. |
| Eastern red bat (*Lasiurus borealis*) | | Foliage of trees and shrubs, clumps of Spanish moss. |
| Big brown bat (*Eptesicus fuscus*) | | Hollow trees, rock crevices, mine tunnels, caves, buildings; occasionally in cliff swallow nests. |
| Townsend's big-eared bat (*Plecotus townsendii*) | Species of concern | Caves, mine tunnels, and abandoned buildings. |
| Spotted bat (*Euderma maculatum*) | Species of concern | Cracks and crevices in rocky cliffs or under loose rocks. |
| Big free-tailed bat (*Nyctinomops macrotis*) | Species of concern | Crevices in rocky cliffs, buildings. |

eastern Colorado) have been reviewed together. Information in this paper has been drawn from state mammal fauna texts (Findley et al. 1975; Bee et al. 1981; Hoffmeister 1986; Schmidly 1991; Armstrong et al. 1994), related literature, and personal observation. The United States Fish and Wildlife Service classification for the species and types of structures used as summer roosts are in table 1.

The structure and complexity of vegetation and the physical environment are factors that determine the use of habitats by vertebrates (Humphrey 1975; Grant et al. 1982; Parmenter et al. 1994). The apparent lack of vertical structure in grasslands seemingly indicates a lack of roosts and roost diversity for bats. However, animal size and mobility determines the scale at which habitat selection occurs. A high degree of mobility allows bats to select habitats at the landscape level and to utilize patches of resources that are separated by significant distances (Kunz 1982; Schmidly 1991). Their small size allows them to exploit practically any sheltered site. Most grasslands encompass patches of other habitat types (Parmenter et al. 1994) and thus provide a surprising diversity and abundance of roost sites. Bat roosts within grasslands may include crevices in and under stones and rocks, excavated or natural holes in the ground, and the foliage of scattered shrubs and trees. Interspersed within grasslands, patches of other habitat types such as rock escarpments, talus slopes, cliff faces, lava flows and tubes, caves, open mines, and bridges, provide a host of different roost environments for grassland bats. In addition, bats may roost within the foliage, bark, and cavities of riparian vegetation along arroyos, tributaries, and rivers that pass through grasslands.

Bat species commonly captured within Southwestern grasslands and short-grass prairies are the more xeric-adapted bats, including small-footed myotis (*Myotis ciliolabrum*), California myotis, western pipistrelle, pallid bat, cave myotis (*M. velifer*), and the Mexican free-tailed bat. Small-footed myotis are grassland-adapted bats that often roost in rocky outcrops found throughout short-grass prairies (Bogan In press). This species is documented from chalk bluffs and canyons in western Kansas and the grasslands of eastern Colorado (Robbins et al. 1977, Armstrong et al. 1994). Twenty-four percent of the small-footed myotis museum specimens in the Museum for Southwestern Biology were collected from grasslands or riparian habitats within grasslands (Findley et al. 1975).

Occurring from deserts to ponderosa pine forests, California myotis is one of the more common species captured in grasslands (O'Farrell and Bradley 1970; Findley et al. 1975). Aside from nursery colonies, which may roost communally in one location most of the summer, small groups and individual California myotis show little roost site fidelity. California myotis appear to have flexible roosting habits and a ubiquitous supply of roosts; thus, they have little loyalty to any one site (Krutzsch 1954; Hirschfield et al. 1977).

Western pipistrelles occur from desert scrub to ponderosa pine forests, but are most commonly found near rocky cliffs and canyons in desert and grassland environments (Findley et al. 1975; Hoffmeister 1986). Although pipistrelles typically roost in canyon walls, rocky cliffs and outcrops, and under rocks on the ground, they are also found dayroosting in mine shafts and buildings.

A common inhabitant of Southwestern deserts and grasslands, the pallid bat is frequently found around rock outcrops and water, but also in areas devoid of these features (O'Farrell and Bradley 1970; Findley et al. 1975). Roosting in rock crevices and man-made structures, males and female pallid bats are gregarious with members of the same sex (Hermanson and O'Shea 1983).

Another desert and grassland bat, the cave myotis, is found in the grasslands of Texas, western Oklahoma, southcentral to southwest Kansas, and southern New Mexico and Arizona (Kunz 1974; Findley et al. 1975; Bee et al. 1981; Caire et al. 1984; Hoffmeister 1986; Schmidly 1991). The cave myotis roosts colonially in caves and mines and is often found foraging over watercourses in deserts and grasslands (Hayward 1970; Findley et al. 1975; Fitch et al. 1981).

