# Species Status Assessment Report

# For the

# Mexican Long-nosed bat *(Leptonycteris nivalis*)

# Version 1.1

*Mexican long-nosed bat*
*Photo Credit: Carson M. Brown*

***U.S. Fish and Wildlife Service***
***Region 2***
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Species Status Assessment Report for the
Mexican long-nosed bat (*Leptonycteris nivalis*)
Prepared by the
U.S. Fish and Wildlife Service

# EXECUTIVE SUMMARY

This species status assessment reports the results of a comprehensive status review for the Mexican long-nosed bat (*Leptonycteris nivalis*) and provides an account of the species' overall viability and extinction risk based on the best available data. The Mexican long-nosed bat is a migratory, nectar-feeding species found in Mexico and the southwestern United States. They generally occupy cool-temperature caves at high elevation. The species relies on nectar and pollen resources of several flowering plant species along their presumed migratory route between wintering and mating areas in southern Mexico and summer maternity areas in northern Mexico and the United States.

To evaluate the biological status of the Mexican long-nosed bat both currently and into the future, we assessed a range of conditions to allow us to consider the species' resiliency, redundancy, and representation (the 3 Rs). The Mexican long-nosed bat is currently considered a single population based on genetic evidence but is characterized by multiple subpopulations corresponding to the major roost sites across the known distribution that are used seasonally. Several factors influence resilience of colonies of Mexican-long nosed bats. These factors are generally in two categories: availability of foraging resources and existence of adequate roost sites. The species needs multiple resilient subpopulations distributed across its range to maintain its persistence into the future and avoid extinction.

The needs of the Mexican long-nosed bat are strongly influenced by their migratory habits. Males and females appear to remain in central and southern Mexico during the winter when mating occurs, but females leave in the spring to migrate north to give birth in caves in northern Mexico and southwestern United States (Texas). This subpopulation of females and juveniles then migrate south to central and southern Mexico in the fall. This migratory subpopulation forages on flowering plant species (primarily *Agave*) along the route forming a "nectar corridor" and therefore the timing and availability of these resources are critical to their survival.

The Mexican long-nosed bat faces a variety of risks that we have evaluated based on the knowledge and expertise of biologists working with this species as well as published reports. The primary stressors to the population include the availability of adequate roost sites and sufficient forage plant species and habitat connectivity to support annual migratory movements. Climate modeling shows that changing climate will exacerbate all of these risk factors. Currently, disease does not appear to be a major risk factor affected the Mexican long-nosed bat.

Roost site disturbance or loss is the primary threat to this species. Factors such as human disturbance due to vandalism, recreation, and vampire bat control can impact a colony. Because the colonial roosting behavior results in large proportions of the population being congregated, it increases the likelihood of significant declines or extinction if major roost sites are impacted.

Mexican long-nosed bats are known to consume the nectar or pollen from at least 49 different species of flowering plants across the range, however species in the genus *Agave* are a very important component of the diet. Therefore, declines in availability of flowering *Agave* were identified as a major stressor to colonies of Mexican long-nosed bats both near their roost site and along migratory routes. Foraging resources within 50km of a roost site were considered most important to the bat. Loss of foraging resources due to drought, fire, *Agave* harvest, and urban development has the potential to greatly impact the viability of the species.

Currently, Mexican long nosed bats are known from approximately 30 roost sites, primarily in Mexico. Eleven of these roost sites have been studied or monitored in the last 20 years, two of these are in the United States (Mount Emory Cave and Romney Cave). For a few sites, especially in the extremes of the distribution, the roosts have been well-studied and seasonality, colony size, reproductive aspects, diet and foraging habits have been characterized. Little or no information is available for the species and roosts along the migratory path.

> Resiliency - Overall northeastern Mexico and southwestern United States have resilient roosts mainly due to the isolation of the roosts and subsequently less disturbance to their foraging grounds. These two regions are most vulnerable from a lack of floral diversity. Central and east Mexico are less isolated and therefore have greater disruption to flowering ability of floral resources. These two regions are also vulnerable to human disturbance of the caves with lower resilience in terms of barriers to cave disturbance and level of protection.
>
> Representation - Currently, central Mexico has the greatest representation with 5 extant roosts, one that has high resiliency, three of which are moderately resilient, and one that has low resiliency. East Mexico has the lowest representation with one moderately resilient roost. Northeastern Mexico and the southwestern United States each have one moderately resilient roost and one highly resilient roost.
>
> Redundancy - Using the best information available, the bat has a low to moderate redundancy in terms of total number of roosts because of the lack of resilient roosts across its broad range. However, if the roost type is considered, redundancy is even lower. There are three known maternity roosts, one that is moderately resilient and two that are highly resilient. More importantly, there is only one known mating roost (Cueva Del Diablo) in central Mexico that is moderately resilient. Disturbance of Cueva Del Diablo could have significant effects on the entire species regardless of the number of other roosts, making the Mexican long-nosed bat vulnerable in terms of redundancy.

For the purpose of the status assessment, we considered future risks and evaluated their potential impact on the Mexican long-nosed bat. Our analysis of future scenarios was driven by uncertainties in changing habitat use, changing climate, and changing levels of protection, and was complicated by the lack of knowledge for the species. However, we identified three scenarios and evaluated the effect of each to the best of our ability on the future availability of appropriate roost conditions and the availability of forage resources for nine major roost sites. We projected the expected future resiliency, representation, and redundancy for each roost under each scenario to the year 2050 (Table ES-1).

## Optimistic scenario:

## Status Quo scenario:

- Aguacatitla Tunnel, Xoxafi and Tziranda Caves: Urbanization and land use change further impact foraging resources. Hotter and drier climate affect phenology of floral resources, increasing risk of roost abandonment.
- Cueva del Diablo: Levels of roost disturbance and loss of foraging habitat due to land use and climate change increase, increasing the probability of roost abandonment.
- De La Peña Cave: Loss of foraging habitat due to urbanization, land use change and climate change greatly reduces the probability of occupation of this roost.
- El Infierno Cave: Urbanization and agricultural land use will increase moderately in the area surrounding the roost, leading to a decrease in habitat condition and abundance of flowering plant species. Climate change and drought will more severely affect *Agave* flowering phenology and survival. Roost disturbance will remain at low to moderate levels, but without increased conservation actions and mitigation projects to counteract changes in foraging resources, the risk of the species' extirpation at this roost is moderate.
- El Rosillo Cave: Urbanization will have little effect on foraging resources, but increased agriculture and the development of shale gas wells in the area will lead to a moderate decrease in habitat condition and abundance of flowering plants. Climate change and drought will more severely affect *Agave* flowering phenology and survival and will moderately increase the harvest of *Agave* for livestock fodder. Roost disturbance will remain low, but without increased conservation actions and mitigation projects to counteract changes in foraging resources, the risk of the species' extirpation at this roost is moderate.
- Mount Emory Cave: Even with increased urbanization in surrounding areas, impact on foraging areas should be minimal. Climate change and drought will severely impact *Agave* survival and flowering phenology, reducing foraging resources. Climate change is expected to increase temperature of the roost that could cause extirpation if severe.
- Romney Cave: No impact of increased urbanization expected because of remote location and protected status. Moderate negative effects of climate change and cattle grazing on the foraging resources are expected.

## Pessimistic scenario:

- Aguacatitla Tunnel, Xoxafi and Tziranda cave: Direct disturbance of roosts increases. Further increase in land use change. Climate change exacerbates wildfire risk, affecting foraging habitat and increasing risk of abandonment.
- Cueva del Diablo: Levels of direct disturbance of roost by urbanization and visitors, greatly increase risk of abandonment. Foraging habitat further decreases due to the combined effects of land use changes and climate changes.
- De La Peña Cave: Loss of foraging habitat due to urbanization, land use change and climate change greatly reduces the probability of occupation of this roost.
- El Infierno Cave: Urbanization and agricultural land use will increase moderately in the area surrounding the roost, leading to a decrease in habitat condition and abundance of flowering plant species. Because of severe impacts of climate change and drought, the timing of *Agave* flowering will not match the timing of

the bats' migration. Roost disturbance will increase due to increased access by visitors. Without education and regulation of access, this will cause disturbance to the bats and possible extirpation of the bats from this roost, particularly in combination with changes in foraging resources.

- El Rosillo Cave: Increased agriculture and the development of shale gas wells in the area will lead to a moderate decrease in habitat condition and abundance of flowering plants. Because of severe impacts of climate change and drought, the timing of *Agave* flowering will not match the timing of the bats' migration and the use of *Agave* for livestock fodder will be significant. These severe effects may lead to abandonment of the roost.
- Mount Emory Cave: Urbanization in surrounding areas could make *Agave* restoration projects more difficult. Severe impact of climate change expected that will reduce available *Agave* habitat. Increased in human disturbance could ultimately result in reduction of the size of the colony. Warming of cave due to climate change could also increase the risk of extirpation.
- Romney Cave: Loss of *Agave* foraging grounds, loss of protection, and an increase in human disturbance would result in drastic reduction in colony size or change in migration patterns.

***Table ES-1.*** *Summary of future resiliency of each roost as a result of each scenario in year 2050, shown by region. Average score (out of 3) across all seven resiliency categories considered is given in parenthesis. There are no estimates for the Eastern Mexico region.*

**Table ES-1 for Central Mexico**

| Roost | Current Conditions | Scenario 1 – Optimistic | Scenario 2 – Status Quo | Scenario 3 – Pessimistic |
|---|---|---|---|---|
| Aguacatitla Tunnel | **High (-2.7)** | **High (-3)** | **High (-2.9)** | **Moderate (-1.8)** |
| Del Diablo Cave | **Moderate (-2.1)** | **Moderate (-2.3)** | **Moderate (-1.7)** | **No Colony** |
| De la Pena Cave | **No Colony** | **Moderate (-1.7)** | **No Colony** | **No Colony** |
| Xoxafi Cave | **Moderate (-2.1)** | **High (-2.9)** | **Moderate (-2.3)** | **Low (-1.4)** |
| Tziranda caves | **Moderate (-2)** | **High (-2.9)** | **Moderate (-2.3)** | **Low (-1.1)** |

**Table ES-1 for Northeastern Mexico**

| Roost | Current Conditions | Scenario 1 – Optimistic | Scenario 2 – Status Quo | Scenario 3 – Pessimistic |
|---|---|---|---|---|
| El Infierno Cave | Moderate (-2.4) | High (-2.6) | Moderate (-2) | Low (-1.1) |
| El Rosillo Cave | High (-2.7) | High (-2.7) | Moderate (-2) | Low (-1.4) |

**Table ES-1 for Southwestern United States**

| Roost | Current Conditions | Scenario 1 – Optimistic | Scenario 2 – Status Quo | Scenario 3 – Pessimistic |
|---|---|---|---|---|
| Mount Emory Cave | High (-2.7) | High (-2.6) | High (-2.6) | Moderate (-2.1) |
| Romney Cave | Moderate (-2) | Moderate (-2.1) | Moderate (-2.1) | Low (-1.4) |

In summary, we have identified the main stressors affecting the viability and extinction risks of Mexican long-nosed bat to be loss of food resources and loss of suitable roosting sites. Impacts from climate change are expected to exacerbate these factors. In addition, human disturbance of roosts and persecution are also potential stressors that could be alleviated by careful management of protected lands where roost sites occur and supporting education measures near important roost sites that are not on protected lands. Restoration of foraging sites could also be important conservation measures in the future. Research into basic life history such as the location of stopover sites, roosts, or foraging grounds along the migratory route is needed. In addition, it is important to have information on the dynamics of several colonies (connectivity, seasonality, stability) in order to best inform future successful management strategies.

# TABLE OF CONTENTS

# CHAPTER 1. INTRODUCTION

The Mexican long-nosed bat (*Leptonycteris nivalis*) is a nectar-feeding species found in Mexico and the southwestern United States. The Mexican long-nosed bat has been listed under the Endangered Species Act of 1973, as amended (Act), since 1988 (53 FR 38456-38460). In Mexico the species is listed as threatened under NOM-059-SEMARNAT-2010, which is Mexico's equivalent to the endangered species list. The species is also listed as Endangered under the IUCN Red List of Threatened Species (Medellin 2016, entire). The Species Status Assessment (SSA) framework (USFWS 2016, entire) is intended to support an in-depth review of the species' biology and threats, an evaluation of its biological status, and an assessment of the resources and conditions needed to maintain long-term viability. The intent is for the SSA Report to be easily updated as new information becomes available and to support all functions of the Endangered Species Program from Listing to Consultations to Recovery. As such, the SSA Report will be a living document upon which other documents, such as listing rules, recovery plans, and 5-year reviews will be based on.

For the purpose of this assessment, we generally define viability as the ability of colonies of Mexican long-nosed bats to survive and persist. Using the SSA framework, we consider what the species needs to maintain viability by characterizing the status of the species in terms of its resiliency, redundancy, and representation (Wolf et al. 2015, entire).

- Resiliency describes the ability of individual roost sites to withstand stochastic events (arising from random factors). We can measure resiliency based on metrics of population health; for example, birth versus death rates and population size. Highly resilient populations are better able to withstand disturbances such as random fluctuations in birth rates (demographic stochasticity), variations in rainfall (environmental stochasticity), or the effects of anthropogenic activities.

- Representation describes the ability of a species to adapt to changing environmental conditions. Representation can be measured by the breadth of genetic or environmental diversity within and among populations and gauges the probability that a species is capable of adapting to environmental changes. The more representation, or diversity, a species has, the more it is capable of adapting to changes (natural or human caused) in its environment. In the absence of species-specific genetic and ecological diversity information, we evaluate representation based on the extent and variability of habitat characteristics across the geographical range.

- Redundancy describes the ability of a species to withstand catastrophic events. Measured by the number of populations, their resiliency, and their distribution (and connectivity), redundancy gauges the probability that the species has a margin of safety to withstand or can bounce back from catastrophic events (such as a rare destructive natural event or episode involving many populations).

To evaluate the biological status of the Mexican long-nosed bat both currently and into the future, we assessed a range of conditions to allow us to consider the species' resiliency, redundancy, and representation (together, the 3Rs). This SSA Report provides a thorough assessment of biology and natural history and assesses demographic risks, stressors, and limiting factors in the context of determining the viability and risks of extinction for the species.

The format for this SSA Report includes: (1) the resource needs of individuals and populations (Chapter 2); (2) the Mexican long-nosed bat historical distribution and a framework for determining the distribution of resilient populations across its range for species viability (Chapter 3); (3) reviewing the likely causes of the current and future status of the species and determining which of these risk factors affect the species' viability and to what degree (Chapter 4); and (4) concluding with a description of the viability in terms of resiliency, redundancy, and representation (Chapter 5). This document is a compilation of the best available scientific and commercial information and a description of past, present, and likely future risk factors to the Mexican long-nosed bat.

# CHAPTER 2. LIFE HISTORY AND RESOURCE NEEDS

The Mexican long-nosed bat (*Leptonycteris nivalis*) is a nectar-feeding species found in Mexico and the southwestern United States. The species roosts in caves and engages in long distance movements coinciding with the blooming of cacti and *Agave* in the deserts and pine-oak habitats at elevations between 1490 and 2300 meters. The ecosystem services of the species include pollination of a number of *Agave* and cactus species which contributes to the reproductive success of these plants. *Leptonycteris nivalis* is known from 26 roost sites based on studies and museum records and the majority of these are in Mexico. Because the species occupies roosts isolated from one another and only inhabits these roosts seasonally, it has been challenging to determine the size of the population. Further complicating this process is the fact that females tend to make the migration northward, while males tend to remain in the southern part of the distribution. The Mexican long-nosed bat is currently listed as endangered under the United States Endangered Species Act of 1973 (1998, Federal Register 53(190):38456-38460). The loss of food resources due to conversion of foraging habitat to agriculture and ranching in addition to the disturbance by humans is thought to have contributed to the decline of the population sizes of this species. A U. S. Recovery Plan was completed for *L. nivalis* in 1994.

This chapter presents basic biological and life history information about the Mexican long-nosed bat, *L. nivalis*, with special emphasis on updating information produced since the last revision for the Recovery Plan in 1994 (USFWS 1994, entire).

## 2.1 Taxonomy and Phylogeny

*Leptonycteris nivalis* belongs to the Order Chiroptera, suborder Yangochiroptera, family Phyllostomidae (Kunz 1982; Neuweiler 2000). This family, endemic to America, includes tropical and subtropical species, ranging from southern Texas to northern Argentina. The genus *Leptonycteris* belongs in the subfamily Glossophaginae, that includes nectar and pollen feeding bats (Simmons 2005, p. 401). The currently accepted classification is:

| | |
|---|---|
| Phylum: | Chordata |
| Class: | Mammalia |
| Order: | Chiroptera |
| Suborder: | Yangochiroptera |
| Family: | Phyllostomidae |
| Subfamily: | Glossophaginae |
| Species: | *Leptonycteris nivalis* |

*Leptonycteris nivalis* was first described in 1860 by Saussure (1860) who first named it *Ichnoglossa nivalis*. The genus name was changed to *Leptonycteris* in 1891 by Lydekker (Flower and Lydekker 1891, p. 674). Type locality for the species is the snowline at the Pico de Orizaba volcano in the state of Veracruz (Saussure 1860).

The genus *Leptonycteris* includes three species: *L. nivalis, L. yerbabuenae* and *L. curasoae* (Hall 1981; Honacki et al. 1982; Koopman 1994). Phylogenetically, *L. nivalis* is more closely related to *L. curasoae* than to *L. yerbabuenae* based on morphological data (Carstens et al. 2002, p. 29). However, based on the mitochondrial control region, *L. yerbabuenae* and *L. curasoae* share a common ancestor that split from *L. nivalis* approximately 1 million years ago (Wilkinson and Fleming 1996, p. 335).

Hoffmeister (1957, p. 454) recognized three subspecies of *L. nivalis* (*L. n. nivalis, L. n. curasoae, and L. n. sanborni*) and various revisions to the taxonomy were proposed in the following years. Later, Arita and Humphrey (1988, entire) clarified and summarized the confusing taxonomic history of the species in this genus and conducted a thorough review of museum specimens. Despite the somewhat stable taxonomy since that time, references to older museum specimens of *L. nivalis* or the taxonomic designations used in the older literature (before 1980) cannot automatically be assumed to be *L. nivalis* as currently recognized. This taxonomic turmoil has contributed to confusion with regard to understanding the ecology and distribution of *L. nivalis* because some of the findings in the literature actually refer to *L. yerbabuenae* or *L. curasoae* and must be interpreted carefully.

## 2.2 Morphological Description

*Leptonycteris nivalis* is a relatively large glossophagine bat: total length 83 mm; forearm ≥ 55mm (averaging 57 mm); fur long (7 to 8 mm in dorsum). The average body mass is 26-28 g (Davis 1974) and it has a drab brown color, darker in the dorsum and paler ventrally (Hall 1981). Dental formula is i 2/2, c 1/1, p 2/3, m 2/2, total 30 (Davis 1974).

The three species in the genus *Leptonycteris* are similar. However, *L. curasoae* distribution is limited to South America and does not overlap with *L. nivalis.* Distribution of *L. nivalis* and *L. yerbabuenae* do overlap in both Mexico and the United States (Arita 1991, p. 709; Bogan et al. 2017, p. 323), and overlap is almost complete in Central Mexico (Arita and Humphrey 1988, p. 36-37; Arita 1991, p. 709). *Leptonycteris nivalis* has a slender skull and elongated muzzle with a long extensible tongue tipped with long papillae (Greenbaum and Phillips 1974, p. 491). The uropatagium is relatively reduced and moderately hairy with a 3-4 mm hairy fringe (Hall 1981, p. 132). *Leptonycteris nivalis* differs from *L. yerbabuenae* in that the former is larger in several external and cranial measurements (Davis and Carter 1962). *Leptonycteris nivalis* has a longer (10% or more) head and longer (>105 mm) third finger (Hoffmeister 1957, p. 458) with the third phalanx greater than 15 mm (Medellin et al. 2008, p. 41) compared to *L. yerbabuenae.*

Other similar glossophagines include the genus *Lichonycteris* and *Choeronycteris*. While *Leptonycteris* and *Lichonycteris* both lack third molars, *Leptonycteris* normally has lower incisors and upper incisors that form an almost continuous line with the only noticeable space (if present) at the midline, in contrast with the evenly and widely spaced upper incisors in *Lichonycteris* (Hall 1981, p. 132). *Choeronycteris mexicana* can be distinguished by its smaller size, lengthened muzzle and its protruding, short tail (Ammerman et al. 2012, p. 55).

## 2.3 Resource Needs of Individuals

Mexican long-nosed bats typically use caves as day roosts (and to a lesser extent, mines) found at elevations of 1,000 to 2,300 m typically in pine-oak habitats (Baker and

Cockrum 1966, p. 331, Arita 1991, p. 712, Table 1). They tend to occupy higher elevations than *L. yerbabuenae* where they are sympatric in Mexico (Arita 1991, p. 710), but this is not true in northern locations (Bogan et al. 2017, p. 325). *Leptonycteris nivalis* seem to be physiologically adapted for cool environments (Ayala-Berdón et al. 2013, p. 626-627). In roosts where the temperature has been measured, the caves are generally cool. Temperatures of cave roosts occupied by the bats average 10.8 -18°C (Moreno-Valdez et al. 2004, p. 456; Ammerman et al. 2009, p. 4). Specific characteristics of individual caves that have been studied are discussed in section 3.2 below.

This species is migratory. Males and females are both present in the southern extent of their range during winter (November - February), but females are more abundant in the northern roost locations during summer (April - September; Easterla 1972, p. 291; Brown 2008, p. 17; Adams 2015, p. 20). Details about migration are scarce but it is assumed that females move northward tracking available nectar sources (nectar corridor), after having mated in the southern caves, especially Cueva del Diablo. They are presumed to use unknown caves as stopover sites on their way to maternity caves in the north where they will raise their young. Juveniles and adult females are thought to return to southern sites in the late summer or early fall, however much is unknown about the migratory paths of this species throughout the year.

Because *L. nivalis* is a nectarivore, it potentially serves as an important pollinator for many plant species. Mexican long-nosed bats feed on more than 50 species of plants with the dominant species from the families Agavaceae (Asparagaceae, Chase et al. 2009, p. 134) and Convolvulaceae, specifically those in the genus *Agave* and *Ipomoea*. Over 30 species of *Agave* have been reported in the diet of *L. nivalis* (see section 3.3). In addition, Valiente-Banuet (1997, p. 454) reports *L. nivalis* as the main pollinator of *Neobuxbaumia* spp., a dominant columnar cactus genus in Central Mexico. Mexican long-nosed bats in New Mexico were found to travel 20-30 km one-way each night to forage on *Agave* (Bogan et al. 2017, Figure 4 and p. 327). In Texas, they have been found to make foraging trips ranging from 13-30 km round-trip and twice as much *Agave* habitat overlapped with the home ranges used by adults compared to juveniles (England 2012, p. 18-19).

***Table 1.*** *Resource needs of the Mexican long-nosed bat (Leptonycteris nivalis)*

| **Needs** | **Description** |
|---|---|
| Day Roosts | caves, mines, crevices with appropriate temperatures and humidity; reduced access to predators; free of disease-causing organisms (fungus that causes white-nose syndrome, etc.); limited human disturbance; structural integrity maintained; diversity of locations to provide for maternity, mating, migration, and transition roost sites |
| Night Roosts | protected areas in caves, mines, crevices, and structures such as buildings; limited human disturbance; protection from predators; in proximity to forage resources and day roosts |
| Local foraging habitat | sufficient stands of *Agave*, flowering tree species, columnar cactus, and other documented diet items in proximity to maternity, mating, and transition roosts |
| Foraging habitat along migration pathways | sufficient stands of *Agave*, flowering tree species, and other documented diet items distributed across the range of the species and along migration pathways forming a "nectar corridor" with blooming and phenologies that support the seasonal migrations of the species |
| Migration pathways | intact habitat that provides cover, forage, and roosts to support the hypothesized migration pathways connecting areas from south and south-central Mexico to northern Mexico and southwestern U.S. These pathways should be free of impediments or threats such as wind turbines, large urban areas, etc. |

Sources for the day roost description come from Arita 1991, Moreno-Valdez et al. 2004, Brown 2008, and Ammerman et al. 2009.

Sources for the local foraging habitat come from Sánchez and Medellín 2007, England 2012, and Bogan et al. 2017

# CHAPTER 3. POPULATION AND SPECIES NEEDS AND CURRENT CONDITION

## 3.1 Distribution

*Leptonycteris nivalis* inhabits areas in central Mexico, along the eastern coast, to southwestern United States. It is found as far south as the states of Guerrero and Puebla in Mexico. In the United States this species is known from western Texas (Presidio and Brewster Counties) and Hidalgo County, New Mexico (Figure 1). Specimens from Arizona and northwestern Mexico collected before 1980 exist in several museum collections but should be re-examined for proper identification because during that time the name *L. nivalis* was assigned to individuals currently recognized as *L. yerbabuenae*. *Leptonycteris nivalis* is not found in Arizona (Hoffmeister 1986, p. 64).

The species spends fall and winter in Central Mexico, migrating northward to northern Mexico and the southwestern United States at the end of February/early March. *Leptonycteris nivalis* remains in this area forming maternity colonies during spring and early summer and starts migrating to central Mexico by mid-summer (Easterla 1972; Arita 2005). Téllez-Zenteno (2001, p. 121) reports that this migration is mainly made by pregnant females (moving northward by the end of winter) and post-lactating females (moving southward by the end of summer) while it is still uncertain what happens to males and research suggests they remain scattered in roosts in central Mexico.

Cockrum (1991, p. 194) and Fleming et al. (1993, p. 75) suggest that migratory movements of *Leptonycteris* are driven by the need to find floral resources, therefore, they take advantage of seasonal blooming of different cacti and *Agave* species along a nectar corridor. More recently, Gómez-Ruiz and Lacher (2017, entire) have modeled the geographic distribution of the species in relation to the distribution of floral resources and describe a "nectar corridor" across Mexico and the southwestern United States.

## 3.2 Roosting

*Leptonycteris nivalis* is known from 30 roost sites based on studies or museum records (Table 2). Some of these are newly recorded (less than ten years) roosts for the species. In most of these, however, no monitoring program or conservation actions have been implemented. Eleven of these roosts have been monitored or studied. At least two of the previously reported roosts have been monitored almost yearly (Emory Cave in Big Bend National Park, Texas since 2005; Cueva del Diablo, Tepoztlán, México since 2001) and conservation actions continue to be implemented. Fortunately, nine of the known roosts are located on federally protected land. However, protection and conservation actions in some on theses roosts are rarely implemented. Unfortunately, some roosts reported in the 1994 Recovery Plan have received little to no attention during the last twenty years. Only recently, survey efforts are being conducted to corroborate whether *L. nivalis* is still present in these roosts and to determine the size of these colonies.

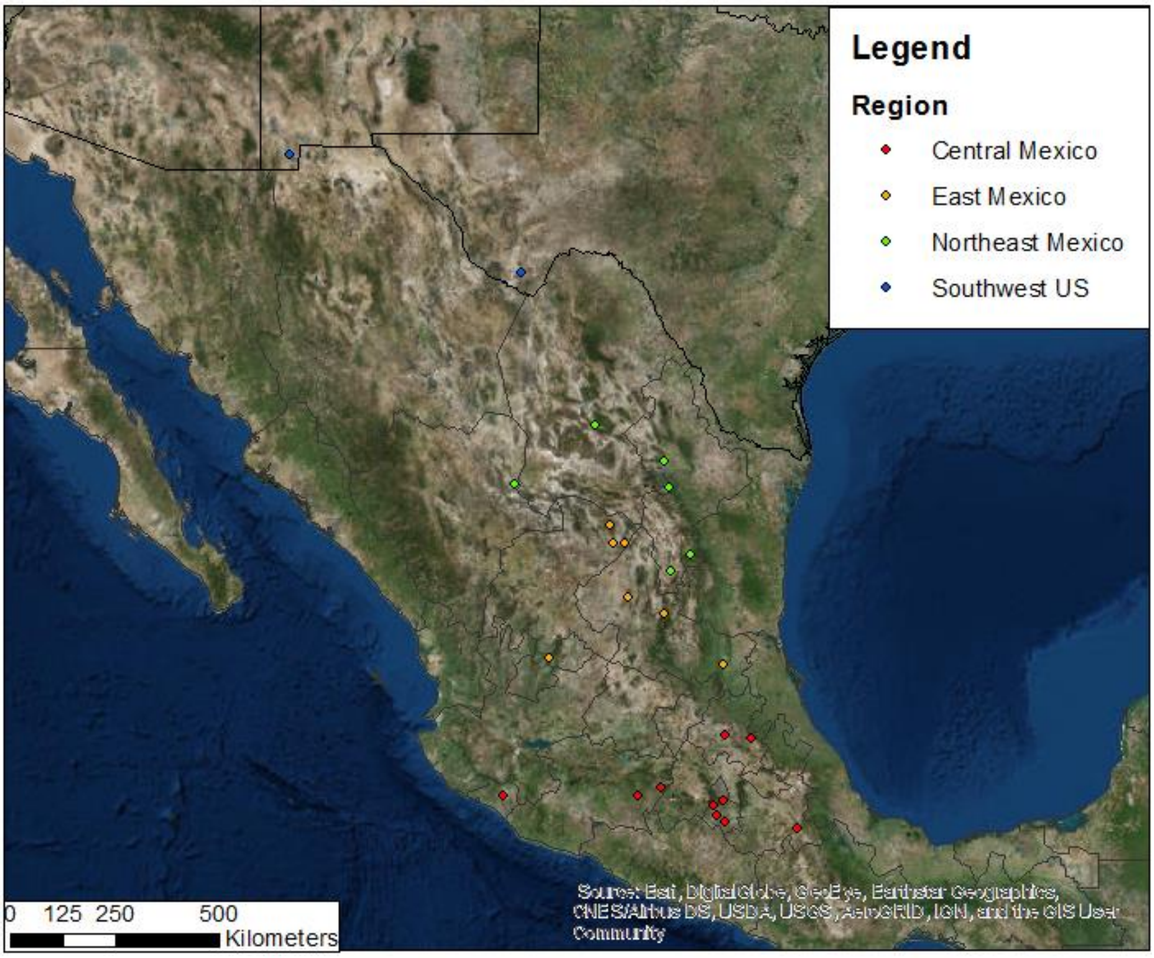


***Figure 1***. *Locations of all Mexican long-nosed bat roosts that have been confirmed to be inhabited by the bat either in the past or currently (Table 2). Roost locations are divided into four regions: central Mexico, eastern Mexico, northeastern Mexico, and southwestern United States. Museum specimens from two caves do not have confirmed coordinates: El Coyote Cave and El Murcielago Cave. Subsequently, these caves are not on any of the maps with roost locations.*

***Table 2***. *Locations of previously reported and potential roosts of L. nivalis across its distribution, shown by region. Source of information (or collection for specimen records) is cited in the source column. Roost type is reported for those locations where published information is available. Monitoring scheme and group cited for the caves that have been regularly monitored or for which at least a recent estimation (after 1994) is available. SICOM designation (Site of importance for the conservation of bats) or AICOM designation (Areas of Importance for Bats Conservation) is specified, according to RELCOM (Network for the Conservation of Bats in Latin America). Regions based on Arita and Humphrey (1988, p. 36) and USFWS (1994, p. 29-30).*

**Table 2 for Central Mexico**

| Roost | Roost type | Are studies or monitoring reports available?<br><br>If no, information is based solely on museum specimens (no study or monitoring effort have been conducted in such roosts). | Monitoring scheme/ AICOMs or SICOMs | Source (s) |
|---|---|---|---|---|
| Aguacatitla tunnel, Aguacatitla, Hidalgo, MEX | Maternity | Yes | Annual monitoring/ AICOM-A-Mx-002 | Laboratorio de Ecologia de Poblaciones, Universidad Autonoma del Estado de Hidalgo; (Rojas-Martínez et al. 2010, 2011; Bolaños-García & Rojas-Martínez 2013; Ramos-Frias 2013) |
| Cueva del Diablo, Tepoztlán, Morelos, Mex | Mating | Yes | Winter annual monitoring by LECVT, Instituto de Ecologia-UNAM/ None | (Sánchez 2004; Sánchez & Medellín 2007; López-Segurajáuregui 2010; Salinas-Galicia 2013), Ibarra pers. comm. |
| Del Ferrocarril cave, San Juan Tlacotenco, Morelos, MEX | Unknown | No | None/None | Collection: Museo Alfonso Luis Herrera, Facultad de Ciencias, UNAM |
| Del Salitre cave, Ticuman, Morelos, MEX | Unknown | No | None/None | Collection: Coleccion Nacional de Mamiferos, Instituto de Biologia, UNAM; American Museum of Natural History |
| De la Chichihuiteca cave, Morelos, MEX | Unknown | No | None/None | Collection: Coleccion Nacional de Mamiferos, Instituto de Biologia, UNAM |

| | | | | |
|---|---|---|---|---|
| De la Peña cave, Valle de Bravo, Estado de Mexico, MEX | Potential mating | Yes | None/None | (Téllez-Zenteno 2001) |
| El Amate cave, Tlaltenango, Morelos, MEX | Unknown | No | None/None | Collection: Mammalogy Collection-Royal Ontario Museum; Escuela Nacional de Ciencias Biologicas, IPN |
| El Coyote cave, Tonatico, Estado de México, MEX | Potential mating roost | No | None/None | (Torres-Knoop 2014) |
| La Fábrica cave, el Gallo, Colima, MEX | Unknown | No | None/None | Collection: LECVT, Instituto de Ecologia-UNAM |
| Ídolo cave, Tepoztlán, Morelos, MEX | Unknown | No | None/None | Colección Nacional de Mamíferos, Instituto de Biología, UNAM |
| San Lorenzo cave, Tehuacán, Puebla, MEX | Summer | Yes | None/AICO M-A-Mx-004 | (Téllez-Zenteno 2001; López-Segurajáuregui 2010) |
| Tziranda caves, Ciudad Hidalgo, Michoacán, MEX | Unknown | Yes | None/None | (Téllez-Zenteno 2001; López-Segurajáuregui 2010) |
| Xoxafi cave, Santiago de Anaya, Hidalgo, MEX | Unknown | Yes | None/None | Collection: LECVT, Instituto de Ecología-UNAM, (López-Segurajáuregui 2010) |

