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Literature Review

**Macrohabitat Metrics to Identify Presence of Chiroptera on the Landscape in the
United States**

Christina L. Saltus and Eric R. Britzke

September 2022



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Literature Review

Macrohabitat Metrics to Identify Presence of Chiroptera on the Landscape in the United States

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Abstract

This special report reviews current scientific literature to identify the most commonly cited metrics used to describe the macrohabitat criteria important for Chiroptera presence in the United States. The review evaluates 69 scientific articles from 1994 to 2018. The most commonly cited metrics were divided into four main categories: tree-species-level metrics, landscape-level metrics, distance metrics, and topographic and atmospheric metrics. Of all metrics found, the top six most common metrics noted across all articles were percent canopy cover, diameter at breast height (DBH), forest type, distance to water, distance to roads or other urban features, and tree density. In addition, 27 of the 47 (57%) bat species located within the United States were represented. These metrics provide important insight into the regional or national species-level distribution and assist with modeling the relationship between species distribution and habitat change.

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Preface

This literature review was conducted by the Ecosystem Management and Restoration Research Program (EMRRP) for the US Army Engineer Research and Development Center (ERDC)–Environmental Laboratory (EL) under Project 2015-ER-7, “Impacts of Habitat Management on Bats.” The technical monitor was Dr. Brook Herman (Acting).

The work was performed in cooperation between the Environmental Systems Branch (EEC) and the Ecological Resources Branch (EEE) in the Ecosystem Evaluation and Engineering Division (EE), ERDC-EL.

At the time of publication of this special report, Mr. Mark Graves was branch chief of EEC and Mr. Joseph Minter was branch chief of EEE, Mr. Mark Farr was division chief of EE, Dr. Jen Seiter-Moser was the EMRRP acting technical director, Dr. Brandon Lafferty was deputy director, and Dr. Edmond J. Russo Jr. was director of EL.

Dr. David Pittman was director of ERDC, and COL Christian Patterson was commander.

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1 Introduction

1.1 Background

Identifying Chiroptera distribution throughout the United States is needed for conservation, management, and species research efforts. Currently, 47 species of bats are known to inhabit the United States (BCI 2018) with 7 (14%) listed as either threatened or endangered species by the US Fish and Wildlife Service (USFWS, n.d.). The majority of the US bat population is insectivorous and belongs to one of the following four bat families: Vespertilionidae, Molossidae, Mormoopidae, and Phyllostomidae. Bats are important components of ecosystems, because they consume a large number of insects, including many pest species. Determining bat occurrence on the landscape is an important part of protecting bat populations. However, bats are highly mobile, with habitat ranges that can exceed 1,000 mi (1,609 km)* between roost, hibernation sites, and foraging areas (Broders and Forbes 2004) making surveying large areas costly using standard techniques. Therefore, a better understanding of habitat requirements is needed to assess optimal habitat selection and evaluate how changes in habitat such as habitat loss, alteration, and condition affect species distribution.

1.2 Objective

This literature review provides a summary of previous research on roosting bats, which highlights variables identified as significant in predicting bat-roost occurrence on the landscape. These variables were then used as a starting point for developing a landscape-occurrence model for multiple bat species.

* For a full list of the spelled-out forms of the units of measure used in this document, please refer to *US Government Publishing Office Style Manual*, 31st ed. (Washington, DC: US Government Publishing Office, 2016), 248–52, <https://www.govinfo.gov/content/pkg/GPO-STYLEMANUAL-2016/pdf/GPO-STYLEMANUAL-2016.pdf>.

1.3 Approach

This literature review identifies macrohabitat indicators of Chiroptera presence in the United States. The survey includes literature on roosting, hibernating, and foraging bat populations and expands on previous literature reviews conducted by Miller, Arnett, and Lacki (2003); O'Shea, Bogan, and Ellison (2003); Lacki, Hayes, and Kurta (2007); and Weller, Cryan, and O'Shea (2009) that focused mainly on forest roosting, bat detection, and bat population studies. In addition, the literature investigation provides some details on the methods used to drive relevant metrics important in quantifying bat occurrence. After identifying these generalized metrics for predicting spatial distributions of bat species throughout the United States, the literature review then uses these metrics as the basis for future modeling efforts to predict bat occurrence on the landscape.

