



## REVIEW

# Maximizing benefits to bat populations through management of power line corridors

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**Abstract**

1. Power line corridors are ubiquitous worldwide and are commonly used by bats as habitat. Targeted management of these corridor habitats has the potential to aid bat populations, which is critically important given the multifaceted threats facing bat species, including the emerging infectious disease white-nose syndrome (WNS) in North America.
2. Here, we review known and potential impacts of management of existing power line corridors on three bat behaviours: foraging, roosting and commuting. We also identify bats in the United States that would benefit from changes to management of power line corridors for improvements to roosting and foraging habitats, particularly species of conservation concern that roost and forage along forest edges.
3. Key recommendations are to avoid disturbance to roosting bats when maintaining vegetation along power line corridors, apply integrated vegetation management to maximize native plant diversity to improve prey options for bats and apply targeted interventions (e.g. artificial roost creation, creation of ponds) in a well-justified ecological context.
4. *Practical implication.* We highlight high-priority research topics to fill knowledge gaps, including testing whether vegetation management treatments targeting plant and insect communities increase bat fitness and cause positive population-level responses in focal bat species. We conclude that building evidence on how bats are affected by power line corridor management is a conservation need.

**KEYWORDS**

Chiroptera, electric power transmission, integrated vegetation management, renewable energy, right of way, transmission lines

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## 1 | INTRODUCTION

Bats are among the most threatened and least-understood groups of mammals worldwide (Frick et al., 2020). In North America, bats are threatened by multiple stressors, including climate change, habitat loss and degradation, wind energy development and the infectious disease white-nose syndrome (WNS; Cheng et al., 2021; Frick et al., 2020; O'Shea et al., 2016). WNS is the single dominating threat to a number of hibernating bat species in North America (Cheng et al., 2021), and it remains unclear if diminished remnant populations will stabilize and recover. Although disease-induced mortality from WNS primarily occurs during winter hibernation, targeted conservation interventions at other times of the year are promising avenues to increase individual fitness that can aid population resilience and recovery (e.g. feeding stations to improve WNS survivorship as in Frick et al., 2023). Additionally, such interventions could help mitigate other pressures that might adversely affect bat populations already weakened by WNS, such as habitat loss and disturbances during the maternity season. Thus, there is considerable interest in scalable solutions to facilitate recovery and resilience of bat populations, especially those affected by WNS.

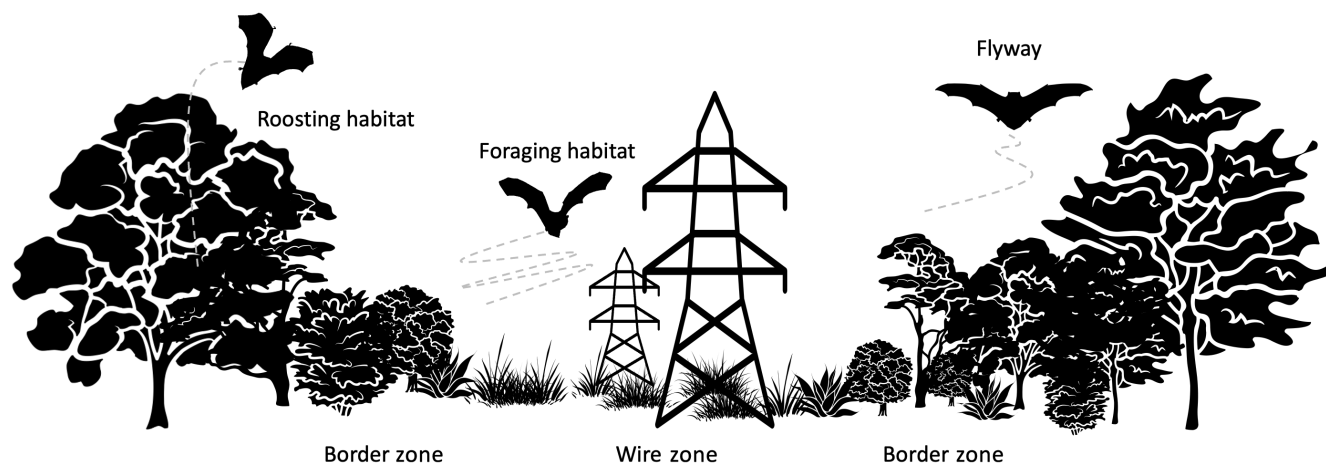
Utility power transmission lines are ubiquitous throughout natural and developed areas around the world. For example, as of 2018, there were roughly 700,000 miles of high-voltage electric transmission lines across the United States (U.S. Energy Information Administration, 2018). With growing energy demand and conversion to renewable energy, the number of new within-region lines required to meet high-load/high-clear energy scenarios is likely almost 1.5 times that of existing lines in 2020 (United States Department of Energy, 2023, p. 144). The spaces cleared of tall vegetation for utility transmission lines (i.e. power line corridors) can be used by bats for roosting, commuting and foraging habitats (Figure 1; e.g. Brack Jr. et al., 2022; Johnson & Strickland, 2004; Saugey et al., 1989; Tella et al., 2020). Given their ubiquity on the landscape and interest from electric power companies in mitigating impacts to protected species,

there is great potential in managing power line corridors to maximize potential benefits to bat populations.

