NATIONAL SYSTEM OF PUBLIC LANDS
U.S. DEPARTMENT OF THE INTERIOR
BUREAU OF LAND MANAGEMENT

Bats and Artifical Lighting:

Best Management Practices

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The BLM's multiple-use mission is to sustain the health and productivity of the public lands for the use and enjoyment of present and future generations. The Bureau accomplishes this by managing such activities as outdoor recreation, livestock grazing, mineral development, and energy production, and by conserving natural, historical, cultural, and other resources on public lands.

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ON THE COVER: Top Left: Light pollution map by NASA Earth Observatory. Top Right: A Japanese house bat (Pipistrellus abramus), photo by Yushi and Keiko Osawa, BCI. Bottom Left: Mexican free-tailed bat emergence from Congress Avenue Bridge, photo by Amanda Stronza, BCI .Bottom Right: Streetlight, Shutterstock.

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Contents

1 Background

Bats comprise nearly a quarter of all the planet's mammals, totaling over 1,300 known species. Bats are also one of the slowest-reproducing mammals for their size, averaging just one young per year, with some species living up to 30 years in the wild.[1] Bats are ecologically and economically vital to ecosystems and human economies. They are primary predators of insect pests that cost farmers and foresters billions of dollars annually and bats pollinate and disperse the seeds of hundreds of economically important plants.[2,3] Unfortunately, bats are also one of the most imperiled taxa worldwide, with more than half of all species known or suspected to be in decline; the primary causes being habitat loss, overharvest, disease, and impacts from energy development.[4,5]

More than half of the 46 bat species known to occur in the U.S. are found on lands administered by the Bureau of Land Management (BLM), with the majority on one or more BLM State Sensitive species lists (see Appendix I). The primary stressors to bats on BLM-administered lands are habitat modification and loss, including environmentally-induced habitat changes, and collisions with turbines at wind energy facilities.[5] Both globally and within the U.S., another stressor is increasing in prevalence and recognition: light-pollution.[6,7] Bats are particularly affected by light pollution due to their nocturnal nature. Considerable physiological and behavioral evidence suggests that bats are sensitive to and avoid bright light. Cones are the receptors in the eye that are sensitive to bright light and rods are the receptors that work in low light, detecting basic motion. Rods are more sensitive to faint light than cones, therefore bats' visual sensitivity declines as ambient light increases towards daylight. Most bats have no cones at all. The species that do have cone-like structures emerge early to forage, and several studies have shown that bat vision works better in dim light than in bright light.[8,9] The sensitivity to different light levels however varies considerably between the different families and species.[10]

Life evolved over millions of years with predictable daily, monthly, and seasonal patterns of light and dark, and these patterns underlie the natural rhythms of nearly all living organisms. Increasing urbanization has resulted in a corresponding increase in artificial lighting for roads, bridges, housing, recreational facilities, and other developments. Increased lighting on the landscape has reduced dark sky availability, resulting in impacts to bats and many other light-sensitive animals.[7] These impacts include changes in activity patterns, behavior, and habitat loss and

Early anatomical studies suggested the retinas of microbats, which use echolocation to navigate and forage in complete darkness, completely lack cones. More recent studies have found cones and cone opsins in a small number of species, including this short-tailed fruit bat (Carollia perspicillata). Photo by Shutterstock.

fragmentation.[11] Forty three of the 46 U.S. bat species feed exclusively on insects, which are also significantly affected by artificial light.[12,13,14] Impacts to bats are complex, as they may be direct or indirect, vary between species, affect different bat behaviors differently (i.e. roosting, foraging, commuting, etc.), occur over dissimilar time and spatial scales, and be cumulative. Estimating and measuring the precise impact of lighting on bats is difficult as this is an emerging issue with many knowledge gaps.[15,16,17]

The direct effects of artificial lighting on bats include changes to roost emergence times, existing and potential roost quality, foraging and commuting patterns, and endogenous rhythms. [16,18,19,20] Indirect effects include changes in prey abundance and availability, habitat quality, and risk of predation.[6, 11,12,17] Although the overall effect of artificial lighting on bats is decidedly negative, some species appear to benefit by increased foraging opportunities at lights, although these benefits can be counterbalanced by adverse impacts at the population scale.[21, ,22, 23, 24] Fortunately, the effects of lighting on bats can be reduced, and in some cases, eliminated completely.

