CONSERVATION OF MEXICAN LONG-NOSED BATS ALONG THE MIGRATION ROUTE AND SURROUNDING MATERNITY CAVES

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by

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ABSTRACT

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Abstract

The nectar-feeding Mexican long-nosed bat (*Leptonycteris nivalis* or *L. nivalis*) population has been experiencing a steep decline over the past ten years. Conservation of this species is vital for the mutualistic relationship between the plant genus *Agave* and the bat species *Leptonycteris nivalis*. Bat pollination promotes genetic diversity of the agave plant and ensures maintenance of the plant community structure. To gain an understanding of critical habitat locations for conservation, I developed high-resolution species distribution models with data on current and historic sites and observations. These revised models were used to hypothesize the most likely migratory route of the species, which will be used to guide the search for additional roosting caves along the migration.

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CHAPTER I

INTRODUCTION

The nectar-feeding Mexican long-nosed bat (*Leptonycteris nivalis* or *L. nivalis*) is a vital component of arid ecosystems, and is recognized as an endangered species in the United States, Mexico, and International Union for Conservation of Nature (IUCN; Medellin 2016). It is estimated to have population declines of up to 50 percent in the past 10 years (IUCN 2016). For nectivorous bats, their survival depends on the availability of food and places of refuge (Gomez-Ruiz et al. 2015). Bats spend the majority of their lives in roosts, which is a critical limiting factor for their survival (Penuela-Salgado and Perez-Torres 2015).

Role of the Mexican Long-Nosed Bat

The role of these airborne mammals includes pollination of the agave (genus *Agave* or *A.)* plant along their migration route from Mexico to the Big Bend National Park region of Texas (Gomez-Ruiz and Lacher 2017). Following the paniculate agave bloom, the Mexican long-nosed bat feeds on nectar, and cross-pollinates the agave plants that are adapted specifically for nocturnal pollinators. This ensures stability of wild and cultivated agave by enhancing the genetic diversity and increasing resilience against environmental stressors (Gomez-Ruiz and Lacher 2017). Maintaining the agave plant is not only essential to the bat population, but also is important in preventing soil erosion, creating habitat for other desert wildlife, and sustaining the socio-economic use of agave for tequila, mescal, and agave nectar.

Limiting Factors

For *L. nivalis* to migrate through the endangered pollination corridor of central Mexico to the Big Bend region of Texas, the conditions must favor the species' movement through the area. Favorable conditions include the presence of roosting sites and agave patches being within a maximum of 50 km between roosts to permit the colony's survival and minimize mortality. 50 km is defined as the foraging radius based upon minimal available data, because there is little research on how far the colony is able to travel in one night (Gomez et al. 2015). To reach the roosting sites within the deciduous forest, pine-oak forest, and desert scrub ecotype regions that *L. nivalis* occupy through the migration route, the climate must be arid to semi-arid for the agave food resources to exist, and mountain caves must be present within 50 km from the resource for roosting (Gomez et al. 2015). According to IUCN (2016), *L. nivalis* can be found between a lower elevation limit of 500 m and an upper elevation limit of 3,500 m. However, the bat species requires an elevation equal to or greater than 1,000 m for roosting, breeding, and maternity sites (Arita 1991; IUCN 2016).

Urban and suburban zones, patchy habitat, monocultures, mountain presence/absence, and elevation serve as constraints for the migratory pathway of this species. The local species pool also requires various agave species present that the bat is reported to consume, and the proximity of agave patches to each other must be a maximum of 50 km with agave at various stages of inflorescences for the bat to pass through the region (Gomez et al. 2015). The Mexican long-nosed bat are found to forage on along the migration route on the following species of *Agave*: *A. Americana, A. asperrima, A. palmeri, A. gentry, A. parryi, A. inaequidens, A. salmiana, A. havardiana, A. horrida* (Gomez et al. 2015). Community abiotic and biotic requirements for migration include roosting sites, and agave in bloom during the spring and summer, permitting *L. nivalis* migration. Since the bats will need to rest at the end of the night, there should be an available site in any stretch of the migration route. An individual agave blooms once after several years then dies; therefore, it is vital that there is an abundance of agaves of different species and of different ages to allow for agaves to bloom along the migration route. For the Mexican long-nosed bat to exist along the historic endangered pollination corridor and migration route, these major filters must be overcome for agave presence/absence and roosting sites.

