Power Lines, an Understudied Cause of Avian Mortality in Mexico

Authors: Escobar-Ibáñez, Juan Fernando, Aguilar-López, José Luis, Muñoz-Jiménez, Oscar, and Villegas-Patraca, Rafael

Source: Tropical Conservation Science, 15(1)

Published By: SAGE Publishing

URL: https://doi.org/10.1177/19400829221130479

Research Article

Tropical Conservation Science
Volume 15: 1–17
© The Author(s) 2022
Article reuse guidelines:
sagepub.com/journals-permissions
DOI: 10.1177/19400829221130479
journals.sagepub.com/home/trc
SAGE

Power Lines, an Understudied Cause of Avian Mortality in Mexico

Juan Fernando Escobar-Ibáñez[1,2,3], José Luis Aguilar-López[3], Oscar Muñoz-Jiménez[3], and Rafael Villegas-Patraca[3]

Abstract

Background and Research Aims: Power lines are one of the main anthropogenic causes of bird mortality on a global scale, but research is scarce in some countries with a high diversity of birds, such as Mexico. In this study, we assessed the impact of bird collisions and electrocutions with power lines on avian communities at three wind farms located in three different states in Mexico.

Methods: Carcass searches were carried out at sites in Tamaulipas (4 months in 2021), Guanajuato (2 months in 2020, 4 months in 2021), and Oaxaca (55 months from 2014 to 2021).

Results: A total of 579 bird carcasses from 65 different species were recorded. The White-winged Dove (*Zenaida asiatica*) was the most frequently found species (282 records) across the three sites. When considering the number of species identified per family, Icteridae had the highest number of species at the Oaxaca site, Columbidae and Passerelidae at the Tamaulipas site, and Anatidae at the Guanajuato site. At the order level, Passeriformes had the highest number of species at the Tamaulipas and Oaxaca sites, and Anseriformes in Guanajuato. Of the total species recorded, 12 are within some category of risk according to Mexican legislation and the IUCN Red List, and 18 are migratory species.

Conclusions: Our results, together with evidence from previous studies, indicate that power lines represent one of the main causes of anthropogenic mortality in Mexico in terms of the number of affected bird species. Further research is urgently needed to explore the effect of power lines on bird populations in the country, particularly those at risk of extinction, and migratory species.

Implications for Conservation: The high diversity of species found to be affected in this study highlights the wide-ranging impact of these structures and the need to implement mitigation strategies at the three sites studied, particularly for the most affected species, the White-winged Dove (*Zenaida asiatica*).

Keywords
anthropocene, avifauna, collision, deaths, electrical power

Introduction

Both the establishment of communication and transportation structures in human societies and the development of structures for generating and transmitting electrical power represent numerous threats to biodiversity. Among the main threats are isolation of populations, habitat loss, death from collisions with vehicles, and death due to collision with and electrocution by power transmission and distribution lines (Balkenhol & Waits, 2009; Bernardino et al., 2018). Birds are

[1]Gnósis – Naturaleza con Ciencia A.C., Guadalajara, Mexico
[2]Instituto de Estudios Superiores de la Ciudad de México "Rosario Castellanos", Ciudad de México, Mexico
[3]Instituto de Ecología, A.C., Unidad de Servicios Profesionales Altamente Especializados (USPAE), Xalapa de Enríquez, México

Received: 24 May 2022; accepted: 16 September 2022

Corresponding Author:
Rafael Villegas-Patraca, Unidad de Servicios Profesionales Altamente Especializados (USPAE), Instituto de Ecología, Carretera Antigua Xalapa-Coatepec esq. camino a Rancho Viejo no. 1, Fraccionamiento Briones, 91520 Xalapa de Enríquez 91070, México.
Email: rafael.villegas@inecol.mx

one of the groups most affected by the latter threat; in fact, power lines are one of the main sources of avian mortality worldwide, and it is estimated that in the United States and Canada alone, they kill more than 60 million birds per year (Loss et al., 2015).

Power lines are associated with population decline in several avian species (see Biasotto & Kindel, 2018; Slater et al., 2020 and references therein), many of which are endangered (Dwyer et al., 2019; Guil et al., 2011), motivating an increase in the study of bird mortality associated with these structures around the world (Bernardino et al., 2018; Biasotto & Kindel, 2018). Moreover, the continuous growth of human settlements and the growing demand for electricity in modern societies together result in a 5% annual increase in power lines around the world (Jenkins et al., 2010). Therefore, it is essential to identify which species are affected, to better understand the impact of power lines on bird populations, and take action to reduce this impact.