Stone et al.[6] recommends that when planning mitigation for the impacts of artificial lighting on bats, the following key questions should be considered: Do we need light? Where does the light need to be?, What is the light required for?, How much light is actually needed to perform the tasks required?, and, When is the light required?

Light pollution in the U.S. grew 6% annually from 1947 to 2000. Photo by NASA.

2 General BMPs for Bats & Light Pollution

The primary management actions that can reduce, eliminate, or mitigate the negative effects of light pollution on bats fall into five basic strategies: 1) *Need;* avoid the use of lighting when not absolutely necessary; keeping dark areas dark, especially those deemed important for bats; 2) *Spectrum*; choose the correct color spectrum; avoid lights with shorter wavelengths; 3) *Intensity*; reduce lighting intensity; 4) *Direction;* shield and direct lighting to reduce light spill-over and illumination of important habitat components (incudes the use of light screening; i.e. berms, hedgerows, etc.; and 5) *Duration*; use timers and motion detectors to reduce the time that lighting is used.

Because there will be variation in suites of species and habitat quality between sites, biologists with knowledge of local or regional bat ecology should be consulted to determine if light pollution is an issue that needs to be addressed, and if so, the best way to do so. When evaluating the impacts of lighting on bats it is important to keep in mind that impacts can be cumulative in the context of other disturbances, may occur over short and longer time scales, and may be direct or indirect, i.e. effect bats by affecting individuals/colonies, their prey, or even species community composition and interractions.[6]

The following general BMPs should be considered for any new or existing developments where bats or bat habitat may be present, however, natural resource managers should review all bat and light pollution BMPs to reduce the effects of light pollution on local and regional bat populations.

2.1. CONSIDER LIGHT POLLUTION AND BAT CONSERVATION MEASURES AT EARLY STAGES OF PLANNING.

The project team should start at an early stage of development planning to inform the design and installation of lighting schemes before they are installed to increase the effectiveness and efficiency of bat conservation measures.[6,15,21] This information is important for informing management direction and improving the effectiveness of post-development mitigation, monitoring, and evaluation.

While some species, like this European pipistrelle, will forage on insects attracted to street lights, many other species such as bats from the genus Myotis typically avoid lights. Photo by Daniel Lewanzik.

Biologists should use a lux meter to conduct pre-development light surveys in addition ot bat surveys and habitat evaluation to guide light-related disturbance reducton and mitigation. Photo by Shutterstock.

2.2 CONDUCT PRE-DEVELOPMENT BAT AND LIGHT SURVEYS AND HABITAT ANALYSIS

Whenever possible, biologists familiar with regional bat species and habitats should conduct baseline data at the early planning, pre-development stage, including standardized light-level (lux) surveys, bat surveys, as well as bat habitat evaluation (i.e. denote high-quality foraging habitat, existing or potential roosting habitat, etc.) to ensure that light related disturbance reduction and mitigation measures are appropriate and effective.

Bat and light surveys should be standardized (using the same effort and timing) to ensure they are comparable before and after development.

Survey results should be used to make a bat habitat map that shows species presence across the site and key roosting, foraging, and commuting areas/sites, including an index of relative activity at each.

Surveys should be done to determine roost sites that host colonies of major conservation concern.[21]

Surveys of anthropogenic use of the surrounding areas should be obtained as a means of identifying which roosting habitats are most at-risk of human disturbance.[21]

Areas in which bat presence has been detected in the past should be taken into account.[21]

Surveys should reveal which roosting sites are most active as a means of anticipating the return of bats to their birth place, where they will predictably roost themselves.[21]

Biologists should obtain predicted post-development light distribution maps and detailed descriptions of the lighting scheme from the lighting contractor/engineer, which can then be evaluated against the information gathered during bat and bat habitat surveys.

3 Lighting Technology

Light intensity and wavelength are major factors affecting bats' response to lighting.[6,14,15] Some bat species may require very low light levels to minimize or avoid impacts to their behavior. Many insects have evolved eyes capable of detecting UV (a short-wave length) light and use it for navigation, foraging, and mate choice. Therefore, lights with shorter wave-lengths, especially in the ultraviolet spectrum (UV), attract insects and should be avoided. Yellow light that does not contain blue, violet, or UV wavelengths does not attract substantial numbers of insects, nor does warmer LED lights, and red light.[12,13,14]