**Table 2 for Eastern Mexico**

| Roost | Roost type | Are studies or monitoring reports available?<br><br>If no, information is based solely on museum specimens (no study or monitoring effort have been conducted in such roosts). | Monitoring scheme/ AICOMs or SICOMs | Source (s) |
|---|---|---|---|---|
| Cueva Azul, Zacatecas, MEX | Unknown | No | None /None | Collection: Museo Alfonso Luis Herrera, Facultad de Ciencias, UNAM |
| De los Coyotes cave, Los Amoles, San Luis Potosí, MEX | Unknown | No | None/None | Smithsonian. National Museum of Natural History |
| El Chiquihuite cave, Zacatecas, MEX | Unknown | No | None/None | Collection: Museo Alfonso Luis Herrera, Facultad de Ciencias, UNAM; (Sánchez 2004) |
| El Durazno mine, La Pardita, Zacatecas, MEX | Unknown | Yes | None/None | Collection: Museo Alfonso Luis Herrera, Facultad de Ciencias, UNAM; (Sánchez 2004) |
| El León cave, El Calvillo, Aguascalientes, MEX | Unknown | No | None/None | Base de datos Aguascalientes, Colección zoológica de la Universidad Autónoma de Aguascalientes |
| El Murciélago cave, El Calvillo, Aguascalientes, MEX | Unknown | No | None/None | Base de datos Aguascalientes, Colección zoológica de la Universidad Autónoma de Aguascalientes |
| La Montaña mine, between La Laja and Mazapil, Zacatecas, MEX | Unknown | Yes | None/None | Collection: Museo Alfonso Luis Herrera, Facultad de Ciencias, UNAM; (Sánchez 2004) |
| San Pedro de la Anonas mine, Paligual, San Pedro de las Anonas, San Luis Potosí, MEX | Unknown | No | None/None | Smithsonian. National Museum of Natural History |
| Todos los Santos mine, Zacatecas, MEX | Potential maternity roost | No | Recently described/ None | Collection: LECVT, Instituto de Ecologia-UNAM |

**Table 2 for Northeastern Mexico**

| Roost | Roost type | Are studies or monitoring reports available?<br><br>If no, information is based solely on museum specimens (no study or monitoring effort have been conducted in such roosts). | Monitoring scheme/ AICOMs or SICOMs | Source (s) |
|---|---|---|---|---|
| Del Guano cave, Durango, MEX | Unknown | No | None / None | Collection: Colección regional de Durango, Universidad Autónoma de Durango |
| De los Guzmán mine, Doctor Arroyo, Nuevo León, MEX | Unknown | No | None/None | Collection; Mamíferos de Nuevo León, Universidad Autónoma de Nuevo León |
| El Infierno Cave, Las Cumbres National Park, Monterrey, Nuevo León, MEX | Maternity roost | Yes | In the process of establishing a standardized annual monitoring/ None | (Moreno-Valdez et al. 2004; Brown 2008; Gómez-Ruiz et al. 2015) |
| El Rosillo cave, Área de Protección de Recursos Naturales Cuenca Don Martin, Coahuila, MEX | Potential maternity roost | Yes | In the process of establishing a standardized annual monitoring/ None | (Gómez-Ruiz et al. 2015) |
| La Joya Honda cave, General Zaragoza, Nuevo León, MEX | Unknown | No | None/None | Collection: Mamíferos de Nuevo León, Universidad Autónoma de Nuevo León |
| San Antonio mine, General Escobedo, Nuevo León, MEX | Unknown | No | None/None | Collection: Mamíferos de Nuevo León, Universidad Autónoma de Nuevo León |

## Table 2 for Southwestern United States of America

| Roost | Roost type | Are studies or monitoring reports available?<br><br>If no, information is based solely on museum specimens (no study or monitoring effort have been conducted in such roosts). | Monitoring scheme/ AICOMs or SICOMs | Source (s) |
|---|---|---|---|---|
| Mount Emory cave, Big Bend National Park, Texas, USA | Maternity | Yes | Annual monitoring/ NA | (Easterla 1972; Brown 2008; Ammerman et al. 2009; Adams 2015) |
| Romney Cave, Big Hatchet Mountains, Hidalgo Co., New Mexico, USA | Summer/ mixed male and female | No | Began 2017 | (Bogan et al. 2006) |

Recovery task 1 in the Recovery Plan (USFWS 1994, p. 39) calls for the protection, monitoring and location of roosting sites. These activities are considered top priority for the recovery of *L. nivalis* along its distribution. Since 1994, when the recovery plan was published (USFWS 1994, entire), numerous studies and anecdotal reports have contributed to increased knowledge on distribution of roosts of *L. nivalis*. For a few sites, especially in the extremes of the distribution, the roosts have been well-studied and seasonality, colony size, reproductive aspects, diet and foraging habits have been characterized. Little or no information is available for the species and roosts along the migratory path. The location of stopover sites, roosts, or foraging grounds along migratory path are unknown. In addition, more knowledge is needed on the dynamics of several colonies (connectivity, seasonality, stability). The characteristics of each of the 11 roost sites that have been studied are described in the following pages.

### 3.2.1 Central México

#### Aguacatitla tunnel, Aguacatitla, Hidalgo, México.

The Aguacatitla tunnel is in the Aguacatitla Canyon, in the community of Aguacatitla in the Huasca de Ocampo municipality of the state of Hidalgo (Figure 2). This area is in the southern end of the Metztitlán Canyon at 2,200 m elevation and is part of the Barranca de Metztitlán Biosphere Reserve (Rojas-Martínez et al. 2010, p. 14).

The Barranca de Metztitlán has an intricate relief and displays a great array of vegetation types that go from pine-oak and *Juniperus* forests at higher elevations, to tropical dry forest, xerophytic scrubs, grassland and gallery forest associated with watercourses at the deepest part of the canyon system (Rojas-Martínez et al. 2010, p. 14). The main vegetation associations show Nearctic affinities (CONANP 2003) from 1,000-2,000 m elevation, with a great proportion of endemism (Rzedowski 1983). Members of the families Agavaceae (Asparagaceae) and Cactaceae are abundant and widely distributed in the area (CONANP 2003).

The Aguacatitla tunnel is part of a tunnel network, built approximately 90 years ago, to transport water from the San Miguel Regla damn to a hydroelectric plant of the Federal Electricity Commission (CFE). This plant ceased operations in the early 1990´s. In 1997, a group of CFE retirees, in agreement with CFE, established an ecotourism center that takes advantages of the small canyon, river, tunnels and ponds on what once was the hydroelectric plant. Since then, this ecotourism group has been in charge of maintaining the tunnels and associated infrastructure.

*Leptonycteris nivalis* established a maternity colony in one of the main tunnels at least since the early 2000´s. Rojas-Martinez, at the State University of Hidalgo, has been studying and monitoring this colony continuously since 2007 (Rojas-Martínez et al. 2010, entire). This colony occupies the last tunnel, located just before the water holding ponds. This roost tunnel is approximately 100 m long, 6 m high and 1.6 m wide. A couple of short segments (< 1m long) of the tunnel have partially collapsed and allows for the intrusion of some light and a continuous air current that maintains a relatively cool temperature in the tunnel. Average temperature in the maternity roost tunnel is 17.2°C and 100% relative humidity (Rojas-Martínez et al. 2010, p. 20; Rojas-Martínez et al., in press). The maternity colony roosts in the darkest part of the tunnel, located between the two openings (Rojas-Martínez et al. 2010, p. 29).

As reported by Rojas-Martínez et al. (2010, p. 31-32; 2011, p. 1), the colony occupying the Aguacatitla tunnel is a maternity colony. The colony, mostly pregnant females, starts arriving at Aguacatitla by mid to late March. Rojas-Martínez et al. (2010, p. 29) report the presence of pregnant and lactating females from March until August. Among these females, some juveniles of both sexes are also present at the beginning of the season. The proportion of juveniles increases as females give birth and newborns recruit into the juvenile class.

*Colony size* — Colony size fluctuates as the season progresses, and increases towards June, when most of the females have given birth and newborns are still non volant. Maximum estimated colony size varies from year to year and has ranged from 7,489 individuals in 2010, to 13,596 individuals in 2015 (Rojas-Martinez pers. comm.). Estimates were made using still photographs and extrapolation to the area covered by the colony.

*Foraging habitat* — Preliminary studies of diet for this colony report that female diet in this colony consists of 87% *Agave* spp., 9% columnar cacti pollen, and species in the families Bombacaceae, Convulvulaceae, Leguminoseae and Pinaceae. This last component seems to be ingested accidentally (Rojas-Martínez pers. comm). *Agave salmiana* and *A. lechuguilla* are the two *Agave* species with a flowering season that overlaps with the presence of *L. nivalis* in the area (Rojas-Martínez, pers. comm.). Currently, foraging habits and home range are being investigated (Mejía-Vera and Rojas-Martínez, pers. comm.).

*Barriers to cave disturbance and level of protection* — As previously mentioned, the Aguacatitla roost is part of an ecotourism park, maintained and managed by a cooperative association. As a group, the cooperative embraces the conservation of bats, and the *L. nivalis* colony in particular. Visiting the roosting tunnel and seeing the bats are one of the main attractions in the park. However, the managers of this park strictly enforce a set of rules so these visits cause minimum disturbance to the colony and the roost. During these visits, they share information about the bats, their ecological role, ecosystem services and the importance of this tunnel for the species. They actively maintain the integrity of the tunnel system and make restorations when needed. Rojas-Martínez (pers. comm.) collaborates closely with the group that manages this park, offering advice on management, responsible practices and public outreach and education. Being part of privately owned lands, access to the site is strictly controlled and always under supervision of a guide. For this reason, conservation threats due to anthropogenic activities is low. In addition, the Aguacatitla Canyon is within the boundaries of the Barranca de Metztitlán Biosphere Reserve, which also confers federal and state protection to the site.

Currently, there is not a long-term monitoring program for this roost. However, Dr. Rojas-Martínez and students in his lab, from the State University of Hidalgo, conduct annual visits to the roost while the colony is present (March-August). They have a series of ongoing studies that include photographic record of the colony (to estimate size and fluctuations) and collection of naturally deceased pups in order to study sex ratios of newborns and describe neonatal development. All this information is currently in preparation for publication. In 2017, Instituto de Ecología-UNAM started a collaboration with Rojas-Martínez and the Aguacatitla managers in order to establish a regular monitoring program and a PIT tag study in this roost (Ibarra pers. comm.).

**Cueva del Diablo, Tepoztlán, Morelos, México.**

Cueva del Diablo, in the municipality of Tepoztlán in the state of Morelos, México (Figure 2), is, so far, the only known mating roost for *L. nivalis*. Cueva del Diablo is within the boundaries of National Park El Tepozteco, a federally protected natural area. Parque Nacional El Tepozteco is encompassed within the Chichinautzin Biological Corridor. Within the corridor, the dominant vegetation types are different types of forest that vary according to the elevational gradient (*Pinus* forest between 2,800-3,500 m, *Pinus-Quercus* forest between 1,600-2,800 m), interspersed with mountain cloud forest in canyons and wet areas. Below this elevation, vegetation transitions into tropical dry forest and xerophytic scrub (Rzedowski 2006).

Cueva del Diablo is in the Tepoztlan mountain range, at 1,957 m, close to the limit of the tropical dry forest of the Pacific coast (Téllez-Zenteno 2001, p. 36). C3 plants, or those that utilize the C3 carbon fixation pathway, dominate the vegetation (especially *Ipomoea arborescens*), although it is possible to find some *Quercus*, which increases in relative abundance with elevation.

Cueva del Diablo is possibly the best described and studied site for *L. nivalis* in Mexico. Several researchers have conducted studies on the biology and ecology of *L. nivalis* in this roost, including studies on diet (Sánchez and Medellín 2007, entire; López-Segurajáuregui 2010, entire), reproductive patterns and mating activity (Caballero-Martínez 2004, entire; Toledo-Gutiérrez 2009, entire), ecological niche modeling (Torres-Knoop 2014, entire) and carrying capacity (Salinas-Galicia 2013, entire).

Cueva del Diablo is volcanic in origin, formed by subterranean currents that carved out a tunnel system. The main entrance is approximately 4 m high and 8 to 10 m wide. There are three secondary entrances (< 2m wide) but two of them are partially closed by collapses of the tunnels. The cave is approximately 2 km long, distributed in 28 galleries of various heights and widths with a total depth of 110 m (relative to the main entrance). *Leptonycteris nivalis* roosts in the furthest chamber at the end of the main gallery. Here, the roof is approximately 11m high, and temperature is around 16°C. The floor is covered by guano of *L. nivalis* and has a pH between 5 and 6 (Hoffman et al. 1986, p. 101-104).

*Colony size* — Regular visits to the cave, mainly as a result of research activities, have provided estimates of presence and abundance of *L. nivalis* throughout the year for more than 10 years. The presence of *L. nivalis* at this cave is highly seasonal (fall-winter), with individuals arriving by mid to late September, reaching their highest numbers by October-November, and departing by mid-February to early March (Téllez-Zenteno 2001, p. 55; Caballero-Martínez 2004, p. 52-53; Toledo-Gutiérrez 2009, p. 38; López-Segurajáuregui 2010, p. 65-66; Salinas-Galicia 2013, p. 78-79). Toledo-Gutierrez (2009, p. 39) reported a few individuals (<100 males) in June and July of 2005, possibly due to an atypical year. These different reports agree that October-November is when the colony reaches the greatest size. However, different authors report different estimates for colony size for this same period, and these estimates range from 3,000 individuals (Téllez-Zenteno 2001, p. 70) to 4,000-5,000 individuals (López-Segurajáuregui 2010, p. 66; Salinas-Galicia 2013, p. 78-79) to 7,000-8,000 individuals (Caballero-Martínez 2004, p. 52; Toledo-Gutiérrez 2009, p. 39). Although differences in estimates are likely due to human error and variability in methods among observers, anecdotal qualitative estimate by the local park ranger suggests that current colony size estimates are indeed lower than in years previous to 2001 (Ibarra pers. comm.). From 2011 to 2016, Ibarra (unpublished data) has regularly monitored colony sizes every month during winter. Colony size has remained stable with approximately 3,500-4,000 individuals.

Cueva del Diablo is the only known roost where both sexes occur during the winter and is considered to be the only mating roost for the species. Téllez-Zenteno (2001, p. 56) reports a 1:1 sex ratio. The highest proportion of reproductively active males and copulation has been observed in November-December in this cave. Although other authors (Caballero-Martínez 2004, p. 53; Toledo-Gutiérrez 2009, p. 43-49), have reported biased sex ratios in this cave, they also report copulation activity concentrated in October-December. Téllez-Zenteno (2001, p. 56) reports a couple of pregnant females were present by the end of February and suggest these females got pregnant in this same cave around October- November based on the small size of the fetuses.

Given the relevance of mating roosts in the winter range for the species, considerable effort has been devoted to find other mating roosts in the area in order to protect them. Torres-Knoop (2014, entire) developed a niche model to guide the search for potential mating roosts in Central Mexico. The model suggested an area in the south of the states of Puebla, Morelos and the state of Mexico with high likelihood to have roosts for *L. nivalis*. Torres-Knoop (2014, p. 50-53) visited some of the potential sites and found small caves containing small numbers (< 20) of *L. nivalis*, including a couple of females that could have been sexually receptive, indicating the potential for the presence of mating roosts. Ibarra (unpublished data) has continued the search for potential roosts in Central Mexico, without success.

The Instituto de Ecologia-UNAM, through the Laboratory for Ecology and Conservation of Terrestrial Vertebrates (LECVT) has continuously monitored Cueva del Diablo during fall-winter since 2011. Starting in late August, the cave has been visited monthly to conduct visual inspections of the main roosting chamber to determine time of arrival of first individuals. An emergence census was conducted monthly from October to December, using video assisted by infrared lighting, to estimate colony size. Thirty to 40 individuals were captured using a harp trap, in order to determine physical state, sex and age composition, reproductive status, and parasite loads. Fecal samples have been collected to determine diet composition. In 2013, a PIT tagging study was started, in collaboration with Dr. Loren Ammerman's work in Big Bend National Park in Texas, in order to study migratory connectivity between Cueva del Diablo and Emory Cave. In 2016, an automated antenna was installed in Cueva del Diablo for detection of individuals with PIT tags.

*Foraging habitat* — In the region around Cueva del Diablo, *L. nivalis* includes up to 19 species in its diet with the dominant species from the families Agavaceae (Asparagaceae, Chase et al. 2009, entire) and Convolvulaceae, specifically those in the genus *Agave* and *Ipomoea* (Table 3) (Sánchez 2004, p. 54; Sánchez and Medellín 2007, p. 1755; López-Segurajáuregui 2010, p. 66-67).

*Barriers to cave disturbance and level of protection* — As mentioned earlier, Cueva del Diablo is the only mating roost for the species and is the only major roost known for the winter range of the species. However, this site is under serious threat due to anthropogenic activities. This cave is a popular site for professional speleological groups and amateur explorers and visitors are regularly present (Téllez-Zenteno 2001, p. 37; Ibarra pers. comm.). Despite being part of a federally protected area (El Tepozteco National Park), the land where the cave is located is privately owned and subject to urban development. Each year the expansion of urban settlements encroaches on surrounding lands and even on the land directly above the cave. Currently, LECVT is actively collaborating with the Commission of Natural Protected Areas, local landowners and the general public to manage and protect this cave and surrounding foraging areas. In 2016, in collaboration with CONANP, a protective fence was placed surrounding the entrance to the cave. The purpose of this fence is to control the access of visitors to the cave, ensure that they are accompanied by the local park guard and follow recommendations to prevent disturbance to the cave and the bat colony. The installation of this fence was accompanied by an extensive environmental education program with local tourist guides, landowners and general public.

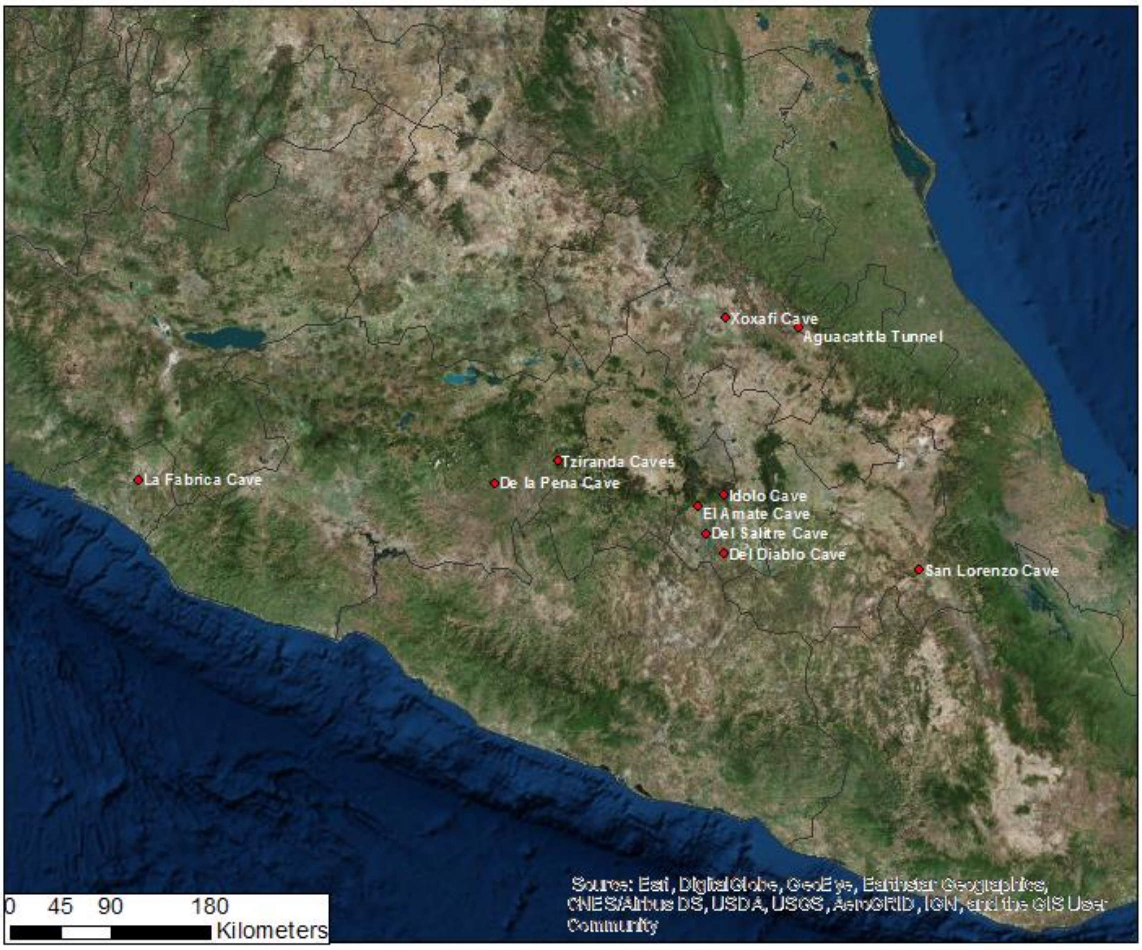


***Figure 2.*** *All central Mexico roosts with confirmed coordinates that have been documented to be used by L. nivalis (Table 2). Cueva del Diablo is the only known mating roost. Aguacatitla Tunnel is the only known non-migratory maternity roost for this species.*

**La Peña Cave, Valle de Bravo, State of México, México.**

La Peña Cave is a stone outcrop at the top of a hill. It is in La Peña locality, in Valle de Bravo municipality, in the State of Mexico (Téllez-Zenteno 2001, p. 35). Most information referring to *L. nivalis* from this cave comes from a single study conducted by Téllez-Zenteno (2001, entire) where he provides data on colony size, seasonality, sex ratios, reproductive patterns and diet.

The Valle de Bravo region ranges in elevation from 1,200 to 3,100 m. The dominant vegetation type is *Pinus-Quercus* mixed forest, although there are some grasslands (Téllez-Zenteno 2001, p. 35; INEGI 2009). The cave is, however, surrounded by secondary vegetation and housing complexes that cover most of the hill (Téllez-Zenteno 2001, p. 35).

The roost in La Peña has two entrances, considered to belong to two different caves by local people. However, both entrances connect to one main chamber. The biggest entrance, also known as Cueva del Diablo (not to be confused with the previous section on a different Cueva del Diablo), appears as a crack in the main face of the stone outcrop, as a result of collapse of the interior. This entrance is approximately 20 m high and 2 m wide, widening up to 5 m to the interior of the chamber. This gallery continues for 25 m, narrowing until it closes completely (Téllez-Zenteno 2001, p. 35). The second entrance, also known as Cueva del Viento is only a minor opening on top of the stone outcrop and it is inaccessible by humans (Ibarra pers. comm.).

*Colony size* — According to Téllez-Zenteno (2001, entire), who conducted research at this cave from 1998-2000, small numbers of *L. nivalis* (<50 individuals, mostly males) arrive at the cave around September. Téllez-Zenteno (2001, p. 72) reported up to 200 individuals for November and December, the time of maximum occupancy. Their numbers start to decrease towards February, and some individuals remain until May, abandoning the cave completely by June. Sex ratio is approximately 1:1, according to Téllez-Zenteno (2001, p. 58). Males at this cave are reproductively active (scrotal testis) around October-November, and Téllez-Zenteno (2001, p. 59) reported pregnant females by February, similar to what he reported for Cueva del Diablo, suggesting this also could be a mating roost.

No other bat studies have been conducted in La Peña after Téllez-Zenteno (2001, entire) and there was no conclusive evidence to determine it as a permanent mating roost for the species. In January 2017, LECVT personnel visited the cave as part of the effort to locate alternate mating roosts. At that time, evidence of nectarivorous feces was detected on the floor of the cave. Although some bats (<20) were flying inside the cave, visual inspection was not conclusive for the presence of *L. nivalis* in the cave and the species was not captured during mist netting sessions at both cave entrances.

*Foraging habitat* — Information on diet composition of *L. nivalis* for this roost is limited. Based on stable isotope data, Téllez-Zenteno (2001, p. 62) reported that *L. nivalis* fed predominantly on CAM plants (*Agave* and cacti) during fall and increasingly changes to C3 plants (e.g., genus *Ipomoea* and family Bombacacea) by winter. Téllez-Zenteno (2001, p. 62) considered the latter information to be inconclusive because it is based on analyses of samples from only two individuals.

*Barriers to cave disturbance* — Monitoring is not conducted at this site regularly and it is highly disturbed by human activities. The stone outcrop where the cave is located is part of a popular lookout into Valle de Bravo area and the lake. This makes it a site heavily visited by tourists all year long (Camilo C. Reyes pers. comm.). Visitors can hike around the stone outcrop and access the lookout and even the cave with little or no supervision. As a result, the area is heavily littered and vandalized with graffiti.

**San Lorenzo Cave, Tehuacán, Puebla, México.**

San Lorenzo cave is located in the Tehuacán municipality in the state of Puebla, at a small plateau known as Mesa de San Lorenzo, within the Tehuacán-Cuicatlán Biosphere Reserve. This region is characterized by xerophytic vegetation, and columnar cacti are the dominant element of the vegetation (Rzedowski 2006). The area surrounding the cave is xerophytic scrub dominated by *Opuntia* spp., *Agave* spp., and *Yucca* spp. (Ávila-Flores 2000, p. 28; Téllez-Zenteno 2001, p. 38). The cave was formed by the natural collapse of the layers of calcareous rocks, forming a circular horizontal chamber, approximately 30 m in diameter. A narrow crevice connects to a well-lit chamber, approximately 30 m in diameter and 6 m high. This chamber continues downwards and forms a crevice that connects to a series of smaller, dark chambers, at least 150 m deep. This is the area where bats roosts (López-Segurajáuregui 2010, p. 46).

*Colony size* — According to Téllez-Zenteno (2001, p. 61) and López-Segurajáuregui (2010, p. 63-64), *L. nivalis* uses this cave during summer months (June and July). Téllez-Zenteno (2001, p. 61) reports up to 2,000 individuals in June 1998. However, in July less than 100 individuals remained. Both authors concluded that the presence of *L. nivalis* in this cave is temporary and highly seasonal and it is linked to the flowering season of *Agave* spp. in the area. *Leptonycteris nivalis* in the area feed predominantly on *Agave* and *Ceiba* (López-Segurajáuregui 2010, p. 63-65). None of the captured individuals were reproductively active, rejecting the hypothesis that San Lorenzo could be a mating or maternity cave (Téllez-Zenteno 2001, p. 61).

*Foraging habitat* — In the area around San Lorenzo cave, 23 plant species have been confirmed in the diet of *L. nivalis*, particularly species from the families Agavaceae (Asparagaceae, Chase et al. 2009, entire) and Cactaceae (Table 3). Valiente-Banuet and collaborators (1997, p. 454) reports long-nosed bats (*Leptonycteris* and *Choeronycteris*) as the main pollinators of *Neobuxbaumia*, a dominant columnar cactus species in Central Mexico.

*Barriers to cave disturbance and level of protection* — Despite being in the Tehuacán-Cuicatlán Biosphere Reserve, monitoring is not conducted at this site regularly and it is highly disturbed by human activities. This cave is constantly visited by tourists that litter and cause disturbances with noise. The area surrounding the cave is also strongly disturbed by all-terrain vehicles and irresponsible camping practices (López-Segurajáuregui 2010, p. 46).

**Tziranda cave system, Ciudad Hidalgo, Michoacán, México.**

The Tziranda cave system is located 5 km south and 4.5 km east from Ciudad Hidalgo, in the municipality of Ciudad Hidalgo, in the State of Michoacán (Téllez-Zenteno 2001, p. 36; López-Segurajáuregui 2010, p. 138-139).

This cave system is part of the Transversal Neovolcanic mountain range (Eje Neovolcánico Transversal). Mean annual temperature ranges between 16 and 24 °C (INEGI 1999). Vegetation in the area surrounding the cave consists of tropical dry forest. *Yucca filifera, Acacia pennatula, Erythrina* spp., *Opuntia* spp., *Ipomoea* spp., *Bursera* spp. and *Quercus* spp. are abundant in the area (Téllez-Zenteno, p. 36). Agriculture is prominent in the area. Communal lands, closest to the caves, are devoted to the production of produce (Huerta-Zamacona 1991).

The Tziranda cave system is located in the canyon of the Turundeo river (Téllez-Zenteno 2001, p. 36) and is the result of frequent seismic and volcanic activity in the area. The caves are part of a major cave that runs from San Andres hill to Tuzuntla (López, 1980). This major cave is estimated to be more than 10 km in length (Téllez-Zenteno 2001, p. 36). The Tziranda cave system has two main entrances, approximately 59 m apart. One of the entrances splits into two galleries with a running stream. The second entrance leads to three chambers, approximately 8 m deep and 15 to 20 m high where *L. nivalis* roosts (Téllez-Zenteno 2001, p. 60).

*Colony size* — Téllez-Zenteno (2001, p. 60) reports that *L. nivalis* was present at this cave during autumn-winter between 1997-1999. López-Segurajáuregui (2010, p. 111-112) reports the highest capture rates of *L. nivalis* between August-October of 2006. This same author reports a colony of around 500 individuals in July detected by visual inspection in one of the chambers. However, this same author reports it was almost impossible to conduct a visual census in the interior of the cave and raised the possibility that the species present in the cave could have been a group of *L. yerbabuenae*.

The colony in this cave reaches its maximum size in October-November, when the sex ratio is even and most of the males are reproductively active (Téllez-Zenteno 2001, p. 60). *L. nivalis* abandons this cave by mid-February and only a few individuals have been reported later in the year. Téllez-Zenteno (2001 p. 60-61) suggested that *L. nivalis* in this cave have a similar reproductive pattern as the one at Cueva del Diablo and could be a potential mating roost. However, the data reported by López-Segurajáuregui (2010, p. 61-63) does not support this idea. The colony was no greater than a few hundred individuals, most captures occurred between August-October, the sex ratio was biased towards males, and all captured individuals (males or females) were reproductively inactive (López-Segurajáuregui 2010, p. 111-112).

*Foraging habitat* — The diet of *L. nivalis* at Tziranda is almost completely made up by *Agave* spp., although some *Ipomoea* spp. have also been reported (López-Segurajáuregui 2010, p. 62-63). López-Segurajáuregui (2010, p. 80-81) tracked the blooming seasonality of different resources and reported that the diet of *L. nivalis* in the Tziranda caves is dominated by species in the genus *Agave* during summer (July) but diet shifts to $C_3$ plants (e.g., genus *Ipomoea*) during September - November.

*Barriers to cave disturbance and level of protection* — The Tziranda caves are part of an eco-park, “Las Grutas Tziranda”, visited by a great number of tourists. The park has a guard in charge of security and guided visits to the caves. Visitors have access only to tunnels and chambers not occupied by bats. The cave remains in relatively good shape, even though dynamite was used in the 1980s to modify it for tourism activities. The landscape surrounding this cave is highly disturbed by anthropogenic activities like agriculture and cattle ranching. The canyon where the cave is located retains mostly original, undisturbed vegetation (Medellín 2002). The LECVT and the PCMM (Program for the Conservation of Bats of Mexico) have conducted research and environmental education and outreach activities at this cave. Tziranda is currently proposed to be designated as a wildlife sanctuary to confer it official protection.

**Xoxafi Cave, Lagunilla, Santiago de Anaya, Hidalgo, México.**

Xoxafi cave is located in the Teptha hill, 6 km from the town of Lagunilla, in the municipality of Santiago de Anaya, in the State of Hidalgo (López-Segurajáuregui 2010, p. 47-48).

Vegetation in the area consists predominantly of xerophytic scrub, but also grasslands and thorny forests with a high degree of endemism. Vegetation surrounding the cave has succulent cacti species and *Acacia* spp.*, Prosopis* spp. and *Mimosa* spp. are also present. This area is highly disturbed by agriculture and original vegetation is restricted to the hill tops and lands not suited for agriculture (Rzedowski 2006; INEGI 1992). Mean annual temperature ranges between 9.4 and 17.3 °C (INEGI 1992).

The cave is a system of intricate tunnels and chambers with approximately 1,000 $m^2$. The main entrance to the cave is approximately 5m in diameter on the side of the Teptha hill that leads into a system of galleries (45 x 25 x 8 m). Bats occupy a smaller chamber (8 x 20 m) within this system of galleries (López-Segurajáuregui 2010, p. 48).

*Colony size* — Álvarez and González (1970) captured thirteen *L. nivalis* in Xoxafi. López-Segurajáuregui (2010, p. 68), during a year of monthly sampling, captured only four individuals in late August (two males and two females, all reproductively inactive). Xoxafi also hosts a large colony of *L. yerbabuenae* (approximately 10,000 individuals) that reaches its largest size by late August. López-Segurajáuregui (2010, p. 82) suggests that both *Leptonycteris* species compete for floral resources in this area and the presence of *L. nivalis* in Xoxafi coincides with the time that floral resources are dwindling and *L. yerbabuenae* has started migrating from this site, lessening some of the competitive pressure and likely allowing some individuals of *L. nivalis* to visit the area, if only briefly.

