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Mexican Fauna in the Anthropocene

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Foreword

The Anthropocene is known as the geological epoch whose main characteristics of change are the results of human activity, from the origin of agriculture to the present day, and we do not know for how much longer this perturbation can no longer be sustainable for the human race. It is a time marked by technological advances that have generated huge imbalances in ecosystems, fragmenting, polluting, and destroying them. Human intelligence and its capacity to modify the environment are outstanding, but this capacity has not been accompanied by an awareness of the long-term consequences of these modifications. In the same way that we build cities, we annihilate natural spaces and extirpate plants and animals. We have polluted the oceans, cleared much of our forests, caused faunal extinction (defaunation), and in general depleted the natural resources. All this started with apparently simple and innocuous actions by a very small human population a few thousand years ago, which has been accelerated in the last hundred years, putting all life on Earth at risk.

Some of the consequences are the drastic environmental imbalances in natural ecosystems, global warming, and the effects of pollution by agrochemicals, plastics, and microplastics. The present great threats to biodiversity include an increasing number of species in danger of extinction combined with the decline in the abundance of populations of many animals due to the loss of their habitats. This represents by some the sixth great mass extinction event of the planet. Significant decreases in abundance have been detected in many animal groups. Besides the well-known threats to large vertebrates, now even many small-sized fauna, such as insects and other arthropods, are recognized as threatened. Their reduction of populations causes important effects on ecosystem functions, such as pollination and the reduction of population control of pest species. Whole ecosystems are being threatened, such as coral reefs and tropical forests. Additionally, in marine ecosystems, decreases have been observed in useful species for man and for the maintenance of ecosystems, such as sharks and many fish species. For birds, losses of 30% in their abundance have been estimated in the last 50 years, and the impact on ecosystems is clearly significant but difficult to determine.

The present book has 27 chapters written by national and international authors examining the actual state, threats, and future of Mexican fauna in the face of the various and current ecological, social, and economic threats unique to the country. It presents not only a panorama of the present state and threats to distinct faunal taxonomic groups, but their associated ecosystems and processes associated with human impacts; a work that elucidates the details and magnitude of the problems and provides guidelines to carry out actions to reduce the consequences for the fauna of Mexico.

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Chapter 11
Mexican Bats: Threats in the Anthropocene

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11.1 Introduction

Bats are one of the most diverse groups of mammals in the world. This diversity is, likewise, accompanied by a wide number of trophic guilds, varied morphologies, behaviors, and use of specific habitats and a great variety of ecosystems (Fig. 11.1). Due to their capacity of using different habitats, they have a plethora of reported biotic interactions, such as pollination, seed dispersion, parasitism, and predation (Jones et al. 2009; Fleming et al. 2020). These biotic interactions are related to ecosystem functions resulting in the provision of important ecosystem services (Díaz

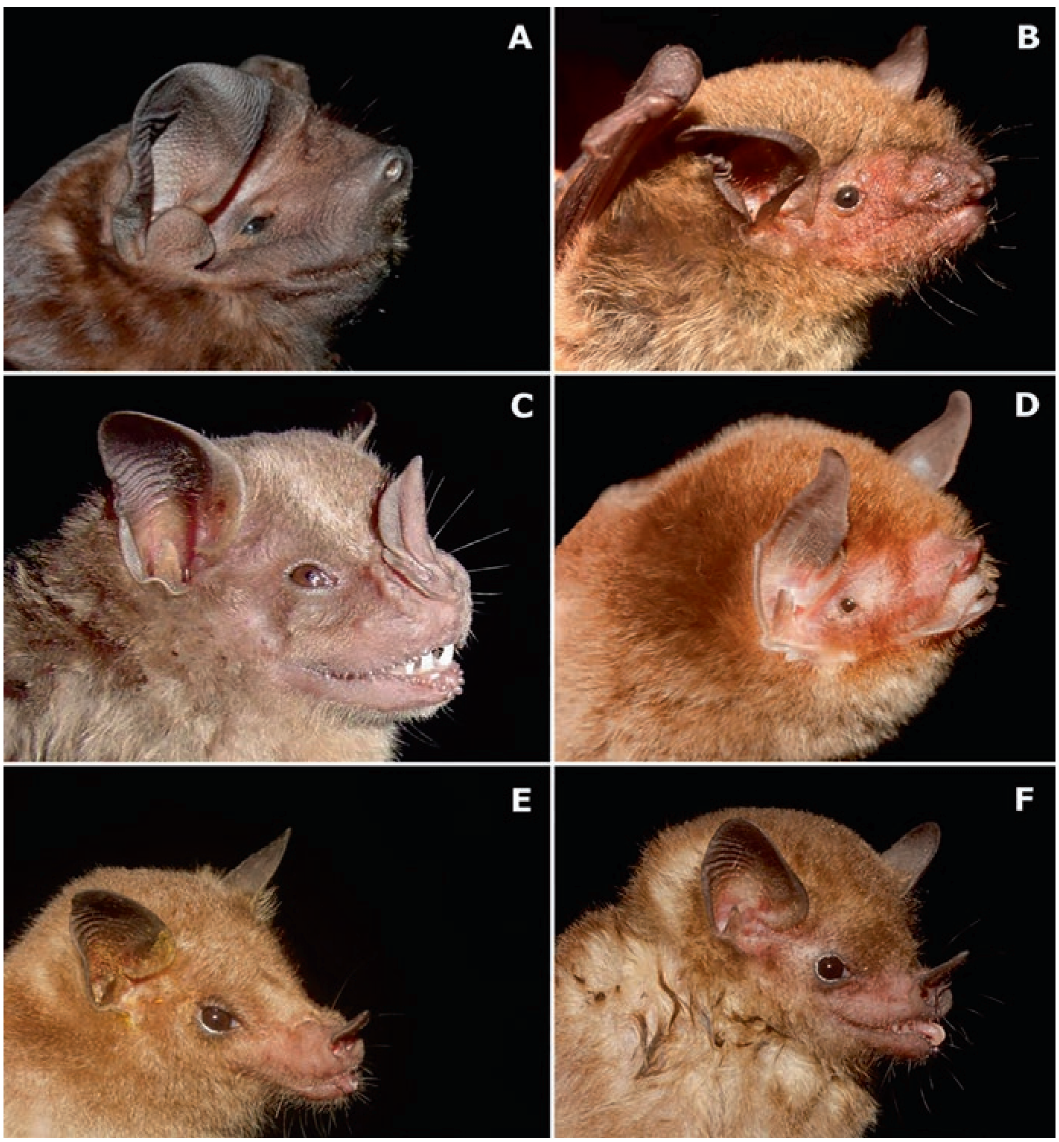

Fig. 11.1 Some species of common bats in Mexico's cities. (**a**) *Molossus nigricans* (insectivorous), (**b**) *Myotis velifer* (insectivorous), (**c**) *Artibeus jamaicensis* (frugivorous), (**d**) *Pteronotus fulvus* (insectivorous), (**e**) *Leptonycteris yerbabuenae* (nectarivorous), (**f**) *Glossophaga mutica* (phytophagous). (Photos by: Juan Cruzado Cortés (**a**, **b**, **d**, **e**, **f**) and Cristina Mac Swiney (**c**))