2 Methodology

The literature review assessed scientific articles included in peer-reviewed literature, theses and dissertations, government reports, and professional conference proceedings. Scientific articles were located by using the web databases Google Scholar, JSTOR, BioOne, and ERDC Knowledge Core (<https://erdc-library.erdcdren.mil/jspui/>) using the keywords *bat*, *habitat*, *presence/absence*, and *ecology*. See Table 1 for a list of article sources. The initial search returned 111 articles, which were then sorted and evaluated to determine relevance and usefulness of metrics to define bat habitat. Only articles with study areas located within North America were used. Articles excluded from analysis were specific to urban or developed areas, since natural habitats were desired. Also, disease-based studies such as white-nose syndrome, wind-energy-related fatality studies, and natural disaster studies were removed from consideration to limit bias in the review. Since most studies focused on limited spatial extents, articles were specifically selected to encompass varying bat species, study locations, bat behavior (roosting, foraging, hibernating), and year published. A total of 69 scientific articles were used in the literature review to capture the metrics used to describe the habitat criteria important for Chiroptera presence in the United States (see appendix). The literature review consisted of articles published during the years 1994–2018. For each article, the study location and year, metrics used, metric measurement method (field-based versus geospatial), and bat species were documented. All metrics identified were then categorized into groups using four main categories: tree-species-level metrics, landscape-level metrics, distance metrics, and topographic and atmospheric metrics. Finally, metrics were ranked according to the number of articles that cited the metric.

Table 1. Scientific sources for bat presence information.

Scientific sources for bat presence information		
Acta Chiropterologica	Environmental Management	Mammalia
American Midland Naturalist	Ethology	Mammalian Biology
American Naturalist	Foliage Zoology	Mammalian Species
Animal Behaviour	Forest Ecology and Management	Molecular Biology
Annals of the New York Academy of Sciences	Frontiers in Ecology and the Environment	Nature
Bat Research News	Functional Ecology	Northeastern Naturalist
Biodiversity and Conservation	Indiana Bat: Biology and Management of an Endangered Species	Northwest Science
Biological Conservation	International Journal of Forestry Research	Oecologia
BioScience	Journal of Animal Ecology	Ohio Journal of Science
Biotropica	Journal of Applied Ecology	Physiological Zoology
Canadian Journal of Zoology	Journal of Comparative Physiology	PLOS ONE
Conservation and Management	Journal of Ecology and Natural Environment	Proceedings of the Annual Conference of the Southeastern Association of Fish and Wild. Agencies
Conversation Biology	Journal of Experimental Biology	Science
Current Biology	Journal of Fish and Wildlife Management	Southeastern Naturalist
Ecography	Journal of Mammalogy	Systematic Zoology
Ecological Modelling	Journal of Urban Ecology	Urban Ecosystems
Ecological Monographs	Journal of Wildlife Diseases	Western North American Naturalist
Ecology	Journal of Wildlife Management	Wildlife Society Bulletin
Écoscience	Landscape Ecology	

3 Results

3.1 Summary of findings

A total of 22 metrics were identified from the literature review. The following 8 metrics (36%) were detected but were removed from consideration since they were reported in fewer than 10 articles (out of 69, <14%) out of all articles reviewed and represent the bottom one-third of all metrics identified. These metrics are *precipitation*, *roost height*, *aspect*, *tree decay stage*, *distance to nearest tree*, *understory clutter*, *insect abundance*, and *number of exits and cavities*. The remaining 14 metrics (64%) were then subdivided into four main categories describing bat presence, including tree-species-level metrics, landscape-level metrics, distance metrics, and topographic and atmospheric metrics (Table 2). Each metric is described below, including methodology used to sample the metric (field-based versus geospatially derived). The top 6 most common metrics (27%) noted across all articles were *percent canopy cover*, *DBH* (diameter at breast height), *forest type*, *distance to water*, *distance to roads or other urban features*, and *tree density*. These 6 metrics were chosen because they represent the top one-fourth of the 22 original metrics identified and are therefore considered the most common factors important to predicting bat habitat use.