*Foraging habitat* — In the Barranca de Metztitlán Biosphere Reserve, near Xoxafi cave, studies found that the presence of *L. nivalis* in the region is associated with blooming season of CAM plants, especially species in the genus *Agave* (Rojas-Martinez et al. 2011, *in prep*.).

*Barriers to cave disturbance and level of protection* — Xoxafi cave lacks official protection as a natural area. However, this cave is part of an ecotourism park, owned and managed by the local community since 2000. This park protects 8 ha of fenced land surrounding the cave. Starting in 2000, all garbage and graffiti were removed from the interior of the cave and prevention of littering actions and removal of litter are continuously conducted. Since 2008, the Program for the Conservation of Mexican Bats (PCMM) collaborates with the local community managing this park and offer environmental education activities and training to local guides on the importance of bats, caves and responsible tourism practices. Some areas of the cave have been modified and lights have been installed to allow safe access to tourists. However, the area where bats roost remains intact and entrance to this area is restricted. There is an initiative to grant the cave the status of a wildlife sanctuary and federal protection (López-Segurajáuregui 2010, p. 48).

### 3.2.2 Eastern México

**El Durazno and La Montaña mines, Concepción del Oro and Mazapil, Zacatecas, México.**

The Durazno mine, located in the Concepción del Oro municipality, and the La Montaña mine (24.57941°, -101.48833°) located in the Mazapil municipality are both in the state of Zacatecas (Figure 3). Vegetation in the area of El Durazno consists of xerophytic scrubs dominated by *Fouquieria splendens*, *Flourensia cernua*, *Larrea tridentata*, *Euphorbia antisyphilitica* and *Parthenium argentatum*. The vegetation surrounding La Montaña mine consists of mixed forests dominated by *Pinus durangensis*, *P. leiophylla*, *P. cembroides*, *Quercus sideroxyla* and *Q. eduardii* (INEGI 2003).

*Colony size* — Information on the structure of the mines, roosting areas and dynamics of *L. nivalis* in these sites is limited. Sánchez (2004, p. 93) captured 27 and 13 *L. nivalis* in La Montaña and El Durazno respectively in late July and early August 2002.

*Foraging habitat* — Using samples from the 40 individuals from both mines, Sánchez (2004, p. 52) determined that the diet of *L. nivalis* in the area consists mainly of *Agave* spp. However, species such as *Stenocereus beneckei*, *Calliandra houstoniana*, *Ipomoea arborescens*, *Bauhinia ungulata* and *Pseudobombax ellipticum* were also present in their diet (Sánchez 2004, p. 52).

*Level of protection* — Although both mines are in communal or privately-owned lands, these lands are located near a federally protected natural area, Sierra La Mojonera. As a result, efforts are being made to extend some of the management and conservation actions from Sierra La Mojonera to these lands, with focus on the importance of these mines as bat roosts. CONANP also conducts monitoring programs of these roosts, and although sporadic, an initiative is under way to establish a regular monitoring program of the roosts and foraging habitat of *L. nivalis* in the area.

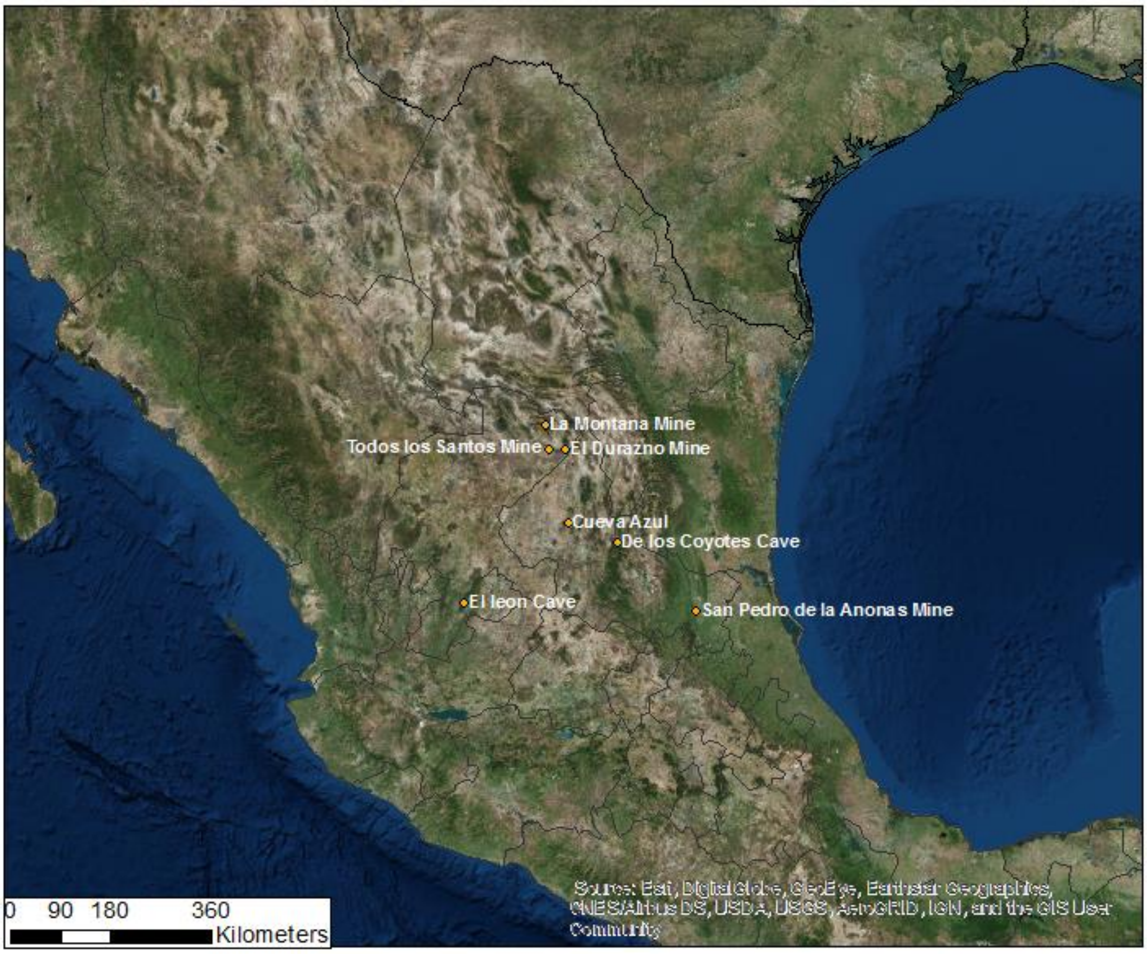


***Figure 3.*** *All eastern Mexico roosts with confirmed coordinates that have been documented to be used by L. nivalis (Table 2).*

### 3.2.3 Northeastern Mexico

**El Infierno Cave, Laguna de Sánchez, Santiago, Nuevo León, México.**

El Infierno Cave is in Laguna de Sánchez, in the Santiago municipality in the state of Nuevo León (Moreno-Valdez et al. 2004, p. 453-454). The cave is located within the Monterrey Cumbres National Park (Parque Nacional Cumbres de Monterrey). Biologically, knowledge on *L. nivalis* and its dynamics at this roost is limited.

Elevation in the area ranges from 440 m to 3470 m (INEGI 1986). El Infierno Cave is surrounded by *Pinus-Quercus* forest. Vegetation varies with the elevational gradient with conifer forests dominated by *Pinus cembroides* at higher elevation, followed by mixed and *Pinus-Quercus* forests and interspersed grasslands (Valdez 1981).

The cave is approximately 80 m deep, and an entrance with a 50-m vertical drop, formed by the dilution of calcareous rock from the Cretaceous. The entrance is 43.3 m long by 20.5 m wide (Moreno-Valdez et al. 2004, p. 454). Temperature in the interior of the cave ranges from 8.3°C in December to 12.1°C in August-September and humidity ranged from 29% in September to 99% in January (Moreno-Valdez et al. 2004, p. 455).

*Colony size* — El Infierno Cave is one of the three maternity roosts recorded for *L. nivalis* in the northern part of their range (Moreno-Valdez et al. 2004, p. 455-456; Gómez-Ruiz et al. 2015, p. 90). Most of the bats that arrive at this roost in April are pregnant or inactive females. Some males have also been reported around this time of year. Pups are probably born by the end of April and early May. In June, most mist netted individuals are lactating females and newly volant juveniles (Moreno-Valdez et al. 2004, p. 455). Emergence counts in June estimated 1,000 to 1,100 individuals leaving the cave every night (Lacher and Gómez-Ruiz 2012). Moreno-Valdez et al. (2004, p. 454) estimated a maximum of 3,500 individuals in July 1997 and 1,750 individuals in July 1998. Between July and August, captures at the entrance of the cave include juveniles of the year, lactating, post-lactating and inactive females and a few sub-adults. In September and October there were only inactive females. In October, the species abandons the cave completely (Moreno-Valdez et al. 2004, p. 454).

*Foraging habitat — Leptonycteris nivalis* feed mainly on *Agave* spp. while at El Infierno. Several *Agave* species (*Agave scabra, A. americana, A. salmiana* and *A. gentryi*) are present in the area (Moreno-Valdez et al. 2004, p. 453). The arrival and presence of *L. nivalis* in the area seem to perfectly match the flowering time of *Agave* (Moreno-Valdez et al. 2004, p. 454). During July and August, when flowering *Agave* reach the maximum abundance, the *L. nivalis* colony reaches its maximum size at El Infierno (Moreno-Valdez et al. 2004, Figure 1).

*Barriers to disturbance and level of protection* — Given its topography (an almost vertical tunnel), El Infierno Cave can only be accessed by experienced climbers with appropriate climbing equipment. However, the cave is a very popular site for speleological groups. Several authors suggest that the protection of the cave and the surrounding foraging grounds is of vital importance for the conservation of *L. nivalis* (Moreno-Valdez et al. 2004, p. 456, 458; Gómez-Ruiz et al. 2015, p. 93). Despite being part of a National Park, the cave is not included in the official management and conservation plan of this park. Private organizations and researchers, in collaboration with CONANP, have implemented a series of educational and outreach programs with the communities that live in the area in order to raise awareness about bats in general, and *L. nivalis* in particular, their ecological role, the relevance of *Agave* for the species, threats and conservation actions (ESHAC-CONANP 2013, p. 56-70; Gómez-Ruiz et al. 2015, p. 93, 94). In 2017, efforts to start a standardized, long-term monitoring program and a PIT tag study were initiated. These studies aim to understand migratory patterns and connectivity among the main roosts of the species in Mexico (Cueva del Diablo) and the United States (Mount Emory Cave and Romney Cave). In 2018, CONANP, under the Protected Areas Management Program (PROMANP), announced funding for monitoring *L. nivalis* at El Infierno cave with three specific objectives: 1) understand the population structure at the site by conducting population counts using infrared cameras, and obtaining information on site use, site fidelity, and population structure using mark-recapture methods (PIT tagging); 2) characterize the echolocation calls of the species; and 3) estimate the abundance and phenology of foraging resources within the Cumbres National park. This funding opportunity indicates that CONANP - Parque Cumbres de Monterrey has recognized the importance of protecting *L. nivalis* and is an important step to secure needed funding for long-term monitoring of the site.

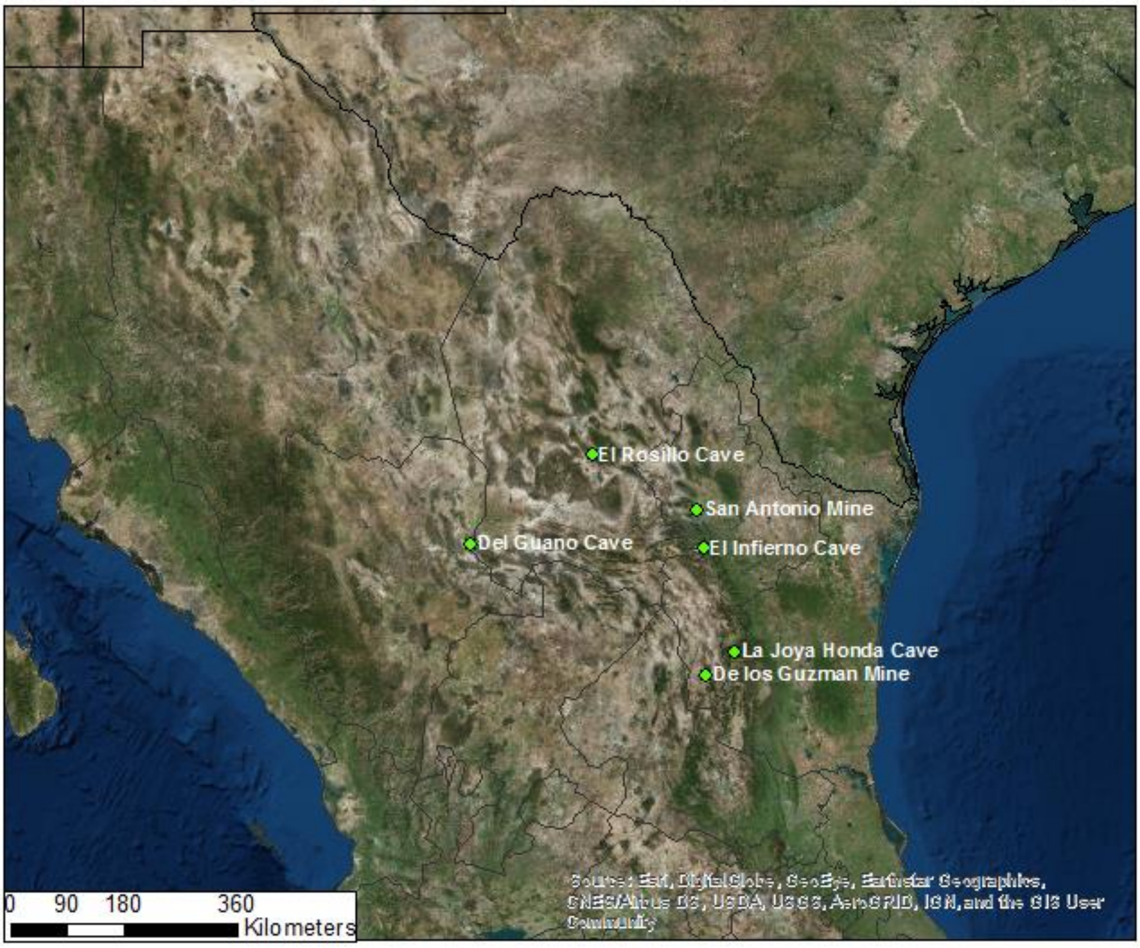


***Figure 4.*** *All northeastern Mexico roosts with confirmed coordinates that have been documented to be used by L. nivalis (Table 2).*

**El Rosillo Cave, Sabinas, Coahuila, México.**

El Rosillo cave is in the municipality of Cuatro Ciénegas, in the state of Coahuila and within the Don Martin Basin Natural Resources Protected Area (Área de Protección de Recursos Naturales Cuenca Don Martin), a federally protected area (Gómez-Ruiz et al. 2015, p. 94).

El Rosillo cave was originally a mine, active between 1940 and 1960. The entrance to this abandoned mine is quite large and is located on the face of a cliff. The cave consists of a main tunnel, 930 m long, and between 6 and 20 m wide with a generally rectangular shape. The tunnel narrows in the last section due to sedimentation. All along the tunnel, several domes and niches have formed due to corrosion by guano deposits (Piccini et al. 2007, p. 89, 90).

*Colony size* — Dynamics of this roost are poorly known. During July 2012, the presence of nectarivorous bats in the cave was supported by the presence of fresh guano, typical of nectarivorous species. This guano was under a small group of bats identified as *L. nivalis* by Lacher and Gómez-Ruiz (2012). The area of the cave where this group roosted (300 m deep inside the tunnel) is very high, and capture of the individuals was difficult. In early August 2012, mist netting efforts in the area surrounding this cave resulted in the capture of females. However, later visits to the same area in 2012 yielded no captures of *L. nivalis*, the guano reported in July was no longer fresh, and the individuals in the small group were no longer present (Lacher and Gómez-Ruiz 2012). Surveys done early August 2013 resulted in the capture of an adult female (not lactating), and 2015 surveys resulted in the discovery of a mummified carcass inside the cave. Although there has been poor success capturing individuals, surveys in late July 2017 report evidence of abundant yellowish guano in the cave floor (Emma Gómez-Ruiz pers. comm.). Due to its location and proximity (approx. 210 km) to El Infierno Cave, this cave is suspected to be a maternity roost for *L. nivalis* in the northern part of the range. This cave was also used by a large colony of *Tadarida brasiliensis* (Gómez-Ruiz et al. 2015. p. 93).

*Barriers to cave disturbance and level of protection* — The entrance to the cave is located on the face of a cliff, requiring a steep climb to reach; therefore, access is difficult. While the cave is located within a Natural Resources Protected Area, no official conservation or management plan exists for the cave and associated fauna. However, the Don Martin Basin Natural Resources Protected Area included *L. nivalis* as a target species in their recently announced climate adaptation plan (CONANP, 2017). The plan considers protection of roosting sites and foraging resources to maintain connectivity of the corridor and highlights as specific actions to identify and protect roosting sites and do an inventory and monitoring of *Agave* as the main foraging resource. Communities surrounding El Rosillo cave participated in the educational and outreach programs implemented for El Infierno cave (ESHAC-CONANP 2013; Gómez-Ruiz et al. 2015, entire) with the objective of informing people on the relevance of bats and their ecological roles and the importance of the area for the conservation of *L. nivalis.* In 2018, CONANP, under the Species-at-risk Protection Program (PROCER), announced funding for protecting and monitoring *L. nivalis* and *Choeronycteris mexicana* in five protected areas in Coahuila (Cuatro Ciénegas, Distrito de Riego 004 Don Martín, Maderas del Carmen, Ocampo y Río Bravo del Norte). It considers three specific objectives: 1) contribute to the understanding of the bats distribution, identify roosting sites and the distribution and abundance of foraging resources; 2) improve local capacity by training community teams (promotores y brigadistas) to participate in monitoring activities; and 3) increase social involvement through environmental education and participatory workshops to identify actions that the local communities can take to protect the nectar feeding bats and their habitats.

### 3.2.4 Southwestern United States

#### Mount Emory Cave, Big Bend National Park, Texas, USA.

Emory cave is probably one of the best studied *L. nivalis* roosts and up to now, the only under regular monitoring for the USA. This roost is located at an elevation of 2140m within the Chisos Mountains of Big Bend National Park in Brewster County, Texas in Chihuahuan Desert (Figure 5). It has recently been documented as a tectonic cave formed in rhyolite that is the 16th deepest in Texas at 86 m with a traverse length of 562 m (Veni 2016, p. 8-9).

Emory cave is surrounded by *Pinus-Quercus* forest (Easterla 1973, p. 20 and 48; Poulos and Camp 2010, p. 1144). The main cave entrance is almost completely obstructed by a *Ostrya chisosensis* (Fagales: Betulaceae) tree (Ammerman et al. 2009, p. 2). This cave has other potential entrances, indicated by a continuous cool air flow, but none that seem to be large enough for bat emergences (Veni 2016, p. 8). One of these entrances is a skylight, not known to be used by bats (Ammerman et al. 2009, p. 3) . The cave is composed of three rooms with hallways and deep chambers accessible only with technical climbing equipment (Veni 2016, p. 9). This is a cold cave, with summer temperatures that range between 15.2-18.3°C (Ammerman et al. 2009, p. 90). The temperature of the chamber used as roost by *L. nivalis* ranges between 11.4 and 18.7°C between April and September (Brown 2008, p. 16). Average humidity was 87% (Ammerman et al. 2009, p. 4). A small number of individuals of other species such as *Myotis thysanodes* and *Corynorhinus townsendii* roost along with *L. nivalis. Antrozous pallidus*, *Eptesicus fuscus*, *Myotis ciliolabrum* and *Myotis volans* occasionally use this site (Adams 2015, p. 8).

*Colony size* — Emory Cave is considered a maternity roost and *L. nivalis* is present in this cave between April and September (Adams 2015, p. 21). This colony consists mainly of pregnant (early in the season) and lactating females, and inactive females and juveniles of both sexes (later in the season). Historic colony size estimates (Easterla 1972, p. 288) range between 0-10,000 individuals. However, different survey methods, and the fact that the bats roost in areas inaccessible to humans, make it hard to detect real fluctuations in the colony size. Standardized emergence counts using thermal imaging (Ammerman et al. 2009, p. 2-3) since 2008 report that colony size ranges between 294 to 3,238 (mean=2,111) with the highest numbers usually reached in early July each year (Ammerman, unpublished data).

*Foraging habitat* — In this area, the diet of *L. nivalis* consists mainly of *Agave havardiana* (Kuban 1989, p. 108; England 2012, p. 24) that grows within the protected area of Big Bend National Park. Easterla (1972, p. 290) suggested that the diet of this species in Big Bend National Park could also include *Agave chisoensis*, *Agave lechuguilla*, and *Agave scabra* (=*A. asperrima*) among others, but this has not been confirmed. According to GIS specialist Betty Alex (cited in the government document, Biological Opinion on the Fire Management Plan for Big Bend National Park, 2005) there are 20,775 hectares of primary and 28,839 ha of secondary *Agave* habitat available to *L. nivalis* in BBNP.

*Barriers to cave disturbance and level of protection* — Emory Cave, being within Big Bend National Park, is federally protected. In addition, its remoteness and inaccessibility reduces the probability of visitation by tourists and disturbance. However, the cave opening is visible from a hiking trail and there is nothing to prevent curious hikers from hiking to and entering the cave. Plans have been made with Raymond Skiles, resource manager at Big Bend National Park, to erect a sign near the cave to inform visitors of the presence of an endangered bat species as well as the risk of introducing the fungus that causes white nose syndrome. As mentioned earlier, colony size is monitored yearly using thermal imaging to estimate emergence counts (Dr. Loren Ammerman, Angelo State University). In addition, in 2014, a PIT tagging program was started and a PIT tag detection antenna is installed each year during the summer to monitor bat activity and cave use patterns (Adams and Ammerman 2015, entire).

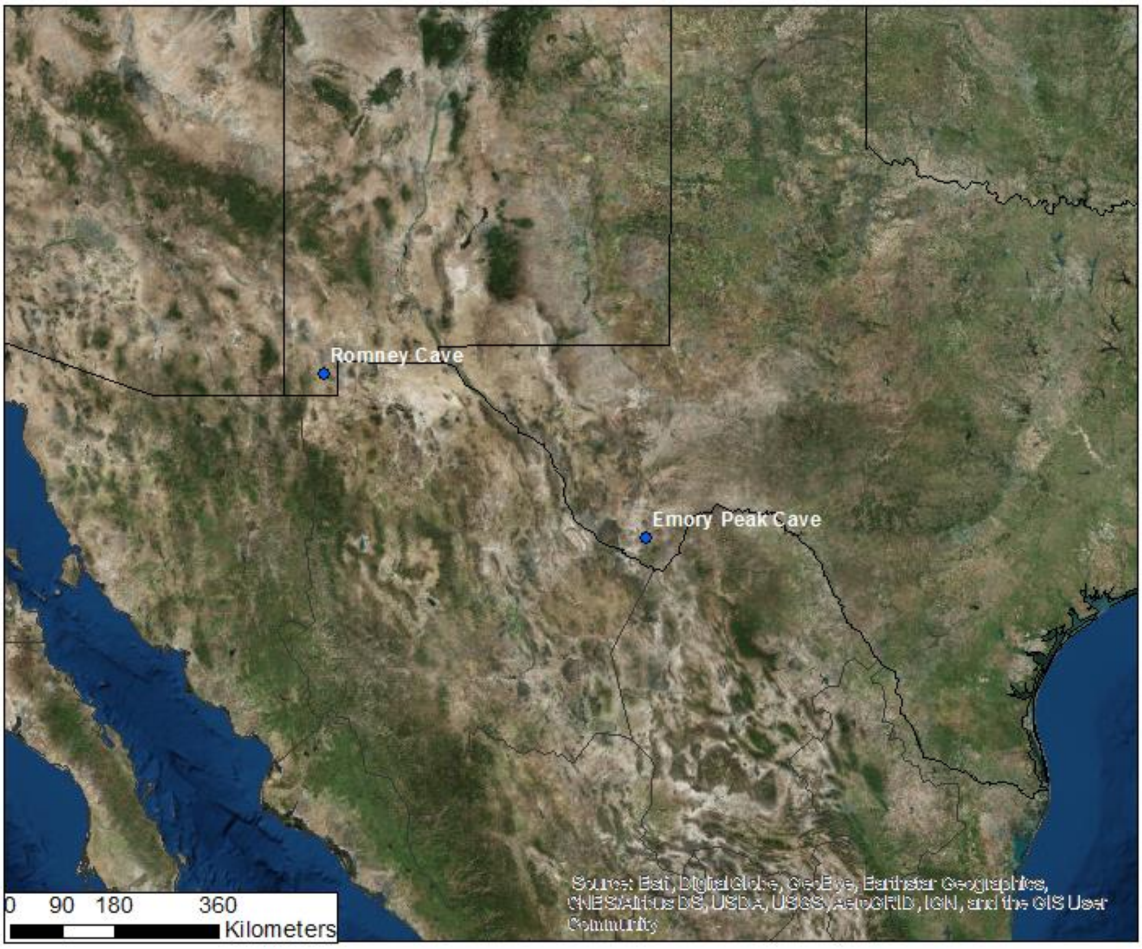


***Figure 5.*** *All southwestern United States roosts with confirmed coordinates that have been documented to be used by L. nivalis (Table 2).*

**Romney Cave, Big Hatchet Mountains, Hidalgo County, New Mexico.**

Romney Cave was discovered to be used by *L. nivalis* in 2005 in the Big Hatchet Mountains of Hidalgo County, New Mexico (Bogan et al. 2006, p. 4; Bogan et al. 2017, p. 318-319). Romney Cave has two separate entrances and is located on the ridge of a hill in a rock dome of limestone at an elevation of 1750m (Weise 2005, p. 6). Both *L. yerbabuenae* and *L. nivalis* co-occur in the Romney roost and in a nearby roost in the Animas Mountains (Bogan et al., 2006; Hoyt et al., 1994). The Big Hatchet Mountains are characterized by limestone cliffs and slopes whereas the Animas mountains are volcanic in origin (Bogan et al. 2006, p. 8). Generally, *L. yerbabuenae* are present throughout the summer in these areas and *L. nivalis* are present late summer (mid-July through September) and are less common (Bogan et al. 2017, p. 323).

*Colony size* — Romney Cave is currently the largest known colony containing both *Leptonycteris* species in the United States. This factor makes it difficult to get an accurate census of *L. nivalis* in Romney Cave. In 2005 the colony was approximately 600 bats in late July, 5,000 bats in August and September, but by 23 September was 380 bats (Weise 2005, p. 8). This was also the time that all observed *Agave* had finished blooming (Weise 2005, p. 10). Romney Cave was estimated to contain at least 7,000 *Leptonycteris* bats in 2008, with individuals dispersing primarily to the west presumably to foraging grounds in the Animas Mountains 20 km away (Bogan et al. 2017, p. 326). However, an ongoing recent study in the summer of 2016 and 2017 estimates less than 500 bats (K. Stoner, pers. comm.). Continuous monitoring at this site has not occurred.

*Foraging habitat* — In New Mexico, *Agave palmeri* is suspected to be the main component of the diet of *L. nivalis* (Bogan et al. 2017, p. 319). During radiotelemetry of both *Leptonycteris* species in 2004-2005, the densest patches of *Agave* were encountered on rocky, precipitous slopes primarily in the Animas Mountains (Bogan et al. 2017, p. 319). In parts of New Mexico, *Agave* in areas close to the Arizona border begin blooming in late June and by mid-July in the Big Hatchet Mountains (Bogan et al., 2006). The surrounding habitat, as described by Brown (1994), is dominated by semi-desert grassland, with Madrean Evergreen Woodland, lower Interior Chaparral, and Interior Southwest Riparian Deciduous Forest occurring in patches at higher elevations (Bogan et al. 2017, p. 319). In radiotelemetry studies, Bogan et al. (2017, p. 326) found no difference in nightly movements, activity timing, or general habitats used by *L. nivalis* and *L. yerbabuenae*. Both species were found to forage most often in the Animas Mountains and commute >20km from the roost in the Big Hatchet Mountains. Other studies also suggest that bats from this roost forage nearby first, then commute to other areas in the Animas (England, 2012).

*Barriers to cave disturbance and level of protection* — Romney Cave occurs on a Bureau of Land Management (BLM) Wilderness Protected Area. The roost is difficult to access with vertical drop-offs >70m at the "crevice" entrance (photos in Figure 15 and 16 in Bogan et al. 2006). The slopes leading to the roost are very steep with minimal vegetation. Due to difficult access and remote location disturbance from people is not a factor affecting conservation of the Mexican long-nosed bat in this roost.

### 3.2.5 Lesser Known Roost Locations

There are 17 roost locations (caves and mines) where *L. nivalis* have been documented to occur but have not been well studied. Therefore, the type of roost, seasonal use of the roost, and size of the colony is unknown at these sites. These sites are included in Table 2 along with the source of the information (which collection houses the specimens) and their locations are illustrated on Figures 1, 2, 3, and 4. El Coyote Cave and El Murcielago Cave do not have confirmed coordinates, so they are not on Figures 1, 2, or 3, but are included in Table 2. Because of the lack of information regarding these roost locations, it is difficult to determine the conservation concerns at these sites

## 3.3 Foraging

Recovery task number 2 in the recovery plan (USFWS 1994, p. 29, 37) addressed the need to determine diet, foraging requirements, and protection of foraging grounds. There are now numerous studies that describe and inventory the plant species included in the diet of *L. nivalis*, especially for the central México region (Table 3). Other tasks in this category, such as foraging behavior and patterns, foraging movement patterns and areas have received some attention (Rojas-Martínez 1996, entire; Moreno-Valdez et al. 2000, 2004, entire; Trejo-Salazar 2007, entire; Espinosa-Ávila 2008, entire; Salinas-Galicia 2013, entire; Ayala-Berdon et al. 2013, entire; Gómez-Ruiz et al. 2015, entire; Trejo-Salazar et al. 2015, entire; Gómez-Ruiz and Lacher 2017, entire; Bogan et al. 2017, entire), although knowledge is still limited (Torres-Knoop 2014, entire).

Several studies have corroborated that species in the genus *Agave* are a very important component of the diet of *L. nivalis* (Moreno-Valdez et al. 2000, entire; 2004, p. 455-458; Sánchez and Medellín 2007, entire; Trejo-Salazar 2007, p. 71-72; López-Segurajáuregui 2010, entire; Trejo-Salazar et al. 2015, p. 366; Gómez-Ruiz and Lacher 2017, entire) especially in the northern part of their range (Kuban 1989, p. 115-130). However, it is now evident that *L. nivalis* uses a wider array of floral resources (Table 3) in the central and southern part of its range. Care has been taken to present only plant species in Table 3 that have been confirmed in the diet of *L. nivalis*. Those diet items in the older literature that referred to what is now *L. yerbabuenae* have been removed. Therefore, at this point in time, there are 49 plant species known to be used by *L. nivalis* and additional studies into their diet, especially in regions outside of central Mexico, are needed.

Diet of *L. nivalis* in the southern part of its range has been thoroughly described, especially in the state of Morelos and Puebla, Mexico (Rojas-Martínez 1996, entire; Valiente-Banuet et al. 1997, entire; Téllez-Zenteno 2001, entire; Sánchez 2004, entire; Sánchez and Medellín 2007, entire; López-Segurajáuregui 2010, entire). In Morelos, studies focused on describing the diet in and around Cueva del Diablo, Tepoztlan, the only mating roost known for the species (Sánchez 2004, p. entire; Sánchez and Medellín 2007, entire; López-Segurajáuregui 2010, p. 65-67). In this region, *L. nivalis* includes up to 19 species in its diet with the dominant species from the families Agavaceae (Asparagaceae, Chase et al. 2009, entire) and Convolvulaceae, specifically those in the genus *Agave* and *Ipomoea* (Table 3, Figure 6) (Sánchez 2004, p. 54; Sánchez and Medellín 2007, p. 1755; López-Segurajáuregui 2010, 65-67).