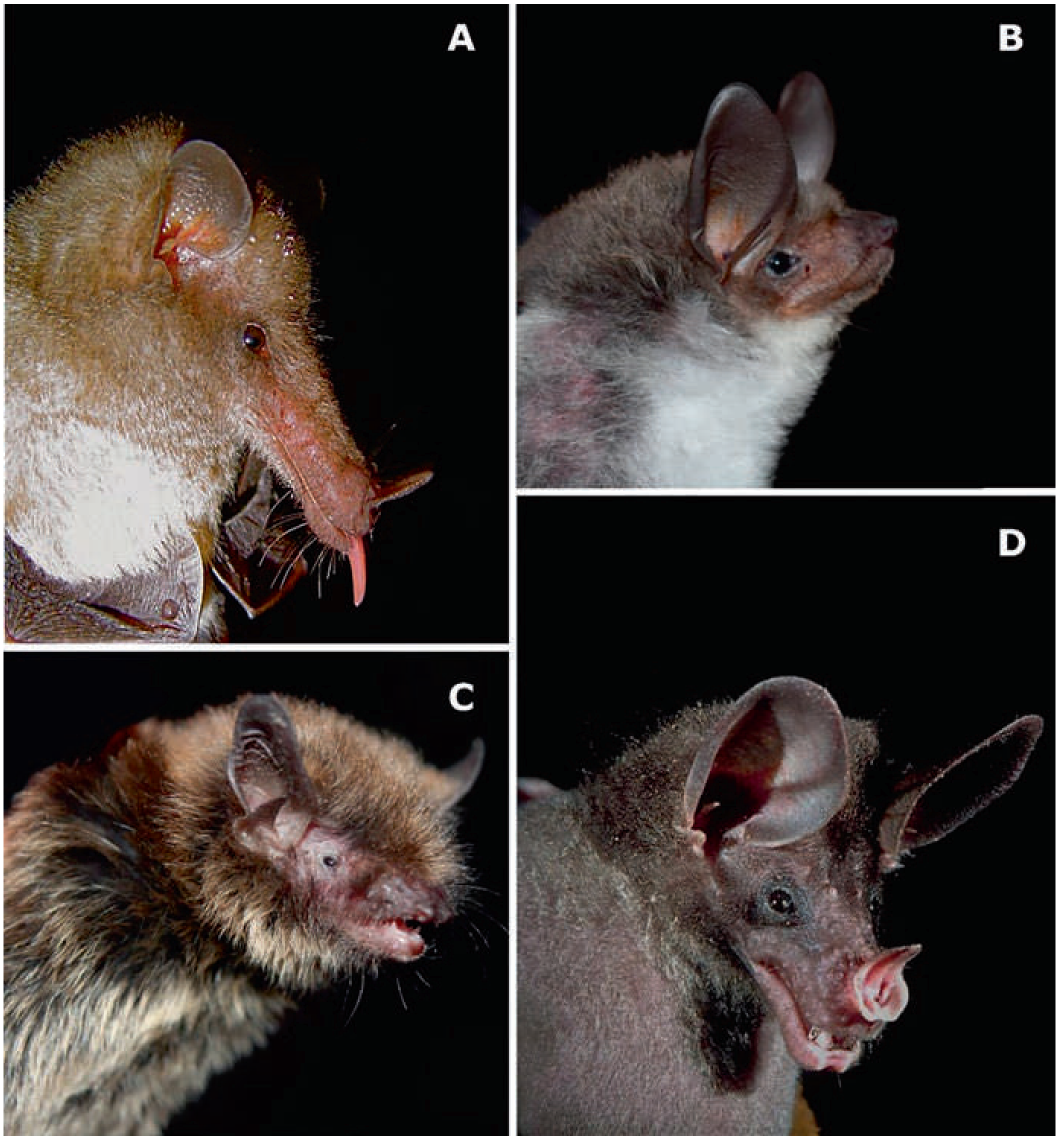

Fig. 11.2 Bat species of Mexico categorized in extinction risk by Mexican government. (**a**) *Musonycteris harrisoni*, (**b**) *Myotis vivesi*, (**c**) *Myotis planiceps* and (**d**) *Vampyrum spectrum*. (Photo by Romeo A. Saldaña-Vázquez (**a**), Edgar G. Gutierrez (**b**), Juan Cruzado (**c**), y Frank Clarke (**d**))

et al. 2018). Some of the most important bat contributions to humans are plant pollination, insect population control, and seed dispersal (Maas et al. 2016; Ratto et al. 2018; Saldaña-Vázquez et al. 2019). For this reason, the well-being of many human populations is highly related with the stability of bat species populations.

Mexico holds the world's fifth place in bat species richness, with nearly 140 bat species in 8 families (Wilson and Mittermeier 2019). With this high richness, it is not surprising that an important number of Mexican species are threatened. According to the Mexican Official Standard for Threatened Species NOM-059-SEMARNAT-2010, there are four bat species in extinction risk; these are

Musonycteris harrisoni, *Vampyrum spectrum*, *Myotis planiceps*, and *Myotis vivesi*. This risk category is related to their reduced distribution size and their specific ecological demands such as specialized diet or specialized habitat. For example, *Musonycteris harrisoni* is a hyper-specialized nectarivore that has a small distribution and only occurs in six out of the 32 states of Mexico (Fig. 11.2). This species is highly sensitive to anthropogenic changes and found to have reduced feeding activities in fragmented forests when compared to continuous forests (Tellez and Ortega 1999; Stoner et al. 2002). Moreover, there are 34 more species with some degree of risk, as the result of low population densities or the susceptibility to rapid population declines due to human activities. The origin of risks to the species of Mexican bats is related to the geologic epoch that we are now experiencing, the Anthropocene. The Anthropocene is defined as the geological moment that humanity is currently experiencing on planet Earth (Crutzen 2006). This is characterized by the global environmental change of human origin which began with the industrial activities, and which has left a chemical signature in the deep sediments of the soil and the environment. The main indicators of the beginning of this epoch are found in the increase in global temperature of more than one degree and in the increase in atmospheric carbon dioxide above 300 parts per million (Zalasiewicz et al. 2008).

Previous studies have discussed the principal threats derived from the Anthropocene that affect bat populations (Table 11.1). However, there is no present research that examines the prevalence of these threats in Mexico, and how the country's bats will respond within the unique and complex environmental characteristics of the territory. Therefore, the objective of this chapter was to conduct a revision of the knowledge of the effects of human activities of the Anthropocene epoch on Mexican bat diversity and ecology. In addition, we predict some responses that are expected based on previous studies and our knowledge about Mexican bat ecology (Table 11.1). To achieve this goal, we designed a literature review protocol (see below) that may be used in future revisions of these topics for Mexican bats.

11.2 Material and Methods

We made 11 literature searches (Table 11.2) based on the 11 bat threats (see Table 11.1) related to the Anthropocene. We used Google Scholar (GS) and Web of Science (WoS) as literature research engine and literature repository, respectively. Searches were carried out in March of 2021, and they were not limited by year or publication type. In Table 11.2, we summarize the number of documents found by search, keywords, search engine, or repository. Additionally, we made secondary searches in documents resulting from the searches and in our personal literature libraries.

The document screening was carried out by one or two of the authors; the study eligibility criteria were as follows: (1) study was done with bats; (2) study has been done in Mexico; (3) the studies are related to bat Anthropocene treats. Documents that accomplished the eligibility criteria were then selected for this narrative review.