Mexican free-tailed bats are common in pinyon-juniper woodlands, desert grasslands, and desert. This species typically roosts colonially in caves, rock crevices, under bridges, or in buildings (Findley et al. 1975; Wilkins 1989). Adapted for fast and long distance flight, these bats are known to travel up to 50 miles to forage in a single night (Hoffmeister 1986).

Other features within grasslands provide additional types of roosting and foraging habitat and allow many nonxeric-adapted bat species to occupy grasslands. Trees along streams and rivers provide roosts to hoary bats (*Lasiurus cinereus*), silver-haired bats (*Lasionycteris noctivagans*), and eastern red bats (*Lasiurus borealis*) (Findley et al. 1975; Hoffmeister 1986; Armstrong et al. 1994). Watercourses, trees, and man-made structures also provide foraging and roosting habitat for broadly distributed species such as big brown bats (*Eptesicus fuscus*), little brown bats (*M. lucifugus*), and Yuma myotis (Jones 1965; Findley et al. 1975; Barclay and Cash 1985; Hoffmeister 1986; Armstrong et al. 1994). Scattered caves, mines, buildings, and lava tubes found throughout grasslands provide roosts for Townsend's big-eared bats and big free-tail bats (*Nyctinomops macrotis*) (Findley et al. 1975, Humphrey and Kunz 1976; Kunz and Martin 1982; Caire et al. 1984; Genter 1986; Hoffmeister 1986). A Townsend's big-eared bat and Yuma myotis captured over an isolated desert spring in Nevada indicate that these species may venture into desert areas practically devoid of water (O'Farrell and Bradley 1970). Rocky cliffs and canyons may provide summer roosts for spotted bats (*Euderma maculatum*) (Findley et al. 1975; Schmidly 1991). Originally thought to occur primarily in mesic areas like ponderosa pine and mixed conifer, spotted bats have also been found in xeric habitats of Utah (Geluso 1978; Storz 1995). The ability of spotted bats to concentrate their urine indicates that this species may have evolved in more arid environments such as deserts and grasslands (Geluso 1978).

Species with centers of distribution in other habitat types that may occur peripherally in grasslands include the fringed myotis and long-legged myotis. Although long-legged myotis and fringed myotis typically occur in pinyon-juniper, oak woodland and higher elevations, they have been occasionally captured in grasslands and desert in New Mexico and Arizona (O'Farrell and Bradley 1970; Findley et al. 1975; Hoffmeister 1986). A maternity colony of fringed myotis near Isleta Cave in New Mexico likely foraged in nearby grasslands (Findley et al. 1975). In Texas, the long-legged myotis is rare, but fringed myotis are present and seem to prefer grasslands at intermediate elevations (Schmidly 1991). In pinyon-juniper woodlands of New Mexico, long-eared myotis frequently nested in folded bark and wood of junipers, tree stumps, and small groups of rocks (pers. obs.). Thus long-eared myotis may be found using these structures where available in grasslands.

Information on habitat distribution and roost selection by different bat species comes from netting records, museum specimens, and observations. However, records are not complete throughout each species' geographic range, not all habitat types have been sampled equitably, and all sampling techniques are somewhat biased. Thus, sampling techniques used and areas and habitats sampled should always be considered when evaluating the geographic presence or absence, habitat associations, and habitat requirements of different bat species. Southwestern grasslands and short-grass prairies probably have not been sampled as extensively and thoroughly as other habitat types. Additional studies (e.g., surveys, radiotelemetry, light tagging, etc.) in grassland areas would contribute to a comprehensive understanding of which bat species use grasslands and which habitat components are important.

## EFFECTS OF CURRENT AND HISTORIC MANAGEMENT PRACTICES

The quantity, quality, and distribution of resources available to bats in grassland environments have been altered by historic and current management practices. Activities that have probably had major influences on roost, water, and foraging resources of bats in grassland areas include grazing, fire suppression, mining, road and bridge construction, agriculture, and urbanization. Human activities often change the structure, composition, and distribution of vegetation and other resources at a local or landscape level. Because of different resource requirements, some wildlife species benefit from human-induced changes and some experience negative impacts. Grazing outside a cattle exclosure resulted in a shift to bird and small mammal species that preferred more xeric and open habitats. Inside the exclosure, species preferring mesic and densely vegetated habitats remained (Bock et al. 1984). Grassland fires adversely affect wildlife species that prefer dense litter and woody plant cover, but enhance habitat for species that prefer large-seeded herbaceous dicots (MacPherson 1995).