***Table 3**. List of plant species confirmed as part of the diet of L. nivalis (includes studies at specific roosts and studies at capturing/collecting sites). All known nectar sources are angiosperms. All of the diet items were documented from study sites within Central Mexico except for those which are roosts found in the southwestern United States or are from an undetermined site in Mexico.*

| Order | Family | Latin Name | Location where species has been reported as part of local diet of *L. nivalis* | Reference (s) |
|---|---|---|---|---|
| Caryophyllales | Cactaceae | *Cephalocereus chrysacanthus* | Tehuacán-Cuicatlán Valley | Rojas-Martínez 1996 |
| Caryophyllales | Cactaceae | *Hilocereus undaus* | Tehuacán-Cuicatlán Valley | Rojas-Martínez 1996 |
| Caryophyllales | Cactaceae | *Myrtillocactus geometrizans* | Hidalgo, MEX | Gardner 1977 |
| Caryophyllales | Cactaceae | *Neobuxbaumia macrocephala* | Zapotitlán de las Salinas, Tehuacán, Puebla, MEX | Valiente-Banuet et al. 1997 |
| Caryophyllales | Cactaceae | *Neobuxbaumia mezcalaensis* | Zapotitlán de las Salinas, Tehuacán, Puebla, MEX | Valiente-Banuet et al. 1997 |
| Caryophyllales | Cactaceae | *Neobuxbaumia tetetzo* | Zapotitlán de las Salinas, Tehuacán, Puebla, MEX | Valiente-Banuet et al. 1997 |
| Caryophyllales | Cactaceae | *Pachycereus (Mitrocereus) fulviceps* | Tehuacán-Cuicatlán Valley | Rojas-Martínez 1996 |
| Caryophyllales | Cactaceae | *Pachycereus weberi* | Zapotitlán de las Salinas, Tehuacán, Puebla, MEX | Valiente-Banuet et al. 1997 |
| Caryophyllales | Cactaceae | *Pilosocereus chrysacanthus* | Zapotitlán de las Salinas, Tehuacán, Puebla, MEX | Valiente-Banuet et al. 1997 |
| Caryophyllales | Cactaceae | *Stenocereus beneckei* | Cueva del Diablo and San Lorenzo cave | Sánchez 2004; Sánchez & Medellín 2007; López-Segurajáuregui 2010 |
| Caryophyllales | Cactaceae | *Stenocereus proinosus* | Zapotitlán de las Salinas, Tehuacán, Puebla, MEX | Valiente-Banuet et al. 1997 |
| Caryophyllales | Cactaceae | *Stenocereus stellatus* | Chinango town, lower Mixteca Baja, Tehuacán Valley, Oaxaca, MEX | Arias-Coyotl et al. 2006 |
| Asterales | Compositae | - | Cueva del Diablo, San Lorenzo cave, and Tziranda caves | Rojas-Martínez 1996; López- |

| | | | | |
|---|---|---|---|---|
| | | | | Segurajáuregui 2010 |
| Fabales | Fabacaeae | *Bauhinia ungulata* | Cueva del Diablo | Sánchez 2004; Sánchez & Medellín 2007; López-Segurajáuregui 2010 |
| Fabales | Fabacaeae | *Calliandra houstoniana* | Cueva del Diablo | Sánchez 2004; Sánchez & Medellín 2007; López-Segurajáuregui 2010 |
| Lamiales | Bignoniaceae | *Crescentia alata* | Undetermined site in Mexico | Dobat & Peikert-Holle 1985 |
| Lamiales | Bignoniaceae | *Crescentia cujete* | Undetermined site in Mexico | Dobat & Peikert-Holle 1985 |
| Malvales | Bombacaceae | *Ceiba aesculifolia/* | Cueva del Diablo | Sánchez 2004; Sánchez & Medellín 2007; López-Segurajáuregui 2010 |
| Malvales | Bombacaceae | *Ceiba spp.* | San Lorenzo cave and Tziranda caves | Sánchez 2004; Sánchez & Medellín 2007; López-Segurajáuregui 2011 |
| Malvales | Malvaceae | *Pseudobombax ellipticum* | Cueva del Diablo | Sánchez 2004; Sánchez & Medellín 2007; López-Segurajáuregui 2010 |
| Solanales | Convolvulaceae | *Ipomea arborescens* | Cueva del Diablo | Sánchez 2004; Sánchez & Medellín 2007; López-Segurajáuregui 2010 |
| Solanales | Convolvulaceae | *Ipomea murucoides* | Cueva del Diablo and Tziranda caves | López-Segurajáuregui 2010; Salinas-Galicia 2013 |
| Solanales | Convolvulaceae | *Ipomea intrapilosa* | Tziranda caves | López-Segurajáuregui 2010 |
| Asparagales | Asparagaceae | *Agave americana/A. parryi* | Cueva del Diablo**,** San Lorenzo cave**, and** Tziranda caves | López-Segurajáuregui 2010 |

| | | | | |
|---|---|---|---|---|
| Asparagales | Asparagaceae | *Agave aplanata* | Cueva del Diablo, San Lorenzo cave, and Tziranda caves | López-Segurajáuregui 2010 |
| Asparagales | Asparagaceae | *Agave angustiarum/A. penducilifera* | Cueva del Diablo, San Lorenzo cave, and Tziranda caves | López-Segurajáuregui 2010 |
| Asparagales | Asparagaceae | *Agave asperrima* | Cueva del Diablo | López-Segurajáuregui 2010 |
| Asparagales | Asparagaceae | *Agave atrovirens* | Cueva del Diablo | López-Segurajáuregui 2010 |
| Asparagales | Asparagaceae | *Agave cupreata* | Tziranda caves | López-Segurajáuregui 2010 |
| Asparagales | Asparagaceae | *Agave dasyliroides* | Cueva del Diablo | Sánchez 2004; Sánchez & Medellín 2007; López-Segurajáuregui 2010 |
| Asparagales | Asparagaceae | *Agave difformis* | Metztitlan Canyon, Hidalgo, MEX | Trejo-Salazar 2007; Trejo-Salazar et al. 2015 |
| Asparagales | Asparagaceae | *Agave ellemeettiana* | Tziranda caves | López-Segurajáuregui 2010 |
| Asparagales | Asparagaceae | *Agave filifera* | Cueva del Diablo | López-Segurajáuregui 2010 |
| Asparagales | Asparagaceae | *Agave garciae-mendozae* | Metztitlan Canyon, Hidalgo, MEX | Trejo-Salazar 2007; Trejo-Salazar et al. 2015 |
| Asparagales | Asparagaceae | *Agave gentryi* | El Infierno Cave, Nuevo Leon, MEX | Gomez-Ruiz & Lacher 2017 |
| Asparagales | Asparagaceae | *Agave havardiana* | Found in the southwestern United States- Big Bend National Park, Texas, USA | Kuban 1989; England 2012 |
| Asparagales | Asparagaceae | *Agave hookeri* | Tziranda caves | López-Segurajáuregui 2010 |
| Asparagales | Asparagaceae | *Agave horrida* | Cueva del Diablo, San Lorenzo cave, and Tziranda caves | Sánchez 2004; Sánchez & Medellín 2007; López-Segurajáuregui 2010 |

| | | | | |
|---|---|---|---|---|
| Asparagales | Asparagaceae | *Agave inaequidens* | Cueva del Diablo | Sánchez 2004; Sánchez & Medellín 2007; López-Segurajáuregui 2010 |
| Asparagales | Asparagaceae | *Agave mapisaga* | Cueva del Diablo and San Lorenzo cave | López-Segurajáuregui 2010 |
| Asparagales | Asparagaceae | *Agave marmota* | Tehuacan-Cuicatlan Valley Puebla and Oaxaca, MEX | Rojas-Martínez 1996 |
| Asparagales | Asparagaceae | *Agave oscura* | San Lorenzo cave | López-Segurajáuregui 2010 |
| Asparagales | Asparagaceae | *Agave palmeri* | Found in the southwestern United States-New Mexico | Bogan et al. 2017 |
| Asparagales | Asparagaceae | *Agave potatorum* | Tehuacan-Cuicatlan Valley Puebla and Oaxaca, MEX | Rojas-Martínez 1996 |
| Asparagales | Asparagaceae | *Agave salmiana* | Cueva del Diablo, San Lorenzo cave, and Tziranda caves | Sánchez 2004; Sánchez & Medellín 2007; López-Segurajáuregui 2010 |
| Asparagales | Asparagaceae | *Agave scaposa* | San Lorenzo cave | López-Segurajáuregui 2010 |
| Asparagales | Asparagaceae | *Agave schidigera* | Tziranda caves | López-Segurajáuregui 2010 |
| Asparagales | Asparagaceae | *Agave striata* | Metztitlan Canyon, Hidalgo, MEX | Trejo-Salazar 2007; Trejo-Salazar et al. 2015 |
| Asparagales | Asparagaceae | *Agave tequilana* | Tziranda caves | López-Segurajáuregui 2010 |
| Asparagales | Asparagaceae | *Agave titanota* | San Lorenzo cave | López-Segurajáuregui 2010 |

***Figure 6***. *Two of the many species of plants found in the diet of Leptonycteris nivalis. Agave havardiana (left) and Ipomea (right)*

Diet has been studied in the state of Puebla near San Lorenzo cave, but also from individuals captured in foraging grounds in San Juan Raya, San Antonio Texcala, Coxcatlán, Río Salado and Zapotitlán de las Salinas in the state of Puebla (Rojas-Martínez 1996, entire). In this area, Valiente-Banuet and collaborators (1997, p. 454) report nectar-feeding bats, including *L. nivalis*, as the main pollinators of *Neobuxbaumia*, a dominant columnar cactus species in Central Mexico. In the state of Hidalgo, also in Central Mexico, *L. nivalis* is reported as one of the main pollinators of *Agave* (Trejo-Salazar et al. 2015, p. 366).

Several studies have described seasonal variation in the diet of *L. nivalis.* In the State of Mexico, Téllez-Zenteno (2001, p. 119-120) determined that CAM plants (e. g. *Agave* spp.) make up the diet of *L. nivalis* during summer but $C_3$ plants (e. g. genus *Ipomoea* and family Bombacacea) increase in relative importance during fall-winter. In the state of Michoacán, López-Segurajáuregui (2010, p. 61-63), tracked the blooming seasonality of different resources and reported that the diet of *L. nivalis* in the Tziranda caves is dominated by species in the genus *Agave* during summer (July) but diet shifts to $C_3$ plants during September-November. In the Barranca de Metztitlán Biosphere Reserve, studies found that the presence of *L. nivalis* in the region is associated with blooming season of CAM plants, especially species in the genus *Agave* (Rojas-Martinez et al. *in prep.*).

During the summer, *L. nivalis* relies heavily on resources offered by *Agave* spp. in Big Bend National Park and other areas of the southwestern United States. In New Mexico, *Agave palmeri* is suspected to be a main component of the diet (Bogan et al. 2017, p. 319) while in the Big Bend National Park area the diet of *L. nivalis* is predominantly *Agave havardiana* (Kuban 1989, p. 115-130; England 2012, p. 24). Easterla (1972, p. 290) suggested that the diet of this species in Big Bend National Park could also include *Agave chisoensis, Agave lechuguilla*, and *Agave scabra* (=*A. asperrima*) among others, but this has not been confirmed. At Emory Cave, Brown (2008, p. 26) discovered insect parts in feces from *L. nivalis* late in the spring before *Agave havardiana* had begun to bloom and suggested that the consumption of insects might be more widespread in this migratory species because of the potential unreliability of nectar resources. The capture of *L. nivalis* in Big Bend National Park in April reported by Higginbotham and Ammerman (2002, p. 10) and multiple observations of this species at Emory Cave before *Agave* are typically blooming (Brown 2008, p. 18; Adams 2015, p. 21 and 50) is consistent with the use of insects as a supplement to their diet. Further investigation into the importance of insects to the diet of *L. nivalis* are warranted.

Foraging patterns, distance traveled, and location of foraging grounds are scarcely known. Based on studies of a related bat species, *L. yerbabuenae*, we know this species is capable of flying up to 49 km in one direction from day roosts to foraging grounds in the Sonoran desert (Medellin et al. 2018, p. 4) although other studies (Sahley et al. 1993, p. 596; Horner et al. 1998, p. 583) found one-way foraging distances of 25-35 km. These studies suggest that *L. nivalis* could forage over a large area. Bogan et al. (2017, entire) studied the foraging patterns of *L. nivalis* in Hidalgo County New Mexico near Romney Cave and found no obvious differences in foraging activity compared to sympatric *L. yerbabuenae*. At this site both species were found to share common roosts and commute at least 20 km one way to forage in areas of high density of *A. palmeri* (Bogan et al. 2017, p. 327).

England (2012, p. 24) investigated foraging patterns for *L. nivalis* in Big Bend National Park area and found that *L. nivalis* tended to center their activity around areas with high concentration of resources (*Agave havardiana*). However, nightly activity was not restricted to these areas, and how far and where an individual traveled depended on age and sex. While females tended to remain closer to the roost and in areas with high concentrations of resources, juveniles tended to make long-distance expeditions most likely related to landscape exploration (England 2012, p. 22). The author suggests that this exploration could help juveniles acquire a navigational map in preparation for migration but also could reflect the use of unidentified roosts or foraging grounds. Determining foraging grounds for a species that can fly dozens of kilometers from day roosts to foraging grounds every night and that migrates seasonally is inherently complex.

Studies at the landscape level by Gómez-Ruiz and Lacher (2017, entire) and Espinosa-Ávila (2008, entire) indicate that *L. nivalis* seem to track seasonal availability of floral resources and climatic conditions along its migratory route. Moreno-Valdez et al. (2004, p. 454) found that the abundance of *L. nivalis* in El Infierno Cave, a major roost in northern Mexico, was correlated with the frequency of blooming *Agave* and ambient air temperature. Adams (2015, p. 34) reports a similar positive correlation between seasonal blooming *Agave* and colony size of *L. nivalis* in Emory Cave. Téllez-Zenteno (2001, p. 61) reports a similar phenomenon in central Mexico, where at least one of the studied roosts was occupied only in years when there was ample abundance of *Agave* blooming in the area. In areas where the distribution of *L. nivalis* does not overlap with the distribution of *Agave* spp., *L. nivalis* includes other species in its diet such as *Pseudobombax*, *Calliandra*, *Ceiba*, and *Ipomoea* (Sánchez and Medellín 2007, p. 55; López-Segurajáuregui 2010, p. 61-69; Gómez-Ruiz and Lacher 2017, p. 74).

Location of specific foraging grounds have been determined as a by-product of pollination studies of *Agave* and cacti (Valiente-Banuet et al. 1997, entire; Arias-Coyotl et al. 2006, p. entire; Trejo-Salazar et al. 2015, entire) where pollinators, including *L. nivalis*, are reported as being present in certain areas of the Metztitlan Canyon in Hidalgo, Mexico. Rojas-Martínez (1996, entire) conducted a study of *L. nivalis* on foraging grounds in the Balsas basin and the Tehuacán-Cuicatlán Biosphere Reserve in central Mexico and found several important foraging grounds. This finding suggests that, in areas where *Agave* and cacti are the main resource, the conservation of *L. nivalis* will require the maintenance of relatively large areas of wild *Agave* and cacti.

Despite the available information on potential foraging grounds associated with specific roosts (England 2012, entire; Bogan et al. 2017, entire) or of potential foraging grounds in certain areas (Rojas-Martínez pers. comm.), we still do not know the location or extent of foraging grounds in most of the species distribution and have to rely on niche models of the distribution of the plant species included in the diet of *L. nivalis*. However, these modeling efforts need to be refined and incorporate the phenology of plant species to accommodate the seasonal nature of the distribution of *L. nivalis*. Studies like the one by Rojas-Martínez (1996, entire), conducted 20 years ago, need to be updated since landscapes have been heavily modified since that time and foraging resources reported may not be available for the species any longer. Certain areas that represented potential foraging grounds are now converted to agricultural use, cattle ranching and urban development or under exploitation by the liquor industry (Téllez-Zenteno 2001, p. 34-38; Salinas-Galicia 2013, p. 87; Rojas-Martínez pers. comm.).

*Agave* require many years (approximately 8-20) to grow, mature, and produce a flowering stalk that will eventually, in monocarpic species, drain the plant of energy and die (Gentry 1982, p. 30). Seeds are produced in most wild *Agave* populations, but asexual reproduction is also a possibility in the form of bulbils or rhizomatous suckers (Gentry 1982, p. 30). When an *Agave* plant flowers, from the spiny rosette of leaves rises an inflorescence that can be paniculate or spicate. Most of the species used by bats are paniculate species that produce clusters of deep-tubed, geotropically erect flowers which are structurally important for holding the nectar that *L. nivalis* feed on (Gentry 1982, p. 42). The anthers dehisce at night in many *Agave* species which enable cross-pollination mediated by nectar-feeding bats. In North America, *Agave* have been valued by people for fibers, food, drink, and other natural products for more than 10,000 years (Gentry 1982, p. 3). *Agave* plantations grown for the production of tequila and mescal throughout Mexico are typically clones. For these distilled liquors, the short broad stem (leaf bases) is cut when an *Agave* plant begins to flower and prepared for the fermentation process. Because the plants in these commercial plots are not allowed to flower they are not a foraging resource for *L. nivalis*. Conservation of foraging resources, considered in tasks 2.22 and 2.23 of the Recovery Plan, entail working with agricultural users and liquor industries to protect foraging habitats (USFWS 1994, p. 37). In this respect, initiatives are under way in different parts of Mexico. In Central Mexico, Dr. Rodrigo Medellin and National Autonomous University of Mexico (UNAM), along with the Tequila Interchange Project have launched the Bat Friendly Tequila and Mezcal program. In this program, tequila and mezcal producers that cultivate and harvest *Agave* have introduced management practices that provide foraging resources for bats and also benefit the genetic variability of *Agave* plants (Trejo-Salazar et al. 2016, entire). Trejo-Salazar et al. (2016, p. 526-527) calculated that one *L. nivalis* bat would need the nectar produced by 2.48 inflorescences of *Agave angustifolia* each night and used this information to promote the “bat-friendly” tequila concept. By convincing farmers to adopt the practice of leaving 5% of their plantation to flower, the bats have access to nectar and the *Agave* benefit from the increased genetic diversity that cross pollination provides. This program has been supported by an extensive outreach and environmental education program by the PCMM (Program for the Conservation of Bats of Mexico).

In the state of Hidalgo, Dr. Rojas-Martinez, is conducting local outreach with communities and government agencies to encourage the use of local *Agave* species for reforestation and traditional (live fences) and ornamental uses. In northern Mexico, landscapes associated with El Infierno Cave in Nuevo León, and El Rosillo Cave in Coahuila, Gómez-Ruiz and collaborators (2015, entire) have been conducting an outreach and environmental education program since 2013. Preliminary studies in Nuevo Leon and Coahuila analyzed pollen collected from the fur of *L. nivalis* and identified exclusively *Agave* pollen (TEL and EPGR unpublished data).

Gómez-Ruiz and Lacher (2017, p. 67-78) tested the hypothesis of the *Agave* migratory corridor by modelling the distribution of nine relevant *Agave* species (Figure 7) and testing whether bat records are significantly related to *Agave* species richness (Figure 8). *Agave* were selected according to the following criteria: (1) paniculate *Agave* (genus *Agave* subgenus *Agave*) occurring within *L. nivalis* northern range, (2) reported in *L. nivalis* diet studies and (3) documented to be flowering at the time *L. nivalis* was present in a particular area. The authors found that *L. nivalis* presence points co-occur in areas with more than one *Agave* more often than random (Figure 9) and concluded that areas with higher number of *Agave* species are distributed along mountain chains and may provide foraging resources for *L. nivalis* for longer period of time during its migration. Further studies are necessary to confirm which *Agave* species *L. nivalis* is foraging on and prioritize the maintenance of those species' populations. The authors recommend the implementation of a long-term annual monitoring program to obtain information on *Agave* phenology that will help identify potential mismatches in *Agave* flowering and presence of *L. nivalis.*

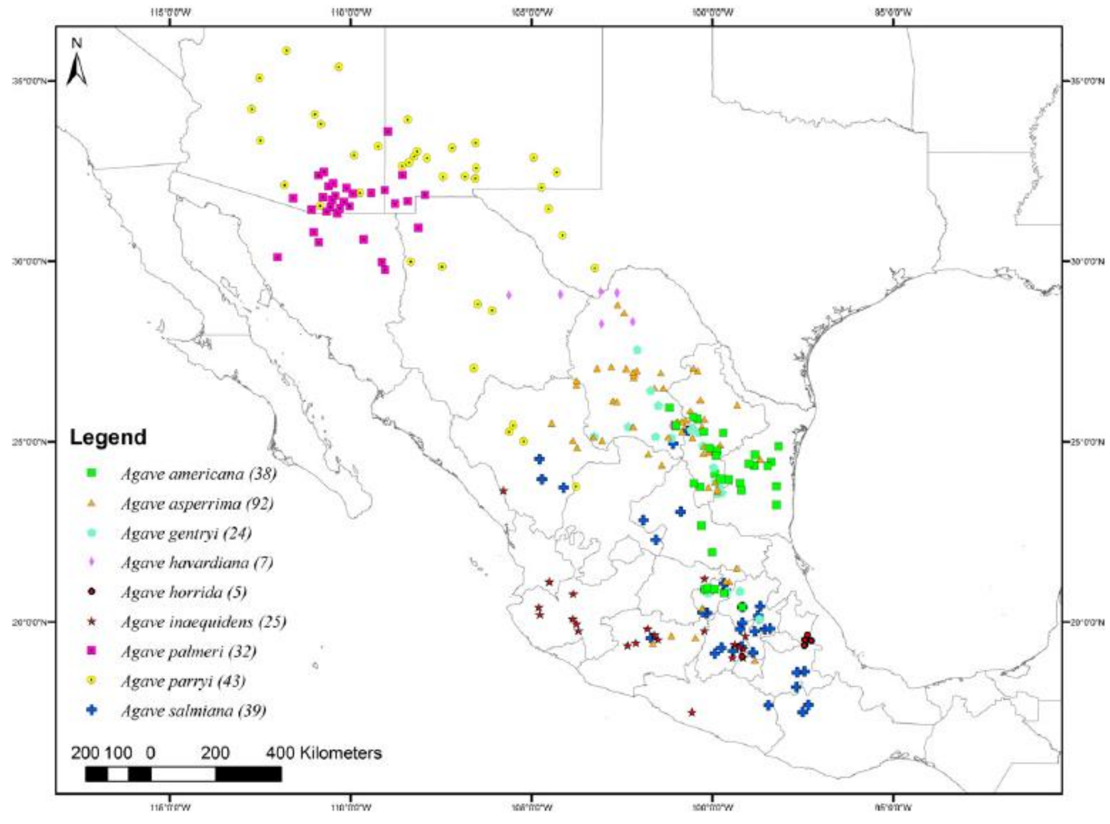


***Figure 7***. *Occurrences of selected Agave species. Total number of occurrence points is shown in parentheses (from Gomez-Ruiz and Lacher 2017).*

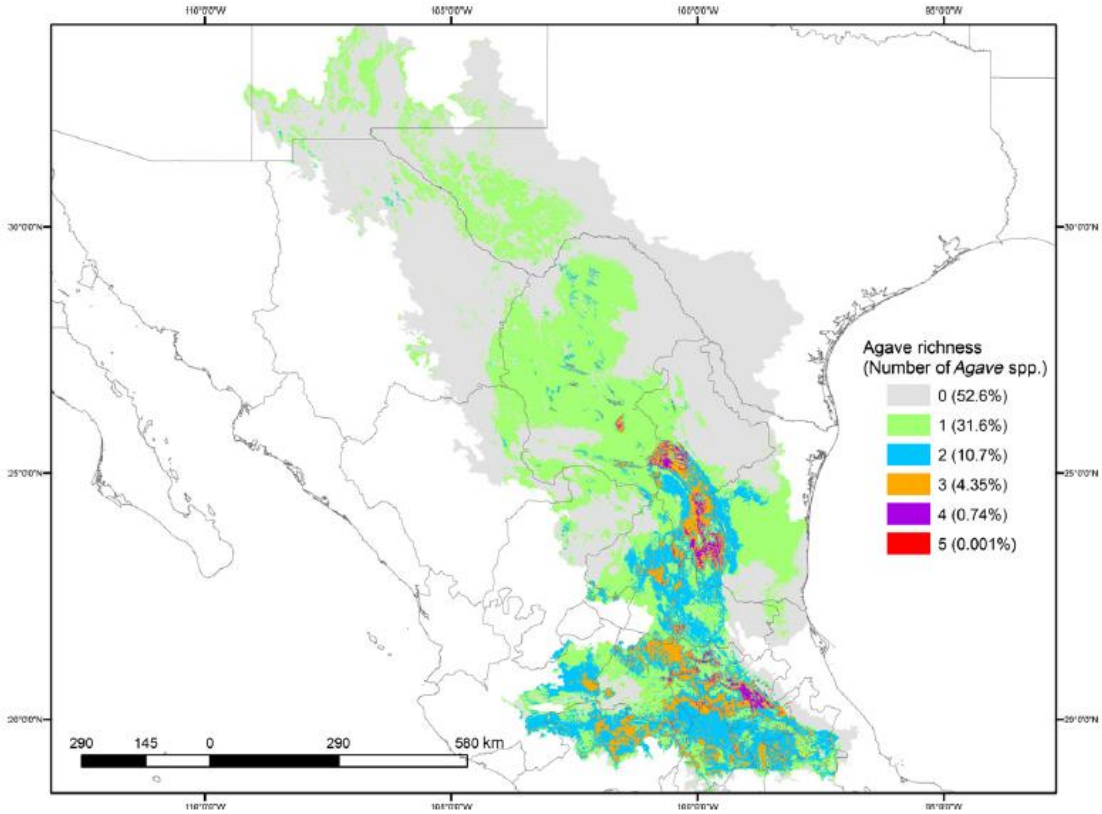


***Figure 8**. Distribution of Agave richness (number of Agave species). The percentage of area per number of Agave spp. is shown in parentheses (from Gomez-Ruiz and Lacher 2017).*

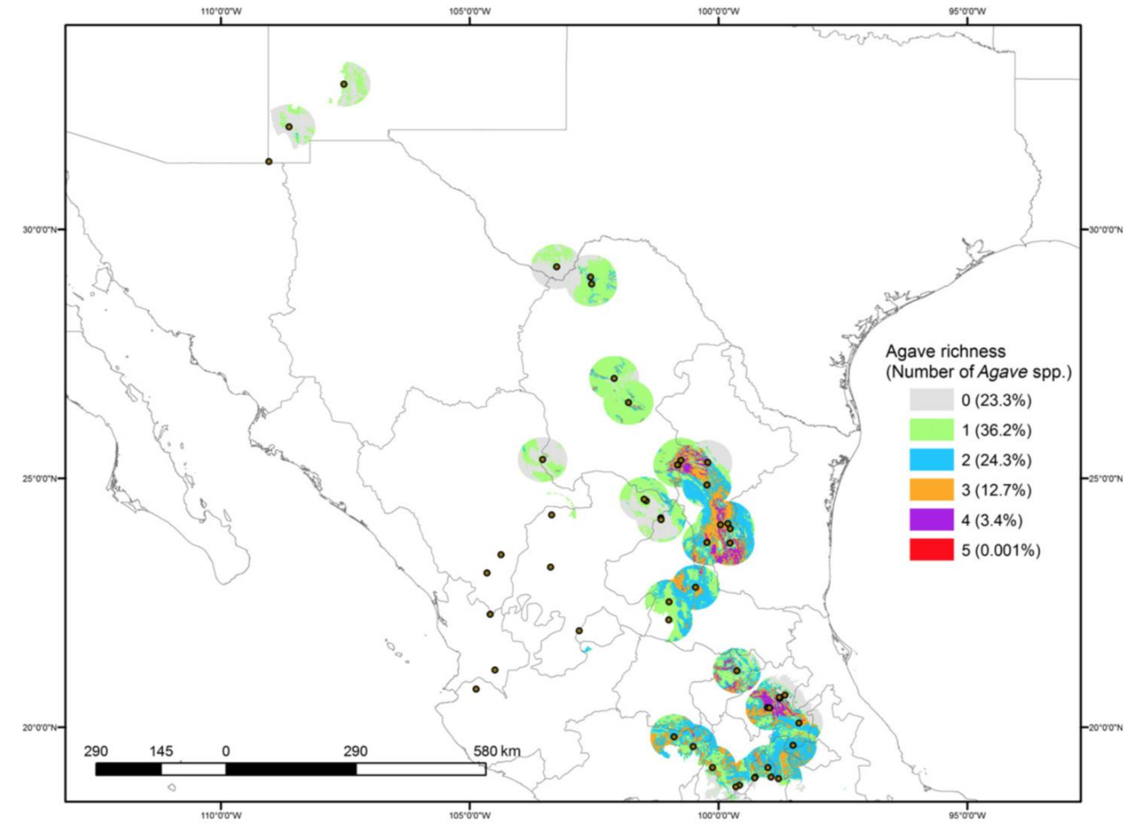


***Figure 9***. *Leptonycteris nivalis occurrence points considering 50 km radius area and Agave spp. richness. The percentage of area per number of Agave species is shown in parenthesis. Occurrence points with no color indicating Agave richness are located outside the range of the Agave species considered (from Gómez-Ruiz and Lacher 2017).*

## 3.4 Reproduction

Davis (1966, in Racey and Entwistle 2000, p. 374) determined that *L. nivalis* has a monoestrous reproductive pattern, mating and giving birth only once a year (Racey and Entwistle, 2000). Accordingly, *L. nivalis* gathers in Central Mexico during fall-winter to mate (Téllez-Zenteno 2001, p. 116-118). Cueva del Diablo (Tepoztlán, Morelos) is the only known mating roost where males and females concentrate in the winter range and likely is where most mating occurs (Téllez-Zenteno 2001, p. 55). Females and males have been reported from other roosts in Central Mexico during winter but groups of *L. nivalis* in these roosts are only a few dozen (Téllez-Zenteno 2001, p. 55-60; Torres-Knoop 2014, p. 50-54).

Mating system and seasonality have been described for Cueva del Diablo (Toledo-Gutiérrez 2009, entire). By the end of September, the colony at Cueva del Diablo has almost reached the maximum size (up to 4,000 individuals in the last 5 years), with a sex ratio slightly biased toward males (males: 58%; females: 42%; A. Ibarra, unpublished data from 2012-2016). All males sampled at this point were reproductively inactive (Toledo-Gutiérrez 2009, p. 48). However, by October the proportion of females increased (up to 68%) (Téllez-Zenteno 2001, p. 55-57; Toledo-Gutiérrez 2009, p. 46). Although males are still mostly inactive at this point, testicle size increases. Reproductive activity concentrates between November and December. During this period most males are scrotal with enlarged testes (Téllez-Zenteno 2001, p. 55-57; Toledo-Gutiérrez 2009, p. 43-48), while the proportion of females in estrous increases (Ibarra pers. comm.) and copulation is frequently observed (Toledo-Gutiérrez 2009, p. 66). Although a sticky, odiferous dorsal patch has been observed in reproductive males of *L. yerbabuenae* and *L. curasoae*, it does not form in *L. nivalis* (Nassar et al. 2016, p. 625). These authors captured a total of 458 males between September 2010 and February 2015 of which 210 were sexually active (Nassar et al. 2016, p. 625). By January, the colony size starts decreasing, most males are inactive and although the sex ratio is 1:1, by February the sex ratio deviates toward males suggesting females have already started their northward migration. By the end of February some authors have reported early stage pregnant females in Central Mexico roosts, the results of mating during October-November (Téllez-Zenteno 2001, p. 55-60; Torres-Knoop 2014, p. 51). In March, only small groups (mostly inactive males) remain in the cave (Téllez-Zenteno 2001, p. 55-60).

During the mating season, a few groups of multiple males and females are formed and these groups move between chambers inside the cave (Toledo-Gutiérrez 2009, p. 58). Studies of mating behavior in Cueva del Diablo have not reported any type of female guarding, group, or harem defense by the males, nor any type of courting behavior by the males. Females, however, have been observed defending the male from other females while copulating, suggesting some sort of mate selection behavior by the females (Toledo-Gutiérrez 2009, p. 68). During one single season, one female mates with different males indicating a promiscuous mating system and potential sperm competition for the species (Toledo-Gutiérrez 2009, p. 58, 73).

As previously mentioned, other caves in Central Mexico have been reported as potential mating roosts (e.g., La Peña and Tziranda), following a similar seasonal pattern as the one described for Cueva del Diablo (Téllez-Zenteno 2001, p. 55-57). However, these roosts could be only sporadically used when resources are abundant because they typically have no more than a few dozen individuals (Téllez-Zenteno 2001, p. 55-60). During a recent visit to La Peña cave during the winter, the species was not present

(Ibarra pers. comm.). Whether annual variation in occupancy or whether the cave was permanently abandoned due to disturbance was hard to determine (Ibarra pers. comm.). More thorough and permanent monitoring of historically occupied roosts is needed to establish abandonment or temporal variation in occupancy. Currently, efforts are being conducted to locate alternate mating roosts of *L. nivalis* in Central Mexico but have not been successful (Torres-Knoop 2014, p. 50-57; Ibarra pers. comm.).

Reproductive data has also been gathered from captures in foraging grounds in Central Mexico. Rojas-Martínez (1996, p. 35-39, 41), in the Tehuacán Valley and Balsas river basin, reported captures of *L. nivalis* between March and June, and in December. Sex ratio varied among these months, with male skewed sex ratios in December (active males) and April while balanced sex ratios in May can be seen, but these ratios change progressing into female skewed sex ratios by June.

Records of pregnant females in Central Mexico in mid to late February suggests that *L. nivalis* females start their northward migration in the early stages of pregnancy to reach maternity colonies in the northern edge of the distribution. Emory Cave in Big Bend, Texas and El Infierno Cave in Nuevo Leon, Mexico, are the two main known maternity colonies reported for the species (Easterla 1972; Moreno-Valdez et al. 2004, p. 455-456; Gómez-Ruiz et al. 2015, p. 93). Records of pregnant females in Big Bend National Park in April suggest that at least some females arrive in the area before parturition (Higginbotham and Ammerman 2002; Adams 2015, p. 21).

Emory Cave, in Big Bend National Park in Texas is the best-studied maternity colony for the species (Easterla 1972; Adams 2015, entire). *Leptonycteris nivalis* arrives here as early as April and capture records indicate the colony is composed mainly of pregnant females early in the season and lactating females as the season progresses (Brown 2008, p. 16-17; Adams 2015, p. 21). No pups have ever been observed in this cave, but the parts of the cave used by the bats are in deep inaccessible crevices (Adams 2015, p. 6, 35). By July and August, the colony contains mostly post-lactating females and juveniles of the year (Brown 2008, p. 21). A PIT tag study in this cave recorded females using the cave in consecutive years (marked in 2014, redetected in 2015) (Adams 2015, p. 21). Ongoing monitoring at this roost site has resulted in the documentation of several females that have returned to the cave each of the last 4 years (Ammerman, unpublished data). Adult males only have been documented in three instances (out of 206 total captures from 2014-2017) and they did not remain at the cave for more than a few nights (Ammerman, unpublished data).