Power line corridor management has the potential to support healthy populations of species or communities of conservation interest, an interest compatible with their fundamental purpose of transmitting electric energy. Here, we review the known and possible interactions between bats, power line corridors and power line corridor management actions through narrative review. The aim of this review was to provide guidance and perspective in identifying potential interventions helpful for managing bat populations as well as to identify key knowledge gaps. Although we chose to centre our aims on temperate North American species, particularly those impacted by WNS, we synthesize information on power line management and bat ecology worldwide. Finally, we summarize key recommendations for both current management and areas of future research.

## 2 | MANAGEMENT AND STRUCTURE OF EXISTING POWER LINE CORRIDORS

Power line corridors are strips of land that have been cleared of trees and other vegetation to prevent damage to electric lines and disruption of electric service. In North America, utility companies adhere to North American Electric Reliability Corporation (NERC) standards (FAC-003-5) which mandate the establishment of minimum vegetation clearance distances surrounding high voltage transmission lines using vegetation management practices (the 'wire' and 'border' zones; Figure 1). The required minimum vegetation clearance distance required by NERC will vary depending on line voltage, the type of current carried (e.g. alternating or direct current), ambient temperature, load and elevation (North American Electric Reliability Corporation, 2020). Lower voltage power lines (below 100kV) have less required clearance distances and fall under state and local regulatory oversight. To ensure vegetation clearance distances are not



**FIGURE 1** A conceptual illustration of a power line corridor and common behavioural uses by North American bats. Maintenance of power line corridors generally includes a low-growing area immediately beneath and adjacent to power lines (the 'wire zone') and a 'border zone' free of tall vegetation and debris.

violated, utilities systematically inspect lines and periodically address immediate vegetation threats (e.g. trees at risk of falling on power lines), as well as implement long-term system-wide vegetation management plans.

Vegetation management across the entire line system typically occurs across a 3- to 5-year cycle, depending on the utility company, with vegetation management targeting a section of the system each year. Standard techniques for maintaining power line corridor vegetation height include general or targeted mowing, cutting, hand removal or herbicide application to maintain compatible low-growing vegetation. Many companies use integrated vegetation management (IVM) practices which predominantly use a combination of targeted chemical and mechanical methods to control tall-growing trees and shrubs while favouring a competitive herbaceous layer that naturally inhibits re-establishment of incompatible vegetation (Miller, 2021; Tree Care Industry Association, Inc, 2012). IVM can provide significant cost savings over the long term compared to more traditional cycle-based programmes that are not responsive to changes in vegetation in power line corridors (Turk, 2015; Yahner & Hutnik, 2004). Furthermore, IVM approaches can include promoting native plant communities by planting native seed mixes, and controlling invasive species that likely benefit insects and other wildlife.

## 2.1 | Habitat types maintained by power line corridors

The plant communities within power line corridors often represent a subset of the native and non-native regional plant diversity. A key aspect of these plant communities is that their structural compositions are managed to maintain limited vegetation height within the corridor. Three common and overlapping categories of habitat are commonly maintained at power line corridors: early successional habitat, low-vegetation habitats and edge habitats.

Corridors transecting forested environments are often associated with early successional habitat, where tall-growing trees are periodically removed or trimmed, and vegetation management regimens are implemented to favour the growth of stable low-growing plant communities comprising grasses, forbs and shrubs (Nowak & Ballard, 2005). In natural forested ecosystems, early successional habitats represent an initial stage in the regeneration of forests following a perturbation (e.g. fire, flood and storm) and prior to eventual reforestation. The maintenance of power line corridors introduces periodic, artificial perturbation that commonly maintains early-successional plant communities (Niering & Goodwin, 1974). Thus, the sustained vegetation management of power line corridors presents an opportunity to protect and conserve species that depend on early successional habitat (Oki et al., 2021).

Power line corridors can also support prairie, grassland, scrub and other low-vegetation habitats that are not early successional (Askins, 2001; Garfinkel et al., 2022; Lampinen et al., 2015).