Multiple studies worldwide have evaluated characteristics of bird mortality related to power lines. Among the main factors associated with collisions with power lines are as follows: (1) factors related to the characteristics of the individual birds (e.g., the ratio of the wing area to weight, age, flight behavior such as gregariousness, or in-flight displays related to the courtship process in large wingspan species (Janss, 2000); (2) characteristics of the site where the power lines are located (e.g., topography, vegetation, climate, visibility conditions); and (3) the characteristics of the power lines (e.g., number of wires, their height and diameter; Bernardino et al., 2018; Jenkins et al., 2010). However, there is a clear geographic bias in the evidence base, with numerous studies in Europe and North America (Bernardino et al., 2018; Loss et al., 2015), while some of the regions and countries with the greatest diversity (e.g., megadiverse countries) lack even basic information, such as which species are most affected (Guil & Pérez-García, 2022), that would enable a better understanding of the impact of these structures on avifauna, and support the development of strategies to reduce avian mortality.

Mexico has the 10th highest avian diversity of any country (Navarro-Sigüenza et al., 2014), but also has an extensive electrical grid that in 2004 included 746,911 km of power lines distributed throughout the country (Rosellón, 2007). This figure has continued to increase with the establishment of new power plants, urban expansion, and the move towards wind farms. For example, the Isthmus of Tehuantepec, one of the main migration routes for Neotropical birds (Cabrera-Cruz et al., 2017), is the region with the greatest presence of wind energy in the country, including 52 km of transmission lines and a place to expand to an estimated 145 km of power lines in the medium-term future (SEGOB, 2015). Despite the extension and imminent growth of electrical lines, we know of only five published studies that have evaluated the impact of power lines on bird mortality in Mexico. Four of the five studies were carried out in northern states of the country (i.e., Chihuahua, Baja California Sur, Sonora) between 1999 and 2006 (Cartron et al., 2000, 2005, 2006; Manzano-Fischer et al., 2007), and were mainly focused on the evaluation of bird mortality by electrocution, although in many cases it was not possible to determine the cause of death accurately (Cartron et al., 2006). Manzano-Fischer et al. (2007) identified 423 bird carcasses during their investigation in the state of Chihuahua, including: 24 Golden Eagles (*Aquila chrysaetos*), 28 Ferruginous Hawks (*Buteo regalis*), and one Bald Eagle (*Haliaeetus leucocephalus*), while 15 carcasses were found in Sonora and one in Baja California (Cartron et al., 2006). The authors highlighted the fact that methodological differences between studies prevented detailed comparisons.

Given the lack of information about the impact of power lines on bird species in Mexico and Latin America, and the imminent increase in the extension of power lines in regions of importance for threatened and Neotropical migratory species, we aimed to provide information on the species affected by power lines associated with three wind farms in Mexico, located in the states of Oaxaca, Tamaulipas, and Guanajuato. We carried out this study to use the findings to make an urgent appeal to social actors across Latin America to pay attention to this issue and establish a regional agenda that may serve as a basis for decision-making in the future, for the benefit of the regional avifauna.

Materials and Methods

Study sites

The fieldwork was carried out along power lines and power poles (namely hereafter as "power lines") associated with wind farms in the states of Tamaulipas, Guanajuato, and Oaxaca, located in northeast, central, and southcentral Mexico, respectively (Figure 1). The specific characteristics of the power lines and the search methodology for each site are described below, but in general, the power lines did not have any type of line markers, and the searches were carried out along these structures to identify carcasses. When a bird carcass was found, the geographical coordinates were recorded and photographs were taken to identify the species and provide evidence of the record. In cases where only feathers were found (more than three feathers close to each other), these were used to identify the species, where possible. Additionally, all carcasses were removed to avoid recounting them in subsequent visits.

Tamaulipas. The power line sampled at this site (midpoint of transect; 23° 25′ 53.68″ N, 98° 54′ 45.82″ W) had a voltage of 115 kV, a width of 6 m, and a height of 15 m from the ground. The sampled segment was 12.7 km long and was supported by 30 towers. The vegetation around the transmission lines and surrounding area was secondary vegetation of Tamaulipan scrub. Intensive searches were conducted both under the power lines and around the support towers. The searches