El Infierno Cave, in Nuevo Leon, Mexico, is also reported as a maternity roost. Capture data from this cave indicates the dynamics of the *L. nivalis* colony at this site are similar to that of Emory Cave where *L. nivalis* arrives in April and remains in the cave until September. Early in the season (April), the colony contains mostly pregnant females (75% of 20 adult females captured). By June-July, lactating females increase in proportion and few juveniles are present. By July-August, the cave contains mostly post-lactating females. By September, most individuals are reproductively inactive (adults and juveniles) (Moreno-Valdez et al. 2004, p. 456). PIT tagging monitoring efforts started at this cave in 2017 and will continue to try to obtain more detailed and recent information about the sex-ratio throughout the months that the bats are at Infierno cave (Gómez- Ruiz (UANL), and Flores-Maldonado (ESHAC), pers. comm.).

Two more potential maternity roosts have been reported for northern Mexico. El Rosillo cave in Coahuila, and Todos Santos mine in Zacatecas. Data on seasonality and dynamics for these roosts is limited, however, based on their latitude they could correspond to maternity roosts. Gómez-Ruiz and collaborators (2015, p. 93) reported capture of females in foraging grounds near El Rosillo cave while sporadic captures in Todos Santos mine have recorded the presence of potentially pregnant females in late March (Ibarra, unpublished report).

The existence of all the maternity roosts in the north agree with most authors in that *L. nivalis* mating occurs in Central Mexico, during fall-winter, after which most of the females migrate to maternity colonies in the north where they will stay during spring-summer giving birth and raising pups before migrating south again by August-September (Moreno-Valdez et al. 2000, p. 120-124, Téllez-Zenteno 2001, p. 121). Recently Rojas-Martinez et al. (2011, entire) reported a maternity colony in Central Mexico. The Aguacatitla tunnel, in the state of Hidalgo in Central Mexico hosts a maternity colony during spring-summer coinciding temporally with maternity activity in the northern roosts (May-August). In March, most individuals in the roost are pregnant females. Between April and June most females give birth and start lactating (Rojas-Martínez et al. 2011, entire). Rojas-Martinez suggests that females remain and give birth in this area in Central Mexico given the availability of floral resources during the birthing season thus releasing the pressure to migrate.

Téllez-Zenteno (2001, p. 121) and Brown (2008, p. 53-54) suggests that the species forms a single reproductive population. However, in the Species Recovery plan, Wilson (1985) suggests that the species might be comprised of two reproductive populations -- one represented by an early reproductive colony in Central Mexico which are followed closely in time by the reproductive colonies reported in the northern part of the range (Nuevo Leon and southwestern United States). Genetic evidence based on both nuclear and mitochondrial data suggests that there is no obvious subdivision of the populations and instead complete panmixia and a single breeding population (Brown 2008, p. 53-62). However, recently reported evidence of an early reproductive colony (March-April) in central Mexico (Rojas-Martinez pers. comm.) supports the idea of separate reproductive populations.

## 3.5 Migration and Population Dynamics

Continued monitoring of main roosts in the southern (mating) and northern (maternity) part of the distribution has provided information on seasonality, colony dynamics, and habitats used during these two life history stages. Yet migration paths and their relation to food resources are still not well known. Data on seasonal presence/absence along the distribution of *L. nivalis* combined with modeling approaches allow inferences about migration routes. However, empirical data on migration routes, stop-over sites, foraging grounds during migration, and population connectivity along potential migratory routes is lacking.

Gómez-Ruiz and Lacher (2017, p. 67-78) tested the hypothesis of the *Agave* migratory corridor by modelling the distribution of nine relevant *Agave* species with occurrences in northern Mexico and southern United States and testing whether bat records are significantly related to *Agave* species richness (Figure 8). The authors found that *L. nivalis* presence points co-occur in areas with more than one *Agave* species more often than random (Figure 9) and concluded that areas with higher number of *Agave* species are distributed along mountain chains and may provide foraging resources for *L. nivalis* for longer period of time during its migration.

*Leptonycteris nivalis* is considered a long-distance migratory species (Medellín et al. 2009) presumably traveling up to 1200 km between the two furthest roosts in the distribution range, Cueva del Diablo in Central Mexico and Emory Cave in Big Bend National Park in Texas. However, there is no direct evidence (from bats tagged between 2014 and 2017 at Emory Cave) that individuals visit both roosts (Adams 2015, p. 18; Ammerman, unpublished data). It is assumed that during fall-winter *L. nivalis* remain in the southern extreme of its distribution, an area located along the Trans-Mexican Volcanic Belt and the Balsas river basin in the states of Morelos and Guerrero (Arita and Humphrey 1988; Arita 2005). By late February and early March, most of the population abandons these southern roosts (Téllez-Zenteno 2001, p. 55-60, 121; Toledo-Gutiérrez 2009, p. 38; López-Segurajáuregui 2010, p. 65; Salinas-Galicia 2013, p. 77-79) and start a northward migration to northern Mexico and southern United States. During spring-summer, the species is present in the Chihuahuan desert, in Big Bend National Park in Texas (Easterla 1972; Brown 2008, p. 16-21; Ammerman et al. 2009, p. 87; Adams 2015, p.21-26), and a few localities in southeastern New Mexico along the Peloncillo and Animas mountains (Arita and Humphrey 1988, p. 35-37; Hoyt et al. 1994; Bogan et al. 2017, p. 319). By September, *L. nivalis* abandons these northern roosts (Moreno-Valdez et al. 2004, p. 20-21; Bogan et al. 2017, p. 319) suggesting that they migrate towards Central Mexico at this point.

Concrete knowledge on specific factors driving migration and the routes followed is still lacking. Cockrum (1991, p. 191-194) and Fleming et al. (1993, entire) suggest *Leptonycteris* migrates as a response to seasonal availability of floral resources and follow blooming of certain groups especially of Cactaceae and Agavaceae (Asparagaceae, Chase et al. 2009) species along a nectar corridor. These assumptions are supported by different lines of evidence. Migration of *L. nivalis* closely correlates with blooming and nectar production phenology of several *Agave* spp. along the latitudinal gradient (1200 km) between Cueva del Diablo (mating roost in Central Mexico) and Emory Cave (maternity roost in Texas) (Moreno-Valdez et al. 2000, p. 121-123, 126; Gómez-Ruiz and Lacher 2017, p. 72-73). In addition, there seems to be a positive correlation between altitude and *Agave* spp. richness and presence of *L. nivalis*, suggesting that greater diversity and availability of resources attracts *L. nivalis* (Gómez-Ruiz and Lacher 2017, p. 72-73). According to Gómez-Ruiz and Lacher (2017), *Agave* fields along the mountain ranges in Nuevo León and Coahuila work as the stepping-stones that support the migration of *L. nivalis.*

The correlation between *Agave* abundance and richness and the migration of *L. nivalis* is not perfect. In many areas, especially in the southern part of the range, the distribution of *L. nivalis* and *Agave* do not overlap. Gómez-Ruíz and Lacher (2017, p. 74-75) suggest that in this area *L. nivalis* takes advantage of other resources and diversifies its diet to include species of different families (Convolvulaceae, Bombacaceae, Amaryllidaceae) (Table 3). Additionally, modelling efforts suggest that seasonal changes in the distribution of *L. nivalis* are driven by the search for floral resources and is correlated to climate factors that influence blooming of many plant species used by *L. nivalis* (Espinosa-Ávila 2008, p. 69-72; Gómez-Ruiz and Lacher 2017, p. 74-75).

Based on seasonal presence/absence patterns along its distribution, supporting sex segregation and mark-recapture evidence (Brown 2008, p. 29), it was assumed that all reproductive *L. nivalis* females migrated between mating roosts in Central Mexico to maternity roosts in northern Mexico and southern U.S. as a single loosely formed colony. Téllez-Zenteno (2001, p. 121) suggests that females that mate in Central Mexico are the same that migrate to maternity roosts in the northern part of the distribution. The fate of males during spring-summer is uncertain, although it is assumed that most remained scattered in different roosts in Central Mexico. Bogan et al. (2017, p. 326) noted a surprising number of adult males in late summer (47% of adult *L. nivalis*) in the Animas and Big Hatchet mountains of New Mexico but cautioned that these individuals might be older young-of-year with well developed wing joints.

New evidence (Bolaños-García and Rojas-Martínez 2013, entire) suggests that not all individuals conduct long-distance migration as described above. The Aguacatitla tunnel, recently described as a maternity colony, is in Central Mexico at a more southern latitude than all other reported maternity roosts. It is thought that the colony has established only recently since the tunnel used to be part of an active hydroelectric plant. Ramirez-Rojas (pers. comm.) suggests that this colony could have been established as recently as 2007 but no earlier than 2000. Pregnant *L. nivalis* arrive at this roost as early as March (compared to April-May in El Infierno and Emory Cave), giving birth in May, juveniles are volant by July and the colony is abandoned by August. Whether the females in this colony come from Cueva del Diablo is still uncertain. One single female captured in Cueva del Diablo in February 2016 was detected in Aguacatitla in May 2017 (Ibarra pers. comm.) suggesting that at least part of the population of females in Cueva del Diablo do not migrate north and instead establish and give birth in Central Mexico. This maternity roost in Aguacatitla is noteworthy given the size of the colony (>7,000), potentially greater than the one in Big Bend and El Infierno (Easterla 1972; Moreno-Valdez et al. 2004, p. 454; Ammerman et al. 2009, p. 4) combined (Table 4).

The Aguacatitla maternity roosts indicate that not all segments of the population need to migrate to reproduce given that enough resources are available at the right season for a maternity colony to establish in the south (Rojas-Martinez et al. in prep). This opens the possibility that other maternity roosts could exist in the intertropical area where conditions are favorable (enough floral resources and adequate roosting conditions).

Population size is difficult to ascertain because of the migratory behaviors of the species. Roosts that have been studied rarely contain more than 2,000 individuals (Table 4). Data on colony sizes are sparse and hard to interpret because of the variation in methods used, but both Cueva del Diablo and Emory Cave have been studied most consistently (Figures 10 and 11). One approach to estimating the effective population size for *L. nivalis* is with genetic data. Currently, Loren Ammerman and Roxanne Pourshoushtari (Angelo State University), in collaboration with Trejo-Salazar (UNAM), are collecting the microsatellite data to calculate this parameter and better understand the current levels of genetic variability within this species.

***Table 4.*** *Estimates of colony sizes for Leptonycteris nivalis at roost sites that have been studied, shown by region. Estimates were opportunistically obtained in different years using different methods (see the text in Roosting, section 3.2).*

**Table 4 for Central Mexico**

| Roost name | State | Do the sites have good protective measures in place? | Colony size estimate | Season occupied | Comments |
|---|---|---|---|---|---|
| Aguacatitla | Hidalgo | **Yes** | 7,489-13,596 | March-August | Privately owned, within biosphere reserve |
| Diablo | Morelos | **Yes** | 3,000-8,000 | Sept-February | Within National Park El Tepozteco |
| La Peña | State of Mexico | **No** | 200 | Fall-Winter (Sept-February) | Highly disturbed |
| San Lorenzo | Puebla | **No** | 2,000 | Unknown (June-July) | In biosphere reserve but highly disturbed |
| Xoxafi | Hidalgo | **No** | <20 | August (generally after *L. yerbabuenae* leave) | Ecotourism park, lacks official protection |

**Table 4 for Eastern Mexico**

| Roost name | State | Do the sites have good protective measures in place? | Colony size estimate | Season occupied | Comments |
|---|---|---|---|---|---|
| Durazno and La Montaña mines | Zacatecas | **Yes** | <50 | July/August | Privately owned, near protected area |
| Tziranda | Michoacan | **No** | <500 | Winter | Ecotourism park, ranching agriculture disturbance near cave |

**Table 4 for Northeastern Mexico**

| Roost name | State | Do the sites have good protective measures in place? | Colony size estimate | Season occupied | Comments |
|---|---|---|---|---|---|
| El Infierno | Nuevo Leon | Yes | 1,000 | April-October | In national park |
| El Rosillo | Coahuila | Yes | ? | July | Protected land |

**Table 4 for Southwestern United States**

| Roost name | State | Do the sites have good protective measures in place? | Colony size estimate | Season occupied | Comments |
|---|---|---|---|---|---|
| Mount Emory | Texas | Yes | 500-3,000 | April-August | In national park |
| Romney | New Mexico | Yes | 500-7,000 | July-September | Protected land |

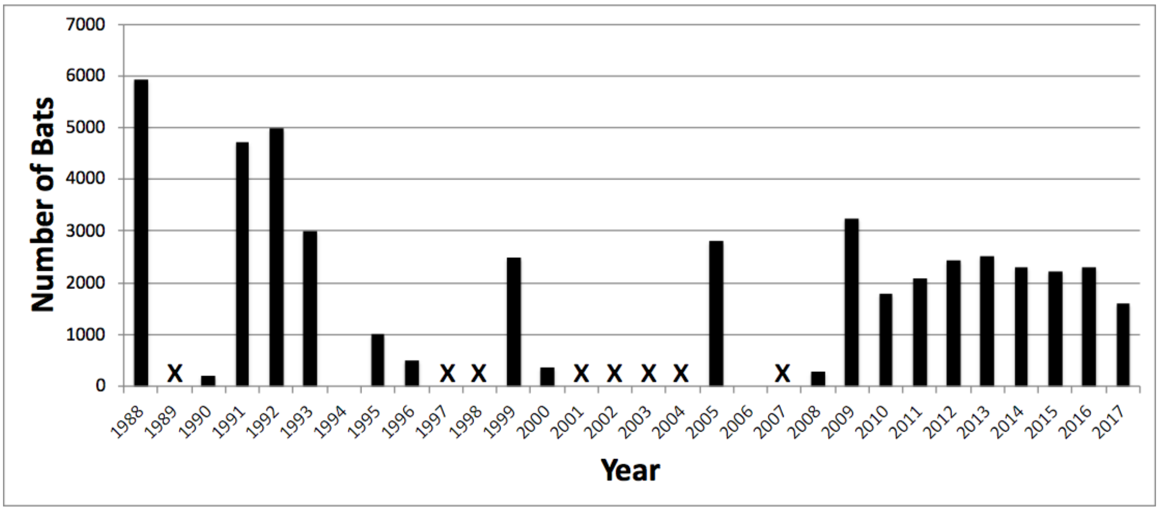


***Figure 10***. *Census of bats at Emory Cave, Texas using surface area counts (1988-2000) and thermal census methods (2005-2017) around July of each year. The midpoint of ranges reported in 1988 (5240-6630 bats) and 1991 (4289-5127 bats) are presented here. There were 2,000 bats estimated in 2006. There was no census in years marked with an X. Zero bats were observed in 1994, but they likely occupied the inaccessible areas of the cave (Ammerman et al. 2009 and unpublished data).*

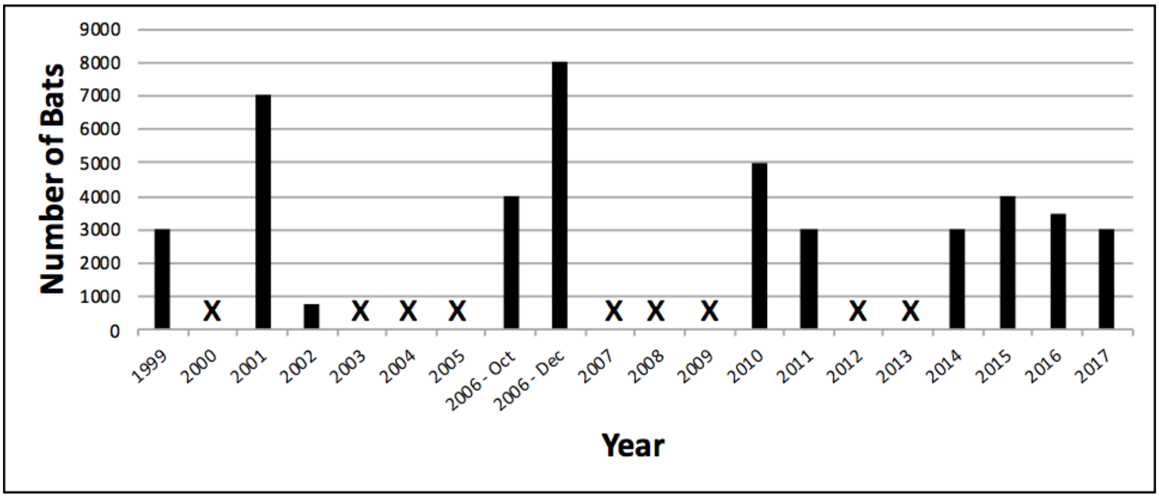


***Figure 11***. *Census of bats at Cueva del Diablo during October-December from various years compiled from Tellez-Zenteno (2001), Cabellero-Martinez (2004), Lopez-Segura (2010), Toledo-Gutierrez (2009), Salinas-Galicia (2013), and Ibarra-Macias (unpublished data). Most studies estimated the number of bats per square meter and extrapolated to the area covered by the colony (surface area counts). In recent years, estimates are from emergence videos. There was no census in those years marked with an X.*

## 3.6 Population Genetics

Task 4.3 of the Recovery plan (USFWS 1994, p. 38) established the need to evaluate the genetic diversity of the species and the degree of genetic differentiation among colonies or populations. Since then, only two studies have evaluated these parameters for *L. nivalis*. Brown (2008, entire) evaluated the amount of genetic variation, population subdivision and explored the hypothesis of female philopatry for the species using a combination of maternally inherited mitochondrial DNA marker (mtDNA) and biparentally inherited nuclear markers (amplified fragment length polymorphism, AFLP) with samples from eight localities along the distribution range. This study determined that while *L. nivalis* has relatively low to moderate genetic variability for a migratory bat species, its genetic diversity is not as low as might be expected for an endangered bat. Brown (2008, p. 42, 53) also found relatively high levels of mtDNA haplotypic diversity and no intra-specific phylogenetic structure, thus not supporting the hypothesis of female philopatry. Additionally, he found evidence that the species had undergone a historic population expansion. Levels of genetic differentiation were moderate and not significant between sites based on nuclear markers and suggested a lack of geographic structuring throughout the range of *L. nivalis* (Brown 2008, p. 53-54). Brown (2008, p. 54) interpreted these patterns of a lack of genetic substructure as evidence of panmixia and is consistent with the fact that Cueva del Diablo is the only known mating cave for the species where individuals gather in winter to mate.

Ramos-Frias (2013, entire) described levels of genetic diversity for the maternity roost in Aguacatitla, Hidalgo and individual bats captured in a foraging ground nearby (27 km) using four microsatellites. This author found relatively high levels of genetic diversity for these four markers, even when compared to other migratory bats (Ramos-Frias 2013, p. 47-48) and no difference between sexes. Ramos-Frias (2013, p. 54) also determined that there was greater connectivity and gene flow between the two *L. nivalis* localities in comparison to the *L. yerbabuenae* localities in her study. The presence of exclusive alleles in individuals from both sites, the maternity roost in Aguacatitla and the nearby foraging ground, suggest the existence of alternative roosts and foraging grounds in this area of Central Mexico.

## 3.7 Needs of the Mexican Long-nosed Bat

### 3.7.1 Population Resiliency

For the Mexican long-nosed bat to maintain viability, the roosts or some portion thereof that have housed bats must be resilient. Specifically, for the one population of bats that make up this species, it is vital for the one known mating roost to be resilient. Stochastic events that have the potential to affect Mexican long-nosed bat roosts include disease, human disturbance, drought, and illegal harvest of wild *Agave*. A number of factors influence the resiliency of roosts, those factors can be divided into two categories: foraging and roost conditions. Foraging factors include habitat condition, abundance of floral resources, diversity of nectar plant species, and disruption to flowering ability. Roost condition factors include barriers to cave disturbance, colony size, and level of protection. Foraging and roost condition factors are discussed below and shown in Table 5. The details of how we arrived at the condition for each roost can be found in section 3.2, Roosting.

**Foraging Habitat Factors**

*Habitat Condition* **-** Sufficient stands of *Agave*, flowering tree species, columnar cactus, and other documented diet items for the bat in proximity to a roost is a necessity for a healthy colony. The value of 50 km is based on the known foraging distance for *L. nivalis* (Bogan et al. 2017, p. 327) and *L. yerbabuenae* (Horner et al. 1998, p. 579). Distances of 20-35 km appear to be a valid estimate of the distance between roost sites and foraging areas. However, Medellin et al. (2018, p. 4) report some *L. yerbabuenae* traveling up to 49 km to foraging areas. Therefore, we estimate that *L. nivalis* would require intact foraging habitat within 50 km of the roost. Subsequently, habitat condition is measured by the amount of human impact on the landscape within 50 km of the roost, specifically urbanization and agriculture, decreasing the amount of available foraging habitat. The less human development of the landscape within 50km of the roost, the healthier the roost is considered.

*Abundance of Nectar Plants* **-** As discussed above, the Mexican long-nosed bat needs sufficient stands of *Agave*, flowering tree species, and columnar cacti. Nectar plants that are part of the bat's diet are listed in Table 3.

*Diversity of Nectar Plants* **-** Having a greater diversity of food sources increases the resiliency of the Mexican long-nosed bat to stochastic events. Some of the northern roosts may only rely on one or two *Agave* species, whereas roosts in central Mexico could have over ten sources of nectar plants. Roosts with low diversity of nectar plants may be healthy because the available nectar plants are abundant, but they are more vulnerable than roosts with high diversity of nectar plants because of their reliance on fewer species of plant.

*Disruption to Flowering Ability* **-** This category primarily pertains to *Agave* species used by the bat because of their unique characteristic of flowering only once during their life cycle. *Agave* are an important food source for the Mexican long-nosed bat, therefore the bat needs an abundance of *Agave* that are allowed to flower. In the tequila industry *Agave* are usually stopped from flowering because they are harvested before they flower. Illegal harvesting of *Agave* by moonshiners also poses a barrier to flowering, reducing available food sources.

**Roost (cave) Condition Factors**

*Barriers to Cave Disturbance* **-** Mexican long-nosed bats have been noted to be especially sensitive to human disturbance. They need to have little disturbance to reduce stress from unnecessary flights and movement. This category encapsulates disturbance in two ways. First, how difficult it is to find and/or access a roosting cave. The farther the roost is from human populations and the harder it is to find due to difficult terrain, low visibility from obstructions, and difficulty navigating the cave, the less chance of disturbance occurring. However, some caves are well known and visited despite being difficult to access. Subsequently, the second way disturbance is measured for this category is the number of visitors to the cave there are. Even if a cave is difficult to access, if it is still disturbed because of its popularity, then it is categorized as having less resiliency.

*Colony Size* **-** In order for a roost to be highly resilient to stochastic events, we considered a colony of at least 1,000 bats to be sufficient. Many caves that are known to have been occupied by the Mexican long-nosed bat in the past are not consistently surveyed. Because of inconsistent surveys, the most recent survey done in the past ten years is used for current conditions. Colony size refers to the peak number during the year. Surveys done more than ten years ago are not counted and instead labeled as having no information.

*Level of Protection* **-** As mentioned under the category “barriers to cave disturbance” Mexican long-nosed bats need to have as little human disturbance as possible. If the cave is within a protected area, such as a national park, disturbance can be reduced not only directly from human intrusion into caves, but also indirectly from sources like noise pollution, light pollution, and other impacts from urbanization and agriculture. The healthiest caves are within protected areas that are consistently regulated, while the caves in poorer conditions have little to no protection and/or enforced regulation. It should be noted that some of the caves in Mexico are in protected areas, but regulations are not consistently enforced, resulting in some land development and human intrusion into caves. These caves are considered to be in moderate condition.

### 3.7.2 Species Representation

Maintaining representation in the form of genetic or ecological diversity is important to maintain the capacity of the Mexican long-nosed bat to adapt to future environmental changes. As discussed earlier in section 3.6, based on the limited genetic work done on the species it is believed to be one large migratory population owing to the fact that there is only one known mating roost. Therefore, it is important for the bat to maintain ecological diversity across its range. To maintain ecological diversity, multiple resilient roosts in each region is needed.

### 3.7.3 Species Redundancy

Redundancy reduces the risk that a large portion of the species’ range will be negatively affected by a catastrophic natural or anthropogenic event at a given point in time.

The Mexican long-nosed bat needs to have multiple resilient roosts spread throughout its range and multiple resilient types of roosts to provide redundancy. The more roosts, and the wider the distribution of those roosts, the more redundancy the species will exhibit. Specifically, the bat needs sufficient numbers of resilient maternity roosts distributed throughout the northern part of its range to migrate and give birth to their offspring. Ideally multiple resilient mating roosts in central Mexico would also provide greater redundancy to the species, though there is currently only one known mating roost (Cueva del Diablo).

## 3.8 Current Conditions

The Mexican long-nosed bat inhabits eleven known roosts throughout its range, four of which are not in protected areas. Most importantly, there is only one known mating roost for the entire species located in Central Mexico (Cueva del Diablo). A current population number for the species has not been calculated due to the lack of information on migration pathways, actual number of roosts, and colony size in known roosts.

***Table 5.*** *Description of criteria used to evaluate the current condition of each roost site.*

| | **Foraging Habitat** | | | | **Roost Condition** | | |
|---|---|---|---|---|---|---|---|
| **Condition Category** | **Habitat Condition** | **Abundance of Floral Resources*** | **Diversity of Nectar Plant Species** | **Disruption to Flowering Potential** | **Barriers to Cave Disturbance** | **Colony Size** | **Level of Protection** |
| **High** | Less than 20% habitat loss within 50km of the roost | High abundance of flowering plants within 50km of roost | Greater than 10 species present | Low disruption (<25%) to flowering plants | -Hidden/low visibility *and/or*<br>-Difficult terrain *and/or*<br>-Greater than 4 miles from nearest human settlements *and/or*<br>-Entering the cave is difficult *and/or*<br>-No disturbance | Over 1,000 individuals | -Locally and/or nationally protected site<br>-Active enforcement of regulations |
| **Moderate** | 20-60% habitat loss within 50km of the roost | Moderate abundance of flowering plants within 50km of roost | 3-10 species present | Medium disruption (25-75%) to flowering plants | -Difficult to find/medium visibility *and/or*<br>-Trail to cave over rough terrain *and/or*<br>-Between 2-4 miles from nearest human settlements *and/or*<br>-Entering the cave is moderately difficult *and/or*<br>-Occasional disturbance (movement and noise) | 500-1,000 individuals | -Site designated but not given full protected status<br>-Receives occasional checks and enforcement of regulations |
| **Low** | Greater than 60% habitat loss within 50km of the roost | Low abundance of flowering plants within 50km of roost | 1-2 species present | High disruption (>75%) to flowering plants | -Highly visible *and/or*<br>-Fully accessible *and/or*<br>-Within 1 mile of human settlements *and/or*<br>-Entering the cave is easy *and/or*<br>-Bats regularly disturbed | <500 individuals | -No protection<br>-No enforcement of regulations |
| **0** | 100% habitat loss | No flowering plants within 50km of roost | No species present | | | None recorded in last 10 years | |

### 3.8.1. Current Population Resiliency

*Methodology*

To summarize the overall current conditions of the Mexican long-nosed bat roosts, we sorted them into three categories (high, moderate, and low) based on foraging habitat factors and roost condition factors discussed in section 3.7.1. Roosts that are only known from museum specimens or are currently extirpated were also included (Table 6) to show the entire current condition of the species. The current condition table is a qualitative estimate based on analysis of the four foraging habitat factors and three roost condition factors. In determining the overall status of a roost, each condition category was given a number: high is a 3, moderate is a 2, and low is a 1. An average was then taken of all of the conditions to determine the overall status of the roost; the overall number was rounded to the nearest whole point. Any roost with a colony size of 0 was automatically given an extirpated status.

*Results*

In Central Mexico there is one highly resilient roost, three moderately resilient roosts, and one roost with low resiliency. Four roosts have been extirpated, and four lack enough information. Overall, Central Mexico has a low to moderate resiliency, with the only known mating roost throughout the entire range, Cueva del Diablo, having a moderate resiliency. The two factors that are primarily driving the low to moderate resiliency are barriers to cave disturbance and level of protection, which could be a major threat because of the bat’s sensitivity to disturbance.

Eastern Mexico has only one roost with enough information to estimate resiliency. The Todos los Santos Mine has a moderate resiliency with disruption to flowering ability and level of protection having low conditions.

Northeast Mexico has one roost with a moderate resiliency and one with a high resiliency. These two roosts have higher resiliencies because the foraging habitat is in relatively high condition and they are isolated from human populations, having either high or moderate levels for roost condition.

The Southwestern United States has one roost with a moderate resiliency and one with a high resiliency. The two roosts in the southwestern United States are also isolated from human populations and disturbance. The common stressor on resiliency for both roosts is the low diversity of nectar plant species, so although overall both roosts are resilient, they are vulnerable to stochastic events that could affect the few species they rely on for food. Mount Emory Cave also has a low abundance of floral resources, which, combined with a low diversity of nectar plant species, gives it a moderate current condition.

Overall northeastern Mexico and southwestern United States have resilient roosts mainly due to the isolation of the roosts and subsequently less disturbance to their foraging grounds. These two regions are most vulnerable from a lack of floral diversity. Central and east Mexico are less isolated and therefore have greater disruption to flowering ability of floral resources. These two regions are also vulnerable to human disturbance of the caves with lower resilience in terms of barriers to cave disturbance and level of protection.

***Table 6**. Current conditions for 30 roost sites, shown by region, where Leptonycteris nivalis has been documented based on the best available information. Those marked "best guess" are approximations by individuals most familiar with the roost location. Because roost occupancy fluctuates in many of these locations, only the peak colony size during the year was evaluated for the category "colony size".*

**Table 6 for Central Mexico**

| | Foraging Habitat | | | | Roost Condition | | | |
|---|---|---|---|---|---|---|---|---|
| **Roost** | **Habitat Condition** | **Abundance of Floral Resources** | **Diversity of Nectar Plant Species** | **Disruption to Flowering Ability** | **Barriers to Cave Disturbance** | **Colony Size** | **Level of Protection** | **Current Condition** |
| Aguacatitla Tunnel | **High** | **Moderate, best guess** | **High** | **Moderate, best guest** | **High** | **High** | **High** | **High (-2.7)** |
| Del Diablo Cave | **Moderate** | **High, best guess** | **Moderate** | **Moderate** | **High** | **High** | **Moderate** | **Moderate (-2.1)** |
| Del Ferrocarril Cave | **High** | **High, best guess** | **Moderate** | **Moderate, best guess** | **Low** | 0 | **Low** | No Colony (0) |
| Del Salitre Cave | No data | No data | No data | No data | No data | No data | No data | No data |
| De la Chichihuiteca Cave | **Low** | No data | No data | No data | **Low, best guess** | **Low** | **Low** | **Low (-1)** |
| De la Pena Cave | **Low** | **Low, best guess** | **Moderate, best guess** | **Moderate** | **Low, best guess** | 0 | **Low** | No Colony (0) |
| El Amate Cave | No data | No data | No data | No data | No data | 0 | **Low** | No Colony (0) |
| El Coyote Cave | **Low** | **Moderate** | **Moderate** | No data | **Low, best guess** | **Low** | **Moderate** | **Low (-1.3)** |
| Idolo Cave | No data | No data | No data | No data | **Low** | 0 | **Low** | No Colony (0) |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| San Lorenzo Cave | No data | No data | No data | No data | No data | No data | **Moderate** | No data |
| Xoxafi Cave | **Moderate** | **Moderate, best guess** | **Moderate** | **Moderate** | **High** | **Low** | **High** | **Moderate (-2.1)** |
| Tziranda Caves | **Moderate** | **Moderate, best guess** | **Moderate** | No data | **High** | **Low** | **High** | **Moderate (-2)** |
| La Fabrica Cave | No data | No data | No data | No data | No data | No data | No data | No data |

**Table 6 for Eastern Mexico**

| | Foraging Habitat | | | | Roost Condition | | | |
|---|---|---|---|---|---|---|---|---|
| **Roost** | **Habitat Condition** | **Abundance of Floral Resources** | **Diversity of Nectar Plant Species** | **Disruption to Flowering Ability** | **Barriers to Cave Disturbance** | **Colony Size** | **Level of Protection** | **Current Condition** |
| Cueva Azul | No data | No data | No data | No data | No data | No data | No data | No data |
| De los Coyotes Cave | No data | No data | No data | No data | No data | No data | No data | No data |
| El Chiquihuite Cave | No data | No data | No data | No data | No data | No data | No data | No data |
| El Durazno Mine | No data | No data | No data | No data | No data | No data | **Low** | No data |
| El Leon Cave | No data | No data | No data | No data | No data | No data | No data | No data |
| El Murcielago Cave | No data | No data | No data | No data | No data | No data | No data | No data |
| La Montana Mine | No data | No data | No data | No data | No data | No data | **Low** | No data |
| San Pedro de la Anonas Mine | No data | No data | No data | No data | No data | No data | No data | No data |
| Todos los Santos Mine | **High** | **Moderate, best guess** | **Moderate** | **Low, best guess** | **Moderate** | **High** | **Low** | **Moderate (-2)** |

**Table 6 for Northeastern Mexico**

| | Foraging Habitat | | | | Roost Condition | | | |
|---|---|---|---|---|---|---|---|---|
| **Roost** | **Habitat Condition** | **Abundance of Floral Resources** | **Diversity of Nectar Plant Species** | **Disruption to Flowering Ability** | **Barriers to Cave Disturbance** | **Colony Size** | **Level of Protection** | **Current Condition** |
| Del Guano Cave | No data | No data | No data | No data | No data | No data | No data | No data |
| De los Guzman Mine | No data | No data | No data | No data | No data | No data | No data | No data |
| El infierno Cave | **Moderate** | **Moderate** | **Moderate** | **High, best guess** | **Moderate** | **High** | **Moderate** | **Moderate (-2.4)** |
| El Rosillo Cave | **High** | **High** | **Low** | **High, best guess** | **High** | **Moderate, best guess** | **Moderate** | **High (-2.7)** |
| La Joya Honda Cave | No data | No data | No data | No data | No data | No data | No data | No data |
| San Antonio Mine | No data | No data | No data | No data | No data | No data | No data | No data |

**Table 6 for Southwestern United States**

| | Foraging Habitat | | | | Roost Condition | | | |
|---|---|---|---|---|---|---|---|---|
| **Roost** | **Habitat Condition** | **Abundance of Floral Resources** | **Diversity of Nectar Plant Species** | **Disruption to Flowering Ability** | **Barriers to Cave Disturbance** | **Colony Size** | **Level of Protection** | **Current Condition** |
| Mount Emory Cave | **High** | **High** | **Low** | **High** | **High** | **High** | **High** | **High (-2.7)** |
| Romney Cave | **High** | **Low** | **Low** | **High** | **High** | **Moderate** | **High** | **Moderate (-2)** |

### 3.8.2. Current Species Representation

There is little information on the genetics of the Mexican long-nosed bat, therefore we viewed representation through the lens of ecological diversity. Each of the regions the roosts have been separated into have slightly different food sources, climates, and habitat. Maintaining resilient roosts in each region will provide greater representation. Currently, central Mexico has the greatest representation with 5 extant roosts, on that is highly resilient, three of which are moderately resilient, and one that has low resiliency. East Mexico has the lowest representation with one moderately resilient roost. Northeastern Mexico and the southwestern United States each have one moderately resilient roost and one highly resilient roost.