Table 11.1 Anthropocene bat threats reported in the literature and the expected response of Mexican bats

Threat	General response	Response expected for Mexico	References
Habitat fragmentation	Differences in species richness, evenness, abundance, and assemblage composition between interior, edge, and matrix habitats would decrease with fragment size.	Differences in phyllostomid species richness, evenness, abundance, and assemblage composition between continuous forest and fragments decrease with fragment size, unknown response for other families.	18
Agriculture	Species richness, functional and taxonomic diversity decrease with increasing land use intensity, and disturbance. Frugivore, nectarivore, and omnivore bats are positively associated with agroforestry crops. In contrast, monocultures retain only sanguivores and omnivores bats.	Frugivorous and nectarivorous bats are positively associated with agroforestry crops or agroecosystems.	19, 20, 24
Cattle ranching	Species richness, functional, and taxonomic diversity increase with decreasing land use intensity and disturbance. Large size frugivores, aerial insectivores, and omnivores are more frequently recorded in cattle-ranching areas than carnivores, gleaning insectivores, nectarivores, small size frugivores, sanguivores.	Frugivorous and sanguivorous bats are the most frequent in cattle-ranching areas.	19, 21, 26
Urbanization	Species richness, functional, and taxonomic diversity increase with decreasing land use intensity and disturbance. Bat species that forage in open and edge space and have flexible roosting strategies are more frequently recorded in urban areas.	Species of the Molossidae family and some vespertilionids that feed near lights have higher activity in urban sites than other insectivore’s families, but unknown response for other families and guilds.	19, 22, 27
Air pollution	Reduction of insectivorous bat activity in sites with higher air pollution, there is not a mechanism.	Reduction of insectivorous bat activity, unknown response for other guilds.	1, 2
Water pollution	Insectivorous bats are little affected by water pollution because insects that bats consume tolerate water pollution.	Insectivorous bats do not reduce their activity with water pollution, unknown response for other guilds.	3

(continued)

Table 11.1 (continued)

Threat	General response	Response expected for Mexico	References
Sound pollution	Reduction of insectivorous bat activity in higher sound polluted sites, because sound pollution interferes with echolocation behavior of bats.	Reduction of insectivorous bat activity of bats that catch flying insects, neutral response for other guilds.	4
Light pollution	Bats with low flight speed reduce their activity in light-polluted sites, due to the increase of predation risk and low prey capture success.	Reduction of activity of low flight speed bats and bats that forage in highly cluttered space, neutral response for other guilds.	4, 5, 6
Climate change	Changes in precipitation and increasing temperatures due to climate change will affect global water availability, especially in arid regions. Species that use climatic cues to dictate the timing of foraging, breeding, hibernation, parturition, or migration are expected to respond more immediately to climate change.	Increased drought in arid regions of Mexico due to climate change may affect insectivorous bats‘reproductive success as lactating females require a significant water intake. Migratory nectar-feeding bats in Mexico rely on seasonality of flowering plants to complete their annual migratory and reproductive cycle and are vulnerable to potential effects of climate change on plant phenology and distribution.	7, 8, 28
Human–bat conflicts	Intentional killing of bats is higher in locations where (1) large bats are used for food or medicine, (2) people have negative perceptions of bats due to cultural beliefs, (3) bats live near humans, (4) bats are believed to consume fruits crops, and (5) bats are linked to endemic zoonotic diseases.	Intentional killing of bats is more common in small- to medium-size urban locations and in tropical cattle-ranching areas.	23, 25

(continued)

Table 11.1 (continued)

Threat	General response	Response expected for Mexico	References
Human infrastructure	Wind energy facilities represent a threat to bat populations, especially, but not exclusively, for migratory and open-space foraging species, due to the high rate of mortality caused by direct collision or barotrauma.	Wind energy facilities are a considerable threat for Mexican bats species, due to the high number of migratory genera (*Lasiurus*, *Tadarida*, *Leptonycteris*) and open-space foraging species present in the country.	9, 10, 11
	Road and railway networks may affect bat population stability because they can affect the interpopulation connectivity and can cause a high number of fatal collisions with motor vehicles.	Mexican bat populations are affected by road and railway networks, especially in tropical region where large colonies are present and urban development is higher.	12, 13
	Buildings may be both beneficial and detrimental for bat species. Beneficial when building offers foraging sites, diurnal and/or maternity roosts, hibernacula, and opportunity for geographic expansion. Detrimental when smooth surfaces of buildings (i.e., glass windows) interfere with the echo-sound pathway of bat echolocation calls (acoustic mirror) and increase the risk of collision.	Bridges and other buildings are used for bats such as foraging sites, diurnal, and/or maternity roost and hibernacula. Skyscrapers in cities and other buildings with many smooth surfaces represent a threat for bats. In order of urbanization degree, skyscrapers are more abundant in bigger cities; therefore, suburban areas and urban-transition zones are more susceptible to holding more beneficial human-made structures for bats.	14, 15, 16, 17

The general response was based on the following references: (1) Rachwald et al. (2004); (2) Rachwald (2019); (3) Salvarina (2016); (4) Moretto and Francis (2017); (5) Lewanzik and Voigt (2014) (6) Rowse et al. (2016); (7) Adams and Hayes (2021); (8) Sherwin et al. (2013); (9) Arnett et al. (2016); (10) Grodsky et al. (2011); (11) Wang and Wang (2015); (12) Altringham and Kerth (2016); (13) Fensome and Mathews (2016); (14) Ancillotto et al. (2016); (15) Greif et al. (2017); (16) Russo and Ancillotto (2015); (17) Voigt et al. (2016); (18) Rocha et al. (2017); (19) Farneda et al. (2020); (20) García-Morales et al. (2013); (21) Gonçalves et al. (2017); (22) Jung and Threlfall (2018); (23) Frick et al. (2020) (24) Castro-Luna and Galindo-González (2012); (25) O'Shea et al. (2016); (26) MacSwiney et al. (2007); (27) Rodríguez-Aguilar et al. (2017); (28) Gómez-Ruiz and Lacher Jr (2019)

Table 11.2 Number of documents found by search, keywords, search engine, or repository

ID	Keywords	Spanish	English	WoS	GS
1	Habitat fragmentation	Topic: (Chiroptera OR murciélagos) AND Topic: (bosque continuo OR fragmentos OR matriz OR paisaje) AND Topic: (diversidad OR dieta OR gremios OR abundancia) AND Topic: (México OR Norteamérica OR Neotrópico)	Topic: (Chiroptera OR Bats) AND Topic: (continuous forest OR fragments OR patches OR matrix OR landscape) AND Topic: (diversity OR diet OR guild OR abundance) AND Topic: (Mexico OR North America OR Neotropics)	91	200
2	Agriculture	Topic: (Chiroptera OR murciélagos) AND Topic: (agroecosistemas OR monocultivos) AND Topic: (gremios OR riqueza OR diversidad OR dieta OR abundancia) AND Topic: (México OR Norteamérica OR Neotrópico)	Topic: (Chiroptera OR bats) AND Topic: (agroecosystems OR monocultures) AND Topic: (diet OR guild OR richness OR diversity OR abundance) AND Topic: (Mexico OR North America OR Neotropics)	9	199
3	Cattle ranching	Topic: (Chiroptera OR murciélagos) AND Topic: (pastizales inducidos OR ganadería) AND Topic: (riqueza OR diversidad OR dieta OR gremios OR abundancia) AND Topic: (México OR Norteamérica OR Neotrópico)	Topic: (Chiroptera OR Bats) AND Topic: (induced pasturelands OR grasslands OR cattle ranching) AND Topic: (richness OR diversity OR diet OR guild OR abundance) AND Topic: (Mexico OR North America OR Neotropics)	7	199