3.1. TRACK PRE- AND POST-DEVELOPMENT LIGHT LEVELS

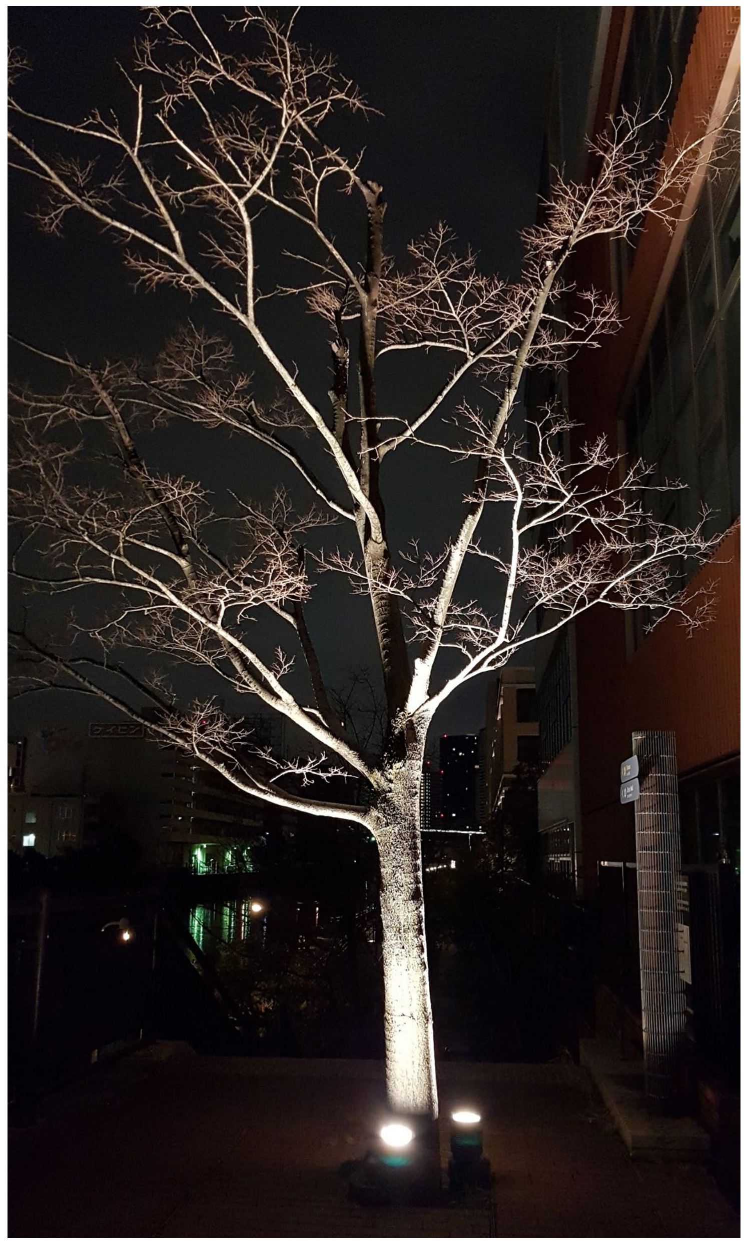
Consider light levels at the site in the context of pre-development lighting (lux data), and where possible, post-development light levels should be as close to the mean naturally-occurring light levels recorded pre-development at key areas of bat use.[6,15,21]

3.2. WHERE POSSIBLE, USE LOW-INTENSITY LIGHTING

Use bat-compatible lighting at the lowest intensity possible while still meeting other lighting objectives.[6,15,.21]

3.3. AVOID LIGHTS WITH HIGH UV CONTENT

In general, avoid broad-spectrum blue-white lights with high UV content such as high-pressure sodium and mercury halide lamps, which have the greatest negative impacts on bats and insects. Use narrow-spectrum lights with no or little UV content such as low-pressure sodium and amber LEDs. Warm-white



Avoid luminaries that point skyward, or use low-intensity, low-UV lighting. Photo by Shutterstock.

"Use the full suite of mitigation measures to reduce the negative effects of lighting at remote energy facilities which may be the only source of light for miles. Photo by Shutterstock.

LEDs have a peak in blue emissions which can attract insects and some bat species, and generates avoidance behavior in light-sensitive species. While white LEDs have little UV content, they are also known to attract some bat species, and elicit avoidance in others.[12, 14,23, 28] See Table 1 for a summary of these recommendations.