Supporting these habitats can offer important opportunities for conservation as grasslands, in particular, have experienced significant declines. For example, <44% of the Great Plains' historical grassland and shrubland remains (Augustine et al., 2021), and only 5% of North America's tallgrass prairies remain intact (Rice et al., 2018). When managed to support grasslands, power line corridors can provide refugia for grassland and scrub plants, including threatened species (Sheridan et al., 1997). Supporting diverse plant communities can, in turn, support higher trophic-level species that rely on grasslands for food resources. For example, declining grassland bird species (Askins et al., 2012) can be supported in low-vegetation habitats occurring along power line corridors (Confer & Pascoe, 2003; Hunter et al., 2022; King & Byers, 2002), as can rare savanna (Forrester et al., 2005), grassland butterflies (Berg et al., 2011, 2013), scrub-dwelling birds (King et al., 2009) and threatened bees (Russell et al., 2005).

When power line corridors intersect habitat distinct from the low-vegetation type maintained within them, edge habitat is inevitably created. In forested landscapes, power line corridors create edges associated with increased visibility, light and open space for animal movement (Murcia, 1995). Forested edges influence the abundance, distribution and behaviour of organisms (Eldegard et al., 2015; Kroodsma, 1982). Although edge habitat is commonly associated with the negative impacts of habitat fragmentation (e.g. Fletcher Jr., 2005; Murcia, 1995; Ries et al., 2004), some species are less sensitive to the effects of habitat edges (Ries & Sisk, 2010) and may be associated with edges, including those along power line corridors (e.g. Kroodsma, 1982).

## 3 | IMPROVING FORAGING FOR BAT POPULATIONS

### 3.1 | Insectivorous bats may use power line corridors as foraging habitat

Early successional, low-vegetation and edge habitats can provide important foraging opportunities for bats, as demonstrated by studies documenting differences in foraging or general activity in various habitat types. Bats that are adapted to forage in open habitats are expected to benefit the most from early successional habitat (Loeb & O'Keefe, 2011), although clutter-adapted bats may also benefit as they can forage in both cluttered and open environments (Brooks, 2017). Bats' use of early successional habitats for foraging varies depending on habitat characteristics, such as patch size and vegetation type (Loeb & O'Keefe, 2011). Landscape-scale features, such as nearby land cover, can influence bat habitat use (Starbuck et al., 2015). Many bats prefer forested and water edges to open prairie and forest interiors (Everette et al., 2001; Hein et al., 2009; Slough et al., 2023). Forest gaps and patches of disturbed habitat, which likely attract bat species that prefer both open and edge habitats, are associated with heightened bat activity across several bat species and foraging guilds (Dodd et al., 2012; Erasmy et al., 2021;

Loeb & O'Keefe, 2011). Habitat heterogeneity, a measure of the complexity of spatially integrated habitat types (e.g. forested cover, forest edge, riparian corridors and wetlands and other water bodies), is likely another important factor in whether a given area can help to support the full annual cycle of bats' needs (Cable et al., 2021; Dodd et al., 2008; Johnson & Lacki, 2013).

Multiple factors may contribute to why many bat species prefer to forage in low vegetation, early successional or edge habitats. These habitats are associated with less clutter than interior forested habitat, which may facilitate higher rates of foraging efficiency (Grindal & Brigham, 1999; Loeb & O'Keefe, 2011). As linear features, forested edges can be used as travel corridors (see Section 4), which may drive higher incidental foraging activity during commutes along and within power line corridors (Grindal & Brigham, 1999; Morris et al., 2010). Another factor that may drive bat preferences for forest edges is heightened insect abundance (Deans et al., 2005; Dodd et al., 2008; Grindal & Brigham, 1999; Johnson & Lacki, 2013; Morris et al., 2010), although early successional habitats have variable relationships relative to mature forests in terms of both insect abundance (Loeb & O'Keefe, 2011) and insect diversity (Burford et al., 1999).

In general, while potentially beneficial features attract some organisms to edges and successional habitats for foraging, others may avoid edges and open areas (Ries & Sisk, 2010). For example, the small-bodied, high-frequency echolocating *Myotis* species tend to be more active within larger, intact forests than open areas or edges (Beilke et al., 2021; Morris et al., 2010; Owen et al., 2004; Patriquin & Barclay, 2003). However, the context of open areas within the broader landscape matrix is likely crucial (Loeb & O'Keefe, 2011), as some *Myotis* species may prefer small natural gaps or forage in low- to medium-density vegetation (Beilke et al., 2021; Loeb & O'Keefe, 2006).