4	Urbanization	Topic: (Chiroptera OR murciélagos) AND Topic: (Urbanización OR ciudades) AND Topic: (actividad OR riqueza OR diversidad OR abundancia) AND Topic: (México OR Norteamérica OR Neotrópico)	Topic: (Chiroptera OR Bats) AND Topic: (urbanization OR cities) AND Topic: (activity OR richness OR abundance) AND Topic: (Mexico OR North America OR Neotropics)	15	200
5	Air pollution	Topic: (Chiropteta OR murciélagos) AND Topic: (contaminación del aire OR OR metales pesados OR polvo) AND Topic: (actividad OR diversidad OR riqueza OR abundancia) AND Topic: (México OR Norte América OR Neotrópico)	Topic: (Chiroptera OR bats) AND Topic: (air pollution OR heavy metals OR dust) AND Topic: (activity OR richness OR diversity OR abundance) AND Topic: (Mexico OR North America OR Neotropics)	2	200
6	Water pollution	Topic: (Chiroptera OR murciélagos) AND Topic: (eutroficación OR drenaje OR nitrógeno OR toxinas OR basura) AND Topic: (diversidad OR riqueza OR actividad Or abundancia) AND Topic: (México OR Norteamerica OR Neotrópico)	Topic: (Chiroptera OR bats) AND Topic: (eutrophication OR sewer system OR nitrogen levels OR toxines OR waste OR sewage) AND Topic: (diversity OR richness OR activity OR abundance) AND Topic: (Mexico OR North America OR Neotropics)	3	200

(continued)

Table 11.2 (continued)

ID	Keywords	Spanish	English	WoS	GS
7	Sound pollution	Topic: (Chiroptera OR murciélagos) AND Topic: (contaminación por ruido OR ruido urbano) AND Topic: (diversidad OR riqueza OR actividad OR abundancia) AND Topic: (México OR Norteamerica OR Neotrópico)	Topic: (Chiroptera OR bats) AND Topic: (noise pollution OR urban noise) AND Topic: (diversity OR richness OR activity OR abundance) AND Topic: (Mexico OR North America OR Neotropics)	0	200
8	Light pollution	Topic: (Chiroptera OR murciélagos) AND Topic: (luz de noche OR luz antropogén* OR contaminación lumínica OR lámpar*, bruma de cielo OR alumbrado público) AND Topic: (diversidad, riqueza, actividad OR abundancia) AND Topic: (México, Norteamérica, Neotrópico)	Topic (Chiroptera OR bats) AND Topic: (light at nigh* OR anthropogen* ligh OR urban light* OR light pollution* OR night-light* OR streetlight* OR streetlamp* OR skyglow*) AND Topic: (diversity OR richness OR abundance OR activity) AND Topic: (Mexico OR Neotropics OR North America)	5	100
9	Climate change	Topic: (Chiroptera OR murciélagos) AND Topic: (sequía OR fenología OR agua OR OR cambio climático) AND Topic (reproducción OR planta-polinizador) AND Topic: (México OR Norteamérica OR Neotrópico)	Topic: (Chiroptera OR bats) AND Topic: (drought OR climate change OR water OR phenology) AND Topic: (lactation OR reproduction OR plant-pollinator) AND Topic: (Mexico OR North America OR Neotropics)	33	200

10	Human–bat conflicts	Topic: (Chiroptera OR murciélagos) AND Topic: (sacrificio OR control poblacional OR erradicación OR exclusión OR guano OR histoplasm* OR rabia) AND Topic: (México OR Norteamérica OR Neotrópicos)	Topic: (Chiroptera OR bats) AND Topic: (culling OR population control OR eradication OR exclusion OR guano OR histoplasm* OR rabies) AND Topic: (Mexico OR North America OR Neotropics)	240	200
11	Human infrastructure	Topic: (Chiroptera OR murciélago) AND Topic: (puente* OR carretera* OR aerogenerador* OR colisión*) AND Topic (México OR Norteamérica OR Neotrópico)	Topic: (Chiroptera OR bats) AND Topic: (bridge* OR road* OR wind turbine* OR collision*) AND Topic (Mexico OR North America OR Neotropics)	69	199

The Google Scholar (GS) and Web of Science (WoS) search engine and repository were used. The parentheses in the keywords section indicate the group of words used in the WoS search engine. From GS results, we only revised the first 30 pages, where more documents related with the topic appeared (Haddaway et al. 2015). The search period in WoS repository was 1980–2021. ID is the identification number of the search

11.3 Results and Discussion

We revised 2571 documents, of which only 68 studies contained empirical data about the effect of anthropic activities on bat ecology. The Anthropocene threat of bats most studied in Mexico was the effect of habitat fragmentation and deforestation on bat diversity, followed by human infrastructure and effects of agriculture on bat diversity and ecology (Table 11.3). These human activities are related to land use change and potential reduction of bat habitat. Other interesting and important phenomena related with human activities such as pollution, or climate change were less studied for Mexican bats.

11.3.1 Effect of Land Use Change on Mexican Bats

Many investigations have been carried out in Mexico to evaluate the response of bats to land use change. These studies compare some attributes of the bat community present in continuous forest or forest fragments with other types of land use. Coffee plantations with different management intensity have been widely studied in different parts of the country, especially in the states of Veracruz and Chiapas (Sosa et al. 2008; Saldaña-Vázquez et al. 2010; Williams-Guillén and Perfecto 2010). Other types of land use studied were citrus plantations (Estrada et al. 2004), mango plantations (Madrid-López et al. 2020), agricultural lands (Briones-Salas et al. 2019), pastures (Estrada et al. 2004; MacSwiney et al. 2007), and urban areas (Avila-Flores and Fenton 2005; Rodríguez-Aguilar et al. 2017). Most of the studies have been carried out in the tropical zone of the country, still leaving gaps of information for temperate and arid zones. Furthermore, a large part of the research performed has a bias toward the Phyllostomidae family, since only mist-nets at ground

Table 11.3 Number of studies selected to make the narrative review of the effects of Anthropocene over bat ecology

Human activity or Anthropocene phenomena	No. of studies selected
Habitat fragmentation or deforestation	21
Agriculture	11
Cattle ranching	4
Urbanization	5
Air pollution	1
Water pollution	0
Sound pollution	2
Light pollution	2
Climate change	2
Human–bat conflicts	7
Human infrastructure	13

level were used to monitor the bat community, which limits the knowledge about the response of other bat families to land use change. In urban areas, acoustic or mist-net monitoring has been used separately (Avila-Flores and Fenton 2005; García-Méndez et al. 2014); few studies utilized both methods (Medina-Cruz 2019), emphasizing the need of use complementary sampling methods to better understand the response of bat community to their habitat modification.