Representation of the varying ecological settings, divided into regions, is low for the Mexican long-nosed bat. While central Mexico has five roosts, the highest number in any other region is two. It should be noted, however, that the low representation is counting known roosts. Information on potentially other undiscovered roosts in each region is limited because of the difficult terrain and isolation from towns or cities.

### 3.8.3. Current Species Redundancy

A total of 30 roosts that have documented occurrences of Mexican long-nosed bat imply a species with high redundancy. The issue is the lack of knowledge on the current condition of a majority of these roosts. Only eleven of the roosts have housed bats within the past ten years, while an additional four in central Mexico are extirpated. Of the eleven extant colonies, three are highly resilient, six are moderately resilient, and two have low resiliency. It should be noted the two roosts with low resiliency, De la Chichihuiteca Cave and Coyote Cave, are not well studied and are lacking information.  Using the best information available, the bat has a low to moderate redundancy in terms of total number of roosts because of the lack of resilient roosts across its broad range.

Specifically looking at the number of each roost type, redundancy is even lower. There are three known maternity roosts, one that is moderately resilient and two that are highly resilient. More importantly, there is only one known mating roost (Cueva del Diablo) in central Mexico that is moderately resilient. Disturbance of Cueva del Diablo could have significant effects on the entire species regardless of the number of other roosts, making the Mexican long-nosed bat vulnerable in terms of redundancy.

# CHAPTER 4. INFLUENCES ON VIABILITY

In this chapter, we evaluate and summarize the past, current, and future influences on the long-term viability of individual *L. nivalis*. We organize the influences based on the stressors and discuss the sources of those stressors.

## 4.1 Human Disturbance

Anthropogenic activities, such as disturbance from people entering a roost, pollution (e.g., trash), noise, vibrations, and development around roosts are the main threat to the conservation of roosts. These anthropogenic threats can lead to changes in *L. nivalis* roosting behavior and potential abandonment of the roost. All roosts of *L. nivalis* discussed in this document have a threat of disturbance and vandalism unless they are located within a protected area with well-enforced regulations. Even those roosts with a protected status are still at risk from human disturbance unless access is well-regulated.

Human disturbance is one of the main threats to Cueva del Diablo in Morelos, Mexico. Human visitation of colonies roosting in Cueva del Diablo used to be frequent, even though the cave is officially protected as part of a National Park. Although there is a park ranger in charge of supervising the cave, this person is not at the cave constantly. Also, the open nature of the terrain used to make it easy to access the cave without being noticed by the guard. Visitors (local or tourists) and speleologists would visit the cave without supervision, usually disturbing the colonies due to noisy activities, light, and flash photography. This disturbance usually caused the colonies to move between different chambers inside the caves, in a more or less temporary fashion. During monitoring visits (2011-2015), evidence of disturbance was found (trash in the cave, remains of fire torches, and even ritual statues) and the colony would be found roosting in chambers not usually occupied by the colonies. After a couple of weeks of this behavior, if no disturbance was detected, the colony would be back in the usual chambers (Ibarra pers. comm.)

In 2015, unsupervised visits were stopped by installing a fence surrounding the main entrance to the cave, accompanied by an environmental education program directed to local communities and tourist and speleologist guides. During a series of workshops, local guides were advised on the importance of the cave and the bat species using it and on responsible visits practices. In addition, in order to enter the cave, every visitor has to report to the park ranger, who supervises that the visitors are accompanied by a responsible guide and follow the rules (Ibarra pers. comm.).

Construction work, vibrations, and noise on top of the main roosting tunnels continue to be major threats to the persistence of the *L. nivalis* colony roosting in Cueva del Diablo and the stability of the cave itself. Despite being part of a National Park, the land on top of the cave is of communal property. Some of the owners have built houses in the land. These used to be small, low impact buildings. However, due to the urbanization trend in the area, land is now being sold and new owners (usually people from outside the local communities) are developing bigger houses. During the last earthquake (September 19, 2017), the cave sustained minor damage, but with increased development and the associated vibrations, the risk of collapse continues to be a threat. Cases in which urban development has encroached on roosting caves, possibly causing roost abandonment, have been detected (e.g., at Del Ferrocarril cave in Morelos, Mexico), and this continues to be a risk at Cueva del Diablo (Ibarra pers. comm.)

La Peña Cave (State of Mexico, Mexico) and San Lorenzo Cave (Puebla, Mexico) are both highly disturbed by human activities. At La Peña Cave, the stone outcrop where the cave is located is part of a popular lookout into Valle de Bravo area and the lake there. This makes it a site heavily visited by tourists all year long (Camilo C. Reyes pers. comm.). Visitors can hike around the stone outcrop and access the lookout and the cave with little or no supervision. As a result, the area is heavily littered and vandalized with graffiti. San Lorenzo cave is frequently visited by tourists that litter inside the cave and cause disturbances with noise. The area surrounding the cave is also strongly disturbed by all-terrain vehicles and irresponsible camping practices (López-Segurajáuregui 2010, p. 46).

At El Infierno cave in Nuevo Leon, Mexico, speleological activities are known to occur inside the cave, but the level of activity is unknown. In the past, the cave (which is a large sinkhole) was used by locals as a trash dump, which may have negatively impacted the bats roosting inside.

Some known *L. nivalis* roosts have been abandoned by the bats, likely due to human disturbance. For example, during the summer of 2013 researchers visited Del Guano cave in Durango, Mexico finding evidence of vandalism, particularly fire inside the cave and *L. nivalis* was not present (pers. comm. Celia López González, CIIDIR-IPN), no one has returned to the cave after.

Finally, drug trafficking and immigration across the U.S. – Mexico border also pose threats to roosts in northern Mexico and the U.S. Southwest. These activities can introduce additional sources of roost disturbance (e.g., drug traffickers or immigrants entering and using caves) that may impact bats. Crime and violence also hinder research and educational programming. For example, Del Guano cave has not been monitored regularly for several years due to drug cartel-related conflicts in the area, and access to Romney Cave in New Mexico, United States, is often limited to daytime visits because of potential conflicts in the area. The decline in research and conservation activities can have lasting impacts on the knowledge and conservation of roosts in these areas.

While visits by people can negatively impact roosts, as discussed above, at some *L. nivalis* roosts there is successful regulation of human access and therefore reduced threats to the bats. At the Aguacatitla tunnel in Hidalgo, Mexico, visiting the roosting tunnel and seeing the bats are one of the main attractions in the park. However, the managers of this park strictly enforce a set of rules, so these visits cause minimum disturbance to the colony and the roosts. During these visits, they share information about the bats, their ecological role, ecosystem services and the importance of this tunnel for the species. Being part of privately owned lands, access to the site is strictly controlled and always under supervision of a guide. For this reason, conservation threats due to anthropogenic activities is low. The Tziranda cave system in Michoacan, Mexico, receives many visitors throughout the year, but the park has a guard in charge of security and guided visits to the caves. Visitors have access only to tunnels and chambers not occupied by bats. At the Xoxafi cave in Hidalgo, Mexico, some areas of the cave have been modified and lights have been installed to allow safe access to tourists. However, the area where bats roost remains intact and entrance to this area is restricted. Therefore, disturbance to roosting bats is kept to a minimum at these sites (Ibarra pers. comm.)

## 4.2 Persecution of Vampire Bat Colonies

In Mexico, cattle rabies outbreaks are commonly associated with the common vampire bat (*Desmodus rotundus*). Small colonies (usually no more than a couple dozen individuals) roosts in caves. The common vampire bat is considered a harmful and dangerous species due to its relation to rabies, especially cattle rabies. As a result, the Mexican government (DOF 2011, entire) has established control programs that specifically target the species. However, sometimes cattle owners and community members apply control measures that involve the destruction of caves where bats roosts. Most times, these roosts are inhabited by species other than vampire bats. As a result, entire colonies of other bats (insectivorous, frugivorous or nectarivorous) are annihilated, with little to no effect on vampire bat population (Ibarra pers. comm.). Although common vampire bats and *L. nivalis* are not usually found together due to latitude and altitudinal restrictions, cave destruction to control vampire bat population is an important threat for the species, especially in Eastern and Central Mexico. Range expansion of common vampire bats might increase negative sentiments towards bats in other areas of the *L. nivalis* range and lead to increased roost disturbance or vandalism. For example, common vampire bats have been recently captured at Infierno Cave over several years (usually one specimen, Kristen Lear, pers comm), which may lead to future negative sentiments towards the bats.

## 4.3 Loss of Food Resources

Although *L. nivalis* utilizes a wide array of floral resources, species in the genus *Agave* remain a very important component of their diet. This is supported by Gómez-Ruiz and Lacher (2017) who found that *L. nivalis* presence records are highly correlated with the distribution of *Agave* species and their migratory route is characterized by *Agave* availability. The loss of any floral resources listed in Table 3, but especially *Agave*, near roosts and along migratory corridors will have a detrimental effect on the health of the population.

Evaluating and monitoring the impact that each one of the mentioned anthropogenic activities have on the conservation of *L. nivalis* is difficult without knowing their location. The study conducted by England (2012, p. 156) suggests monitoring *L. nivalis'* main roosts should include efforts to determine location of potential associated foraging grounds. Currently, efforts are under way to initiate a study that includes using micro-GPS technology for *L. nivalis* at Cueva del Diablo to locate potential foraging grounds (Ibarra pers. comm.). The main threats to *L. nivalis* food sources are thought to be land use change and harvesting of *Agave*.

*Land use change* — Areas that once represented potential foraging grounds have been, and continue to be, threatened with conversion for agricultural use, cattle ranching and urban development (Téllez-Zenteno 2001, p. 34-38; Salinas-Galicia 2013, p. 87-88; Rojas-Martínez pers. comm.). Out of a potential 60 million hectares of desert scrub habitat in Mexico, only 44.2 million ha was estimated to remain by 2002 as primary vegetation (mainly in the Baja California peninsula, northern plains and the central Plateau), with at least 10.2 million ha converted for agriculture/livestock and nearly 5 million ha changing to secondary vegetation (mainly in Tamaulipas, San Luis Potosí y Zacatecas) (Sánchez-Colón et al. 2009, p. 106-110). Temperate forests in Mexico have faced similar declines, with ca. 10 million ha of habitat loss between 1970-2002 (Sánchez-Colón et al. 2009, p. 102-106).

Gómez-Ruiz (2015, p. 50-67) studied the land cover change in three vegetation types where chiropterophilous *Agave* occur in Coahuila and Nuevo León, Mexico over three decades (1985-2011) and found an overall reduction on the three vegetation types and an increase in fragmentation. Desert scrub had the largest negative net change from 1985 to 2011. Most of the change occurred between 1985 and 2002 with most of the area transitioning to agriculture. Human settlements were the class with highest increase (84%) occurring between 1985 and 1993. The reduction and fragmentation of *Agave* habitat can reduce the foraging areas available to *L. nivalis* and increase the time and energy needed by the bats to find foraging resources. The changes in foraging habitat may also impact the migration patterns of the species.

*Local and industrial scale harvesting of Agave*—The rising popularity of tequila and mezcal has meant that 1) there has been an increase in the number of remaining wild Agave plants being harvested and 2) an increase in the size of Agave plantations (which typically consist of clones). With the exception of the Tequila Interchange Project's "Bat Friendly Tequila", harvesting Agave plants will occur before it is allowed to flower meaning these plants cannot be considered as a foraging resource for L. nivalis. As Agave plantations will occur on suitable land for wild (flowering) Agave, this has to be considered as a reduction in foraging habitat for L. nivalis.

*Unregulated harvesting of Agave (Agave moonshiners)*—Due to the lack of information on this topic it is impossible to conclude what impact it has on L. nivalis foraging habitat. However, there are reports that harvesting of hundreds or even thousands of wild Agave in Miquihuana, Tamaulipas, occurred three years ago (Arnulfo Moreno, pers. comm.). It is believed that each plant or "piña" can sell on the black market for around 900 pesos. A similar report of the Procuraduría Federal de Protección al Ambiente (PROFEPA) seizing a shipment of Agave heads in Durango illustrates that this may have a considerable impact on L. nivalis foraging habitat.

## 4.4 Disease

The infection of *L. nivalis* with the fungus that causes White-nose syndrome, *Pseudogymnoascus destructans,* has not been documented. White-nose syndrome generally affects hibernating bats, but use of cold caves and use of torpor for long periods could make this species susceptible to the disease (Verant et. al. 2012 pp. 2-3).

## 4.5 Climate Change

While habitat conversion is still the primary driver of global endangerment for most taxa, if current projections are correct, climate change will pose a considerable threat with many species going extinct over the next century. An increase in extreme weather conditions (e.g. severe drought or rain) can cause the total loss of plant resources, prompt range shifts of the bats to areas where there is limited foraging potential or cause changes in the flowering phenology of nectar plants, reducing the availability of foraging resources. Microclimates of the roosts themselves may also be affected, making some caves unsuitable for the bats to use. Periods of extreme drought will also increase fire risk which can affect both foraging habitats and the caves themselves. While the predicted effects of climate change are highly dependent on the modeling efforts being used, a study by Zamora-Gutierrez et al. (2018, table S1) looking at the effect of climate and land use change predicts that even under an optimistic scenario, 59% of the *L. nivalis* range will be unsuitable by 2050.

There is particular concern that climate change will affect plant-pollinator relationships directly by shifting the distribution of the plants and the pollinators and by delaying flowering periods and causing a mismatch with the presence of key migratory pollinators. This might be the case for the *Agave-Leptonycteris nivalis* interaction. Gómez-Ruiz (2015, p. 26-45) studied the potential climate change impacts on *L. nivalis* and *Agave* for the years 2050 and 2070. Models show that the suitable environments for *L. nivalis* and the *Agave* species studied are reduced under future scenarios (Table 7, Figure 12 - 14). Models for *L. nivalis* show a reduction of up to 80% in its area of environmental suitability by 2070. Moreover, the overlap between *Agave* and *L. nivalis* will be reduced by at least 75%. In addition, the results reveal a change in the *Agave* richness pattern with smaller proportion of areas with one or more *Agave* species in future scenarios than under current climate conditions. In general, for all *Agave* species, most of the seeds produced fall from the fruit capsules near the parent plant, but others in strong wind may be blown several meters (Gentry 1982, p. 42). This suggests that *Agave* have a limited dispersal potential and incorporating this variable in the models will likely restrict even more the size of the areas with suitable environments in future scenarios. Changes in temperatures and precipitation will also affect *Agave* phenology in ways we do not clearly understand. There is little information about the specific cues that trigger flowering in *Agave*, but there is consensus that precipitation is an important variable (Gentry 1982, p. 418, 521; Pau et al. 2011, p. 3633).

As a result of predicted increases in hot temperatures and drier climate, fire frequency is expected to increase. The effects of fire on *Agave* is a concern because of the bats' reliance on this genus for nectar in the northern part of their range. Slauson and Dalton (1998) showed minimal effects on the *Agave* plant regarding seed production, and the burned plants they studied produced more nectar with higher sugar concentrations. In southeastern Arizona, Slauson (2002, p. 7) found less than 4% of *Agave* (*A. palmeri*) in the burned area died due to fire and there was no effect on nectar and pollen production. It was suggested that there was a long-term benefit to the *Agave* and the fire actually increased germination. However, the size of the plant and the specific fuel load around the *Agave* might affect survival. Johnson (2001, p. 34) studied the effects of fire on *A. palmeri* and found more mortality in small *Agave*, unless the *Agave* was in an environment with higher fuel loads and then larger *Agave* also were affected. *Agave* associated with mesquite (*Prosopis*) or *Acacia* trees during a fire had higher mortality in the Johnson (2001, p. 37-38) study and she suggested that patches of dead parent *Agave* that burn would have the same impact on mortality on live plants in the area. *Agave* might be less likely to die though if they are found on rocky slopes where there are low fuel loads. Further research is needed to understand if *Agave* that are used by *L. nivalis* change nectar volume or sugar content after a fire, if fruit or seed set is affected, how burn intensity affects flowering (and non-flowering) rosettes, and how it affects bat foraging behavior/migration.

***Table 7.*** *Percentage of no change, loss and gain in each species' environmentally suitable area under four different future climate scenarios (4.5 plausible optimistic, 8.5 pessimistic for year 2050) (from Gómez-Ruiz 2015).*

| Species | Scenario | No Change | Loss | Gain |
|---|---|---|---|---|
| *Agave americana* | RCP 4.5 2050 | 44 | 56 | 0 |
| | RCP 8.5 2050 | 39 | 61 | 0 |
| *Agave asperrima* | RCP 4.5 2050 | 26 | 73 | 1 |
| | RCP 8.5 2050 | 35 | 63 | 1 |
| *Agave gentryi* | RCP 4.5 2050 | 14 | 85 | 0 |
| | RCP 8.5 2050 | 17 | 82 | 0 |
| *Agave havardiana* | RCP 4.5 2050 | 27 | 73 | 0 |
| | RCP 8.5 2050 | 45 | 55 | 0 |
| *Agave horrida* | RCP 4.5 2050 | 20 | 80 | 0 |
| | RCP 8.5 2050 | 1 | 99 | 0 |
| *Agave inaequidens* | RCP 4.5 2050 | 51 | 48 | 1 |
| | RCP 8.5 2050 | 51 | 48 | 1 |
| *Agave palmeri* | RCP 4.5 2050 | 26 | 70 | 5 |
| | RCP 8.5 2050 | 17 | 80 | 3 |
| *Agave parryi* | RCP 4.5 2050 | 9 | 91 | 0 |
| | RCP 8.5 2050 | 29 | 69 | 2 |
| *Agave salmiana* | RCP 4.5 2050 | 12 | 88 | 0 |
| | RCP 8.5 2050 | 10 | 90 | 0 |
| *Leptonycteris nivalis* | RCP 4.5 2050 | 19 | 79 | 2 |
| | RCP 8.5 2050 | 34 | 64 | 1 |

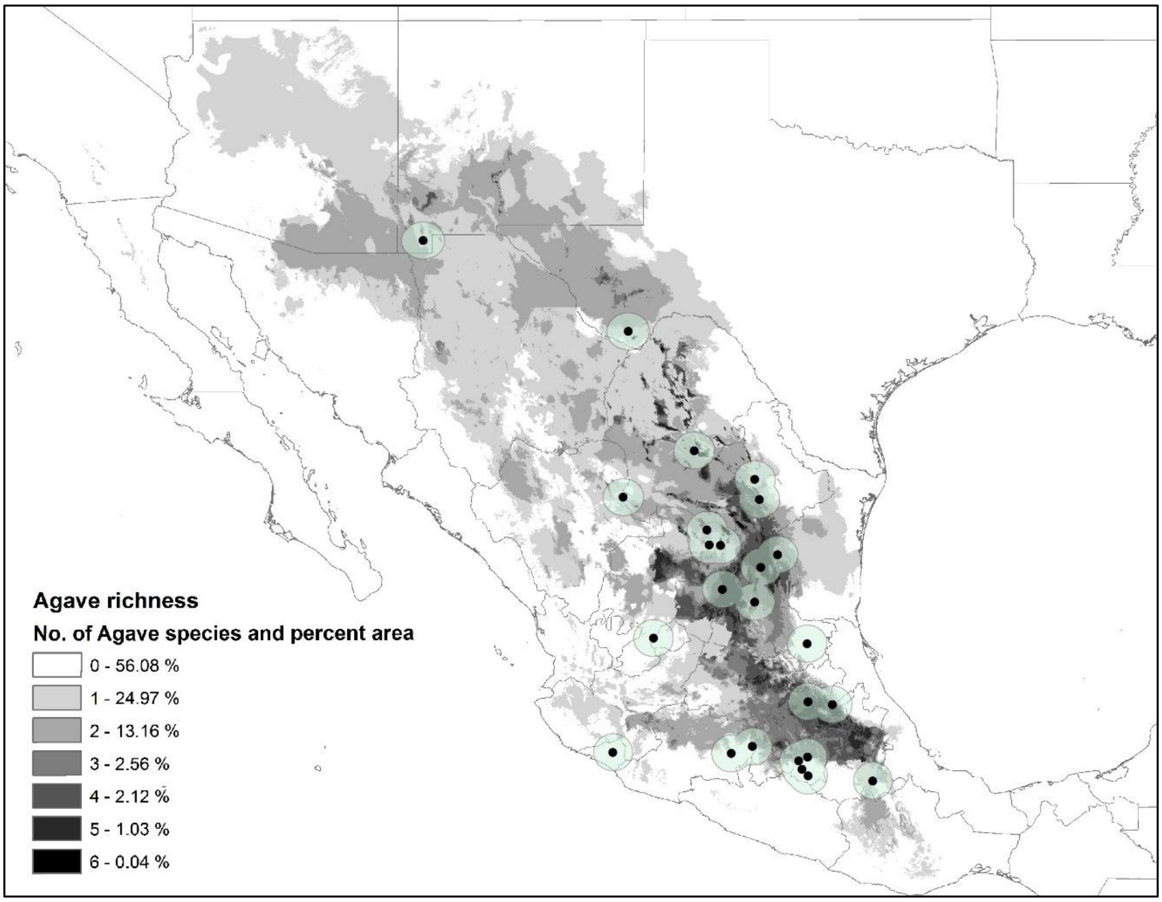


***Figure 12.*** *Agave richness pattern based on current climate data (Gomez-Ruiz 2015) and known roosting sites (points) with a 50km buffer.*

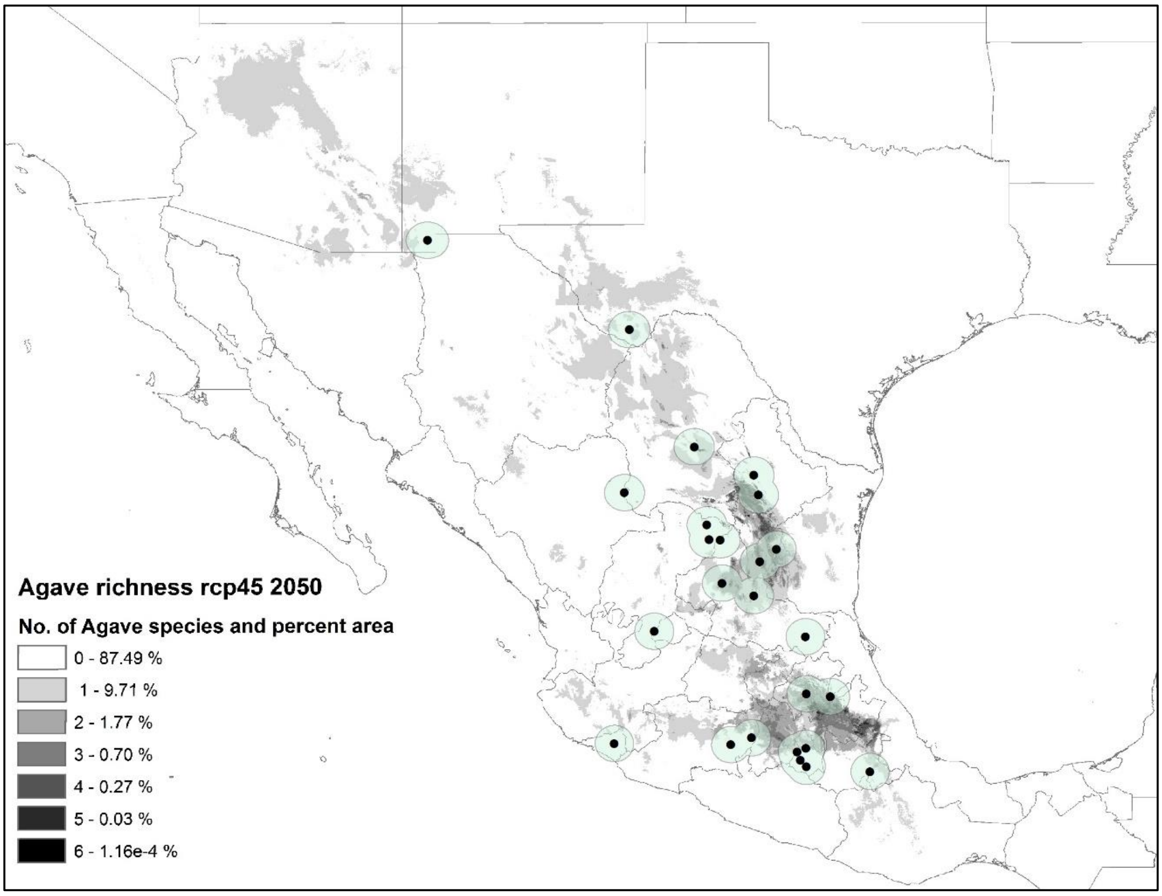


***Figure 13***. *Agave richness pattern based on a plausible optimistic future climate scenario RCP 4.5 (Gomez-Ruiz 2015) and known roosting sites (points) with a 50km buffer.*

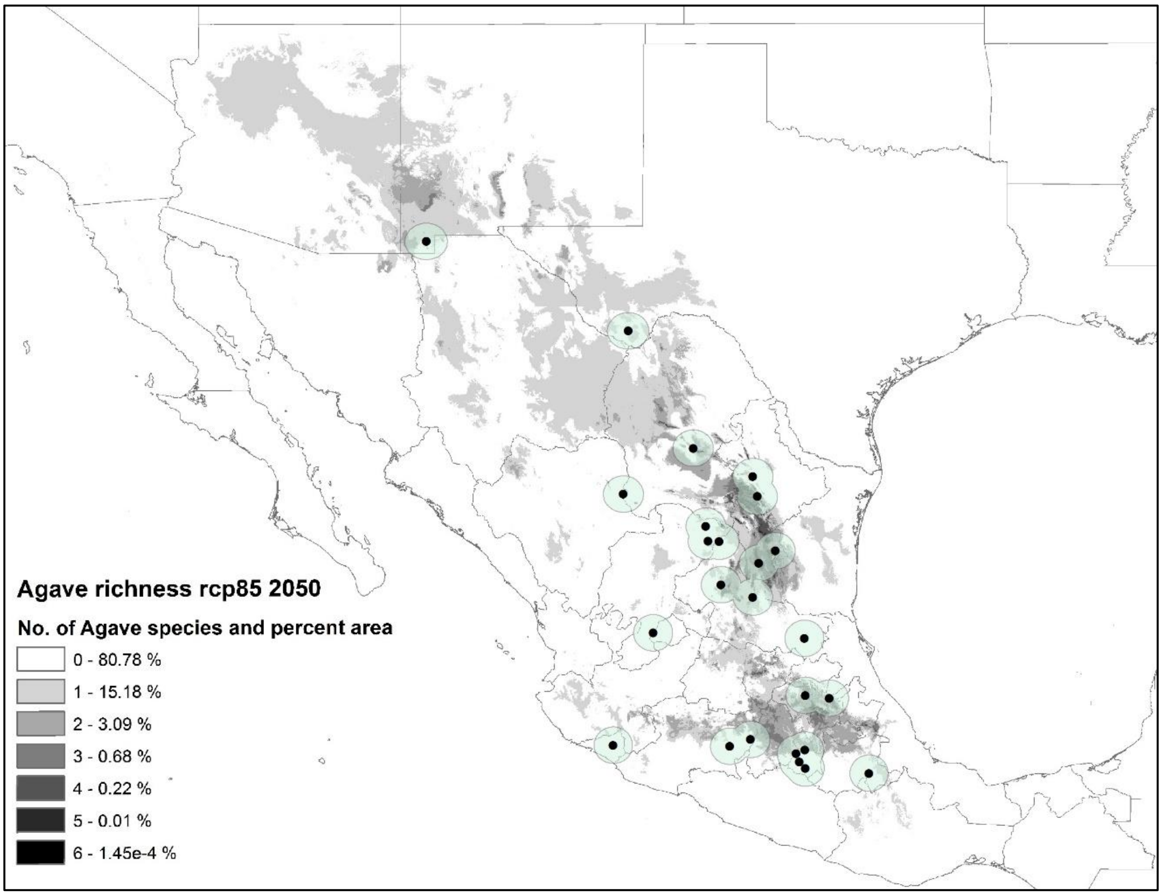


***Figure 14.*** *Agave richness pattern based on a pessimistic future climate scenario RCP 8.5 (Gomez-Ruiz 2015) and known roosting sites (points) with a 50km buffer*

## 4.6 Expansion of Energy Industry and Mining

In a recent study, Hammerson et al. (2017, p. 148) found that wind energy development was the second most serious threat for North American bats. Recent law reforms in Mexico (Reforma Energética, Ley de Cambio Climático) encouraged growth of renewable energy. Several areas in the state of Coahuila and Nuevo Leon had been identified with good potential for wind energy and these areas overlap with the range of *L. nivalis* (Information about wind energy potential inventory areas in Mexico: https://dgel.energia.gob.mx/inere/).

Abandoned mines, in general, could represent potential roosts. In Northeastern Mexico, some bat species, including *L. nivalis,* have established colonies in mines abandoned in the 70´s (e. g. Todos Santos and Santa Rosa mines). At that time, these mines were abandoned because extraction was no longer profitable. However, due to new extractive technologies, some mines could potentially be re-opened, causing these colonies to abandon these roosts.

## 4.7 Conservation Actions

### Cueva del Diablo

Starting in 2012, annual monitoring activities are conducted by LECVT (Ibarra pers. comm.) These activities include monitoring the colony to estimate colony size and demographic parameters, and monitoring of threats to the cave, mainly the presence of active construction sites, deforestation and visitors. Once threats are detected, these are reported directly to CONANP and PROFEPA (in charge of enforcing environmental legislation). Previous to 2015, visitors could access the cave freely (no supervision, no control). In order to control human visitation to the cave, a fence surrounding the entrance was installed in 2015. Now visitors have to report to the local guard, who supervises the visits and enforce visitation rules, including an off-limits season for visits. Conservation action also include an environmental education program specifically designed to meet the conservation requirements of Cueva del Diablo and *L. nivalis.* Even though Cueva del Diablo is part of a national park, the cave is not included in the management plan for the National Park. Currently (2018), actions are underway to declare Cueva del Diablo a wildlife sanctuary, with its own management and conservation plan, nested within the national park. Future conservation actions include to continue actions cited above (funding pending), design and implementation of a strategy that prevents further selling of lands above and surrounding the cave, and raising the status of the cave to wildlife sanctuary, with a management plan of its own (Ibarra pers. comm.)

### Aguacatitla

The Aguacatitla Tunnel is located inside a Biosphere Reserve and its protection and management are in charge of an ecotourism group that preserves and maintains the tunnels were the maternity colony roosts. For the last eight years, Rojas-Martinez has conducted annual monitoring of the colony, while training local guides. Protection measures, such as supervised visits and off-limits seasons are enforced by local guides. Future conservation actions include structural maintenance of the tunnels, inclusion of the management plan of the cave in the management plan of the Biosphere Reserve and design and implementation of an environmental education strategy (Ibarra pers. comm.)

**Xoxafi Cave**

Currently, the cave is privately managed by an ecotourism group (communal, landowners) who conduct constant supervision and conduct a strong environmental education program. Visits to the cave are allowed only during off-season, and visits cease once the colony arrives. Future conservation actions include granting the cave federal protection by declaring it a wildlife sanctuary, promoting *Agave* restoration programs, implement bat-friendly *Agave* harvesting practices (with local communities and tequila industry) and expanding the environmental education activities to other communities around this roost (Ibarra pers. comm.)

**El Infierno Cave**

Private organizations and researchers, in collaboration with CONANP, have implemented a series of educational and outreach programs with the communities that live in the area in order to raise awareness about bats in general, and *L. nivalis* in particular, in particular their ecological role, the relevance of *Agave* for the species, and threats and conservation actions (ESHAC-CONANP 2013, p. 56-70; Gómez-Ruiz et al. 2015, p. 93, 94).

**El Rosillo Cave**

Communities surrounding El Rosillo cave participated in educational and outreach programs (ESHAC-CONANP 2013; Gómez-Ruiz et al. 2015, entire) with the objective of informing people on the relevance of bats and their ecological roles and the importance of the area for the conservation of *L. nivalis*.