Little research has been conducted to determine how human activities may change landscapes to benefit or adversely affect different bat species in Southwestern grasslands. The effects of grazing, fire suppression, urbanization, etc. can only be speculated based on the effects of these activities on known resource requirements of bats.

The distribution and availability of water to grassland bats have largely been influenced by livestock management practices and to some degree by urbanization. In addition to altering plant species composition and abundance in riparian areas, livestock can also eliminate riparian areas through channel widening, channel aggrading, or lowering of the water table (Saab et al. 1995). The impacts of cattle on Southwestern grasslands for over 100 years has likely led to the degradation or elimination of many native water sources (seeps and springs). However, numerous steel and dirt stock tanks created throughout grasslands and other arid habitats have increased the quantity and distribution of water to bats. Thus, populations of native grassland and desert-adapted bat species may have actually benefited from this grazing practice. In addition, less xeric-adapted bat species from adjacent pinyon-juniper, oak woodland, and riparian habitats may have expanded their distributions into grassland areas that were previously unsuitable. However, individuals of these species cannot rely on these man-made water sources. Tank pumps are turned on and off depending on the presence or absence of cattle at particular sites, and the fill status of many dirt stock tanks is dependent on seasonal precipitation. The growth of cities in or bordering on grasslands has also affected the availability of water to grassland-using bats. Pools, ponds, irrigation and drainage ditches, and other accumulations provide water to bats willing to colonize urban areas (e.g., big brown and little brown bats).

The two other essential resources to bats, roosts and food, are either directly or indirectly affected by human activities. The direct influence of stock tanks, mines, and man-made structures on bat roosting behavior, habitat use, and species distribution is evident by their use of these structures. This influence is somewhat quantifiable through capture, mine surveys, and examinations of bridges, buildings, and other structures. However, the effects of other human activities such as grazing, fire suppression, and agriculture are indirect, complex in nature, and not readily apparent. Such effects are difficult to assess and remain unstudied.

Abandoned underground and surface mines in New Mexico have significantly increased the number of potential sites for day and night roosts, maternity colonies, hibernacula, and migratory stopovers for bats. Twenty-nine of the 42 species in the United States use abandoned mines to some degree (Belwood and Waugh 1991). Twenty percent of mine features examined in New Mexico in one year showed enough bat use to warrant the gating of entrances instead of mine closure (Altenbach and Milford 1991). A minimum of 1800 underground mines and 3400 surface mines exist on or near national forests in New Mexico alone (Shields et al. 1995). Mining has created an enormous supply of potential roost sites to cave and rock-dwelling bat species and those that have been displaced from their traditional roosts. However, the closure of abandoned underground mines occupied by reproductive or hibernating bats has probably been the demise of many hundreds or thousands of bats. Bridges, houses, barns, and other man-made structures found throughout grasslands have also increased the number and type of roosts available to many bat species. However, many modern structures are built to exclude bats, older buildings are often bat-proofed by their owners, and newer bridge designs may not be suitable for occupation by bats (Keeley and Bloschock 1995).

Human activities influence the food and roost resources available to bats indirectly by altering the structure and composition of vegetation at local and landscape levels. Grazing and fire suppression interact to influence the number and types of roosts available to bats and perhaps more significantly, the species composition and abundance of their prey base. General consensus exists that historic grazing and a subsequent reduction in fire frequency has led to a decrease in grasslands and an increase in desert shrubland (Branson 1985; Dick-Peddie 1993; MacPherson 1995; Saab et al. 1995). By compacting soil, removing plant cover, and indirectly reducing water infiltration, cattle decrease vegetation density and alter plant community structure and composition (Saab et al. 1995). The reduction of fine fuels to support the spread of fire and fire suppression by humans are probable causes for the decrease in fire frequency in the past 130 years (Wright 1980; MacPherson 1995). Without fire to suppress the recruitment and growth of woody plants and because of the collection of fertile, but loose interspace soils under shrub canopies, many grasslands have been converted to desert shrubland or juniper savanna (Schlesinger et al. 1990; Loftin et al. 1995; MacPherson 1995).