A few limiting factors to the review included the use of articles with localized geographic extent, species-specific studies, or sex-specific studies. Others focused on specific habitat type such as riparian area, pine forest, or linear features. Metrics may include a bias towards Indiana bats or northern myotis habitat, or both, since they were the most-studied species throughout all the articles reviewed. In addition, most studies were related to roosting habitat with sampling of study areas during the summer months.

Table 2. Metrics most commonly noted to describe bat presence.
(DBH—diameter at breast height)

Metric	Articles citing metric
Tree species level	
DBH (cm)	39
Tree/canopy height (m)	20
Bark (%) or amount	15
Tree Age	15
Basal tree area (m ² /ha)	13
Landscape level	
Forest type	34
% Canopy cover	41
tree density	21
snag density	16
forest edge	12
Distance	
Distance to water	27
Distance to roads or other urban features	22
Topographic and atmospheric	
Land elevation	21
Slope of land %	15
Temperature	15

3.2 Bat species

From the results, 27 of the 47 (57%) bat species located within the United States were represented in the articles (Table 3). The most references were to northern myotis (*Myotis septentrionalis*), cited 28 times (41%), and the Indiana bat (*Myotis sodalis*), cited 24 times (35%). Both species are listed on the US Fish and Wildlife Service (USFWS) threatened and endangered species list. Of the species studied, 5 (11%) are threatened and endangered (USFWS, n.d.). While the *Lasiurus cinereus* (hoary bat) in the continental United States is not listed as endangered, the endemic Hawaiian subspecies *semotus* (Hawaiian hoary bat) is listed as endangered (USFWS, n.d.).

Table 3. Bat species represented in literature review.

Species	# times referenced	Threatened or endangered
<i>Myotis septentrionalis</i> (northern long-eared bat)	28	Threatened
<i>Myotis sodalis</i> (Indiana bat)	24	Endangered
<i>Eptesicus fuscus</i> (big brown bat)	16	—
<i>Myotis lucifugus</i> (little brown bat)	14	—
<i>Lasiurus borealis</i> (eastern red bat)	13	—
<i>Lasiurus cinereus</i> (hoary bat)	13	Endangered (Hawai'i only)
<i>Lasionycteris noctivagans</i> (silver-haired bat)	10	—
<i>Nycticeius humeralis</i> (evening bat)	8	—
<i>Perimyotis subflavus</i> (tricolored bat)	9	—
<i>Corynorhinus rafinesquii</i> (Rafinesque's big-eared bat)	6	—
<i>Myotis austroriparius</i> (southeastern bat)	6	—
<i>Myotis evotis</i> (western long-eared bat)	5	—
<i>Myotis seminolus</i> (Seminole bat)	5	—
<i>Myotis californicus</i> (California myotis)	5	—
<i>Myotis volans</i> (long-legged myotis)	5	—
<i>Perimyotis subflavus</i> (tricolored bat, eastern pipistrelle)	5	—
<i>Myotis leibii</i> (eastern small-footed myotis)	4	—
<i>Myotis yumanensis</i> (Yuma myotis)	4	—
<i>Myotis thysanodes</i> (fringed myotis)	3	—
<i>Corynorhinus townsendii</i> (Townsend's big-eared bat)	2	Endangered
<i>Myotis austroriparius</i> (southeastern myotis)	2	—
<i>Tadarida brasiliensis</i> (Brazilian free-tailed bat)	2	—
<i>Antrozous pallidus</i> (pallid bat)	2	—
<i>Myotis grisescens</i> (gray myotis)	2	Endangered
<i>Corynorhinus townsendii virginianus</i> (Virginia big-eared bat)	1	Endangered
<i>Myotis auriculus</i> (southwestern myotis)	1	—
<i>Myotis keenii</i> (Keen's myotis)	1	—

3.3 Tree-species-level metrics

Tree-species-level metrics are those metrics that relate directly to individual roost tree species and those located nearby in the forest stand. Commonly cited metrics in the articles included *DBH*, *tree* or *canopy height*, *percent bark*, *tree age*, and *basal tree area of live or dead trees*.