Conservation Efforts

The specialized nectar-feeding bat, *L. nivalis*, inhabits a range of habitat from pine-oak and deciduous forests to desert scrub and are sensitive to disturbances in their maternity caves of Nuevo Leon and Coahuila in Mexico and Emory Cave in the Big Bend National Park in West Texas (Gomez et al. 2015). Conservation of these mutualisms is critical for maintaining plant community structure, but given their complexity there are few detailed studies (Nabhan and Fleming 1993). Recent work has emphasized the engagement of local communities in conservation as well (Gomez et al. 2015).

Objectives

The bulk of this recent research on the status of *Leptonycteris nivalis* along the US and Mexico border has been conducted in the laboratory of Dr. Thomas Lacher at Texas A&M (Gomez-Ruiz 2013, Gomez et al. 2015, Gomez-Ruiz and Lacher 2017). I will contribute new research to this project by assisting in documenting current and historic sites and observations for this species that will be used in the development of high-resolution species distribution models.

These models are critical for focusing conservation priorities and assisting in the search for additional maternity caves along the US and Mexico border. I have two primary objectives.

1) I consolidated all the available literature to find records of presence of *L. nivalis* at different sites and dates, and georeferenced as best as possible all those sites to create a map for the revised recovery plan.
2) I developed a refined species distribution model using NetLogo to determine movement of *l. nivalis* to focus surveys and help document new records of the presence of the species.

Leptonycteris nivalis has a limited number of maternity caves in the north, which are critical for its survival. My hypothesis is that there are several regions in the Carmen Mountains of Mexico where there is a high probability of the presence of new caves. Our distribution models will allow us to focus efforts for future surveys of this region to find and protect these caves.

CHAPTER II

METHODS

I reviewed historical literature and surveyed current researchers working on *L. nivalis* for unpublished data on the locality of this species. Data collected on observation of this species were georeferenced and each point locality related to a suite of local climatic variables and other environmental variables that are spatially referenced (https://lta.cr.usgs.gov/HYDRO1K , Hijmans et al. 2005). I used the software package NetLogo to model the species distribution and movement in relation to the environmental variables (Wilensky 1999). As this builds upon previous research, I followed exactly the detailed methods as outlined in Gomez-Ruiz and Lacher (2017).

Species Distribution Modeling

Localities of *L. nivalis* were accumulated through literature and museum specimen data. To develop the species distribution model, I created a database with the *L. nivalis* localities from all available literature, then removed duplicates and coded the data for transfer into NetLogo. The study area selected was based on prior reports of *L. nivalis* presence, localities that encompass the migratory route, and presence of agave species richness data. *L. nivalis* localities were removed from the model if they were outside of the study area, or in areas not surveyed for agave by Gomez-Ruiz and Lacher 2017. Then, cave points were selected based prior reports as a large roosting site for *L. nivalis.* The cave site must be present along the endangered pollination corridor and exist in the southern, central, or northern extent of the study area, with the cave elevation greater than 1,000 m for roosting, breeding, or maternity use. Data on habitat suitability were based on the presence of agave modelling and how many different species were represented in a 1 km^2 area (Gomez-Ruiz and Lacher 2017).

Migratory Route Modeling

Species distribution modeling (SDM) was used to find potential caves. Caves along the migratory route are essential for roosting and stop over sites. The optimal route was analyzed according to historical *L. nivalis* presence associated with agave richness. Inclusion of known roosting sites and distance between known caves were also considered when directing the most favorable pathway. The *L. nivalis* localities provide information about where the bat can move to using roosting sites along the way, the agave richness value utilized by the species, and a possible migration path the colonies are following. Agave species *A. americana, A. asperrima, A. palmeri*, *A. gentry*, *A. parryi*, *A. inaequidens, A. salmiana, A. havardiana, A. horrida* were used in the analysis.

CHAPTER III

RESULTS

L. nivalis Localities

After accumulating the localities from literature and museum data, there were 91 non-duplicate locations for use in the spatial distribution model (Table 1). Of these points, 80 were used for modeling the potential migratory path. The cave selections included Emory Peak, Cuevo del Rosillo, Cuevo del Infierno, and Cuevo del Diablo (Table 2).