Mexican bat species richness and composition of different guilds, such as frugivores or insectivores, were statistically similar between forest and polycultures (coffee, mango), monocultures, pastures, or urban areas of the same region (Pineda et al. 2005; MacSwiney et al. 2007; Rodríguez-Aguilar et al. 2017; Briones-Salas et al. 2019; Madrid-López et al. 2020). Although a greater reduction of species richness in urban areas or in highly managed plantations woud be expected than in less managed ones, this trend was observed in very few cases (Avila-Flores and Fenton 2005; Estrada et al. 2006). On the other hand, there is not a clear pattern about the effect of land use change on the relative abundance of Mexican bats. Some studies report a higher abundance or bat activity in forests compared to urban or agriculture land use (Sosa et al. 2008; Saldaña-Vázquez et al. 2010; Briones-Salas et al. 2019), but others report a higher relative abundance in plantations with high or low management intensity, especially for phyllostomids frugivorous bats (Williams-Guillén and Perfecto 2010, 2011; Mendoza-Saénz and Horváth 2013; Madrid-López et al. 2020). These contradictory results are related to the high vagility of bats and the ability for some species to use well-preserved habitats immersed in a mosaic of various types of land use (Moreno and Halffter 2001), or which they could obtain important resources (food, shelter, corridors) in some plantations with high vegetation complexity such as shaded coffee or mango (Cortés-Delgado and Sosa 2014; Hernández-Montero et al. 2015; Lavariega and Briones-Salas 2016; Vleut et al. 2019).

Landscape ecology studies of Mexican bat diversity have clarified these contradictory results of the effects of land use change over Mexican bat relative abundance. It has been documented that some landscape elements such as riparian corridors, in forest or pasture landscape matrices, maintain higher diversity of bat guilds and species (de la Peña-Cuéllar et al. 2015). Even isolated trees may have a role similar to that of riparian corridors in maintaining bat diversity in Mexican-modified landscapes (Galindo-González and Sosa 2003). In addition, it has been found that bat species richness and diversity are positively associated with the amount of forest cover or the amount of mature vegetation in the landscape (Vleut et al. 2012; Arroyo-Rodríguez et al. 2016; García-Morales et al. 2016; Kraker-Castañeda et al. 2017), although other studies only found a positive relation with bat relative abundance and forest cover at landscape scale (García-García and Santos-Moreno 2014). Relative bat abundance does not have a clear relationship with forest cover, as studies have reported a greater abundance in forest fragments than in continuous vegetation (Bolívar-Cimé et al. 2013) or have found no differences (Barragán et al. 2010; Vleut et al. 2012). This contradictory pattern is related to two characteristics of the study sites: (1) the type of ecosystem and (2) the vegetation structure of edge forest fragments. In Mexico, dry forest are sites with low diversity and abundance of phyllostomids bats. In these ecosystems, the forest fragments with sources of water such as rivers or cenotes (water sinkholes) had higher vegetation diversity. Therefore, phyllostomids bats, especially frugivores and nectarivores, can be abundant in forest fragments. In ecosystems, such as tropical rainforests, forest fragments can have "soft" edges that contain great diversity of plants consumed by understory frugivorous bats, resulting in an increase of abundance of this species in forest fragments.

At the guild level, frugivorous and nectarivorous bats are one of the most common phyllostomids bats in Mexico. Their diversity responds positively to the proximity and the mean distance between forest fragments and negatively to the fragments mean size (Avila-Cabadilla et al. 2012; García-García and Santos-Moreno 2014). The abundance of canopy frugivores decreases when secondary vegetation increases and mature vegetation decreases in landscapes, while understory frugivores show the opposite pattern (Arroyo-Rodríguez et al. 2016). Whereas sanguivores fly close to linear elements of the landscape to avoid open areas, thus requiring landscape connectivity (Ávila-Flores et al. 2019; Bolívar-Cimé et al. 2019; Mendoza-Sáenz et al. 2021). However, to better understand the use of landscape elements at the guild or species level, further studies with GPS or radio tracking are needed.

In general, the effects of land use change on bat diversity reported in studies of other parts of the world are in accordance with the results reported for Mexico. Relative abundance was the only diversity parameter that does not correspond with the effects reported in other parts of the world possibly because Mexico contains dry ecosystems (deserts, dry forest, savannas, etc.) with some superficial water availability that promotes that forest fragments maintain similar major bat abundance compared with non-fragmented forests, especially of phytophagous phyllostomid bats. In addition, the effects of urbanization and cattle ranching over Mexican bat diversity are not conclusive yet, and probably the trends are like other parts of the world.

11.3.2 Effect of Pollution on Mexican Bat Diversity

Noise pollution is an invisible threat that affects the health and many other functions in humans and other animals. One of the most common sources of this pollution is the human-generated noise, particularly from transportation in terrestrial environments (Shannon et al. 2016). Traffic noise is mainly generated by the combination of the noises produced by commercial (aircrafts, trains, buses) and private transportation (cars and motorcycles). Traffic noise may affect the echolocation calls of bats. However, until now, this aspect has been poorly investigated in Mexico (see Table 11.3). A recent review found only 12 published papers have dealt with this issue and these investigations were mainly carried out in North America and Europe (Bednarz 2021). As a general finding, bats tended to be negatively affected by traffic noise, decreasing the ability to forage and their foraging intensity (Siemers and

Schaub 2011; Luo et al. 2015), although certain species demonstrated a considerable degree of tolerance to this disturbance (Bednarz 2021).

In Mexico, we found that in recent years four undergraduate and graduate projects have investigated the effect of noise on bat activity or in the echolocation characteristics of some species or guilds. In the first study, Lara-Nuñez (2018) investigated the effect of anthropogenic noise on the echolocation pulses of the aerial insectivorous bats *Molossus sinaloae* and *Mormoops megalophylla* within an urban site (city of Cuernavaca, Morelos) and compared it with a natural habitat (Sierra de Huautla Biosphere Reserve). The results showed that, under the background noise at an intensity of 75 dB in the urban environment, *M. sinaloae* echolocation calls were higher in frequencies on an average of 5.8 kHz. For *M. megalophylla*, statistically significant changes were only observed in the start and end frequencies of the pulses, as well as in the middle of these. The author concluded that the increase in the maximum amplitude frequency for *M. sinaloae* could be a response to the Lombard effect, which is the increase in vocal amplitude in response to the increase in background noise (Lara-Nuñez 2018).

In a second study, Medina-Cruz (2019) characterized the bat assemblages in urban sites in Oaxaca, Mexico, registering bats species with mist-nets and with acoustic monitoring. She found that the site with the highest noise pollution (mainly emitted by cars) showed the lowest species richness of insectivorous bats that hunt at ground level. The third study, Pérez-Pérez (2020) related the structure of echolocation calls of *Molossus rufus* emerging from different urban roosting sites with the environmental noise. The author did not detect an effect on the structure of calls at the emergence of *M. rufus*. However, the effect of urban noise during foraging needs to be investigated, as the traffic noise reduces the effectiveness and efficiency of the foraging in other species such as *Myotis daubentonii* and *Myotis myotis* (Schaub et al. 2009; Luo et al. 2015). Finally, a study by Ferreyra-García (2020) in the Morelia city evaluated the effect of noise pollution, light pollution and vegetation cover over insectivorous bats activity. They found that vegetation cover was the most important variable to explain the bat activity, especially of bats that forage in near to the ground.