More recently, the Don Martin Basin Natural Resources Protected Area where El Rosillo Cave is located has included *L. nivalis* as a target species in their recently announced climate adaptation plan (CONANP, 2017, https://www.gob.mx/conanp/documentos/programas-de-adaptacion-al-cambio-climatico-en-areas-naturales-protegidas.). The plan considers protection of roosting sites and foraging resources to maintain connectivity of the corridor and highlights as specific actions to identify and protect roosting sites and monitoring of *Agave* populations as the main foraging resource in the region.

**Mount Emory Cave**

According to Raymond Skiles at Big Bend National Park, the cave roost has been managed by National Park Service personnel based on the Recovery Plan (USFWS 1994). Efforts have been taken to prevent disturbance by the public, by not publishing coordinates of the cave and performing research activities discreetly. To reduce disturbance, cave mapping was conducted in the winter months when the Mexican long-nosed bats were absent (Veni 2016). An annual census in the summer using various methods has been performed at least 20 times over the past 30 years. Recently signs have been posted at the cave entrance to inform hikers that might explore this remote area of the presence of an endangered species.

**Romney Cave**

Little conservation actions have occurred in this region, but due to difficult access and remote location disturbance from people is not a factor affecting conservation of the Mexican long-nosed bat in this roost.

## 4.8 Ongoing Research

In 2013, efforts to start a standardized, long-term monitoring program and a PIT tag study were initiated. These studies aim to understand migratory patterns and connectivity among the main roosts of the species in Mexico (Cueva del Diablo) and the United States (Mount Emory Cave and Romney Cave).

Foraging studies and community work has been conducted in the areas around El Infierno Cave and El Rosillo Cave since 2016 (K. Lear, pers. comm.). These activities aim to understand the foraging requirements of *L. nivalis* in northeast Mexico, to identify communities and individuals interested in *Agave* restoration for bats, and to understand how best to implement restoration efforts. In 2018, Especies, Sociedad y Habitat, A.C. (an environmental NGO in Monterrey, Nuevo Leon) received a grant from the Mexican Commission of Natural Protected Areas (CONANP) to: continue population monitoring at El Infierno Cave; conduct a study on ectoparasites of *L. nivalis*; analyze echolocation calls of *L. nivalis*; search for new roosts in the region; and assess the abundance and phenology of forage resources around the cave. Foraging studies also occurred at Romney Cave in 2016-2017 (Stoner, pers. comm) to determine bat diet in this region so that appropriate conservation actions can be taken.

Analyses of genetic diversity of Mexican long-nosed bats are underway. These studies will determine if there is any phylogeographic structure across the species range based on mitochondrial gene sequence (R. Trejo, pers. comm.) and will calculate levels of genetic diversity and effective population size based on microsatellite markers (R. Pourshoushtari, pers. comm.).

## 4.9 Summary

We narrowed down the influences on viability for the Mexican long-nosed bat to four main sources: climate change, land use change, human disturbance, and conservation actions. From climate change, we would expect drought and increased temperature to play the largest climate related roles in influencing the viability of the bat, mainly through effects on foraging habitat condition and phenology changes. Land use change could have a significant impact on roost viability due to urbanization, agricultural land use, and increased human disturbance through reduction in foraging habitat and increased roost disturbance. In terms of conservation actions, *Agave* restoration, protection of roosts, and local education have the greatest potential to combat some of the effects of land use change and climate change. Local education could prove to be vital, as there is a consistent risk of human disturbance ranging from trash left in the cave to intentional destruction of the roost coming from a fear of vampire bats, which could be devastating to the species. We considered other factors such as white nose syndrome and energy expansion (wind turbines, mines, etc.), but found they were not as influential in what drives the viability of the species. Climate change, land use change, and conservation actions are carried through into our assessment of future viability. It should be noted that although the roosts are vital to the viability of the species, the Mexican long-nosed bat is migratory. Due to the lack of knowledge on migratory routes it was not feasible to predict the stressors affecting areas that are a part of the migratory routes.

# CHAPTER 5. VIABILITY

We have considered what the Mexican long-nosed bat needs for viability and the current condition of those needs in Chapters 2 and 3, and we reviewed the risk factors that are driving the historical, current, and future conditions of the species in Chapter 4. We now consider what the species' future conditions are likely to be. We apply our future forecasts to the concepts of resiliency, representation, and redundancy to describe the future viability of the Mexican long-nosed bat.

## 5.1 Introduction

The four most influential stressors on the resiliency, representation, and redundancy of the Mexican long-nosed bat are climate change, land use change, human disturbance, and conservation actions. We created three scenarios projected out to the year 2050 that have varying levels of each of the stressors: an optimistic, status quo, and pessimistic scenario. Only nine roosts had enough information to be evaluated for future scenarios (Table 8, 9, 10). Designations of the probability of persistence in each category were given using the following: 90-100% High, 66-90% Moderate, 0-65% Low.

Under the optimistic scenario (scenario 1) we predicted a Representative Concentration Pathway (RCP) projection of 4.5 (IPCC 2014). Despite being on the lower end of RCP estimates, there will be significant changes to habitat condition for the Mexican long-nosed bat (Gomez-Ruiz 2015). In this scenario we predicted the most success for conservation actions such as protection of the roost, restoration of habitat, and education of the public that will help to offset some of the effects of climate change, land use change, and human disturbance.

Under the status quo scenario (scenario 2) we predicted a RCP projection of 6.0 (IPCC 2014). Neither Gomez-Ruiz (2015) or Zamora et al. (2018) created models using the RCP 6.0, subsequently this scenario was evaluated as having levels of impact that fall in between RCP 4.5 and RCP 8.5. In this scenario we predicted moderate success of conservation actions, only slightly mitigating effects of climate change, land use change, and human disturbance.

Under the pessimistic scenario (scenario 3) we predicted a RCP projection of 8.5 (IPCC 2014). Gomez-Ruiz (2015) and Zamora et al. (2018) modeled *Agave* distribution and habitat condition for the Mexican long-nosed bat, respectively. Their models predicted severe declines in *Agave* distribution and habitat condition for the bat. In this scenario we predicted conservation actions would have little to no mitigating effect on climate change, land use change, and human disturbance.

### 5.1.1 Consistencies Through All Scenarios

#### Central Mexico

Under the Optimistic scenario (RCP 4.5, low-end estimates), Gomez-Ruiz (2015) projected the effects of climate change in four species of *Agave* that have been reported in the diet of *L. nivalis* in Central Mexico roosts by Sanchez and Medellin (2007, p.1758). For two *Agave* species (*A. horrida* and *A. salmiana*), the optimistic plausible scenario (RCP 4.5) for 2050 predicts reduction in environmental suitability in Central Mexico. For *A. americana*, and *A. inaequidens*, this scenario predicts no change in amount of area of environmental suitability in areas of Central Mexico. Both *Agave* species predicted to lose environmentally suitable area are within the top five species consumed by *L. nivalis* in Central Mexico (Sanchez and Medellin 2007, p. 1758; Lopez-Segurajauregui 2010, p. 63-67). In general, a reduction in main floral resources is predicted under this scenario.

Currently, we lack spatially explicit projections for the effects of climate change on *Agave* or *L. nivalis* distribution under the Status Quo scenario (RCP 6).

Under the Pessimistic Scenario (RCP 8.5, extreme-high end estimates), for 2050, one species of *Agave* (*A. inaequidens*) will experience no change in environmental suitability in some areas of Central Mexico, indicating that they may be available for *L. nivalis* as a floral resource. However, under this scenario, Gomez-Ruiz (2015) predicted that three *Agave* species (*A. americana*, *A. horrida* and *A. salmiana*) will experience reduction in the area of environmental suitability in Central Mexico. These three *Agave* species are in the top five species of floral resources consumed by *L. nivalis* in Central Mexico. This indicates that these three species may not be available for *L. nivalis* in the future (something similar to the prediction under 4.5 scenario), and climate change alone may greatly reduce the availability of floral resources for migratory *L. nivalis*.

In general, under the three scenarios (including the projections made by Zamora-Gutierrez et al. 2018, p. 371), weather will tend to increase aridity, with moderate to severe humidity decreases and temperature increases, and greater losses in the arid and semi-arid regions, including shrublands, deciduous and temperate forests.

For Cueva del Diablo and some localities in Central Mexico along the Transvolcanic mountain range, the availability of an altitudinal gradient may allow for range shifting and climate niche tracking for both *Agave* and *L. nivalis*. However, changes in phenology of *Agave*, ability of *L. nivalis* to track such changes and their interactions with shifting *Agave* distributions, are hard to predict.

**Northeastern Mexico**

*El Infierno Cave*

In all three Scenarios, urbanization will increase moderately within 50 km of El Infierno Cave (the estimated foraging distance of *L. nivalis*). The cave is located approximately 10 km from Laguna de Sanchez, a town that is a popular tourist destination and a popular area for development of vacation homes. The cave is also approximately 15 km from the larger town of Santiago and the main highway, and approximately 40 km from the large city of Monterrey. Increased urbanization will lead to a moderate decrease in habitat condition and abundance of flowering plant species through clearing of natural *Agave* habitat for development. Agricultural land use, including cattle and goat ranching, will also increase in all three Scenarios, which will also decrease the habitat condition of the area.

Climate change and drought are important factors affecting El Infierno Cave in all three Scenarios. Increased drought will cause changes in the flowering phenology of *Agave* and will impact *Agave* survival in all three Scenarios. Under Scenario 1, there will be a moderate effect of drought on the flowering phenology and survival of *Agave*. Under Scenario 2, the effects will be more severe. Under Scenario 3, the timing of *Agave* flowering will not match the timing of the bats' migration, causing severe consequences for the survival of the bats. Drought will also slightly increase the harvest of *Agave* stalks for cattle and goat fodder under all scenarios, although overall levels of harvest will remain relatively low.

*El Rosillo Cave*

Under Scenario 1, urbanization should not increase within the natural protected area where the cave is located and should be low in surrounding areas. There are several *ejidos* (rural farming communities) located within the protected area, but these towns are small and will not become more urbanized in the future. However, under Scenarios 2 and 3, urbanization will increase moderately in areas surrounding the natural protected area, particularly in the areas surrounding the city of Monclova, Coahuila (located approximately 40 km from the cave). This will lead to a moderate decrease in habitat condition and abundance of flowering plant species through clearing of natural *Agave* habitat for development.

Agricultural land use, including cattle and goat ranching, will increase in all three scenarios, as will the development of shale gas wells. These land use changes will lead to a moderate decrease in habitat condition and abundance of flowering plants in the area.

Climate change and drought are important factors affecting El Rosillo Cave in all three Scenarios. Increased drought will cause changes in the flowering phenology of *Agave* and will impact *Agave* survival in all three Scenarios. Under Scenario 1, there will be a moderate effect of drought on the flowering phenology and survival of *Agave*. In addition, drought will slightly increase the harvest of *Agave* stalks for cattle and goat fodder. Under Scenario 2, the effects of drought on *Agave* flowering and survival will be more severe, and there will be a moderate increase in harvest of *Agave* stalks for livestock. Under Scenario 3, the timing of *Agave* flowering will not match the timing of the bats' migration and the use of *Agave* for livestock fodder will be significant, causing severe consequences for the survival of the bats.

## 5.2 Scenario 1: Optimistic

### 5.2.1 Resiliency

### Central Mexico

*Aguacatitla Tunnel*

Slight increases in urbanization and land use change reduces foraging habitat, but without direct impact on the roost. Increase of temperature and drought affect foraging resources through changes in phenology but bats are still able to track minor changes. Wildfires do not represent a major threat to foraging resources. *Agave* restoration projects are feasible and mitigate some of the effects of past land use change. Current level of protection and local education increases, increasing effects of *Agave* restoration projects. Overall, we expect the persistence of *L. nivalis* at the Aguacatitla Tunnel to be high under the optimistic scenario.

*Cueva del Diablo*

In this scenario, urbanization increases slightly, increasing encroachment on top of the roosting cave and increasing direct disturbance on the cave through constant vibrations, noise, etc. increasing risk of abandonment. Increased urbanization on top of the roosting cave, by increasing indirect levels of disturbance, may cancel out the potential benefits of increasing levels of protection. Urbanization and increase in agricultural land use reduces foraging habitat. Risk of wildfires increases due to drought and increased temperature. Although, in this scenario, ample foraging opportunities still remain. Direct protection of the roost and local education increases, further reducing direct disturbance of the roost by visitors, mitigating some of the effects of urbanization and land use change, and helping habitat restoration projects. Overall, we expect the persistence of *L. nivalis* at Cueva del Diablo to be moderate under the optimistic scenario.

*De la Peña Cave*

This roost is located in the middle of a highly urbanized area. However, a slight increase in urbanization in the surrounding landscape will remove *Agave* habitat, directly decreasing abundance of foraging resources. Land use change will further decrease foraging resources. *Agave* restoration projects can alleviate some of these negative effects. The increase in local education will decrease the direct disturbance to the cave by constant tourism and could increase the probability of re-establishment, given the existence of appropriate foraging resources. Overall, we expect the persistence of *L. nivalis* at De La Peña to be moderate under the optimistic scenario.

*Xoxafi Cave*

A slight increase in urbanization will not directly affect the roost. However, increase in land use change will directly affect foraging resources. Increased temperature and drought will also affect foraging resources. *Agave* restoration projects are feasible and mitigate some of the effects of land use change. Current level of protection and local education will increase, increasing effects of *Agave* restoration projects. Increase of foraging resources increases the probability of colony increase. Overall, we expect the persistence of *L. nivalis* at Xoxafi Cave to be high under the optimistic scenario.

*Tziranda Caves*

A slight increase in urbanization could directly affect the roost. Increases in land use change will affect foraging resources. *Agave* restoration projects are feasible and mitigate some of the effects of land use change. Current level of protection and local education increases, decreasing direct disturbance of the roost and increasing the positive effects of *Agave* restoration projects. Increase of foraging resources increases the probability of colony increase. Overall, we expect the persistence of *L. nivalis* at Tziranda Caves to be high under the optimistic scenario.

**Northeastern Mexico**

*El Infierno Cave*

Despite changes in foraging habitat and floral resources described in Section 5.1., in this Optimistic scenario, there will be funding and support for working with local communities to follow “bat-friendly” *Agave* harvest and management practices and to develop alternative livelihood activities that will reduce the reliance on cattle and goat ranching and in turn will reduce conversion of *L. nivalis* foraging habitat and disruption to the flowering of *Agave*s. Additionally, *Agave* restoration programs will be implemented in this area, which will increase the abundance of flowering plant species (particularly *Agave* spp.). *Agave* restoration programs will maintain planting of *Agave* every couple of years to guarantee the presence of flowering plants every year in the future. Restoration will include several native species of *Agave* to ensure that at least some *Agave* are flowering during the duration of the bats' residency in the area. This will increase the resiliency of *Agave* planted in these programs and therefore the resiliency of the bats' foraging resources. In addition, in this Optimistic scenario, new urban areas will include urban gardens with a diversity of native *Agave* planted for the bats. The *Agave* planted in restoration programs and urban gardens will compensate for the *Agave* lost through urbanization and increased agricultural land use. The diversity of nectar plant species will remain the same. In relation to factors affecting roosting, while El Infierno Cave is a site of interest for speleological groups, under this Optimistic Scenario, entry into the cave by visitors will either decline or visitors will be properly educated about the bats and how to minimize disturbance. There is current funding support to begin regular monitoring of the cave, and in this Optimistic scenario, park managers will continue to show an interest in protecting the cave and educating locals and visitors about the bats. Overall, we expect the resiliency of this site to be high under the Optimistic scenario.

*El Rosillo Cave*

In this Optimistic scenario, there will be funding and support for working with local communities to follow "bat-friendly" *Agave* harvest and management practices and to develop alternative livelihood activities that will reduce the reliance on cattle and goat ranching and in turn will reduce conversion of *L. nivalis* foraging habitat and disruption to the flowering of *Agave*. Additionally, *Agave* restoration programs will be implemented in this area, which will increase the abundance of flowering plant species (particularly *Agave* spp.). *Agave* restoration programs will begin within the next two years and will maintain planting of *Agave* every couple of years to guarantee the presence of flowering plants every year in the future. Restoration will include several native species of *Agave* to ensure that at least some *Agave* are flowering during the duration of the bats' residency in the area. This will increase the resiliency of *Agave* planted in these programs and therefore the resiliency of the bats' foraging resources. The *Agave* planted in restoration programs will compensate for the *Agave* lost through urbanization and increased agricultural land use. The diversity of nectar plant species will remain the same. In relation to roost conditions, the barriers to cave disturbance will not change (i.e. the cave is visible but access to the cave will remain difficult). The colony size will increase under this Optimistic scenario, and the level of protection will increase through increased governmental investment in educational programming with communities to increase awareness of bats and the importance of protection of the cave. Overall, we expect the resiliency of this site to be high under the Optimistic scenario.

**Southwestern United States**

*Mount Emory Cave*

Urbanization should not increase within the national park and should be low in surrounding areas. Because the roost and main foraging resources lie within the Chisos Mountains (and within the national park), the loss of foraging habitat due to urbanization should be minimal. A larger impact is expected due to effects of climate change. With hotter and drier conditions, the concern is reduction in the preferred growing conditions for *A. havardiana*, changes in the phenology of *Agave* (timing of flowering and nectar availability) along the migratory route to Mount Emory Cave, and reduction in flowering success of the single *Agave* species (*A. havardiana*) used by this colony. Restoration projects should enhance persistence as long as appropriate habitat is present.

With increased education and protection of the roost by the national park, impacts to the roost due to human disturbance should be minimal. Climate change has the potential to increase the temperature at the high elevations and increase the temperature of the cave. At some undetermined temperature threshold, an increase could cause Mount Emory Cave to become uninhabitable. Overall, we expect the persistence of *L. nivalis* at Mount Emory Cave to be high under the optimistic scenario.

*Romney Cave*

This site is isolated from the nearest small human population by at least 30 miles (small town of Hatchita, population 49) and from the larger town of Lordsburg (population 3,000) by 70 miles.  Since it is in a BLM Wilderness Protected Area urbanization is not a threat.  *Agave palmeri* is the only species in this region that has been documented in the diet of *L. nivalis* and abundance near the roost is low.  The main foraging ground of *L. nivalis* at this site is found across the valley in the Animas mountain range, which has a moderate to high, but patchily distributed *Agave* population.  Most of the *Agave* populations in the foraging grounds is found on privately owned cattle ranches, which poses a threat due to cattle grazing on *Agave* stalks. The effects of climate change (temperature and drought) on the distribution of *Agave* may also play a role in the overall quality of the foraging grounds of *L. nivalis* in this region.

Due to the isolated location far from human populations, difficult access with an unmarked trail, and protected status as a BLM wilderness study area, we expect no human disturbance to this cave.  The colony size will remain stable under an optimistic scenario, with no increased cattle density destroying *Agave* and no negative effects on the distribution of *Agave* in the region due to climate change.

***Table 8***. *Future Scenario 1 – Optimistic scenario, shown by region. There are no estimates for the East Mexico region.*

**Table 8 for Central Mexico**

| | Foraging Habitat | | | | Roost (cave) Condition | | | |
|---|---|---|---|---|---|---|---|---|
| **Region** | **Habitat Condition** | **Abundance of Floral Resources** | **Diversity of Nectar Plant Species** | **Disruption to Flowering Ability** | **Barriers to Cave Disturbance** | **Colony Size** | **Level of Protection** | **Overall Persistence** |
| Aguacatitla Tunnel | **High** | **High** | **High** | **High** | **High** | **High** | **High** | **High (↔ 3.0)** |
| Del Diablo Cave | **High** | **High** | **Moderate** | **Moderate** | **High** | **Moderate** | **High** | **Moderate (↔ 2.3)** |
| De la Pena Cave | **Low** | **Moderate** | **Moderate** | **Moderate** | **Moderate** | **Low** | **Moderate** | **Moderate (↑ 2.1)** |
| Xoxafi Cave | **Moderate** | **High** | **High** | **High** | **High** | **High** | **High** | **High (↑ 2.9)** |
| Tziranda Caves | **Moderate** | **High** | **High** | No data | **High** | **High** | **High** | **High (↔ 2.9)** |

**Table 8 for Northeastern Mexico**

| | Foraging Habitat | | | | Roost (cave) Condition | | | |
|---|---|---|---|---|---|---|---|---|
| **Region** | **Habitat Condition** | **Abundance of Floral Resources** | **Diversity of Nectar Plant Species** | **Disruption to Flowering Ability** | **Barriers to Cave Disturbance** | **Colony Size** | **Level of Protection** | **Overall Persistence** |
| El Infierno Cave | Moderate | High | Moderate | High | Moderate | High | High | High (↑ 2.6) |
| El Rosillo Cave | High | High | Moderate | High | Moderate | High | High | High (↔ 2.7) |

**Table 8 for Southwestern United States**

| | Foraging Habitat | | | | Roost (cave) Condition | | | |
|---|---|---|---|---|---|---|---|---|
| **Region** | **Habitat Condition** | **Abundance of Floral Resources** | **Diversity of Nectar Plant Species** | **Disruption to Flowering Ability** | **Barriers to Cave Disturbance** | **Colony Size** | **Level of Protection** | **Overall Persistence** |
| Mount Emory Cave | High | Moderate | Low | High | High | High | High | High (↔ 2.6) |
| Romney Cave | Moderate | Low | Low | High | High | Moderate | High | Moderate (↔ 2.1) |

### 5.2.2 Representation

As discussed in the current conditions section, we look at representation through the lens of ecological diversity, separating roosts into four regions: central Mexico, eastern Mexico, northeastern Mexico, and southwestern United States. In the optimistic scenario, representation would be maintained in northeastern Mexico and southwestern United States. Central Mexico would likely maintain representation, however Cueva del Diablo will have a decrease in the abundance of bats.

### 5.2.3 Redundancy

In the Optimistic Scenario, redundancy will increase. All of the currently extant roosts will be maintained, while De La Pena Cave may become inhabited again. With the potential recolonization of De La Pena Cave, central Mexico will see an increase in redundancy. Two central Mexican roosts will see an increase in resiliency and one northeastern Mexican roost will see an increase in resiliency. However, Cueva del Diablo will have a significant reduction in colony size, going from a high condition to a moderate condition, making it more vulnerable to extirpation.

## 5.3 Scenario 2: Status Quo

### 5.3.1 Resiliency

**Central Mexico**

*Aguacatitla Tunnel*

Further increases in urbanization and land use change reduces foraging habitat, but without direct impact on the roost. Increase of temperature and drought affect foraging resources through changes in phenology and start affecting reproduction in this maternity colony (fewer and more scattered resources imply longer traveling distances and negative fitness effects). Wildfires do not represent a major threat to foraging resources. *Agave* restoration projects are feasible and mitigate some of the effects of land use change. Despite increasing levels of direct protection of roost, level of local education may not be sufficient to have successful habitat restoration projects that could mitigate land use change and urbanization effects. For this roost, the main threat could be land use change and its effects on foraging resources. Overall, we expect the persistence of *L. nivalis* at the Aguacatitla Tunnel to be high under the status quo scenario.

*Cueva del Diablo*

Further increase in urbanization rates increases encroachment on top of the roosting cave. Levels of direct disturbance to the cave through constant vibrations, noise, etc. further increases risk of abandonment. Urbanization and land use changes reduces foraging habitat and start affecting availability of foraging resources. Risk of wildfires increases due to drought and increased temperature. Even though direct protection of the roost increases, the combined effect of roost disturbance by urbanization and land use change increases risk of abandonment. No change on level of local education makes it difficult to have successful habitat restoration projects. For this roost, any increase from the current levels of urbanization directly affect the roost and increase risk of abandonment since urbanization will occur directly on top of the roosting cave. Possible increase of direct human disturbance of the roost will exacerbate urbanization effects. Overall, we expect the persistence of *L. nivalis* at Cueva del Diablo to be moderate under the status quo scenario.

*De la Peña Cave*

Further increase in urbanization and land use change for agriculture will further decrease abundance of foraging resources. Increased temperature and drought increase the risk of wildfires. Continuing direct disturbance of the roost by visitors reduce probability of re-establishment. Overall, we expect the colony of *L. nivalis* to not persist at De La Peña Cave by 2050 under the status quo scenario.

*Xoxafi Cave*

Increase in urbanization rate may directly affect the roost and increase abandonment risk. Potential increase in human disturbance of roost increases abandonment risk. Increase in land use change will directly affect foraging resources. Increased temperature and drought will also affect foraging resources. *Agave* restoration projects are feasible and mitigate some of the effects of land use change. Despite increasing levels of direct protection of roost, level of local education may not be sufficient to have successful habitat restoration projects that could mitigate land use change and urbanization effects.

For this roost, the main threats could be land use change, urbanization, and their effects on foraging resources. Given that in this cave, stability of the colony seems to be related to appropriate foraging resources, decreasing foraging habitat quality increases the probability of roost abandonment. Overall, we expect the persistence of *L. nivalis* at Xoxafi Cave to be moderate under the status quo scenario.

*Tziranda Caves*

Increase in urbanization could directly affect roost and increase abandonment risk. Potential increase in human disturbance of roost, increases abandonment risk. Increases in land use change will affect foraging resources. Increased temperature and drought will also affect foraging resources. *Agave* restoration projects are feasible and mitigate some of the effects of land use change. Despite increasing levels of direct protection of roost, level of local education may not be sufficient to have successful habitat restoration projects that could mitigate land use change and urbanization effects. For this roost, the main threats could be land use change, urbanization, and their effects on foraging resources. Overall, we expect the persistence of *L. nivalis* at Tziranda Caves to be moderate under the status quo scenario.

**Northeastern Mexico**

*El Infierno Cave*

While we expect entry into the cave by visitors to remain at low to moderate levels under this Status Quo scenario, without increased conservation actions and mitigation projects to counteract changes in foraging resources, the risk of the species' extirpation at this roost is moderate.

*El Rosillo Cave*

While access to El Rosillo Cave will remain difficult given the terrain, without increased conservation actions and mitigation projects to counteract changes in foraging resources, the risk of the species' extirpation at this roost is moderate.

**Southwestern United States**

*Mount Emory Cave*

Even with increased urbanization, because the roost and main foraging resources lie within the Chisos Mountains (and within the national park) the loss of foraging habitat due to urbanization should be minimal. A larger impact is expected due to effects of climate change. With hotter and drier conditions, the concern is reduction in the preferred growing conditions for *A. havardiana*, changes in the phenology of *Agave* (timing of flowering and nectar availability) along the migratory route to Mount Emory Cave, and reduction in flowering success of the single *Agave* species (*A. havardiana*) used by this colony. The loss of appropriate habitat for *Agave* would make *Agave* restoration projects more difficult.

With continued education and protection of the roost by the national park, impacts to the roost due to human disturbance should be minimal. Climate change has the potential to increase the temperature at the high elevations and increase the temperature of the cave. At some undetermined temperature threshold, an increase could cause Mount Emory Cave to become uninhabitable. Overall, we expect the persistence of *L. nivalis* at Mount Emory Cave to be high under the status quo scenario.

*Romney Cave*

With moderate population growth in this region we expect no effect on the Romney roost because of its isolation and because it is found in a BLM Wilderness Protected Area. Due to the low abundance of *Agave palmeri* in this region and its low abundance near the roost, a moderate increase in cattle density with the subsequent increase of cattle *Agave* grazing may have a negative impact on the foraging ground of *L. nivalis*. This site is found across the valley in the Animas mountain range, which has a moderate to high, but patchily distributed *Agave* population. Most of the *Agave* populations in the foraging grounds is found on privately owned cattle ranches, which poses a threat due to cattle grazing on *Agave* stalks. A moderate negative effect of climate change (temperature and drought) on the distribution of *Agave* may also play a role in decreasing the quality of the foraging grounds of *L. nivalis* in this region.

Due to the isolated location, far from human populations, difficult access with an unmarked trail, and protected status as a BLM wilderness study area, we expect no human disturbance to this cave. Overall we expect the colony size will decrease somewhat under a moderately optimistic scenario, due to increased cattle density and the effects of climate change on their only food source in the region, *Agave*.

*Table 9*. *Future Scenario 2 – Status quo scenario, shown by region. There are no estimates for the East Mexico region.*

**Table 9 for Central Mexico**

| | Foraging Habitat | | | | Roost (cave) Condition | | | |
|---|---|---|---|---|---|---|---|---|
| **Region** | **Habitat Condition** | **Abundance of Floral Resources** | **Diversity of Nectar Plant Species** | **Disruption to Flowering Ability** | **Barriers to Cave Disturbance** | **Colony Size** | **Level of Protection** | **Overall Persistence** |
| Aguacatitla Tunnel | **Moderate** | **High** | **High** | **High** | **High** | **High** | **High** | **High (↔ 2.9)** |
| Del Diablo Cave | **Moderate** | **Moderate** | **Moderate** | **Moderate** | **Moderate** | **Low** | **Moderate** | **Moderate (↔ 1.7)** |
| De la Pena Cave | **Low** | **Moderate** | **Low** | **Low** | **Low** | | **Moderate** | **No Colony (↔)** |
| Xoxafi Cave | **Moderate** | **Moderate** | **Moderate** | **Moderate** | **High** | **Low** | **High** | **Moderate (↔ 2.3)** |
| Tziranda Caves | **Moderate** | **Moderate** | **Moderate** | **No data** | **High** | **Low** | **High** | **Moderate (↔ 2.3)** |

**Table 9 for Northeastern Mexico**

| | Foraging Habitat | | | | Roost (cave) Condition | | | |
|---|---|---|---|---|---|---|---|---|
| **Region** | **Habitat Condition** | **Abundance of Floral Resources** | **Diversity of Nectar Plant Species** | **Disruption to Flowering Ability** | **Barriers to Cave Disturbance** | **Colony Size** | **Level of Protection** | **Overall Persistence** |
| El Infierno Cave | **Moderate** | **Moderate** | **Moderate** | **Moderate** | **Moderate** | **Moderate** | **Moderate** | **Moderate (↔ 2.0)** |
| El Rosillo Cave | **Moderate** | **Moderate** | **Low** | **Moderate** | **Moderate** | **Moderate** | **High** | **Moderate (↓ 2.0)** |

**Table 9 for Southwestern United States**

| | Foraging Habitat | | | | Roost (cave) Condition | | | |
|---|---|---|---|---|---|---|---|---|
| **Region** | **Habitat Condition** | **Abundance of Floral Resources** | **Diversity of Nectar Plant Species** | **Disruption to Flowering Ability** | **Barriers to Cave Disturbance** | **Colony Size** | **Level of Protection** | **Overall Persistence** |
| Mount Emory Cave | **High** | **Moderate** | **Low** | **High** | **High** | **High** | **High** | **High (↔ 2.6)** |
| Romney Cave | **Moderate** | **Low** | **Low** | **High** | **High** | **Moderate** | **High** | **Moderate (↔ 2.1)** |

### 5.3.2 Representation

In the Status Quo scenario, representation is maintained in central Mexico, northeastern Mexico, and southwestern United States. Northeastern Mexico would, however, see a decrease in resiliency in El Rosillo Cave, leaving the representation of the region more vulnerable. Eastern Mexico has no roosts that have enough current data to predict future conditions. Eastern Mexico has become a target for future research and is speculated to have potential maternity roosts.

### 5.3.3 Redundancy

Redundancy is maintained in this scenario, as no roosts become extirpated. Of the three maternity roosts, only El Rosillo Cave will drop from high to moderate resiliency, while El Infierno Cave remains at moderate resiliency and Mount Emory Cave remains at high resiliency. The non-migratory, maternity colony, Aguacatitla Tunnel, will remain at a high resiliency. Cueva del Diablo, the sole mating roost, will maintain a moderate resiliency, but will suffer a large drop in colony size. While the number of roosts remains the same, resiliency of those roosts will drop slightly, making redundancy more vulnerable to change.

## 5.4 Scenario 3: Pessimistic

### 5.4.1 Resiliency

**Central Mexico**

*Aguacatitla Tunnel*

Decreased level of protection of the roost may pose risk of abandonment. Further increases in urbanization and land use change reduces foraging habitat. Increase of temperature and drought affect foraging resources through changes in phenology and affect reproduction in this maternity colony (fewer and more scattered resources imply longer traveling distances and negative fitness effects). Wildfires may represent a major threat to foraging resources. Without *Agave* restoration projects that mitigate negative effects on foraging resources, risk of roost abandonment increases. Level of local education may not be sufficient to maintain level of protection of roost. Overall, we expect the persistence of *L. nivalis* at the Aguacatitla Tunnel to be moderate under the pessimistic scenario.

*Cueva del Diablo*

Increase in direct effects of urbanization and human disturbance to the roost greatly increases risk of abandonment. Decrease in protection of roost site prevent mitigating the effects of human disturbance of the roost. Land use change and climate change reduce foraging resources availability, further increasing risk of abandonment. Decrease in foraging habitat restoration and local education makes it difficult to mitigate effects of other stressors. Overall, we expect the colony of *L. nivalis* will not persist at Cueva del Diablo by 2050 under the pessimistic scenario.

*De la Peña Cave*

Further loss of foraging habitat greatly reduces the probability of persistence. Direct disturbance of the roost by constant visitation of tourist, cave will be permanently abandoned, even by the more resilient bat species present. With limited protective measures for the roost, and restoration and management of foraging habitat, re-establishment is unlikely. Overall, we expect the colony of *L. nivalis* will not persist at De la Peña Cave by 2050 under the pessimistic scenario.

*Xoxafi Cave*

Decreased level of protection of the roost may pose risk of abandonment. Further increases in urbanization and land use change reduces foraging habitat. Increase in land use change will directly affect foraging resources. Increased temperature and drought will also affect foraging resources. Without *Agave* restoration projects that mitigate negative effects on foraging resources, risk of abandonment increases. Level of local education may not be sufficient to maintain level of protection of roost. Overall, we expect the persistence of *L. nivalis* at Xoxafi Cave to be low under the pessimistic scenario.