### 3.2 | Management for insect prey may enhance bat foraging habitat

Existing corridor management may provide foraging habitat for some bats, and targeted management could potentially increase desirable insect prey. Power line corridors located in agricultural areas can serve as refuges for insect pollinators by providing access to greater plant diversity than crop monocultures (Nicholls & Altieri, 2013). Increasing the diversity of native plants in power line corridors while minimizing the spread of invasive plants could increase insect diversity and abundance (Swab et al., 2017). For example, power line corridors maintained as restored prairie or as brush on a 5-year maintenance cycle exhibit increased insect diversity relative to mown turf grass (Garfinkel et al., 2022). Many IVM strategies focus on increasing abundance or diversity of diurnal insect pollinators; enacting strategies such as adjusting the timing and frequency of herbicide spray or vegetation removal (Acklen & Goodrich-Mahoney, 2017), reducing herbicide levels (Russo et al., 2021), and preserving flowers favoured by insect pollinators by avoiding mowing (Hopwood et al., 2015) or herbicide spray

during peak flowering times (Kovács-Hostyánszki et al., 2017) can positively impact pollinator diversity and abundance, which likely increases overall insect diversity and abundance. As bats may be particularly vulnerable to the bioaccumulation of pesticides (Cable et al., 2022; Jones et al., 2009), including chemicals used in broad-spectrum herbicides (Hooper et al., 2022; Kuzukiran et al., 2021; Martín et al., 2023; Schanzer et al., 2022), strategies that reduce overall pesticide use in bat habitat may also improve bat fitness (Frick et al., 2007). Early work suggests that experimentally increasing the local abundance of insect prey increases bat foraging activity by a WNS-affected species (Frick et al., 2023). Less is known about the optimal methods for promoting healthy insect prey populations and how they translate into demographic effects in bat populations (Box 1.2).

## 4 | MANAGEMENT OF CORRIDORS FOR ROOSTING HABITAT

### 4.1 | Bats roost within and near power line corridors

Bats that roost in tree cavities and bark, foliage (either on tree branches or fallen on the ground) or in caves might be impacted by nearby management activities of power line corridors. Roosts provide critical habitat that supports the energetic and biological needs of bats according to their sex, age and reproductive condition, and individual roosting needs vary with seasonal change and across ecoregions (Kunz, 2003). As most temperate bat species shift habitats between the warm and cool seasons, roosts are commonly characterized as 'summer' or 'winter' roosts. Within seasons, bats may use multiple roosts and may switch between roosts regularly. Roost type and behaviour vary by species. A species may roost solitarily, communally or use both strategies. Roosts are often used for sleep and hibernation, but they are also important for raising young, mating and social activity. Bats are particularly vulnerable to roost disturbances while raising their young (Kunz, 2003; The Protection of Bat Roost Guidelines Subcommittee et al., 1992).

Several species of bats are likely to roost along or near power line corridors when corridors pass through forests. Maternity colonies, in particular, often select roosts with high solar exposure, which likely minimizes energy expenditure (Lausen & Barclay, 2006; Willis et al., 2006). Associations between roost selection and locations along forested edges are documented for the following species: *M. evotis* (Rancourt et al., 2005), *M. sodalis* (Callahan et al., 1997; Carter & Feldhamer, 2005) and *Myotis* spp. (Grindal & Brigham, 1999). Several species are known to roost in early successional habitat, including *M. septentrionalis* (Menzel et al., 2001, 2002) and *Lasiurus* spp. (Leput, 2004; Mager & Nelson, 2001; O'Keefe et al., 2009; Perry et al., 2008), as well as in forest gaps (*Lasionycteris noctivagans*, Campbell et al., 1996; *Perimyotis subflavus*, Perry et al., 2008). Although not present in the wire zone, roost trees may be located along the edges of power line corridor border zones (Figure 1).

## BOX 1 Highlighted research areas that would improve capacity and implementation of power line corridor management to support bat populations

**1.1 Describe power line corridor use by bat community assemblages.** Many North American bat species appear to use power line corridors as foraging, roosting and commuting habitats (Table 1), but overall data on this type of habitat use are sparse (Table 1). Improved understanding of species-, season- and region-specific use of power line corridors is essential to inform local and general management of corridors. Identifying species that avoid power line corridors, possibly by comparing community assemblages on and off corridors, would also inform understanding how species might respond to current and future power line installation.