Air pollution is a mixture of solid particles and gasses in the air that include several chemicals, factory and car emissions, pollen, and dust. Air pollution particles have devastating consequences for human and other organisms' health, in the form of lung cancer, brain diseases, neurodegenerative diseases, respiratory infections, heart diseases, among others (Herndon and Whiteside 2019). Despite large amounts of combustion-type pollution particles released into the atmosphere appear to harm the specialized respiratory organs and high metabolism of foraging bats (Voigt et al. 2018), research in this subject has been poorly conducted until now.

One of the few studies investigating different degrees of air pollution and bat activity has been carried out in West Poland, the area of highest impact of heavy industry, where authors found that the largest bat diversity was found at the less polluted forests (Rachwald et al. 2004). In a review, Herndon and Whiteside (2019) highlighted the importance of coal fly ash (CFA), the toxic waste product of coal burning, that can directly enter bat bodies through respiration or trans-dermally. These authors found in their study that CFA is the origin of pollutants on bat tissue and guano, urging authorities to reduce the harmful combustion-type nanoparticle emissions and the implementation of international programs to quantify, monitor, and regulate ultrafine particulate air pollution.

In the Megalopolis of Mexico, one of the largest cities in the world, Ramos-H et al. (2020) investigated the associations between metal exposure and the accumulation patterns in the insectivorous bat, *Tadarida brasiliensis*. They found that higher concentrations of copper (Cu) and zinc (Zn) in bats at two localities were associated with vehicular traffic, whereas higher concentrations of vanadium (V) were attributable in one of the sites where fossil fuel combustion was generated by the Industrial Complex in Tula, in the state of Hidalgo. These results highlight the need for more investigations to uncover the exposure that bats are facing to air pollutants in the human-dominated ecosystems.

Finally, light and water pollution are also poorly studied in Mexico, according to our literature search, although there are some studies that have investigated the effects of water pollution, light pollution, and vegetation cover effects on bat activities. Research results found that contaminated rivers can maintain insectivorous bat activity despite light and noise pollution and that the vegetation cover of the rivers was the principal factor that explained the bat activity in the rivers (Ferreyra-García 2020). On the other hand, it has been documented that light pollution reduces the visitation rate of frugivorous bats to *Ceiba pentandra* flowers in the city of Merida (Dzul-Cauich and Munguía-Rosas 2022). However, this reduction of visit rate does not affect the reproductive success of the plant. With such limited present evidence of the effects of pollution on Mexican bat diversity and ecology, we cannot affirm that the trends are as predicted by literature for other countries.

11.3.3 Climate Change

Anthropogenic climate change is causing multiple effects on fauna, such as the reduction of suitable conditions and changing distributions, changes in phenology, loss or changes in migratory behaviors that are threatening species coexistence and the maintenance of ecological processes affecting the healthy functioning of ecosystems (Blois et al. 2013; Urban 2015). The speed of these changes is also a concern especially for species with limited mobility and dispersal capacity, which although might not be the case for bats directly, but does affect their foraging resources and species assemblages as well as trophic relationships (Harrington et al. 1999; Loarie et al. 2009). Mexico is highly vulnerable to the effects of climate change due to its social, economic, and geographical characteristics. Its location between two oceans along with its latitude and topography exposes the country to extreme hydrometeorological phenomena. About 90% of the country's territory has been affected either by cyclones or by severe drought (INECC 2018).

Studies report different effects of global warming on bats, for example, latitudinal and altitudinal movements, effects on reproductive success due to changes in water availability especially in arid regions, mismatches between foraging resources availability and migratory bats, prey detection ability in echolocating bats, disruption of hibernation and migration patterns, increased vulnerability to disease (Jones and Rebelo 2013; Sherwin et al. 2013; Luo et al. 2015; Hall et al. 2016; Hayes and Adams 2017; Adams 2018; Chattopadhyay et al. 2019; Adams and Hayes 2021). Studies directly addressing impacts of future climate change scenarios on bats in Mexico are scarce and focused on changes in environmental suitability of bat species (Zamora-Gutierrez et al. 2018) and their foraging resources (Gómez-Ruiz and Lacher Jr 2019). Projections in these studies indicate, overall, that bats will be affected by unfavorable conditions in at least 80% of their range and will have to migrate more than 100 km to reach suitable environments in distant regions by the 2050s. Moreover, future climate change scenarios predict severe humidity decrease especially in the arid and semi-arid regions affecting endemic Mexican bat species occurring in the arid regions of Baja California and the Mexican Plateau (Zamora-Gutierrez et al. 2018). Surface water availability is important during lactation in bats and its reduction due to climate change will impact reproduction success and population numbers (Adams and Hayes 2008; Adams 2010; Hayes and Adams 2017). For insectivorous bats, surface water availability offers opportunities for finding insect prey (Korine et al. 2016). Severe drought events due to climate change will decrease surface water area and reduce foraging habitat for insectivorous bats that will need to spend more energy in finding prey.

Climate change affecting bat distributions might result in dispersal of zoonotic diseases (Mills et al. 2010). Hayes and Piaggio (2018) assessed the potential impacts of climate change on the distribution of common vampire bats (*Desmodus rotundus*). Their models indicate range expansion to northern Mexico and southern Texas in the United States where cattle-ranching activities are widespread, and that cattle could be more exposed to rabies virus transmitted by vampire bats.

Migratory bats are exposed to high rates of evaporative water loss; therefore, they need to access drinking water along the way (Popa-Lisseanu and Voigt 2009). Bats have been proposed as indicator species for the effects of climate change on migratory animals. The Mexican free-tailed bat (*Tadarida brasiliensis*) is one of the species suggested as a proxy for cave-dwelling bats in the Tropics because there is a large and long-term population data that correlate the impact of changes in temperature and other regional weather patterns on population size at maternity roost sites (Newson et al. 2009). Migratory nectar-feeding bats are especially vulnerable since they rely on nectar resources and plant phenology, particularly flower availability, which is linked to precipitation and will likely be modified due to climate change resulting in plant–pollinator asynchrony (Gómez-Ruiz and Lacher Jr 2019). Humphries et al. (2002) show evidence that global warming might constrain the suitable habitat for successful hibernation in mammals. Bats hibernation duration may be reduced because of climate change, and insect abundance might not be sufficient to offset the increased energetic costs associated with more frequent arousal by bats (Jones and Rebelo 2013).

Current knowledge on the effects of climate change and bat physiology, lactation, and reproduction is the result of long-term studies (Adams 2010, 2018; Lučan et al. 2013). To better understand how climate change will impact Mexican bats, we need to start collecting data in a systematic manner. Furthermore, bats are bioindicators for monitoring climate change, so it is urgent to implement a global network for monitoring their populations (Jones et al. 2009). At present, the information available concerning Mexican bats is insufficient to conclude that they are responding as global predictions postulate (Table 11.1).