On the species distribution model (Figure 1), the majority of the localities were within the agave richness value of 1 or more, and the points display a tendency to follow where the Sierra Madre Oriental mountains are located. Indicated by the red circle, 2 localities are present in the Carmen Mountains region of Mexico, which is part of the northern-most reach of Sierra Madre Oriental and where I predicted a conservation site for a maternity roost may be present.

The data available provides a possible migratory route of *L. nivalis* by following the localities, agave species richness, and roosting sites. Utilizing the information, the points were connected by a series of lines to represent the path (Figure 1). The route contains large sections without a locality presence between records. To prevent estimating a direction without significant data, the most likely points were connected without additional correction. Comparing the route along with topography of Sierra Madre Oriental mountains, there is a correlation in direction traveled and mountain location.

Table 1. Complete list of georeferenced localities from available literature and museum data.

Species	Latitude	Longitude	Species	Latitude	Longitude
L. nivalis	20.393488	-99.016877	*L. nivalis*	24.265028	-103.348149
L. nivalis	20.578552	-98.765624	*L. nivalis*	23.217164	-103.371548
L. nivalis	20.600045	-98.77613	*L. nivalis*	23.0997576	-104.6478644
L. nivalis	18.834565	-99.581481	*L. nivalis*	25.3614912	-100.7490413
L. nivalis	19.613048	-100.505483	*L. nivalis*	22.157393	-100.998011
L. nivalis	18.9997007	-99.259622	*L. nivalis*	22.81007	-100.457398
L. nivalis	19.191428	-99.006229	*L. nivalis*	32.916485	-107.521977
L. nivalis	18.4376835	-99.923794	*L. nivalis*	27.00833333	-102.0916667
L. nivalis	18.966201	-98.793558	*L. nivalis*	21.939635	-102.79764
L. nivalis	18.9807603	-99.2726515	*L. nivalis*	22.5162811	-100.9904991
L. nivalis	19.188068	-100.118436	*L. nivalis*	23.7008693	-99.7666702
L. nivalis	18.323841	-97.476594	*L. nivalis*	23.7113586	-100.2318517
L. nivalis	21.1345501	-99.625351	*L. nivalis*	32.0565689	-108.6276741
L. nivalis	20.645935	-98.664223	*L. nivalis*	31.362578	-109.031733
L. nivalis	20.0872231	-98.3794479	*L. nivalis*	29.040794	-102.565095
L. nivalis	20.7666664	-104.8666649	*L. nivalis*	28.90263601	-102.547057
L. nivalis	18.803164	-99.651239	*L. nivalis*	25.31703	-100.21428
L. nivalis	19.810318	-100.891804	*L. nivalis*	26.52394703	-101.804465
L. nivalis	22.2666664	-104.5833321	*L. nivalis*	25.3746666	-103.5323333
L. nivalis	21.1518357	-104.4863823	*L. nivalis*	23.46516666	-104.367
L. nivalis	18.99638889	-98.93944444	*L. nivalis*	25.1767	-107.27
L. nivalis	19.64	-98.49777778	*L. nivalis*	18.9757	-99.149
L. nivalis	18.46416667	-98.55222222	*L. nivalis*	19.0059	-99.054
L. nivalis	20.38888889	-98.97277778	*L. nivalis*	29.266	-103.3
L. nivalis	24.54854443	-101.4502333	*L. nivalis*	24.8242	-100.08
L. nivalis	24.20856385	-101.1568489	*L. nivalis*	25.2778	-100.82
L. nivalis	24.58013225	-101.4889775	*L. nivalis*	19.0153	-99.066
L. nivalis	24.1689019	-101.1493823	*L. nivalis*	25.2923	-100.82
L. nivalis	24.868333	-100.231667	*L. nivalis*	26.2525	-99.801
L. nivalis	24.07	-99.96	*L. nivalis*	24.0979	-99.815
L. nivalis	23.99	-99.76	*L. nivalis*	23.9885	-99.767

Table 1. (Continued)