Although some bat species (e.g., California myotis) may benefit from the additional roosts provided by shrubs and other woody plants, the more significant impact on the local bat community may be the change of insect fauna from grassland species to desert shrubland or juniper savanna species. Studies in Parmenter et al. (1994) suggested that grazing and other rangeland disturbances favor pest grasshopper species. Although such changes may affect pallid bats that forage on such large terrestrial prey, the type of influence is unknown and depends on the degree of species-specificity in the pallid bat's diet, the availability of alternative prey, differences in prey behavior, nutritional value, predator defenses, and other factors. The effects of fire on various arthropod species are reviewed in Warren et al. (1987). However, fire suppression, not prescribed fire, is the more prevalent management activity today and the consequence of historic management practices. Considering that more than 1200 insect species from 11 orders feed on grasses in Arizona, New Mexico, Utah, Nevada, and Colorado (Warren et al. 1987), there is an insufficient number of studies to provide a comprehensive overview of the effects of grazing and fire suppression on arthropod community composition, structure, and distribution. In addition, too little is known about diet and prey selection by grassland-dwelling bats to predict their responses to changes in the arthropod community. Knowledge of these factors would be useful for interpreting the effects of agriculture, including the cultivation of monoculture crops and the application of pesticides, on the prey base of bats.

The diversity of arthropod orders found in guano of any one bat species suggests a degree of dietary plasticity in bats. However, differences in size, flight style, and echolocating ability may restrict each bat species to a certain prey size range (Ross 1967). Perhaps as long as certain prey community characteristics (e.g., insect size distribution, activity patterns, seasonal peaks of abundance, etc.) are consistent, changes in insect species composition may not greatly affect bats that have flexible diet preferences. Bats in grasslands may be resilient to changes in insect fauna caused by human activities and even opportunistic of insects associated with agricultural fields, irrigation ditches, street lamps, and other man-made structures, but such speculations should be demonstrated, not assumed.

## RESEARCH IMPLICATIONS

An increasing number of land managers are concerned with conserving bats, protecting critical bat habitat, and maintaining the role of bats in ecosystem processes. Perception of bats by the public is improving as conservation educators focus on the value of bats and dispel myths and negative images. Most importantly, more scientists are reducing the deficit of information on the life history, habitat requirements, community structure, and roles of bats in ecosystems. Much of what is known about bats originates from research focused on bats in forested environments, caves, and manmade structures. The lack of information on grassland-dwelling bats and the potential effects of management activities is apparent from this review. Information from studies examining the resource requirements of grassland-dwelling bats may subsequently be used to predict the potential effects of human activities on bats or to design studies that measure actual effects. Recommendations for future research include:

- Develop a comprehensive understanding of composition, distribution, and abundance of bats in grasslands. Conduct mist net, acoustical, and cave and mine surveys at previously unsurveyed sites to provide a thorough coverage of grassland habitats.

- Determine what landscape features are used by bats in grasslands and for what purposes. Use radiotelemetry and light tagging to observe bat behavior, follow movements, and identify day and night roost sites. Knowledge of which features are used by bats and seasons of use will allow planning of activities to minimize impacts on local bat populations.

- Identify food habits of grassland bats so that dietary flexibility may be determined and the effects of management activities may be predicted. Determine foraging areas, food availability, and diet preference by radiotelemetry, arthropod sampling, and fecal analyses, respectively. Basic studies of the effects of grazing, fire, etc. on arthropod communities are also necessary.

- Examine effects of human activities on bat communities. Compare bat species composition, abundance, and behavior before and after implementation of activities (prescribed fire, new grazing regime, etc.), or between treated and untreated sites.

- Determine if availability and diversity of water, roost, or food resources influence bat species diversity and abundance. Examine such correlations by coupling bat surveys with evaluations of resource availability and diversity in the surrounding area. Studies that manipulate water availability and monitor bat activity may also determine the effect of water availability on use of grasslands by bats in the arid Southwest.

- Investigate winter behavior and roost habits. Determine whether grassland bats migrate to hibernacula or remain locally. If bats remain local, identify structures used as hibernacula and develop recommendations for maintenance and protection of these structures.

Our ability to understand bat ecology and management in grassland and other ecosystems increases as study techniques, technology, and interest by the research community develop. Using this information, managers may make more effective decisions regarding bat habitat, and educators may increase interest and appreciation for bats, their unique ecology and behavior, and their role in ecosystem function.

## LITERATURE CITED


Altenbach, J.S.; Milford H.E. 1991. A program to evaluate bat use and occupancy of abandoned mines in New Mexico. Abstract. Bat Research News. 32: 63.