3.4. IF NECESSARY, REMOVE UV CONTENT WITH FILTERS OR HOUSINGS

If the use of high-UV content lighting such as metal halide or mercury light sources can't be avoided, reduce or completely remove the UV content of the light with UV filters or glass housings.[6,15,21]

3.5. CONSIDER LOW-INTENSITY LIGHTING OPTIONS

Consider low-intensity lighting options that minimize light spill and reduce illumination such as ground-level foot lights and or illuminated handrails or posts for pedestrian footpaths, biking, trails, service roads, etc.[6,7,15,21]

3.6. USE THE MINIMUM AMOUNT OF LIGHT NECESSARY TO MEET MANAGEMENT OBJECTIVES

Many bat species are sensitive to even low-intensity light. Every effort should be made to use the minimum amount of light required to meet other management objectives.[6,10] Prioritization of activation of artificial lighting, with special importance placed on non-activation of lighting during twilight and early hours of darkness is recommended due to the important bat foraging activities during these times.[21]

Recessed lighting on walkways and trails can be used to replace more obtrusive overhead lighting. Photo by Shutterstock.

3.7. TIME ARTIFICIAL LIGHT USAGE TO NATURAL CIRCADIAN RHYTHMS

A species' internal biological clock is developed through coordination with external features, "zeitgebers".[21] Disruption of the species' 24-hour circadian rhythm may result in disruption of the biophysical, physiological, and behavioral processes of that species.[21] To avoid such disruption, time artificial lighting systems to the clock of a natural 24-hour rhythm to the extent possible.[21]

between roosts and foraging areas) and alter foraging patterns for several species. Many bats follow linear landscape features such as riparian corridors/water courses, linear forest strips or patches, hedgerows, and forest roads. Interrupting these flight paths can increase commuting times, which decreases foraging efficiency, increases energy expenditure and can cause an overall reduction in fitness.[6,11, 24] Artificial light was also shown to reduce roost quality, including forced changes in roost entrance use, significant decreases in colony size, and site abandonment.[18,19,20]

TABLE 1: PROS AND CONS OF LIGHTING OPTIONS

LIGHT TYPE	WAVELENGTH	COLOR	EFFECTS ON BATS/INSECTS
Low-pressure sodium lights	No UV, long wavelength	Yellow	• Low insect attraction • Little bat attraction or avoidance
Warm-white LED	Little UV, long wavelength	White	• Low insect attraction • Likely elicits avoidance for some bat species
White LED	UV, short wavelenth	White	• Low to moderate insect attraction • Likely elicits avoidance for some bat species, attraction for others
High-pressure sodium	Broad-spectrum UV	Pinkish/Yellow	• Moderate insect attraction • Likely elicits avoidance for some bat species, attraction for others
Mercury (metal halide) lamps	Very broad, including UV	Blueish White	• Strong attraction for insects and some bat species • Strong avoidance or other bat species

4 Light Placement & Control

The best scenario for bats is to have no artificial light at all in the habitats that they utilize. This may be possible by working with lighting engineers early in the planning stages to ensure no new lighting is installed in these priority habitats or existing lighting is switched off during times of peak bat use. Where possible, these light exclusion (dark) zones can be connected to facilitate bat movement.[6]

While no artificial light is almost always better for bats than artificial light, where human needs for lighting (e.g. safety, recreation, etc.) is important, both human and bat conservation objectives can be met through management actions such as strategic light placement, part-night lighting (delaying initiation and expediting termination of nightly lighting), reducing light spillage, combining motion sensors with low-impact lighting, and designating light-exclusion (dark zones) in or adjacent to important bat habitat.[6,15,17,21, 25]

4.1. PLAN LIGHT CONFIGURATION TO REDUCE LIGHT SPILLAGE

Plan and design light configuration, i.e., spacing, height, and directionality, to reduce the intensity and spillage of light to minimize overall illumination and provide dark habitats for bats.[6,15,21]