Species	Latitude	Longitude	Species	Latitude	Longitude
L. nivalis	29.2502	-103.25	*L. nivalis*	18.4677773	-99.9191666
L. nivalis	18.9833	-99.1	*L. nivalis*	18.4058342	-99.8730545
L. nivalis	21.5752	-102.97	*L. nivalis*	18.4333324	-99.8730545
L. nivalis	18.9833	-99.054	*L. nivalis*	18.3122215	-99.8730545
L. nivalis	23.1514	-104.58	*L. nivalis*	16.625	-97.8472214
L. nivalis	29.9829	-104.45	*L. nivalis*	18.9744453	-99.2488861
L. nivalis	27.0377007	-109.0102005	*L. nivalis*	18.4058342	-99.8730545
L. nivalis	25.2709923	-100.8178635	*L. nivalis*	19.083889	-96.1147232
L. nivalis	18.4447231	-99.921669	*L. nivalis*	18.2766666	-99.9727783
L. nivalis	19.0366669	-99.0425034	*L. nivalis*	18.3286114	-97.4469452
L. nivalis	20.2903633	-102.7095337	*L. nivalis*	18.7411118	-99.1794434
L. nivalis	26.6647015	-103.7438431	*L. nivalis*	18.3122215	-99.8730545
L. nivalis	15.8238888	-97.0280533	*L. nivalis*	25.2248	-103.3194
L. nivalis	19.0588894	-96.1547241	*L. nivalis*	23.2791	-104.2202
L. nivalis	19.1008339	-96.1072235			

Table 2. Sites for modeling use are El Diablo, El Infierno, El Rosillo, and Emory Peak caves.

Cave	Latitude	Longitude
El Diablo	19.188068	-100.118436
El Infierno	25.31703	-100.21428
El Rosillo	26.52394703	-101.804465
Emory Peak	29.144558	-103.181879