Armstrong, D. M.; Adams, R.A.; Freeman, J. 1994. Distribution and ecology of bats of Colorado. Natural history inventory of Colorado No. 15. University of Colorado Museum, Boulder, CO.

Barclay, R.M.R.; Cash, K.J. 1985. A non-commensal maternity roost of the little brown bat (*Myotis lucifugus*). Journal of Mammalogy. 66: 782-783.

Bee, J.W.; Glass, G.E.; Hoffmann, R.S.; Patterson, R.R. 1981. Mammals in Kansas. University of Kansas, Lawrence, KS.

Belwood, J.J.; Waugh, R.J. 1991. Bats and Mines: abandoned does not always mean empty. Abstract. Bat Research News. 32: 66.

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

Bock, C.E.; Bock, J.H.; Kenney, W.R.; Hawthorne, V.M. 1984. Responses of birds, rodents, and vegetation to livestock exclosure in a semidesert grassland site. Journal of Range Management. 37: 239-242.

Bogan, M. A. In press. California myotis. *Myotis californicus*. In: D. E. Wilson (ed.). Mammals of North America. Smithsonian Institution Press, Washington, D. C.

Branson, F.A. 1985. Vegetation changes on western rangelands. Range Monograph No. 2. Society for Range Management, Denver, CO.

Caire, W.; Smith, J.F.; McGuire, S.; Royce, M.A. 1984. Early foraging behavior of insectivorous bats in western Oklahoma. Journal of Mammalogy. 65:319-324.

Dick-Peddie, W.A. 1993. New Mexico Vegetation: Past, Present, and Future. University of New Mexico Press, Albuquerque, NM. 244 pp.

Fitch, J.H.; Shump, K.A.; Shump, A.U. 1981. *Myotis velifer*. Mammalian Species. 149: 1-5.

Findley, J.S.; Harris, A.H.; Wilson, D.E.; C. Jones. 1975. Mammals of New Mexico. University of New Mexico Press, Albuquerque, NM.

Geluso, K.N. 1978. Urine concentrating ability and renal structure of insectivorous bats. Journal of Mammalogy. 59: 312-323.

Genter, D.L. 1986. Wintering bats of the upper snake river plain: occurrence in lava-tube caves. Great Basin Naturalist. 46: 241-244.

Grant, W.E.; Birney, E.C.; French, N.R.; Swift, D.M. 1982. Structure and productivity of grassland small mammal communities related to grazing-induced changes in vegetative cover. Journal of Mammalogy. 63: 248-260.

Grumbine, R.E. 1994. What is ecosystem management? Conservation Biology. 8: 27-38.

Hayward, B. J. 1970. The natural history of the cave bat, *Myotis velifer*. Volume 1. Number 1, Western New Mexico University, Silver City, NM. 1:1-74.

Hermanson, J.W.; O'Shea, T.J. 1983. *Antrozous pallidus*. Mammalian Species. 213: 1-8.

Hill, J.E.; Smith, J.D. 1984. Bats. A natural history. University of Texas Press, Austin, TX.

Hirschfield, J. R.; Nelson, Z.C.; Bradley, W.G. 1977. Night roosting behavior in four species of desert bats. Southwestern Naturalist. 22: 427-433.

Hoffmeister, D. F. 1986. Mammals of Arizona. University of Arizona Press and Arizona Game and Fish Department, Tucson, AZ.

Humphrey, S.R. 1975. Nursery roosts and community diversity of nearctic bats. Journal of Mammalogy. 56: 321-346.

Humphrey, S.R.; Kunz, T.H. 1976. Ecology of a Pleistocene Relict, the western big-eared bat (*Plecotus townsendii*) in the Southern Great Plains. Journal of Mammalogy. 57:470-494.

Jones, C. 1965. Ecological distribution and activity periods of bats of the Mogollon Mountains area of New Mexico and adjacent Arizona. Tulane Studies in Zoology. 12:93-100.

Keeley, B.K.; Bloschock.M.J. 1995. An evaluation of bat use of Texas highway structures. Abstract. Four Corners Regional Bat Conference. Durango, CO. The Colorado Bat Society.

Krutzsch, P.H. 1954. Notes on the habits of the bat, *Myotis californicus*. Journal of Mammalogy. 35:539-545.

Kunz, T. H. 1974. Feeding ecology of a temperate insectivorous bat (*Myotis velifer*). Ecology. 55:693-711.