**1.2 Identify management practices that improve foraging success or efficiency.** Most North American bats are insectivorous, and their populations likely depend on the abundance and diversity of suitable insect prey. Insect diversity and abundance are strongly related to the plant communities that shape habitat structure, the availability of host plants for larval insects and the availability of nectar and pollen resources for pollinators (Borer et al., 2012; Ebeling et al., 2018; Scherber et al., 2010). Research on bat dietary compositions is a growing area (e.g. Bernard et al., 2021; Clare et al., 2009; Clare, Symondson, Broders, et al., 2014; Clare, Symondson, & Fenton, 2014; Ingala et al., 2021). However, little is known about the direct relationships between plant communities, insect communities and bat populations. Priority areas of research include measuring how and if targeted conversion to and support of native plant assemblages (e.g. through seeding or IVM) impacts nocturnal insect abundance and bat foraging activity. Ideally, studies should control for effects of vegetation structure and plant diversity since insects may select for more open versus more sheltered areas based on functional traits like body size (Loeb & O'Keefe, 2011). Detection probability for both bats and insects likely vary with functional traits and vegetation structure (Iknayan et al., 2014).

**1.3 Establish best practices for generating and maintaining bat roosts.** Although much work has been done to study specific techniques for designing and siting artificial roosts and generating snags (see Section 4.2.2), the long-term effects they have on local and regional bat populations remain unclear. Future research should investigate the efficacy of created roosts and examine when and where roost generation is most beneficial. In addition, future research should focus on improving strategies for power line corridor maintenance crews to identify and retain current and potential roost trees and local, site-specific understanding of mitigation best practices that focus on species-, ecosystem- and region-specific contexts. For example, potentially hazardous trees that would otherwise be removed might be 'tree-topped' and converted into artificial snags. We also note that colonization of roost trees and artificial roosts is not an optimal indicator of 'conservation success' (Crawford & O'Keefe, 2023). Instead, we encourage future work into the demographic consequences of roost augmentation and supplementation. For example, does artificial roost installation support survival and reproductive success over time and in different regions? The use of passive acoustic monitoring and passive integrated transponder tags has the potential to support this line of inquiry (O'Shea et al., 2004; van Harten et al., 2019).

**1.4 Expand research on encouraging bat movement through human-modified habitats.** The majority of bat species of current conservation concern in the United States are likely willing to use forest edge habitat and are thus unlikely to be restricted by power line corridors (Table 1). Power line corridors may help some species move through human-modified landscapes. Targeted tracking studies could confirm this and provide insight into whether bats use power line corridors to increase foraging and commuting efficiency. In contrast, bats with limited dispersal capacities (e.g. *Myotis leibii*; Table 1) or clutter-adapted species that may be reluctant to cross open areas (e.g. *M. septentrionalis*; Table 1) might have less connectivity across habitat patches bisected by power line corridors. Targeted research can evaluate the efficacy of methods that may restore genetic connectivity when intervention is necessary (e.g. Berthinussen & Altringham, 2012; Claireau et al., 2019; see also Soanes et al., 2024).

**1.5 Explore the use of constructed ponds to improve habitat.** Construction of artificial ponds within power line corridors has been demonstrated to increase bat activity in a water-limited area (Brack Jr. et al., 2022). Improved access to water bodies may benefit bats, but little is known about the long-term effectiveness of artificial water bodies. As many bats are sensitive to water quality (Kalcounis-Rueppell et al., 2007; Li & Kalcounis-Rueppell, 2018), design or management limitations that result in polluted or eutrophic water bodies may counter ecological benefits. Future research should include monitoring bat activity and fitness relative to use of artificial water bodies and how their features change over time. These studies could also assess if constructing water bodies would be a scalable solution for utilities, given the regulatory, cost and operating constraints of power line corridors.

**TABLE 1** Selected bat species occurring in the United States and Canada, based on their conservation status and/or likelihood of roosting or foraging in proximity to corridors, that may benefit from vegetation management within power line corridors. We included species that have federal listing protection and a selection of species that seemed likely to utilize power line corridors, based on the research conducted as part of this review.