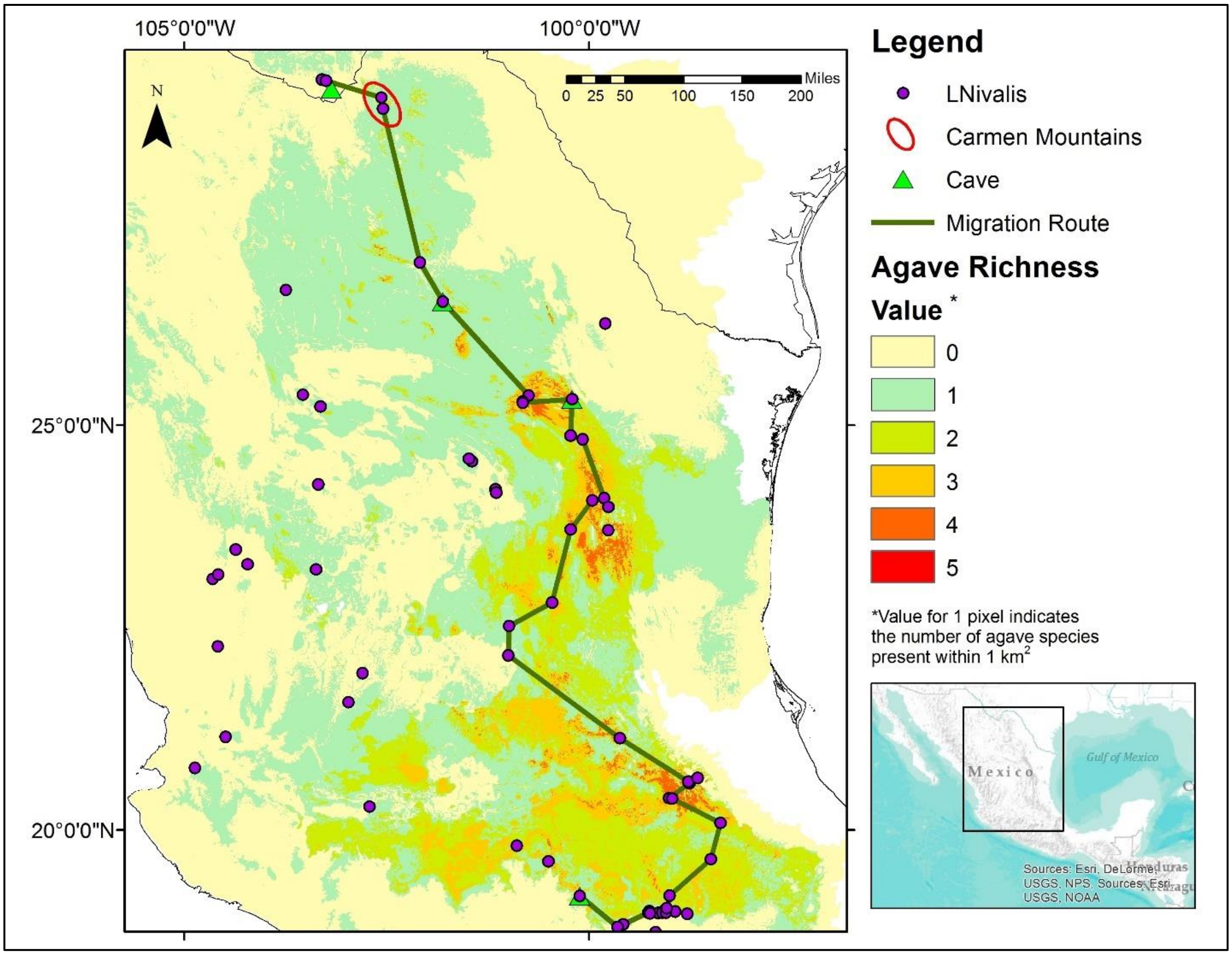

Figure 1. Species distribution model of *L. nivalis* in the selected study area, incorporating agave richness. Circled in red is the Carmen Mountains, where there may be a roosting site for priority conservation. The migratory path is modeled utilizing these properties as well as roosting sites.

Agave Richness

The agave richness values correlate with the topography of Sierra Madre Oriental (Figure 2). Taking a closer look at the agave species richness model, there are patches of habitat without any of the 9 agave species (*A. americana, A. asperrima, A. palmeri, A. gentry, A. parryi, A. inaequidens, A. salmiana, A. havardiana, A. horrida*) that *L. nivalis* feeds on and cross-pollinates.