3.3.1 Diameter at breast height (DBH)

Of the metrics that can be directly measured in the field with instruments such as a caliper or diameter tape, DBH was noted second most often across all articles. The measure is used to determine roosting-tree preferences within the forest stand. Schirmacher et al. (2007) used the DBH measurement to group individual trees into stand classes with DBH sizes included as a parameter for modeling forest structure and species-specific assessments. The metric's significance was noted by Kalcounis-Rüppel, Psyallakis, and Brigham (2005), whose evaluation of 22 articles analyzing tree-roost selection by bats found that roost trees with larger DBH than random trees surrounding it within the forest stand were preferred.

3.3.2 Tree or canopy height

Tree- and canopy-height studies have shown that this measure can be used as a good indicator of bat presence (Fleming and Jones 2013; Kalcounis-Rüppel, Psyallakis, and Brigham 2005; Ford et al. 2005). Numerous studies used a clinometer to measure tree height in the field (Henderson and Broders 2008; Kurta, Murray, and Miller 2002; Foster and Kurta 1999). Studies found that bat species known to roost in trees chose roost trees which were taller than nonroost trees (Ford et al. 2005; Kalcounis-Rüppel, Psyallakis, and Brigham 2005; Perry and Thill 2007). One possible reason for forest-roosting bats' preference for taller trees and canopy height may be due to increased exposure to solar radiation needed for warmth of maternal colonies (Fleming and Jones 2013).

3.3.3 Percent bark

Erickson and West (2003) noted several radio-telemetry studies that indicated the presence and use of roost trees with peeling bark by forest-dwelling bats. Of the 69 articles reviewed, 15 (22%) measured exfoliated bark, with the majority determined through field observations based on a percentage of bark remaining on an individual tree trunk (Kurta, Murray, and Miller 2002; Crampton and Barclay 1995). A four-year study conducted by Kurta, Murray, and Miller (2002) on Indiana bats in Michigan found that the bats roosted more frequently in trees with 10%–20% bark coverage. The use of peeling bark areas for roosting by Indiana

bats was also noted in a study by Carter and Feldhamer (2005), while Crampton and Barclay (1995) noted roosting under bark for little brown bats. In a review of 28 articles on the Indiana bat roosting characteristics, Lacki, Cox, and Dickinson (2009) determined that all populations examined noted 95% use of exfoliated bark for roosting.

3.3.4 Tree age

Knowledge of forest stand age is a good indicator of how bats use forest structure (Krusic 1995). Various methods were discussed in the 15 articles measuring tree age to determine its relationship to bat activity. Krusic (1995) determined tree age by using the US Department of Agriculture (USDA) Forest Service stand-age classification for the White Mountain National Forest and then relating that classification to population frequency detected through Anabat detectors (Titley Scientific, Columbia, Missouri). Bender et al. (2015) grouped forest types into decade-year ranges and used these measurements to compare distance to foraging activities. Erickson and West (2003) determined tree age as the approximate age of the dominant tree at the stand level. Results of their study showed that bat activity was positively related to trees in early stages of decay. In a study of little brown and silver-haired bats in a mixed-aged forest, Crampton and Barclay (2005) found that the majority of roosts were located in older trees and that bat activity was also highest in older mature trees. The preference for older trees is mostly likely due to the increased number of snags and exfoliating bark for roosting.