Species	Conservation status and considerations	Tree roosting? <sup>a,b</sup>	Foraging space <sup>a,b</sup>	Reported activity in power line corridors
<i>Corynorhinus rafinesquii</i> Rafinesque's big-eared bat	SGCN: 17 states <sup>c</sup>	Yes: year-round	Edge	
<i>C. townsendii</i>	SGCN: 13 states <sup>c</sup> ESA: Endangered ( <i>virginianus</i> and <i>ingens</i> subspecies) <sup>d</sup>	No	Edge	
<i>Eptesicus fuscus</i> Big brown bat	SGCN: 21 states <sup>c</sup>	Yes: summer	Edge	Roosts in artificial roost in corridor (Brack Jr. et al., 2022)
<i>Euderma maculatum</i> Spotted bat	SGCN: 9 states <sup>c</sup> COSEWIC and SARA: special concern <sup>e</sup>	No	Open	
<i>Idionycteris phyllotis</i> Allen's big-eared bat	SGCN: 4 states <sup>c</sup>	Yes: summer	Edge	
<i>Lasiurus borealis</i> Eastern red bat	SGCN: 18 states <sup>c</sup> COSEWIC: endangered <sup>e</sup>	Yes: year-round	Edge	Forages within corridors (Saughey et al., 1989)
<i>Myotis austroriparius</i> Southeastern myotis	SGCN: 17 states <sup>c</sup>	Yes: summer	Edge	
<i>M. evotis</i> Long-eared bat	SGCN: 5 states <sup>c</sup>	Yes: year-round	Narrow	
<i>M. grisescens</i> Grey bat	SGCN: 14 states <sup>c</sup> ESA: endangered <sup>d</sup>	No	Edge	
<i>M. leibii</i> Eastern small-footed bat	SGCN: 25 states <sup>c</sup>	No	Narrow	
<i>M. lucifugus</i> Little brown bat	SGCN: 37 states <sup>c</sup> ESA: under review <sup>d</sup> COSEWIC & SARA: endangered <sup>e</sup> IUCN: endangered <sup>f</sup> WNS-caused 96% decline <sup>g</sup>	Yes: summer	Edge	Found within power line corridors (Brack Jr. et al., 2022)
<i>M. septentrionalis</i> Northern long-eared bat	SGCN: 36 states <sup>c</sup> ESA: endangered <sup>d</sup> COSEWIC & SARA: endangered <sup>e</sup> IUCN: near-threatened <sup>f</sup> WNS-caused >99% decline <sup>g</sup>	Yes: summer	Narrow	Roosts adjacent to corridors (Burrell & Bergeson, 2022; Swingen et al., 2018); found within power line corridors (Brack Jr. et al., 2022)
<i>M. sodalis</i> Indiana bat	SGCN: 23 states <sup>c</sup> ESA: endangered <sup>d</sup> IUCN: near-threatened <sup>f</sup> WNS-caused 30% decline <sup>g</sup>	Yes: summer	Edge	Roosts along corridors (Brack, 2006); uses corridors for commuting (Johnson & Strickland, 2004)
<i>Perimyotis subflavus</i> Tricolored bat	SGCN: 30 states <sup>c</sup> ESA: proposed endangered <sup>d</sup> COSEWIC & SARA: endangered <sup>e</sup> IUCN: vulnerable <sup>f</sup> WNS-caused 93% decline <sup>g</sup>	Yes: summer	Edge	Found within power line corridors (Brack Jr. et al., 2022)

<sup>a</sup>Loeb and O'Keefe (2011).

<sup>b</sup>Barbour and Davis (1969).

<sup>c</sup>Species of Greatest Conservation Need (SGCN), [https://www1.usgs.gov/csas/swap/national\\_list.html](https://www1.usgs.gov/csas/swap/national_list.html), accessed 2 July 2024.

<sup>d</sup>U.S. Fish and Wildlife Service Environmental Conservation Online System. <https://ecos.fws.gov/ecp/species/9051>, accessed 2 July 2024.

<sup>e</sup>Committee of the Status of Endangered Wildlife in Canada (COSEWIC) and Species at Risk Act (SARA), <https://www.canada.ca/en/environment-climate-change/services/species-risk-public-registry.html>.

<sup>f</sup>International Union for Conservation of Nature (IUCN), <https://www.iucnredlist.org/>, accessed 2 July 2024.

<sup>g</sup>Cheng et al. (2021).



## 4.2 | Management considerations related to bat roosts

The protection of bat roosts is a major focus of bat conservation (Frick et al., 2020; Medellín et al., 2017; Meierhofer et al., 2023; The Protection of Bat Roost Guidelines Subcommittee et al., 1992). A number of published reports and reviews are available with recommendations on best practices to promote forested habitat for bats (e.g. Hayes & Loeb, 2007; Lacki et al., 2007), and these resources should be referred to when developing strategies to enhance roosting habitat. Here, we summarize general considerations to limit negative effects of vegetation management on roost habitats for temperate insectivorous bats based on our understanding of their roosting ecology. Broadly, corridor management poses potential risks to known or possible bat roosts, a topic that has not been well studied or documented. Type and magnitude of impacts to individual bat roosts are dependent on the temporal and spatial overlap of active bat roosts with the periodic, site-specific management actions that would disturb roosting bats. We focus on responding to general trends for temperate insectivorous bats, and we encourage managers to develop plans specific to their region and species of interest, and to address site-specific threats to roosting habitat, which may vary over time and space.