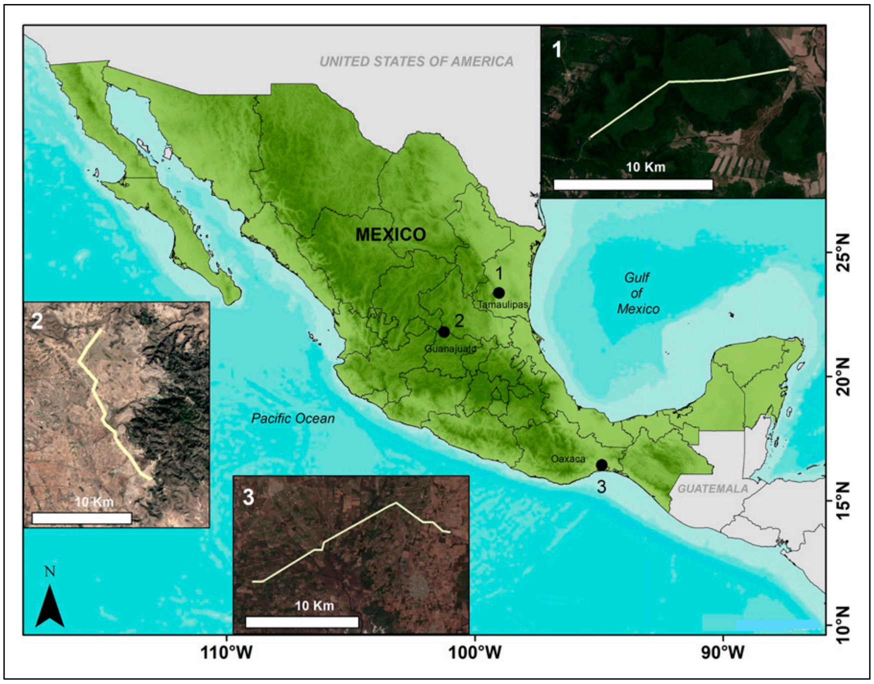

Figure 1. Location and length of transmission lines sampled in the states of Tamaulipas (1), Guanajuato (2) and Oaxaca (3), Mexico.

were carried out by four people covering a 15-m wide transect under the power line. The stretch of power line was sampled twice a month from January to April 2021, and the total area sampled was 190,815 m^2.

Guanajuato. The power line at this site (midpoint of transect; 21° 44′ 53.7″ N, 101° 15′ 8.37″ W) had a voltage of 230 kV, a width of 15 m, a height that varied from 9 to 20 m from the ground. The sampled segment was approximately 17.6 km long and had 53 towers. The area under and around the transmission lines area was mostly devoid of vegetation, but there were also some areas with a dense cover of nopal (*Opuntia* spp.). Water bodies were present on either side of the power line. Intensive searches were carried out under the power lines and surrounding areas by four people, covering an 18-m wide transect. Two sections, one 0.34 km long located between towers 21 and 22 and the other 1.56 long located between towers 39 and 43 could not be sampled due to the presence of dense scrub and nopal that impeded the search. The power line was sampled monthly from November to December 2020 and January to April 2021; the total area sampled was 317,594 m^2.

Oaxaca. The power line at this site (midpoint of transect; 16° 30′ 47.28″ N, 94° 53′ 53.94″ W) had a voltage of 230 kV, a width of 6 m, and a height of 30 m from the ground. The sampled segment was approximately 21 km long and had 70 towers. The vegetation under and around the transmission lines was mainly cropland (mostly sorghum) and secondary deciduous forest vegetation. There was a network of crop irrigation canals in the area. Intensive searches were carried out by four people in a transect that ranged from 40 to 80 m wide, including the area under the power lines and around the support towers. The transect width depended on the density of vegetation and accessibility to private properties. One person searched below the transmission line and one person on each side 50 m away from the line. This transmission line was sampled on either one or two occasions per month, in 2014 (May–Aug, Oct), 2015 (May–Aug, Nov–Dec), 2016 (Apr–Nov), 2017 (Apr–Nov), 2018 (Feb–Mar, May–Nov), 2019 (Apr–May, Jul, Sept, Nov–Dec), 2020 (Jan–Dec, except Apr), and 2021 (Feb–Mar). The total area sampled was 511,340 m^2.

Data Analysis

Once the data from the study sites were obtained, we compiled a list of the species recorded. To find whether each registered species had already been reported as being killed by power lines elsewhere in the world, we carried out a literature review using the search engines Google Scholar and Clarivate Analytics with the words "Bird" OR scientific or common name of each species on the list (including synonyms) AND "Collision" OR "electrocution" OR "Strikes" OR "Deaths" OR "Casualties" AND "Power Lines" OR "Transmission Power Lines" OR "Electric Power Lines" OR "Electric Wires." We also explore all the combinations in Spanish. Additionally, to compile the list of species that have been reported as killed by electric lines in Mexico, we carried out a search in Google Scholar (June and July 2021) using the word combination "birds" AND "power lines" OR "collision" AND "Mexico." We used rank-abundance curves to evaluate the differences between the numbers of recorded carcasses between species within sites (Magurran, 2004).