-------------. 1982. Roosting Ecology. In: T.H. Kunz, (ed.) Ecology of Bats. Plenum Press, New York, NY.

Kunz, T.H.; Martin, R.A. 1982. *Plecotus townsendii*. Mammalian Species. 175: 1-6.

Loftin, S.L.; Aguilar, R.; Chung-MacCoubrey, A.L.; Robbie, W.A. 1995. Desert grassland and shrubland ecosystems. In: D.M. Finch and J.A. Tainter, (eds.) Ecology, Diversity, and Sustainability of the Middle Rio Grande Basin. USDA Forest Service General Technical Report RM-GTR-268. Rocky Mountain Forest and Range Experiment Station, Albuquerque, NM.

Lowe, C.H.; Brown, D.E. 1973. The natural vegetation of Arizona. Arizona Resources Information System 2.

MacPherson, G.R. 1995. The role of fire in desert grassland. In: M. P. McClaran and T. R. Van Devender, (eds.) The desert grassland. University of Arizona Press, Tucson, AZ.

McClaran, M. P. 1995. Desert grasslands and grasses. In: M. P. McClaran and T. R. Van Devender, (eds.) The desert grassland. University of Arizona Press, Tucson, AZ.

McNab, B.K. 1982. Evolutionary alternatives in the physiological ecology of bats. In: T.H. Kunz (ed.) Ecology of bats. Plenum Press, New York, NY. 151-200 pp.

O'Farrell, M. J.; Bradley, W.G. 1970. Activity patterns of bats over a desert spring. Journal of Mammalogy. 51: 18-26.

Parmenter, R.R.; Brantley, S.L.; Brown, J.H.; Crawford, C.S.; Lightfoot, D.C.; Yates, T.L. 1994. Diversity of animal communities on southwestern rangelands: species patterns, habitat relationships, and land management. In: N.E. West (ed.) Biodiversity of rangelands. Natural Resources and Environmental Issues III. College of Natural Resources, Utah State University, Logan, UT.

Robbins, L.W.; Engstrom, M.D.; Wilhelm, R.B.; Choate, J.R. 1977. Ecogeographic status of *Myotis leibii* in Kansas. Mammalia. 41:365-367.

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

Saab, V.A.; Bock, C.E.; Rich, T.D.; Dobkin, D.S. 1995. Livestock grazing effects in western North America. In: Martin, T.E. and D.M. Finch (eds.) Ecology and management of neotropical migratory birds: A synthesis and review of critical issues. Oxford University Press.

Schlesinger, W.H.; Reynolds, J.F.; Cunningham, L.F. Huenneke, W.M. Jarrell, R.A. Virginia, and W.G. Whitford. 1990. Biological feedbacks in global desertification. Science. 247: 1043-1048.

Schmidly, D.J. 1991. The bats of Texas. Texas A&M University Press, College Station, TX.

Shields, D.J.;. Brown, D.D.; Brown, T.C. 1995. Distribution of abandoned and inactive mines on National Forest System Lands. USDA Forest Service General Technical Report RM-GTR-260.

Rocky Mountain Forest and Range Experiment Station. Albuquerque, NM.
Storz, J. F. 1995. Local distribution and foraging behavior of the spotted bat (*Euderma maculatum*) in northwestern Colorado and adjacent Utah. Great Basin Naturalist. 55:78-83.
Thomas, J.W. 1994. The Forest Service ethics and course for the future. USDA Forest Service FS567. Washington, DC.
Warren, S.D.; Scifres, C.J.; Teel, P.D. 1987. Response of grassland arthropods to burning: a review. Agricultural Ecosystems Environment. 19: 105-130.
Whitaker, J.O.; Maser, C.; Cross, S.P. 1981. Food habits of eastern Oregon bats, based on stomach and scat analyses. Northwest Science. 55: 281-292.
Wilkins, K.T. 1989. *Tadarida brasiliensis*. Mammalian Species. 331: 1-10.
Wright, H.A. 1980. The role and use of fire in the semidesert grass-shrub type. Intermountain Forest and Range Experiment Station. USDA Forest Service General Technical Report INT-85. Odgen, UT.
Wright, H.A.; Bailey, A.W. 1980. Fire ecology and prescribed burning in the Great Plains—A research review. Intermountain Forest and Range Experiment Station. USDA Forest Service General Technical Report INT-77. Ogden, UT.