11.3.4 Human–Bat Conflicts

Conflicts between humans and bats in Mexico have been rarely documented in the scientific literature. In a recent review of human-wildlife conflicts in Mexico, not a single study included bats as a source of conflict with people (Flores-Armillas et al. 2019). However, information in gray literature and anecdotal reports suggests that intentional killings may represent a primary force behind human-driven mortality of bats in Mexico. For North America, including Mexico, it has been estimated that intentional killing of bats represents the third cause of multiple mortality events ($\geq$10 individuals found dead), just behind white-nose syndrome and wind turbine collisions (O'Shea et al. 2016). The impact of direct killing on bat populations may be particularly severe, at least at the local scale, for those species living in large colonies. Destruction or entrance blocking of natural and artificial day roosts may result in the death of many resident bats, whereas surviving individuals may abandon the roost with uncertain fate. In urban settings, civil protection offices and pest control companies are regularly called to kill or exclude bats roosting in residential buildings. In Mexico City, for example, 57% of bat roosts were recently vacated after intentional destruction, entrance blocking, or fumigation (García-Bermúdez 2018). Almost as a rule, bat control in Mexico is implemented without previous approval and supervision of environmental agencies. Unfortunately, no data on the actual death rates due to direct killing are available for any bat species in any Mexican location. The exception is for the vampire bat *Desmodus rotundus*, whose culling campaigns for bovine rabies control killed about 90,000 individuals in 2020, assuming a conservative rate of 5 deaths per each individual treated with vampiricide (SENASICA 2020).

In Mexico, direct interventions on bat colonies and their roosts are strongly motivated by negative ideas, perceptions, and emotions toward bats. For example, in the Volcanic Complex of Colima, nearly 40% of local caves were intentionally collapsed by local people due to the fear inspired by bats (Segura-Trujillo and Navarro-Pérez 2010). As occurs globally, negative attitudes toward bats among Mexican people result from two main factors: the cultural links of bats with witchery and evil-oriented mythological stories, and the strong association that people make between bats and infectious diseases (Flores-Monter et al. 2017). In addition, the physiognomy of bats appears repulsive to most Mexicans across the country (Torres

Romero and Fernández-Crispín 2012; Aguilar-Rodríguez et al. 2016; Flores-Monter et al. 2017), which makes it difficult to create empathetic links with bats. Aversion to bats is often enhanced when bat colonies roost inside or adjacent to inhabited houses and buildings, either in urban or in rural settings. In many cases, the presence of odors, moisture, and insects associated with bat guano stimulates rejection, repugnance, or even hatred toward bats (Aguilar-Rodríguez et al. 2016). Negative attitudes may intensify when bat feces and urine fall into home interiors or damage structural components of buildings.

Transmission of infectious diseases is probably the most important factor promoting fear or rejection to bats among Mexican people. Surveys conducted in rural and urban locations of the country indicate that most people believe that bats transmit rabies and other infectious diseases (Aguilar-Rodríguez et al. 2016; Flores-Monter et al. 2017; Hernández-Sánchez 2019). Although human rabies seems to be present in the mind of many Mexican people when thinking about bats, blood-sucking by itself (and secondarily, the death of domestic animals) may cause the greatest fear among people in some rural locations (Torres Romero and Fernández-Crispín 2012; Flores-Monter et al. 2017). A small proportion of Mexican respondents associate bats or bat guano to some kind of fungal disease (i.e., histoplasmosis), but only in urban locations (Aguilar-Rodríguez et al. 2016). Anecdotal observations and informal social networking suggest that the COVID-19 pandemics has strengthened the negative public image of bats, particularly because they are often misidentified as the origin of SARS-CoV-2. However, no study to date has evaluated the changes in perceptions, attitudes, and actions toward bats during the COVID-19 pandemics among Mexican people.

Habituation to the presence of bats in human spaces (urban or rural buildings) and local cultural values may determine more positive bat–human interactions in Mexico (Retana-Guiascón and Navarijo-Ornelas 2012). For example, in the Mixteca Poblana region, bats tend to be more appreciated in towns located near caves harboring large amounts of guano, which is then collected, used, and sold as a fertilizer by local people. In Nahuatl-influenced locations of the same region, symbolic values linked to ancient cultures may result in more respect to bats (Flores-Monter et al. 2017). Appreciation of ecosystem services provided by bats may play a central role in local strategies that promote bat conservation both in urban and in rural locations (Torres Romero and Fernández-Crispín 2012). Knowledge of ecosystem services provided by bats may be prominent both in urban (Flores-Monter et al. 2017) and in rural (Hernández-Sánchez 2019) locations, especially among young people, depending on the way residents interact with bats. In Mexico City, knowledge on ecosystem services of bats is more precise among people with higher education living in proximity to bat roosts (Mendieta-Vázquez 2017). In the latter study, urban residents were willing to donate for conservation of bats (on average, 10.00 USD/year per person) once they were informed that a local colony of insectivorous bats consumed about 500 g of dipterans every night. Clearly, science communication and environmental education may be effective tools to reduce threats to bats in Mexico.

Contrary to other Anthropocene threats, human–bat conflicts in Mexico are like international observations about human–bat conflicts. In addition, the presence of the vampire bats in Mexico promotes that human–bat conflicts being a constant threat to other bat species populations.

11.3.5 Human Infrastructure and Their Impact on the Mexican Bats

The continuous growth of human population implies a proportional growth of human-made infrastructures and the subsequent affections on native fauna. Under the Anthropocene, wind farms, roads or highways, and buildings are the most notorious human-made infrastructures to affect bat fauna worldwide, and Mexico is not the exception. For wind farms, we found seven published articles that met the selection criteria. The topics of these studies were (i) the mortality of bats caused by wind turbines (Torres-Morales et al. 2014; Bolívar-Cimé et al. 2016; Cabrera-Cruz et al. 2020); (ii) the temporal dynamics of scavengers' community in wind farms (Villegas-Patraca et al. 2012); (iii) changes of bat community and activity patterns (Briones-Salas et al. 2017), (iv) detection of physiological stress in bats (Medina-Cruz et al. 2020), and (v) a global synthesis of wind energy impacts on bats (Arnett et al. 2016). Except for the latter, which is a global review, the rest of the studies were done within one of the largest wind farms of Mexico located in the Isthmus of Tehuantepec (IT), in Oaxaca, México. Yet in 2021, Mexico had 68 operating wind farms in 14 states (AMDEE n.d.), which therefore supposes a considerable geographic bias on the knowledge of the effect of wind farms on Mexican bat fauna. The carcasses recovered in the wind farms placed in the IT wind farm corresponded to 28 species and seven indeterminate taxa (Fig. 11.3). These victim species, as was found, in other wind farms in the temperate zone, are adapted to forage and echolocate in open areas (Arnett et al. 2016). However, while the migratory species are the most vulnerable in temperate zones, the resident species too, are highly vulnerable in the IT. Similar results have been observed in other studies of the Neotropics (Rodriguez-Duran and Feliciano-Robles 2015) and may indicate that the impact of wind farms on bat fauna is higher for tropical regions. This supposes an important issue for the development of the Eolic industry in tropical countries such as Mexico as relates to the conservation of the bat fauna. These findings may also apply to the more sub-tropical regions of northern Mexico. On a wind farm in Texas, close to the United States-Mexican border, Weaver et al. (2020) reported bat mortality and that *Tadarida brasiliensis* was the most threatened species. This species has an agriculture-economic relevance due to its role in insect pest control (Cleveland et al. 2006). The authors suggest that due to the similar species composition, the wind farms placed in the more arid subtropics of northeast Mexico may show similar impacts to those in tropical regions.