3.3.5 Basal tree area

Basal tree area is a measurement of the cross-sectional area of a tree at DBH and provides an effective approach to determine not only tree density within a study area, but also the volume. Two different methods were noted in the articles reviewed to use basal area to assess bat presence. The metric was used to determine habitat use by the densities of overstory trees at plot level for roost versus nonroost trees (Hein, Castleberry, and Miller 2008; Erickson and West 2003). The metric was also used in factor-based prism methods of overstory trees based on specific distances from acoustic bat detectors (Bender et al. 2015). Jung et al. (1999) noted that larger basal areas were positively correlated to the presence of *Myotis* species in a mixed-age forest, while Ketzler, Comer, and Twedt (2018)

found that trees with large basal areas were used by tricolored, Rafinesque's big-eared, and myotine bats.

3.4 Landscape-level metrics

Landscape-level metrics are those metrics from the literature review that best describe the roosting, foraging, and hibernation areas for bats. These metrics include stand characteristics such as *forest type*, *percent canopy cover*, *tree density*, *snag density* and *forest edge*.

3.4.1 Forest type

Diversity of tree species and forest stand types in multiple geographic regions were studied throughout all articles reviewed. Of the 69 studies, 34 (49%) specifically examined the association between forest type and bat presence. Several studies found that a majority of bats frequent old-growth forests with increased snag density as well as dead trees with exfoliating bark and cavities and move frequently between roost trees (Perry and Thill 2007; Silvis et al. 2012; O'Shea, Bogan, and Ellison 2003; Taylor 2006). Measures for classifying forest type were conducted either in the field or through geospatially derived methods and depended on the spatial extent of the study area. Starbuck, Amelon, and Thompson (2015) used the National Land Cover Database (NLCD) to classify coniferous and deciduous trees in the Missouri Ozark Highlands to determine the relationship between bat occupancy and forest structure, while Carter and Feldhamer (2005) detected roost versus nonroost tree species such as green ash and pin oak in the field with a GPS unit in the Mississippi River Floodplain region of Southern Illinois. Results of bat presence assessments by Broders and Forbes (2004) and Perry and Thill (2007) noted that different roost preferences were selected by males and females of the species of northern myotis and hoary bats, respectively. Loeb and O'Keefe (2011) provided an assessment of roosting and major foraging areas of several species of bats in the Central Hardwoods Region, United States. The assessment noted the preference of hardwood and pine snags as well as upland and bottomland forests based on species type.

3.4.2 Percent canopy cover

Of the 69 articles reviewed, 41 (59%) assessed percent canopy cover or canopy closure as evidence of bat presence; the most cited metric across all articles. Similar to forest type metrics, calculations of percent cover were conducted either in the field or through geospatially derived methods and depended on the spatial extent of the study area. Convex spherical densiometers were used to measure percent canopy closure in the field (Ketzler, Comer, and Twedt 2018; Medlin, Rex, and Risch 2008; Kurta, Murray, and Miller 2002; Ford et al. 2005), while geospatially derived classifications of satellite imagery and aerial photography were used to obtain percent canopy cover in geospatial methods (Duff and Morrell 2007). Studies by Ford et al. (2005) and Schirmacher et al. (2007) found that northern myotis and Indiana bats were detected in areas of relatively closed forest canopy, whereas the big brown, little brown, eastern pipistrelles, eastern red bats, and hoary bats preferred more open forest canopies. Model results from Schirmacher et al. (2007) suggest that the most significant metric for defining bat habitat of little brown myotis, eastern pipistrelles, big brown, eastern red, Indiana myotis and northern myotis bats in their study sites in south-central West Virginia were simple habitat features, such as open or closed forest.

3.4.3 Tree density

In the Erickson and West (2003) study of bat species in the Pacific Northwest, tree density in mature forest stands was indicated as the best predictor of bat activity. Of the numerous articles reviewed, tree density was calculated as the number of trees within a given circular plot of a study area (Henderson and Broders 2008; Johnson and Gates 2008; Brooks, Loeb, and Gerard 2017). Henderson and Broders (2008) found that densely forested foraging area was favored by northern myotis on Prince Edward Island, Canada. Tricolored, Rafinesque's big-eared, and myotine bats preferred less densely vegetated areas (Ketzler, Comer, and Twedt 2018).