### 4.2.1 | Minimize disturbance to summer maternity colonies

The protection of maternity colonies is a key component in conserving bat populations, and is a major focus of protection in recovery plans for US endangered bat species (Bagley, 1984; Brady et al., 1982). Loss and degradation of summer forested habitat is thought to be one of the main contributing factors leading to the historic declines of *M. sodalis* in the 1960–1970s (Gardner et al., 1990; Garner & Gardner, 1992; U.S. Fish and Wildlife Service, 1983; Whitaker Jr. et al., 2002). Most temperate insectivorous bat species produce only a single pup per female annually, which sets life-history constraints and limits maximum growth rates (Barclay et al., 2003; Racey & Entwistle, 2000). Thus, the destruction of maternity tree roosts is problematic because often it involves, at a minimum, the loss of reproductive effort for an entire colony for the year. Loss of suitable roosts, even when roosts are not currently in use, can also degrade the quality of a network of potential future roosts among groups of breeding females (Bondo et al., 2019; Perry, 2011), increasing the distance travelled between roosts (Silvis et al., 2014) and disrupting the social network of a colony (Silvis et al., 2015).

The timing of vegetation management could reduce direct impacts on reproductive females and their young. Specifically, managers should avoid tree removal of active maternity roost trees. Maternity season varies with species and geographic location, but May to August broadly defines the season for insectivorous bat species in temperate North America (U.S. Fish and

Wildlife Service, 2023). Bats are most vulnerable to disturbance of maternity roost trees in summer after pups are born but before they can fly, generally in June and July (U.S. Fish and Wildlife Service, 2023), although precise timing varies by species and location. Tree-clearing activities that directly impact maternity trees likely pose the greatest direct risk to maternity colonies. However, indirect impacts—which in power line corridors might include noise and chemical exposure from mowing, cutting or spraying of nearby vegetation—can also disrupt existing maternity colonies, which in severe cases could prompt abandonment of roosts (López-Roig & Serra-Cobo, 2014; Sano, 2016).

### 4.2.2 | Artificial and augmented roosts can be installed in power line corridors

Bats select roost trees based on several characteristics and often select larger trees as roosts, including living or dead trees with exfoliating bark, hollow limbs and crevices (Kunz, 2003). A number of species also favour snags, and the creation of snags (an 'augmented roost' generated from an existing tree) is a growing area of research (Box 1.3). Snags can be created through a variety of methods (Schroder & Ward, 2022) and have the benefit of mimicking the thermal properties of naturally occurring roosts in caves and tree cavities, making them potentially more attractive than artificial roosts such as bat boxes (Crawford & O'Keefe, 2023). One study from Australia reported a 50% occupancy rate by bats in cavities created by chainsaws (Rueegger, 2017). Because snags have a shorter lifespan than artificial roosts, they tend to require more maintenance (e.g. generation every few years) than artificial roosts (Schroder & Ward, 2022). Managers could potentially support tree-roosting bats by avoiding complete removal of desirable living trees and creating snags in dead trees when these are a limiting resource.

Artificial roosts, particularly the installation of bat boxes, are a popular means of providing roosting habitat to several bat species, including along and within power line corridors (e.g. Brack Jr. et al., 2022). Installation of artificial roosts is generally conducted as a surrogate for tree roosts (Rueegger, 2016). Provision of artificial roosts is a common low-cost strategy used in bat management in response to exclusion, disturbance or destruction of an existing roost (Holroyd et al., 2023). Because the quality of a roost site has direct influences on the survival and fitness of individual bats (Rueegger, 2016), the design (Crawford et al., 2022; Fontaine et al., 2021; Tillman et al., 2021), siting (Crawford et al., 2022; Mering & Chambers, 2014; Pschonny et al., 2022) and maintenance (Holroyd et al., 2023; Rueegger, 2016) of artificial roosts must be maximized to avoid attracting bats to unsuitable roosts (an *ecological trap*; see Battin, 2004; Holroyd et al., 2023). Bat boxes have been associated with potential disadvantages, including higher internal temperatures that are harmful to bats (Crawford & O'Keefe, 2021), and the potential for increased predation and higher parasite loads than ephemeral roosts in trees (Crawford & O'Keefe, 2023). In general,

artificial roosts continue to be widely deployed with mixed success of colonization by bats (Brittingham & Williams, 2000; Hoeh et al., 2018). Additionally, artificial roosts commonly colonized by bat species that are not the target of conservation efforts. In such cases, artificial roosts might increase competition towards conservation target species (Griffiths et al., 2017; Mering & Chambers, 2014; Ruegger, 2017). The benefits of artificial roosts would be maximized by careful siting, design and deployment in locations where suitable tree roosts have been or must be removed (Box 1.3; Holroyd et al., 2023), including in power line corridors.