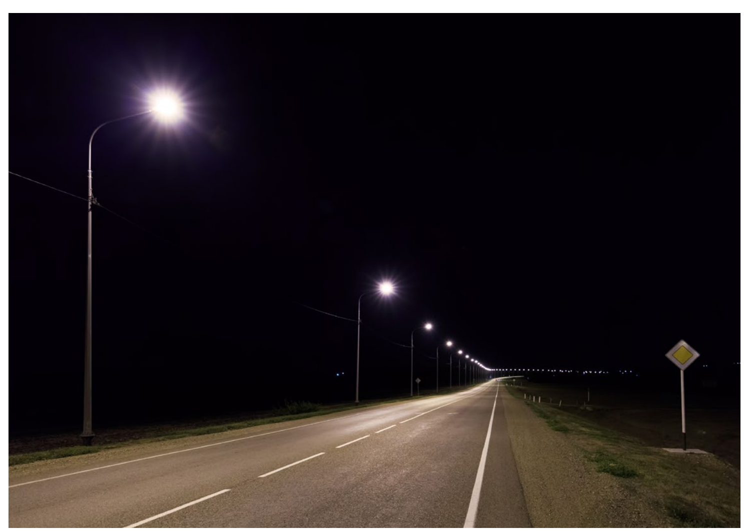
4.2. USE LIGHT BARRIERS TO PREVENT SPILLAGE INTO BAT HABITATS

Plant or use existing vegetation, berms, walls, or other structures to act as a light barrier to screen and prevent light spillage into important bat habitat including foraging and commuting routes. [6,7,21] Particular attention should be paid to allow for existing vegetation to remain, including dense natural hedging and vegetation that provides shade and/or shadows, most notably in the form of trees.[15]

4.3. USE DARK CORRIDORS TO FACILLITATE BAT MOVEMENT

Design and integrate dark corridors to encourage/guide bats away from or around illuminated areas (such as roads). Corridors should be created relative to other landscape features and along likely commuting routes for bats, i.e., along hedgerows, heavily-vegetated low-volume roadways, stream courses, etc.[6,15,]

In order to be effective, dark corridors should:



Consider leaving dark gaps when roads or lighted rails bisect linear features known or likely to be used by bats as commuting or foraging routes. Photo by Shutterstock.

- link to existing flight paths, roosts, and foraging areas;
- contain mature vegetation to provide shelter from predators and weather;
- contain native species to attract insects for foraging;
- be located away from roads;
- and be consistently mantained[6]

4.4. INTEGRATE DARK GAPS INTO LINEAR LIGHTING ARRAYS

Consider leaving dark gaps to facilitate bat crossing when roads with streetlights bi-sect linear landscape or other features that are known or potential bat foraging or commuting routes such as water courses, hedgerows, rights-of-ways, etc. The presence of such unlit stretches avoids disconnection of the bat flight corridor and isolation of bat colonies.[16, 21 21] A buffer of dense vegetation or other light barrier, preferably 10 meters or greater, between lit roadways and linear landscape features that may function as flight corridors is recommended.[15,21] Illumination of existing dark corridors (i.e. river bodies, tributaries, etc.) should be severely limited, with acknowledgement of safety concerns of travelers on such corridors.[15]

Dark corridors along linear features such as streams, canals, old wooded roads, and trails, are used by bats for foraging and communing and should remain unlit or protected from light spillage. Photo by Clementine Azam.

4.5. DO NOT ILLUMINATE IMPORTANT BAT HABITAT FEATURES

Avoid directing light into important bat habitats such as still-water wetlands, ponds, riparian areas, woodland areas, eco-mosaics, etc.[6,15, 21]

4.6. UTILIZE MOTION SENSORS

Use motion sensors to illuminate areas where light is needed, only when it is needed.[6,15,21]

4.7. USE LIGHTING CONTROL SYSTEMS

Most insectivorous bats show a bi-modal peak of activity, with peak foraging activity within the first two hours after sunset, and a smaller peak approximately an hour or more before sunrise. Consider a part-night lighting strategy that uses lighting control systems to reduce or eliminate illumination during the first two hours after sunset and the last two hours before sunrise.[6,15,21,25]

4.8. CONFIGURE LIGHTING TO REDUCE THE VOLUME OF ILLUMINATED SPACE

Reduce the height of lights to keep the lighted area as close to the ground as possible, reducing the volume of illuminated space and allowing bats to fly in the dark space above the lights (if the light doesn't spill over the vertical plane).[6,15,21] Further, allowing for significant distance between lighting will increase darkness between such fixtures.[6]

4.9. AVOID THE USE OF UPWARD POINTING LIGHTS

Avoid the upward spread of light near to and above the horizontal plane; avoid the use of upward pointing lights (e.g., ground-recessed luminaires or ground-mounted floodlights up-lighting trees, buildings and vegetation), keeping light ideally below 90° to horizontal. [6,15,21] Additionally, the use of newer technologies like LEDs provide directional light rather than upward and horizontal emissions.[26] Use caution however, when choosing types of LEDs.