3.4.4 Snag density

Of the 69 articles reviewed, 16 (23%) examined snag density in association with bat habitat selection. Erickson and West (2003) identified snags

according to species and diameter then grouped them into height categories as the average number of snags per hectare at the stand level. Lacki, Cox, and Dickinson (2009) also examined the density of snags in the field as the number of snags per hectare. Little brown bat, Indiana bat, and northern myotis are among some of the species that roost in snags (Broders and Forbes 2004; Hammond et al. 2016; Loeb and O’Keefe 2011). Erickson and West (2003) documented the correlation between the bat occurrence in forest stands and areas of high snag density.

3.4.5 Forest edge

The link between forest edge and foraging bats is considered valuable for flyways, insect abundance, and solar heating. (Tayler 2006; Jackson 2013). Both field-based and geospatially derived methods were specified in the articles for measurement of forest edge. A combination of field methods using the detection of bat locations in the field and geospatially derived distances based on the maximum distance from a detected bat location to the nearest forest edge was used to assess this metric (Henderson and Broders 2008; Brooks, Loeb, and Gerard 2017; Pauli, Badin, and Haulton 2015). Grindal and Brigham (1999) observed forest-edge usage among foraging bats in British Columbia, Canada, and noted that forest edge attracted the largest amount of foraging activity compared to forest habitats.

3.5 Distance metrics

Distance metrics are those metrics that can determine bat presence within home-range traveling distances between roosts, foraging, and hibernating sites. The metrics include *distance to water* and *distance to roads or other urban features*.

3.5.1 Distance to water

Location of permanent freshwater sources from roost trees, foraging areas, or hibernating areas is vital for bat species. In 27 of the 69 (39%) articles reviewed, distance to water was considered a critical determining factor of bat presence (Carter and Feldhamer 2005; Pauli, Badin, and Haulton 2015). Distance to water was geospatially derived by calculating distances from roost trees, bat detectors, or forest edge (Pauli, Badin, and Haulton

2015; Duff and Morrell 2007; Starbuck, Amelon, and Thompson 2015; Brooks, Loeb, and Gerard 2007). Richardson (2017) determined that a 1,000 m distance from a water source was optimal for his study of Indiana bats in Indiana, whereas Starbuck et al. (2015) cited a maximum of 550 m from a water source for big brown bat, eastern red bat, northern myotis, tricolored bat, and evening bat.

3.5.2 Distance to roads and other urban features

Distance to roads and other urban features was investigated in 22 of the 69 (32%) articles reviewed. Similar to forest edges, roadways and other urban features may provide cleared areas for migration flyways or could serve as an area of avoidance because of bat-activity disturbances. The metric was geospatially derived by calculating distances from either roost trees or bat detectors to the nearest road or other urban features (Bender et al. 2015; Fleming and Jones 2013; Starbuck, Amelon, and Thompson 2015). Loeb and O’Keefe’s (2006) investigation of habitat use for big brown bats, red bats, and eastern pipistrelles in northwestern South Carolina noted a connection between the distance to the closest road and field-detected bat locations in their study area. Likewise, Fleming and Jones (2013) noted the importance of distance to roads from roost sites for Rafinesque’s big-eared and southern myotis bats in three different public land areas in Mississippi—especially during the spring for southern myotis, when roost occupancy was preferred at the furthest distance from roads. Close distances of roosts to developed areas (within 320 m) was used as a limiting factor to bat presence by Richardson (2017). Results from the Pourshoushtari et al. (2018) study of bat activity in Indiana found evidence of bat avoidance of developed areas.

3.6 Topographic and atmospheric metrics

Topographic and atmospheric metrics are those metrics that depict the physical configuration of the landscape and atmosphere most commonly cited as suitable for bat presence. The metrics include *land elevation*, *percent slope*, and *air temperature*.