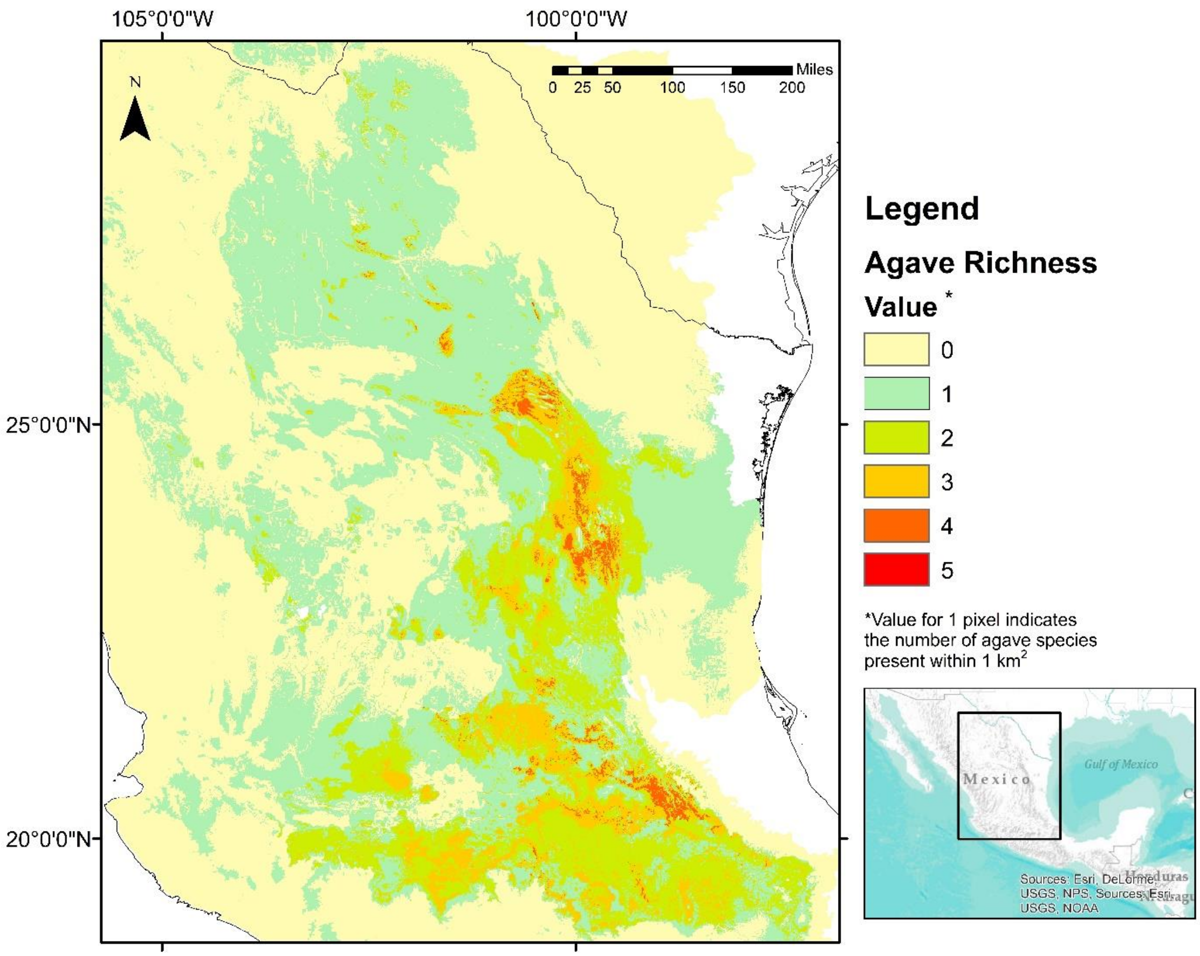

Figure 2. Agave species richness map provided by Gomez-Ruiz and Lacher (2017). The map is based on the 9 species of agave that *L. nivalis* consumes, disregarding monocultures.

CHAPTER IV

DISCUSSION

The optimal migratory route follows the highest agave species richness, presence of *L. nivalis* localities, and known roosting sites, permitting the migratory route model to provide a guideline for discovering stopover sites. This information may be used by biologists to study the adjacent areas of where the bats may be present. In future studies, time of year associated with the colony migration is necessary to efficiently use research resources and to accurately understand the presence/absence of the species within a location. Areas may be explored to discover potential roosting sites at an elevation of 1,000 m or greater before the colony arrives. This permits biologists to survey a newly discovered cave site along the route without disturbing the target bat species.

Position analysis permits conservation management perceptiveness; therefore the model can be used to highlight additional priority conservation sites for an advanced understanding of the migration, additional maternity roosts, and stop-over site locations (Wall et al. 2014). The Carmen Mountains display various presence locations of the Mexican long-nosed bat and this implies a maternity roosting site for priority conservation. Additionally, the model also highlights other sites of conservation priority. These sites include areas of high agave species richness along the migratory route with several adjacent *L. nivalis* localities displayed in Figure 1. The correlation between the topography, agave species richness, and bat localities is logical due to the roosting site requirements of a cave at an elevation above 1,000 m and the forage value associated with the variety of agaves.

Considerations and Limitations

There are several limitations to consider for this project. The localities utilized were not analyzed with dates associated, potentially causing a misunderstanding in the current versus historical migratory route or cave utilization. To reduce the complexity of the model, time of year the locality was recorded was not analyzed. For future field work utilizing the migratory route model as a guideline for priority conservation sites, the dates are required for an efficient use of research resources. However, research on the timing of the agave bloom and bat migration, as well as their ranges must also be conducted in the field to determine if there is a shift due to climate change.

Chavez-Ramirez and Wehtje (2012) notes range distribution shifts in avian species and mammals resulting from a warming climate, suggesting that this is a potential issue for these bat species. A northern range shift has previously been predicted in common vampire bats (Mistry and Moreno-Valdez 2008). Localities recorded away from the optimal migratory route were not analyzed due to the study focusing on agaves for the genetic diversity and conservation sites for migratory route completion.

The bats found in areas without agave presence are potentially feeding on other yuccas or may have been misidentified as *L. nivalis* instead of the close relatives, the lesser long-nosed bat (*Leptonycteris yerbabuenae*) or the southern long-nosed bat (*Leptonycteris curasoae*) by biologists. Additionally, though *L. nivalis* localities were accumulated through a variety of sources (See Locations Cited section), they may be biased due to the difficulty traveling to remote sites in the mountains. As additional literature is released and museum specimen are documented with georeferenced data, the localities should be included in new models.

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