*Tziranda Caves*

Decreased level of protection of the roost may pose risk of abandonment. Further increases in urbanization and land use change reduces foraging habitat. Increase in land use change will directly affect foraging resources. Increased temperature and drought will also affect foraging resources. Without *Agave* restoration projects that mitigate negative effects on foraging resources, risk of abandonment increases. Level of local education may not be sufficient to maintain level of protection of roost. Overall, we expect the persistence of *L. nivalis* at Tziranda Caves to be low under the pessimistic scenario.

**Northeastern Mexico**

*El Infierno Cave*

Under this Pessimistic scenario, interest in this cave by speleological groups and other visitors will increase and entry into the cave will also significantly increase. Without education and regulation of access, this will cause disturbance to the bats and possible extirpation of the bats from this roost. In combination with changes to the timing of *Agave* flowering, we expect the resiliency of this site to be low.

*El Rosillo Cave*

While access to El Rosillo Cave will remain difficult and therefore levels of disturbance will remain low, climate change and drought will greatly impact *Agave* and therefore the bats' foraging resources. Because of increasingly severe drought, the timing of *Agave* flowering will not match the timing of the bats' migration, and the resiliency of this site will be low.

**Southwestern United States**

*Mount Emory Cave*

Even with increased urbanization, because the roost and main foraging resources lie within the Chisos Mountains (and within the national park) the loss of foraging habitat due to urbanization should be minimal. A larger impact is expected due to effects of climate change. With hotter and drier conditions, the concern is reduction in the preferred growing conditions for *A. havardiana*, changes in the phenology of *Agave* (timing of flowering and nectar availability) along the migratory route to Mount Emory Cave, and reduction in flowering success of the single *Agave* species (*A. havardiana*) used by this colony. The loss of appropriate habitat for *Agave* would make *Agave* restoration projects more difficult.

With loss of education, monitoring, and protection of the roost by the national park, impacts to the roost due to human disturbance would be increased. Increased human population could mean more visitation to the national park and more opportunity for roost disturbance. It is difficult to explore the roost cave without special gear/training, but increased visitation at the entrance could cause the colony of *L. nivalis* to reduce use. Climate change has the potential to increase the temperature at the high elevations and increase the temperature of the cave. At some undetermined temperature threshold, an increase could cause Mount Emory Cave to become uninhabitable. Overall, we expect the persistence of *L. nivalis* at Mount Emory Cave to be moderate under the pessimistic scenario.

*Romney Cave*

Large increases in cattle density across the valley combined with negative effects of global warming will decimate the *Agave* foraging ground across the valley. Under a pessimistic view, Romney cave could be negatively affected by human populations if BLM does not continue to monitor and protect this site. The colony size will be reduced drastically as the bats rapidly learn that no foraging grounds are within a reasonable distance of this important roost. They may change their overall migration patterns, but likely total populations numbers will reduce as the learning process will result in deaths due to starvation as they navigate and explore new foraging grounds.

### 5.4.2 Representation

In the Pessimistic Scenario, northeastern Mexico and southwestern United States will maintain representation, but both regions will have a decrease in resiliency. Central Mexico will lose representation, as Cueva del Diablo will become extirpated. Xoxafi Cave and Tziranda Caves will also lose resiliency.

### 5.4.3 Redundancy

In the Pessimistic Scenario, overall redundancy is reduced. Cueva del Diablo is extirpated, which is significant because it is the only known mating roost, meaning the entire species could be at risk. The hope would be that another cave could be colonized and used for mating by the bats. However, all of the roosts in this scenario will see a reduction in resiliency except for Aguacatitla Tunnel. Each roost will be more vulnerable to extirpation with resiliency reduced and the species will be more vulnerable to extinction due to reduced redundancy.

***Table 10***. *Future Scenario 3 – Pessimistic scenario, shown by region. There are no estimates for the East Mexico region.*

**Table 10 for Central Mexico**

| | **Foraging Habitat** | | | | **Roost (cave) Condition** | | | |
|---|---|---|---|---|---|---|---|---|
| **Region** | **Habitat Condition** | **Abundance of Floral Resources** | **Diversity of Nectar Plant Species** | **Disruption to Flowering Ability** | **Barriers to Cave Disturbance** | **Colony Size** | **Level of Protection** | **Overall Persistence** |
| Aguacatitla Tunnel | **High** | **Moderate** | **Moderate** | **Moderate** | **Moderate** | **Moderate** | **Moderate** | **Moderate (↓ 1.8)** |
| Del Diablo Cave | **High** | **High** | **Moderate** | **High** | **High** | No data | **High** | **No Colony (↓)** |
| De la Pena Cave | **High** | **High** | **High** | **High** | **High** | No data | **High** | **No Colony (↔)** |
| Xoxafi Cave | **Moderate** | **High** | **High** | **High** | **Moderate** | **High** | **Moderate** | **Moderate (↔ 2.3)** |
| Tziranda Caves | **Moderate** | **High** | **High** | No data | **Moderate** | **High** | **Moderate** | **Moderate (↔ 2.3)** |

**Table 10 for Northeastern Mexico**

| | Foraging Habitat | | | | Roost (cave) Condition | | | |
|---|---|---|---|---|---|---|---|---|
| **Region** | **Habitat Condition** | **Abundance of Floral Resources** | **Diversity of Nectar Plant Species** | **Disruption to Flowering Ability** | **Barriers to Cave Disturbance** | **Colony Size** | **Level of Protection** | **Overall Persistence** |
| El Infierno Cave | Moderate | High | High | High | High | High | High | High (↓ 2.0) |
| El Rosillo Cave | Moderate | High | High | High | Moderate | Moderate | High | High (↓ 2.0) |

**Table 10 for Southwestern United States**

| | Foraging Habitat | | | | Roost (cave) Condition | | | |
|---|---|---|---|---|---|---|---|---|
| **Region** | **Habitat Condition** | **Abundance of Floral Resources** | **Diversity of Nectar Plant Species** | **Disruption to Flowering Ability** | **Barriers to Cave Disturbance** | **Colony Size** | **Level of Protection** | **Overall Persistence** |
| Mount Emory Cave | High | Moderate | Low | High | Moderate | Moderate | Moderate | Moderate (↓ 2.6) |
| Romney Cave | Low | Low | Low | Low | Moderate | Moderate | Moderate | Low (↓ 2.1) |

## 5.5 Status Assessment Summary

We used the best available information to forecast the likely future condition of the Mexican long-nosed bat. Our goal was to describe the viability of the species in a manner that will address the needs of the species in terms of resiliency, representation, and redundancy. We considered the possible future condition of the species. We considered a range of potential scenarios that we think are important influences on the status of the species. Our results describe a range of possible conditions in terms of how many and where Mexican long-nosed bat roosts are likely to persist into the future (Table 11). It should be noted that these are the only roosts with enough information to reasonably predict future conditions. There are other roosts that have or currently house bats, but lack pertinent information to project conditions into the future (De la Chichihuiteca Cave, El Coyote Cave, and Todos los Santos Mine). It should also be noted that this is a roost-centered approach, the bat likely faces threats to foraging resources and roosts along its migratory route. Unfortunately, basic life history such as the location of stopover sites, roosts, or foraging grounds along the migratory route is lacking.

***Table 11***. *Summary of future resiliency of each roost as a result of each scenario in year 2050. Average score (out of 3) across all seven resiliency categories considered is given in parenthesis. There are no estimates for the East Mexico region.*

**Table 11 for Central Mexico**

| Roost | Current Conditions | Scenario 1 – Optimistic | Scenario 2 – Status Quo | Scenario 3 – Pessimistic |
|---|---|---|---|---|
| Aguacatitla Tunnel | High (-2.7) | High (-3) | High (-2.9) | Moderate (-1.8) |
| Del Diablo Cave | Moderate (-2.1) | Moderate (-2.3) | Moderate (-1.7) | No Colony |
| De la Pena Cave | No Colony | Moderate (-1.7) | No Colony | No Colony |
| Xoxafi Cave | Moderate (-2.1) | High (-2.9) | Moderate (-2.3) | Low (-1.4) |
| Tziranda caves | Moderate (-2) | High (-2.9) | Moderate (-2.3) | Low (-1.1) |

**Table 11 for Northeastern Mexico**

| Roost | Current Conditions | Scenario 1 – Optimistic | Scenario 2 – Status Quo | Scenario 3 – Pessimistic |
|---|---|---|---|---|
| El Infierno Cave | Moderate (-2.4) | High (-2.6) | Moderate (-2) | Low (-1.1) |
| El Rosillo Cave | High (-2.7) | High (-2.7) | Moderate (-2) | Low (-1.4) |

**Table 11 for Southwestern United States**

| Roost | Current Conditions | Scenario 1 – Optimistic | Scenario 2 – Status Quo | Scenario 3 – Pessimistic |
|---|---|---|---|---|
| Mount Emory Cave | High (-2.7) | High (-2.6) | High (-2.6) | Moderate (-2.1) |
| Romney Cave | Moderate (-2) | Moderate (-2.1) | Moderate (-2.1) | Low (-1.4) |

The Mexican long-nosed bat faces a variety of risks from climate change, urban development, and human disturbance of roosts. These risks play a large role in the future viability of the Texas hornshell. If populations lose resiliency, they are more vulnerable to extirpation, with resulting losses in representation and redundancy.

Under Scenario 1 - Optimistic, we would expect the viability of the Mexican long-nosed bat to be characterized by increased resiliency, representation, and redundancy. All roosts will be in a high condition except for Cueva del Diablo and De la Pena Cave in central Mexico and Romney Cave in Southwest United States, which are all in moderate condition. De la Pena Cave may go from currently extirpated to being colonized in this scenario. However, Cueva del Diablo will have a sharp decline in colony size, which is significant because it is the only known mating roost. Cueva del Diablo acts as the limiting factor for the entire species, so although overall resiliency is increasing, the viability of the species is limited to the condition of Cueva del Diablo.

Under Scenario 2 - Status Quo, we would expect the viability of the Mexican long-nosed bat to be characterized by maintained resiliency, representation, and redundancy. The only roost that will change condition is El Rosillo Cave, which will go from a currently high condition to a moderate condition in this scenario. However, similar to the Optimistic Scenario, Cueva del Diablo would have a sharp decline in colony size in this scenario, which is significant because it is the only known mating roost for the species. Subsequently, although overall the condition of most of the roosts remain the same, the species as a whole will be more vulnerable to extinction.

Under Scenario 3 - Pessimistic, we would expect the viability of the Mexican long-nosed bat to be characterized by a loss of resiliency, representation, and redundancy. All roosts will have a decrease in condition except for Aguacatitla Tunnel. All roosts will be in a low condition except for Aguacatitla Tunnel in central Mexico and Mount Emory Cave in southwest United States, which are both in moderate conditions. The most significant projection in this scenario is that Cueva del Diablo will be extirpated. If the Mexican-long nosed bat does not colonize a new cave for mating, then the species will be vulnerable to extinction.

## LITERATURE CITED


Adams, E. R. 2015. Seasonal and nightly activity of Mexican long-nosed bats (*Leptonycteris nivalis*) in Big Bend National Park, Texas. M.S. Thesis, Angelo State University, San Angelo, Texas.

Adams, E. R. and L. K. Ammerman. 2015. A serpentine antenna configuration for passive integrated transponder tag readers used at bat roosts. Southwestern Naturalist 60: 393-397.

Alvarez, T. and L. González-Q. 1970. Análisis polínico de contenido gástrico de murciélagos Glossophaginae de México. Anales Escuela Nacional Ciencias Biológicas 18:137-165.

Ammerman, L. K., C. L. Hice and D. J. Schmidly. 2012. Bats of Texas. Texas A&M University Press, College Station.

Ammerman, L. K., M. McDonough, N. I. Hristov, and T. H. Kunz. 2009. Census of the endangered Mexican long-nosed bat *Leptonycteris nivalis* in Texas, USA, using thermal imaging. Endangered Species Research:1–6.

Arias-Coyotl, E., K. Stoner, and A. Casas. 2006. Effectiveness of bats as pollinators of *Stenocereus stellatus* (Cactaceae) in wild, managed in situ, and cultivated populations in La Mixteca Baja, Central Mexico. American Journal of Botany 93:1675–1683.

Arita, H. T. 1991. Spatial segregation in long-nosed bats *Leptonycteris nivalis* and *Leptonycteris curasoae*, in Mexico. Journal of Mammalogy 72:706–714.

Arita, H. T. 2005. *Leptonycteris nivalis* (Saussure, 1860). Pages 223–224 in G. Ceballos and G. Oliva, editors. Los mamíferos silvestres de México. CONABIO-CFE, México.

Arita, H. T, and S. R. Humphrey. 1988. Revisión taxonómica de los murciélagos magueyeros del género *Leptonycteris* (Chiroptera: Phyllostomidae). Acta Zoologica Mexicana 29:1–60.

Ávila-Flores, R. 2000. Patrones de uso de cuevas en murciélagos del centro de México. Universidad Nacional Autónoma de México.

Ayala-Berdon, J., R. Galicia, C. Flores-Ortíz, R. A. Medellín, and J. E. Schondube. 2013. Digestive capacities allow the Mexican long-nosed bat (*Leptonycteris nivalis*) to live in cold environments. Comparative Biochemistry and Physiology. Part A 164:622–8. Elsevier B.V. Available from http://www.ncbi.nlm.nih.gov/pubmed/23370293 (accessed June 12, 2013).

Baker, R. J. and E. L. Cockrum. 1966. Geographic and ecological of the long-nosed bats, *Leptonycteris*. Journal of Mammalogy 47(2):329-331.

Barbour, R.W., and W. H. Davis. 1969. Bats of America. University Press, Kentucky, United States.

Bogan, M. A., P. M. Cryan, C. D. Weise, and E. W. Valdez. 2017. Landscape movements by two species of migratory nectar-feeding bats (*Leptonycteris*) in a northern area of seasonal sympatry. Western North American Naturalist 77(3): 317-330.

Bogan, M. A., P. M. Cryan, and C. D. Weise. 2006. Roosts and nocturnal movements of long-nosed bats (*Leptonycteris curasoae* and *L. nivalis*) in southwestern New Mexico. Report to Las Cruces Office, Bureau of Land Management.

Bolaños-García, Z.G., and A. Rojas-Martínez. 2013. Determinación del tamaño de una colonia estacional del murciélago *Leptonycteris nivalis* en Huasca de Ocampo, Hgo. Pages 16–20 Foro de los trabajos de investigación UAEH. Área Académica de Biología.

Brown, C. M. 2008. Natural history and population genetics of endangered Mexican long-nosed bat, *Leptonycteris nivalis* (Chiroptera: Phyllostomidae). M. S. Thesis, Angelo State University, San Angelo, Texas.

Caballero-Martínez, L. A. 2004. Observaciones sobre la conducta reproductiva de *Leptonycteris nivalis* (Chiroptera: Phyllostomidae) en Tepoztlán, Morelos, México. Universidad Autónoma del Estado de México. 118 pp.

Carstens, B.C., B. L. Lundrigan, and P. Myers. 2002. A phylogeny of the neotropical nectar-feeding bats (Chiroptera: Phyllostomidae) based on morphological and molecular data. Journal of Mammalian Evolution 9: 23-53.

Chase, M.W., J. L. Reveal, and M. F. Fay. 2009. A subfamilial classification for the expanded asparagalean families Amaryllidaceae, Asparagaceae and Xanthorrhoeaceae. Botanical Journal of the Linnean Society 161: 132–136.

Cockrum, E. L. 1991. Seasonal distribution of northwestern populations of long-nosed bats *Leptonycteris sanborni*, family Phyllostomidae. Anales del Instituto de Biología 62:181–202.

Cockrum, E. L., and B. J. Hayward. 1962. Hummingbird bats. Natural History 71:39–44.

CONANP. 2003. Programa de manejo de la Reserva de la Biosfera Barranca de Metztitlán. México.

CONANP. 2017. https://www.gob.mx/conanp/documentos/programas-de-adaptacion-al-cambio-climatico-en-areas-naturales-protegidas

Davis, W. B. 1974. The mammals of Texas. Bull. Texas Parks Wild. Dept. 41:1–294.

Davis, W. B., and D. C. Carter. 1962. Review of the genus *Leptonycteris* (Mammalia: Chiroptera). Proc. Biol. Soc. Washington 75:193–198.

Dobat, K. and T. Peikert-Holle. 1985. Blüten und Fledermäuse (Chiropterophilie). Frankfurt: Kramer-Verlag.

DOF (Diario Oficial de la Federación). 2011. NORMA Oficial Mexicana NOM-067-ZOO-2007, Campaña nacional para la prevención y control de la rabia en bovinos y especies ganaderas. Secretaria de Agricultura, Ganadería, Desarrollo Rural, Pesca y

Alimentación. Mexico.

Easterla, D. A. 1972. Status of *Leptonycteris nivalis* (Phyllostomidae) in Big Bend National Park, Texas. Southwestern Naturalist 17:287–292.

Easterla, D. A. 1973. Ecology of the 18 species of Chiroptera at Big Bend National Park, Texas. Part I. Northwest Missouri State University Studies 34:1–53.

Eguiarte, L. and A. Burquez. 1987. Reproductive ecology of *Manfreda brachystachya*, an iteroparous species of Agavaceae. Southwestern Naturalist 32(2): 169-178.

England, A. E. 2012. Pollination ecology of *Agave palmeri* in New Mexico, and landscape use of *Leptonycteris nivalis* in relation to agaves. PhD Dissertation, The University of New Mexico, Albuquerque.

ESHAC-CONANP. 2013. Protección y manejo de refugios para la conservación de murciélagos en riesgo. Reporte final del proyecto PROCER/DGOR/18/2013. Monterrey, Nuevo León.

Espinosa-Ávila, L. A. 2008. Análisis de los nichos ecológicos estacionales de murciélagos migratorios. Universidad Nacional Autónoma de México.

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

Fleming, T. H., R. A. Nuñez, and L. S. L. Sternberg. 1993. Seasonal changes in the diets of migrant and non-migrant nectarivorous bats as revealed by carbon stable isotope analysis. Oecologia 94:72–75.

Fleming, T. H., T. Tibbitts, Y. Petryszyn, and V. Dalton. 2003. Current status of pollinating bats in southwestern North America. Monitoring trends in bat populations of the United States and territories: problems and prospects, T. J. O'Shea y MA Bogan (eds.). Biological Resources Discipline, Information and Technology Report. USGS Fort Collins Science Center, 63-67.

Flower, W. H., and R. Lydekker. 1891. An introduction to the study of mammals living and extinct. Adams and Charles Black, London, England.

Gardner, A. L. 1977. Feeding habits. Pages 239–250 in R. J. Baker, J. K. Jones Jr., and D. C. Carter, editors. Biology of bats of the New World. Family Phyllostomidae, part II. Texas Tech University.

Gentry, H. S. 1982. Agaves of continental North America. University of Arizona Press. Tucson, Arizona.

Gómez-Ruiz, E. P. 2015. Potential impacts of global and regional environmental changes on an endangered pollination corridor in Mexico and the USA. Ph.D. Dissertation, Texas A&M University, College Station, Texas.

Gómez-Ruiz, E., and T. Lacher. 2017. Modelling the potential geographic distribution of an endangered pollination corridor in Mexico and the United States. Diversity and Distributions 23:67–78.

Gómez-Ruiz, E. P., C. Jimenez, J. J. Flores-Maldonado, T. E. Lacher, and J. M. Packard. 2015. Conservación de murciélagos nectarívoros (Phyllostomidae: Glossophagini) en riesgo en Coahuila y Nuevo León. Therya 6:89–102.

Greenbaum, I. F., and C. J. Phillips. 1974. Comparative anatomy of and general histology of tongues of long-nosed bats (*Leptonycteris sanborni* and *L. nivalis*) with reference to infestation of oral mites. Journal of Mammalogy 55:489–504.

Hall, E. R. 1981. The mammals of North America. Second. John Wiley and Sons, New York.

Hammerson, G. A., M. Kling, M. Harkness, M. Ormes, and B. E. Young. 2017. Strong geographic and temporal patterns in conservation status of North American bats. Biological Conservation 212: 144-152.

Higginbotham, J. L. and L. K. Ammerman. 2002. Chiropteran community structure and seasonal dynamics in Big Bend National Park. Special Publications, Museum of Texas Tech University No. 44. 44pp.

Hoffman, A., J. G. Palacios, and J. B. Morales-Malacara. 1986. Manual de Bioespeleología. Universidad Nacional Autónoma de México, Mexico.

Hoffmeister, D. F. 1957. Review of the long-nosed bats of the genus *Leptonycteris*. Journal of Mammalogy 38:489–461.

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

Honacki, J. H., K. E. Kinman, and J. W. Koeppi. 1982. Mammal species of the world: a taxonomic and geographic reference. Allen Press Inc. and The Assoc. Syst. Coll., Kansas, Estados Unidos.

Horner, M. A., T. H. Fleming, and C. T. Sahley. 1998. Foraging behaviour and energetics of a nectar-feeding bat, *Leptonycteris curasoae* (Chiroptera:Phyllostomidae). Journal of Zoology 244:575–586.

Hoyt, R.A., J. S. Altenbach, and D. J. Hafner. 1994. Observation of long-nosed bats (*Leptonycteris*) in New Mexico. Southwestern Naturalist 39:175–179.

Huerta-Zamacona, M del C. 1991. Los quirópteros de las Grutas de Hidalgo, Michoacán, México. Universidad Michoacana de San Nicolás de Hidalgo.

INEGI. 1986. Síntesis geográfica del Estado de Nuevo León. Available from h.

INEGI. 1992. Síntesis geográfica del estado de Hidalgo. Available from http://www.inegi.gob.mx/inegi/default.aspx?s=geo&c=&e=16.

INEGI. 1999. Aspectos geográficos de Michoacán de Ocampo. Available from http://www.inegi.gob.mx/inegi/default.aspx?s=geo&c=&e=16.

INEGI. 2003. Síntesis geográfica del Estado de Zacatecas. Available from http://www.inegi.gob.mx/inegi/default.aspx?s=geo&c=&e=16.

INEGI. 2009. Prontuario de información geográfica municipal de los Estados Unidos Mexicanos. Ciudad de México.

Johnson, R. J. 2001. Effects of fire on *Agave palmeri*. Master of Science Thesis. University of Arizona, Tucson, Arizona. 69 pp.

Koopman, K. F. 1994. Chiroptera: systematics. Handbook of Zoology (Mammalia) 8(part 60):1–217.

Kuban, J. 1989. The pollination biology of two populations of the Big Bend century plant, *Agave havardiana* Trel.: a multiple pollinator syndrome with floral specialization for large vertebrate pollinators. Ph.D. dissertation, Syracuse University, Syracuse, New York.

Kunz, T. H. 1982. Ecology of bats. Plenum Press, New York.

Lacher, T. E., and E. Gómez-Ruiz. 2012. Identifying priority sites for the conservation of the migratory endangered bat *Leptonycteris nivalis* in the United States and northern Mexico. Bat Conservation International Final report. pp. 56.

López-Segurajáuregui, G. 2010. Dieta del murciélago magueyero mexicano *Leptonycteris nivalis* (Chiroptera: Phyllostomidae) en cuatro cuevas del centro de México. Undergraduate thesis. Universidad Nacional Autónoma de México. Mexico City.

Medellín, R. 2002. Justificación para la creación de santuarios para conservación de ecosistemas cavernícolas. Comisión Nacional de Areas Naturales Protegidas. Technical Report PNUD MEX/01/005. Print.

Medellín, R. 2016. *Leptonycteris nivalis*. The IUCN Red List of Threatened Species 2016: e.T11697A22126172. http://dx.doi.org/10.2305/IUCN.UK.2016-1.RLTS.T11697A22126172.en.

Medellín, R., A. Abreu-Brobois, M. C. Arizmendi, E. Mellink, E. Ruela, C. Santana, and J. Urban. 2009. Conservación de especies migratorias y poblaciones transfronterizas. Pages 459–515 in Capital Natural de México Vol. II: Estado de conservación y tendencias de cambio. CONABIO, México.

Medellín, R., H. Arita, and O. Sánchez. 2008. Identificación de los murciélagos de México. Segunda. Instituto de Ecología, UNAM, México.

Medellín, R. A., M. Rivero, A. Ibarra, J A. de la Torre, T. P. Gonzalez-Terrazas, L. Torres-Knoop, M. Tschapka. 2018. Follow me: foraging distances of *Leptonycteris yerbabuenae* (Chiroptera: Phyllostomidae) in Sonora determined by fluorescent powder. Journal of Mammalogy *doi.org/10.1093/jmammal/gyy016*

Moreno-Valdez, A., W. E. Grant, and R. Honeycutt. 2000. A simulation of Mexican long-nosed bat (*Leptonycteris nivalis*) migration. Ecological Modelling 134:117–127.

Moreno-Valdez, A., R. Honeycutt, and W. Grant. 2004. Colony dynamics of *Leptonycteris nivalis* (Mexican long-nosed bat) related to flowering agave in northern Mexico. Journal of Mammalogy 85:453–459.

Nassar, J. M., R. Galicia, A. Ibarra, R. A. Medellin. 2016. Tracking the origin of the smearing behavior in long-nosed bats (*Leptonycteris* spp.). Mammalian Biology 81: 623-627.

Neuweiler, G. 2000. The biology of bats. Oxford University Press, New York.

Pau, S., E. M. Wolkovich, B. I. Cook, T. J. Davies, N. J. B. Kraft, K. Bolmgren, J. L. Betancourt, and E. E. Cleland. 2011. Predicting phenology by integrating ecology, evolution and climate science. Global Change Biology 17: 3633–3643.

Piccini, L., P. Forti, I. Giuliyo, and M. Mecchia. 2007. The polygenetic caves of Cuatro Ciénegas (Coahuila, México): Morphology and speleogenesis. International Journal of Speleology 36:83–92.

Poulos, H. M., and A. E. Camp. 2010. Topographic influences on vegetation mosaics and tree diversity in Chihuahuan Desert borderlands. Ecology 91:1140–1151.

Racey, P. A. and A. C. Entwistle. 2000. Life-history and reproductive strategies of bats. Pp. 363–414 in Reproductive biology of bats (E. G. Crichton and P. H. Krutzsch, eds.). Academic Press, San Diego, California.

Ramos-Frias, J. 2013. Genética histórica del género *Leptonycteris* (Mammalia: Chiroptera) en poblaciones del centro de México. Universidad Autónoma del Estado de Hidalgo.

Rojas-Martínez, A. 1996. Estudio poblacional de tres especies de murciélagos nectarívoros considerados como migratorios y su relación con la presencia estacional de los recursos florales en el Valle de Tehuacán y la Cuenca del Balsas. Universidad Nacional Autónoma de México.

Rojas-Martínez, A., A. Aguilar-López, and O. Noguera-Cobos. 2010. Caracterización y protección del hábitat del murciélago magueyero (*Leptonycteris nivalis*) dentro del desarrollo ecoturístico Barranca de Aguacatitla en la Reserva de la Biósfera Barranca de Metztitlán. Comisión Nacional de Areas Naturales Protegidas. Technical Report PROCODES-CONANP 2010.

Rojas-Martínez, A., M. Aguilar-López, O. Noguera-Cobos, and J. Ramos-Frias. *In prep.* Importancia de las floraciones de agave en los refugios de maternidad del murciélago magueyero (*Leptonycteris nivalis,* Suassure 1860) en Norte América.

Rojas-Martínez, A., M. Aguilar-López, J. Ramos-Frías, C. Cornejo-Latorre, J. Cruz-Hernández, and O. Noguera-Cobos. 2011. Reproducción del murciélago polinizador *Leptonycteris nivalis* (CHIROPTERA: GLOSSOPHAGINAE) en Hidalgo, México. Mesoamericana 15:119.

Rzedowski, J. 2006. La vegetación of México. Editorial Limusa, Mexico.

Sahley, C. T., M. A. Horner, and T. H. Fleming. 1993. Flight speeds and mechanical power outputs of the nectar-feeding bat, *Leptonycteris curasoae* (Phyllostomidae: Glossophaginae). Journal of Mammalogy 74(3): 594-600.

Salinas-Galicia, R. 2013. *Ipomoea murucoides* (Convulvulaceae) como recurso de invierno para *Leptonycteris nivalis* (Phyllostomidae) en Tepoztlan, Morelos, Mexico. Universidad Nacional Autónoma de México. 103 pp.

Sánchez, L. R. 2004. Dieta del murciélago magueyero mayor *Leptonycteris nivalis* (Chiroptera: Phyllostomidae) en la Cueva del Diablo, Tepoztlán, Morelos. Universidad Autónoma del Estado de México.

Sánchez, L. R., and R. Medellín. 2007. Food habits of threatened bat *Leptonycteris nivalis* (Chiroptera: Phyllostomidae) in a mating roost in Mexico. Journal of Natural History 41:1753–1764.

Sánchez-Colón, S., A. Flores-Martínez, I. A. Cruz-Leyva and A. Velázquez. 2009. Estado y transformación de los ecosistemas terrestres por causas humanas. Pages 75-129 in  Capital Natural de México, vol. II: Estado de conservación y tendencias de cambio. CONABIO. México.

Saussure, H-R, 1860. "Notes sur quelques mammifères du Mexique", in Revue et magasin de zoologie pure et appliquée, 2e série, 12 :479-494.

Simmons, N. 2005. Order Chiroptera Pages 312-529 in Mammal species of the world: A taxonomic and geographic reference, third edition (Wilson, D. E. and D. M. Reeder, editors). The John Hopkins University Press. Baltimore, Maryland.

Slauson, L. A. 2000. Pollination biology of two chiropterophilous agaves in Arizona. American Journal of Botany 87:825-836.

Slauson, L. A. 2002. Effects of fire on the reproductive biology of *Agave palmeri* (Agavaceae). Madrono 49:1-11.

Téllez-Zenteno, J. G. 2001. Migración de los murciélagos hocicudos (*Leptonycteris*) en el trópico mexicano. Universidad Nacional Autónoma de México. 145 pp.

Toledo-Gutiérrez, K. P. 2009. Hábitos reproductivos del murciélago magueyero mayor *Leptonycteris nivalis* (Chiroptera: Phyllostomidae) en la “Cueva del Diablo”, Tepoztlán, Morelos, México. Universidad Nacional Autónoma de México. 95 pp.

Torres-Knoop, L. 2014. Refugio de apareamiento de *Leptonycteris nivalis*: modelación y búsqueda de un recurso limitante. Universidad Nacional Autónoma de México.

Trejo-Salazar, R. E. 2007. Dinámica de la polinización de *Agave difformis*, *A. garciae-mendoza*e y *A. striata* (Agavaceae) en la Barranca de Metztitlán, Hidalgo. Universidad Nacional Autónoma de México.

Trejo-Salazar, R. E., L. E. Eguiarte, D. Suro-Piñera, and R. A. Medellin. 2016. Save our bats, save our tequila: Industry and science join forces to help bats and agaves. Natural Areas Journal 36:523–530.

Trejo-Salazar, R. E., E. Scheinvar, and L. E. Eguiarte. 2015. ¿Quién poliniza realmente los agaves? Diversidad de visitantes florales en 3 especies de agave (Agavoideae: Asparagaceae). Revista Mexicana de Biodiversidad 86:358–369.

USFWS. 1994. Mexican long-nosed bat (*Leptonycteris nivalis*) Recovery Plan. U. S. Fish and Wildlife Service, Albuquerque, New Mexico. 91 pp.

U.S. Fish and Wildlife Service. 2016. USFWS Species Status Assessment Framework: an integrated analytical framework for conservation. Version 3.4 dated August 2016

Valdez, T. 1981. Contribución al conocimiento de los tipos de vegetación, su cartografía y notas flor´sitico-ecológicas del municipio de Santiago, Nuevo León, México. Universidad Autónoma de Nuevo León.

Valiente-Banuet, A., A. Rojas-Martínez, M. del C. Arizmendi, and P. Dávila. 1997. Pollination biology of two columnar cacti (*Neobuxbaumia mezcalaensis* and *Neobuxbaumia macrocephala*) in the Tehuacan Valley, Central Mexico. American Journal of Botany 84:452–455.

Veni, G. 2016. The exploration and study of Mount Emory Cave, Big Bend National Park, Texas. NSS News, National Speleological Society 74 (12):4-9.

Verant, M., J. Boyles, W. Waldrep Jr, G. Wibbelt, and D. Blehert. 2012. Temperature-dependent growth of *Geomyces destructans*, the fungus that causes bat white-nose syndrome. PLoS ONE 7:1-9

Weise, C. D. 2005. Roost counts and occurrence of bats of the genus *Leptonycteris* in New Mexico. Final report for the New Mexico Department of Game and Fish Grants for Endangered and Threatened Species. Santa Fe, New Mexico.

Wilkinson, G. S. and T. H. Fleming. 1996. Migration and evolution of lesser long-nosed bats *Leptonycteris curasoae*: inferred from mitochondrial DNA. Molecular Ecology 5: 329-339.

Wilson, D. E.1985. Status report: *Leptonycteris sanborni* Hoffmeister, Sanborn's long-nosed bat. U.S. Fish and Wildlife Service, Denver Wildlife Research Center, National Museum of Natural History, Washington, D.C.

Wolf, S., B. Hartl, C. Carroll, M. Neel, and D. Greenwald. 2015. Beyond PVA: Why recovery under the endangerd species act is more than population viability. BioScience 1-8

Zamora-Gutierrez, V., R. G. Pearson, R. E. Green, and K. E. Jones. 2018. Forecasting the combined effects of climate and land use change on Mexican bats. Diversity and Distribution 24: 363-374. doi.org/10.1111/ddi.12686