#### 4.2.3 | Reduce disturbance to winter populations

Winter is a sensitive time for bats, particularly for hibernating species that use torpor to reduce energy expenditure, because disturbances can result in loss of critical fat reserves (Boyles, 2017; Speakman et al., 1991). While many hibernating bats use subterranean features during the winter, a number of species use trees (Kunz, 2003) and even leaf litter (e.g. Moorman, 1999) in the winter. There are some concerns that bats may not be able to arouse from a torpid state in time to escape disturbances in the winter months (Flinn et al., 2021), meaning management activities during this interval could have negative impacts. Timing winter vegetation management to relatively warm days and warmer times of day would decrease energetic expenditure required for bats to escape disturbance (Flinn et al., 2021; Layne et al., 2021).

## 5 | MANAGEMENT OF CORRIDORS FOR BAT MOVEMENT

### 5.1 | Bats use power line corridors as commuting flyways

Bats are sophisticated navigators that will undertake long-distance directed flights between destinations (Harten et al., 2020; Toledo et al., 2020), often using consistent routes known as 'flyways' (Bateman & Vaughan, 1974; Boere & Stroud, 2006; Schaub & Schnitzler, 2007). Forest edges and linear features are likely used as navigational cues by many species (Schaub & Schnitzler, 2007), aiding in the establishment of familiar flight paths and reducing overall commuting time (Bateman & Vaughan, 1974). Flyways are generally associated with higher bat activity levels when compared to open areas (Boughey et al., 2011; Finch et al., 2020; Harms et al., 2020), and bats generally travel closer to treelines when commuting than when foraging (Downs & Racey, 2006; Kalcounis-Rueppell et al., 2013). Linear landscape features serve as flyways for bats because edges provide navigational assistance, likely by maintaining acoustic contact (Verboom & Spoelstra, 1999), and energetically efficient routes sheltered from wind and free of obstructions (Verboom & Huitema, 1997, 2010; Verboom & Spoelstra, 1999). Some bat species strongly prefer routes tracking tall treelines, while others are less selective and follow tree and shrub lines regardless

of vegetation height (Boughey et al., 2011; Downs & Racey, 2006; Finch et al., 2020). Power line corridors may act as flyways for many species, but may also present barriers to bats reluctant to cross open areas, for example, the small *M. leibii* or clutter-adapted *M. septentrionalis* (Box 1).

### 5.2 | Management considerations for bat commuting along power line corridors

Outside of siting considerations during installation, management of power line corridors for bat commuting will broadly be dependent on the context of known bat communities, commuting habits and surrounding environmental conditions. When possible, maintaining consistent treelines along corridors when they pass through forested habitat could maximize the navigational benefits to bats already using them as flyways. Other interventions that may benefit the movements of dispersal-limited species remain in the exploratory research phase (Box 1.5).

## 6 | CONCLUSIONS

There is a continued need for solutions to facilitate recovery and resilience in bat populations, particularly those affected by WNS. Power line corridors remain a pervasive and growing form of human-managed habitat in much of the world that is critical for energy infrastructure. Ecological management of power line corridors has potential to help support bat populations by promoting foraging and commuting habitat and by protecting roosts. Bat prey availability and foraging efficiency may be supported within actively maintained corridors that are periodically disturbed and result in permanent edge, open and early successional habitats. Promotion of desirable foraging habitat near roosts could increase foraging efficiency and lead to increased survival from WNS and increased reproductive success. In addition, active management of trees and instalment of artificial roosts along corridors could support at-risk bat populations.

These corridors represent hundreds of thousands of miles of managed land that could be leveraged and managed in a way to make meaningful positive impacts to bats in need of conservation assistance. To fully capitalize on the potential of power line corridors as conservation spaces, it is necessary to build a body of evidence on their conservation value and the effectiveness of management practices for bat populations. These results would serve as a critical resource in developing vegetation management strategies that might improve conditions for bat populations while meeting energy generation and transmission goals.

### AUTHOR CONTRIBUTIONS

Winifred F. Frick, Christian Newman, Tina L. Cheng, Donald I. Solick, Ashley Bennett and C. J. Campbell conceived the study; Christian Newman coordinated funding to support the study; C. J. Campbell, Tina L. Cheng and Karin L. Akre designed and conducted the review;



Amanda M. Adams and Tina L. Cheng led the data synthesis within Table 1; C. J. Campbell, Tina L. Cheng and Karin L. Akre led the writing of the manuscript. All authors contributed critically to the drafts and gave final approval for publication.

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## CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

## DATA AVAILABILITY STATEMENT

No data were collected as part of this study.

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