4.10. AVOID ILLUMINATING ROOSTS

Never illuminate bat roosts with security or other lighting. If a building known to be used by bats must be illuminated, the lights should be positioned to avoid the sensitive areas. Low wattage (<70W) lamps are preferable as they reduce glare and energy consumption and minimize impacts on bats. Lights can be fitted with movement sensors which turn the light on when the sensor is triggered.[6,19,20,21]

4.11. USE DIRECTIONAL ACCESSORIES TO MINIMIZE LIGHT SPILL

Install directional accessories such as hoods, baffles, and louvres on existing light units to direct light away from sensitive areas and minimize light spill. [6,15,21] Further, reduction of reflected light as a result of light directed to various reflective surfaces (i.e., streetlight to sidewalk surface) may be accomplished through selection of surfaces that produce minimal reflection, thereby reducing the size of the light spill cone.[27] Attention should be paid to "over-lighting" an area that does not require full light.[27]

4.12. USE FULL SUITE OF MITIGATION MEASURES AT REMOTE DEVELOPMENTS IN OPEN COUNTRY

Remote developments, such as oil and gas facilities, are often brightly illuminated at night, and may be the only source of light for miles. Using the full suite of mitigation, i.e. shielding lights, using narrow spectrum and low intensity lighting, and controlling the timing of use should be considered in these situations.[7]

4.13. MONITOR CULTURAL/ HISTORIC SITES FOR BAT ACTIVITY

In roosts found within buildings of cultural or historic significance or previously human-inhabited enclosed spaces, particular attention should be paid to limit future human contact and illumination by monument visitors at all times of day, as these habitats house important resting and reproductive spaces for some bat species.[21] Enclosed spaces and places of anticipated occupation by bat species should be systematically monitored on an ongoing basis by cultural site attendants, adjusting allowance of human visitors to such areas dependent upon cultural site use by the bat species.[21]

4.14 INCREASE PUBLIC BAT EDUCATION

In the absence of knowledge regarding the detrimental effects of light pollution on bat species, the general public's ability to engage on this issue remains limited. Through educational efforts to individual homeowners outlining the negative consequences of light pollution on bat species, homeowners will hold the ability to make more informed decisions regarding alterations to light pollution emitted at the household level.[16] Education is also recommended for local bat groups, who may then be

‡ *This does not imply any commercial endorsement by the BLM*

contacted by light pollution decision makers in the local area.[16]

4.15 ENACT ENVIRONMENTAL ZONING FOR LIGHTING CONTROL

Within the development plans of the local municipality, development of zoning tiers as a rubric for informing the intensity of light pollution allowed, dependent upon the surrounding area, is recommended. Using the zone rubric, municipalities may refer to such guidelines when making important light illumination decisions.[27]

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Bats and Lighting Research Project

APPENDIX I

BAT KNOWN TO OCCUR ON LANDS ADMINISTERED BY THE BLM

(*29 Species*)

FAMILY PHYLOSTOMATIDAE

Choeronycteris

Choeronycteris mexicana – Mexican long-tongued bat

Leptonycteris

Leptonycteris nivalis – Mexican long-nosed bat

Leptonycteris yerbabuenae – lesser long-nosed bat

Macrotus

Macrotus californicus – California leaf-nosed bat

FAMILY VESPERTILIONIDAE

Antrozous

Antrozous pallidus – pallid bat

Corynorhinus (Plecotus)

Corynorhinus townsendii – Townsend's big-eared bat

Eptesicus

Eptesicus fuscus – big brown bat

Euderma

Euderma maculatum – spotted bat

Idionycteris

Idionycteris phyllotis – Allen's big-eared bat

Lasionycteris

Lasionycteris noctivagans – silver-haired bat

Lasiurus

Lasiurus blossevillii – western red bat

Lasiurus cinereus – hoary bat

Lasiurus xanthinus – western yellow bat

Myotis

Myotis auriculus – southwestern myotis

Myotis californicus – California myotis

Myotis ciliolabrum – western small-footed myotis

Myotis evotis – long-eared myotis

Myotis lucifugus – little brown myotis

Myotis occultus – Arizona myotis

Myotis septentrionalis – northern (long-eared) myotis

Myotis thysanodes – fringed myotis

Myotis velifer – cave myotis

Myotis volans – long-legged myotis

Myotis yumanensis – Yuma myotis

Parastrellus

Parastrellus (formerly *Pipistrellus) hesperus* – canyon bat

FAMILY MOLOSSIDAE

Eumops

Eumops perotis – Western mastiff bat

Nyctinomops

Nyctinomops femorosaccus – pocketed free-tailed bat*Nyctinomops macrotis* – big free-tailed bat

Tadarida

Tadarida brasiliensis – Mexican free-tailed bat