3.6.1 Land elevation

Of the 69 articles reviewed, 21 (30%) considered land elevation as a key metric for defining bat presence. Land elevation was normally obtained through existing maps or geospatial data sets such as digital elevation models (Duff and Morrell 2007; Ford et al. 2005) and grouped into elevation ranges according to site conditions. Grindal and Brigham (1999) evaluated the habitat use of California myotis, little brown bat, long-legged myotis, Yuma myotis, big brown bat, silver-haired bat, and hoary bats at varying elevation zones in British Columbia, Canada. The study found that bat activity decreased over an increased elevation gradient because of the lower temperatures and reduced insect abundance. Likewise, the Brooks, Loeb, and Gerard (2017) study of eastern red, evening, and tri-colored bats' foraging activity found that insect abundance declined as elevation increased.

3.6.2 Percent slope

In 15 of the 69 (22%) studies evaluated, percent slope of the land was most commonly derived through calculations based on elevation using geospatial data sets (Fleming and Jones 2013; Loeb and O'Keefe 2006). Hammond et al. (2016) evaluated roost habitat for Indiana bats in selected rugged terrain of public land areas in the Southern Appalachians. The study found that 45% of the roosts were located in areas of midslope, 35% in upper slope, and 25% in low slope. Preference of steep slopes for eastern small-footed myotis and northern myotis day-roosting habitat was indicated by Johnson et al. (2011).

3.6.3 Air temperature

Air temperature is an important factor for roost, foraging, and hibernation selection. It is measured most commonly as ambient temperature in the field via temperature loggers or collected from climatological records and reported in various temporal frequencies (Brooks, Loeb, and Gerard 2017; Johnson et al. 2011; Duff and Morrell 2007). Reports link increased foraging of big brown, silver-haired, eastern red, evening, hoary, Yuma myotis, California myotis, western long-eared, fringed myotis, Brazilian free-tail, and pallid bats in higher ambient air temperatures to increased insect abundance (Duff and Morrell 2007; Brooks, Loeb, and Gerard

2017). In addition, higher temperatures have been correlated with successful development and rearing of young in eastern small-footed myotis roosting locations (Johnson et al. 2011). Using a maximum-entropy model, Barnhart and Gilliam (2016) demonstrated that maximum temperature of the warmest month was a significant parameter for identifying bat habitat for big brown, silver-haired, eastern red, hoary, northern myotis, little brown, western long-eared, and Townsend's big-eared bats in various locations throughout North Dakota.

4 Conclusion

The scientific literature provided a multitude of metrics to describe habitat requirements for bat presence or absence and noted the top six (6) metrics cited: *percent canopy cover*, *DBH*, *forest type*, *distance to water*, *distance to roads or other urban features*, and *tree density*. While the metrics listed in this review are characteristic of the most commonly cited, they are not the sole determining factors of Chiroptera habitat selection. Metrics identified in this study are intended for application to large-scale generalized estimations of bat habitat use.

This review then recorded the methodology as field-based or geospatially derived for each metric measurement. While field-based measurements are useful for bat habitat research, geospatially derived metrics could also be incorporated into spatial models for rapid assessments of species distribution and temporal trends. Of all the metrics identified, the tree-species-level metrics and atmospheric metrics were more commonly measured in the field, while distance and topographic metrics lend themselves more toward geospatial sources. The articles mentioned nongeospatial sources for the air-temperature metric, but these data can also be obtained in a geospatial format at regional or national scales from the National Weather Service or the National Oceanic and Atmospheric Administration. Landscape-level metrics could be measured either by field or geospatial methods.

Overall, this literature review primarily analyzes metrics that support bat presence in forested habitat areas where foraging and roosting are more prevalent. Cave-dwelling habitats were not as well represented in the 69 studies, which limited the inclusion of potential metrics for determining bat presence, especially for hibernation. While this review attempted to select articles with varying bat species, many articles focused on Indiana bat or northern long-eared bats, probably because of their threatened or endangered species status and disturbance vulnerability. Reported metric sampling was mostly centered on the summer months, which could underestimate bat-presence metrics during the fall months, when foraging activity is increased.

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Appendix A: Full List of Studies Reviewed

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