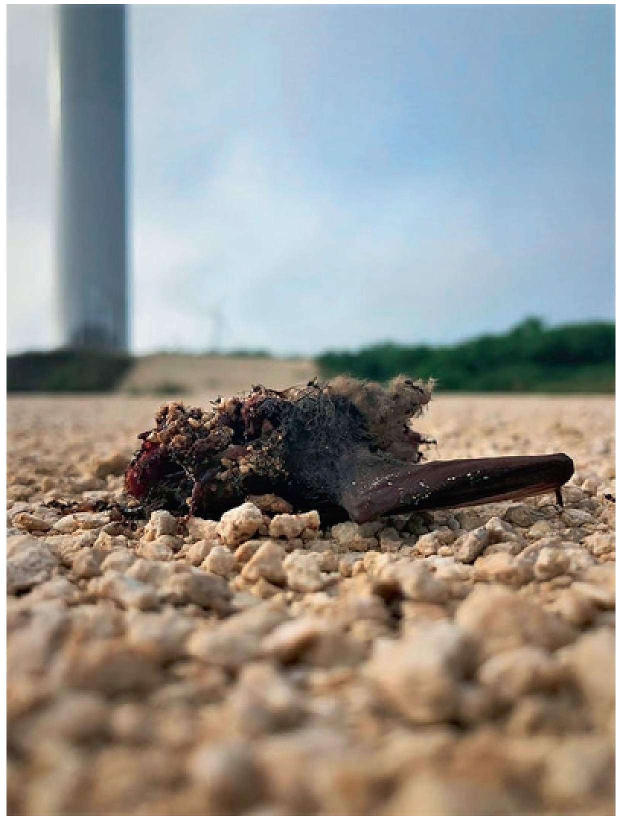

Fig. 11.3 A Northern Yellow Bat (*Lasiurus intermedius*) killed by collision with a wind turbine. (Photo by Juan Cruzado)

Several challenges exist for the bat researchers and wildlife managers dedicated to the study of the impact of wind turbines on Mexican bat fauna. The lack of knowledge for the rest of the wind farms that are operating in Mexico and the unresolved scientific questions are some of these challenges. However, bat researchers face social and political challenges that are not always considered. For example, most of the wind turbines are placed in crop fields (Bolívar-Cimé et al. 2016; Cabrera-Cruz et al. 2020) where conducting ecological studies requires interaction among bat researchers and landowners. On the other hand, the diffusion of data associated with the measurements of the impact of wind farms is urgently needed; however, this information is not always available to researchers due to strict data use policies. With this panorama, we recommend enhancing the collaboration among landowners, farmers, bat researchers, ecologists, engineers, and windfarm administrations.

With respect to roads, we found only six studies that report bat casualties by roadkill (Grosselet et al. 2004; Escobedo-Cabrera and Calmé 2005; González-Gallina and Benítez-Badillo 2013; Nahuat-Cervera et al. 2021; Sánchez-Acuña and Benítez 2021; Vargas-Contreras et al. 2021). These studies were done on highways located in the states of Yucatan, Campeche, Oaxaca, Puebla, and Veracruz. From these studies, only two reported a detailed list of road-killed bat species (González-Gallina et al. 2013; Nahuat-Cervera et al. 2021; Vargas-Contreras et al. 2021). Third research (González-Gallina et al. 2013) mentioned *Lasiurus borealis*, and "Chiroptera sp." and the rest of studies did not identify at the level of species and just referred such as "Chiroptera" or "bats."

Despite a variety of studies that report mammal roadkill, bat species are not always reported. Why do some Mexican highways result in being more dangerous for bats? Ecological traits, presence and location of roosts, and highways characteristics may answer this question but further studies are needed (Altringham and Kerth 2016). For example, bat refuges close to the roads look like a perfect catastrophic scenario. In Campeche, El Volcán de los Murciélagos (VM) located in the Balam-kú reserve is the largest cave in the neotropics and houses 2.2 millions of bats of eight species (Vargas-Contreras et al. 2021). The 186th highway is located 400 meters from the VM and the roadkill rate is relatively high as showed Vargas-Contreras et al. (2021) who analyzed a 2000 m transect of the highway divided into subsections of 50 m. They estimated a mortality rate of 23.3 individuals/year-1 per each 50 m subsection. Despite this number do not seem high, the study of Vargas-Contreras et al. (2021) just focused on a section of 2000 m of the ~150 km length of the Escarcega-Xpujil 186th highway placed along the Mayan jungle. Other larger colonies refuges such as El Sótano de Cerro Colorado in Apazapan, Veracruz, and La Cueva de los Murciélagos in Mavirí, Sinaloa are located close to roads, but we found no roadkill data for bats at these sites.

Worldwide, those bat species that fly near the ground are the most threatened by roads (Altringham and Kerth 2016). This same pattern is shown in the VM, where the low flying species, *Natalus mexicanus* and *Pteronotus mesoamericanus,* have the highest reported mortality (Vargas-Contreras et al. 2021). In addition, other species that do not fly at low altitude are also killed and it is presumed that collision occurs when they move among roosts, or they are searching for water or food resources (Altringham and Kerth 2016; Vargas-Contreras et al. 2021). What other factors could increase the risk of roadkill in bat species not typically threatened by roads? This is an open area for future research. In Mexico, "Road Ecology" is a research field with a recent development and with several gaps of information in particular taxa such as bats. Many unresolved questions remain, and this highlights the need for further studies related to roadkill of bat fauna and how we can mitigate this negative impact.

Finally, human-made buildings (HMB) may positively affect bats when these serve as daily roost sites (Russo and Ancillotto 2015). However, some structures may have negative effects exposing bats to: (i) collision risk, (ii) native or exotic predators, (iii) diseases or infection agents, or (iv) persecution by humans (Voigt et al. 2016). In Mexico, positive outcomes have been reported where bats use HMB as daily roosts (Borges-Jesús et al. 2021), hibernating refuges (López-González and Torres-Morales 2004), and reproduction sites (León-Galván et al. 2015). However, to our knowledge, no studies report negative effects in Mexico. Urban bat ecology and particularly the interaction among bats and HMB is a research field with many gaps of knowledge and unresolved questions. Further studies are needed to understand how species are responding to changes imposed by urban growth and particularly, determination of the main threats that bats are facing in this new "ecosystem."

11.4 Conclusion and Perspectives

We conclude that, in general, the responses expected by each threat of human activities on Mexican bats were fulfilled. This was particularly true for topics such as land use change, human–bat conflicts, and human infrastructure. To reduce the impact of these threats in Mexican bat populations, it is necessary to promote public policies that preserve their habitats, as well as the conservation of forest fragments, regardless of their vegetation successional stage. Avoiding intentional killing or roost disturbance is essential, but to achieve this it is important to recover and promote the cultural values that link human life with bats. Agriculture with low environmental impact, agroecology, and conservation agriculture also needs to be promoted. These challenges demand the use of interdisciplinary science, with co-construction knowledge from local people. These actions will promote changes in human infrastructure and the use of new technologies to reduce the impact of Mexican bat populations. Finally, there are important issues related with the Anthropocene such as pollution and climate change that need scientific data to assess the potential impact and make decisions. Both are the result of human activities, and they demand the use of new technology and long-term research given the limitations of the scientific information of Mexican bats, and the effects of these phenomena on Mexican bats populations could be slowly or cryptic.

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