Results

We found a total of 579 carcasses on the three sampled sites, of which 496 (85%) were identified as one of 65 species, while the remaining 83 could not be identified to species level (Table 1). The most frequently recorded species was the White-winged Dove (*Zenaida asiatica*) with 282 records, followed by the Cattle Egret (*Bubulcus ibis*) with 40, and the Mourning Dove (*Zenaida macroura*) with 17 (Table 1). Of the 27 families recorded, those with the highest number of species identified in the searches were Anatidae, Ardeidae, and Icteridae with six species each (Figure 2a). The best-represented order was Passeriformes with 23 species, followed by Pelecaniformes with eight species and Anseriformes with six (Figure 2b). Of the 65 species that we identified, 18 were migratory (281 carcasses), the White-winged Dove was by far the most frequently identified of these (236; however, it was reported as a migratory species in Oaxaca but not in Guanajuato nor Tamaulipas). Among the species we recorded, only the West Mexican Chachalaca (*Ortalis poliocephala*) was endemic to the country (Table 1).

According to Mexican legislation (SEMARNAT, 2010), three of the species affected by power lines are included in risk categories: two species (Mexican Duck [*Anas diazi*], and Limpkin [*Aramus guarauna*]) are classified in the category of "Threatened" (A; Amenazada), and one species (Orange-fronted Parakeet [*Eupsittula canicularis*]) in the category of "Subject to special protection" (Pr; Sujeta a Protección Especial); According to the Red List (IUCN, 2021) two species identified in our study (Northern Bobwhite [*Colinus virginianus*], and Eastern Meadowlark [*Sturnella magna*]) are classified as "Near Threatened" (NT), one species (Orange-fronted Parakeet [*E. canicularis*]) as "Vulnerable" (VU), and one (Mexican Duck [*A. diazi*]) has "Not been evaluated" (NE) (Table 1).

The results we found by site were as follows. In Tamaulipas, we found evidence of 66 bird deaths in the search area along power lines. We could identify 54 of these birds as belonging to 15 different species. We identified one carcass at the genus level (*Setophaga*), four at the family level (Columbidae), and we could not identify seven (Table 1). Of the total carcasses that we could identify to the species level, the most frequent was the White-winged Dove, with 38 records (~70% of the total; Figure 3a). The families with the highest number of recorded species were Passerellidae and Columbidae, with three species each, and the order that presented the highest number of species was Passeriformes with eight, equivalent to 53.3% of the total (Figure 4a, b, Table 1).

At the site located in the state of Guanajuato, we found evidence of 42 carcasses, of which 33 belonged to 11 species, while we could not identify nine (Table 1). The White-winged Dove was the species with the highest number of records (eight, ~24% of the total number of records identified to species level; Figure 3b), the family with the most species recorded was Anatidae (four species), and the order with the most recorded species was Anseriformes, with ~36% of the total (Figure 4c, d, Table 1).

At the site located in the state of Oaxaca, we found 471 carcasses, of which 409 belonged to 48 species. We identified seven carcasses to the genus level (of the genus *Icterus*—three carcasses, *Columbina*—three carcasses and *Chordeiles*—one carcass), seven could be identified only at the family level (Columbidae), and 48 could not be identified (Table 1). Of the total carcasses that we found and could identify to species level, the species we recorded most frequently was the White-winged Dove with 236 carcasses (58%), followed by the Cattle Egret with 40 carcasses, and the Great-tailed Grackle (*Quiscalus mexicanus*) and Blue-winged Teal (*Spatula discors*) with 10 carcasses each (~2%) (Figure 3c). The family with the highest number of recorded species was Icteridae with six species, while the order with the highest number of species identified was Passeriformes (16) equivalent to ~33% of the total (Figure 4e, f, Table 1).

Discussion

Data on the association between power lines and avian mortality are scarce, particularly in tropical areas where the diversity of this biological group is especially high (Bevanger, 1998; Hyde et al., 2018). We provide novel information on the impact of power lines on Mexican bird diversity. Through an extensive search of the scientific literature, we also demonstrate that further research is urgently needed to explore the effect of these structures on bird populations in Mexico, in order to inform the design and implementation of effective mitigation actions.

In this study, we identified 65 species affected by transmission lines in Mexico, which is the most comprehensive list identified in the country to date. This illustrates the magnitude of the lack of information that exists on this topic in Mexico. For 38 of the 59 species that had not been previously identified as victims of power line associated mortality in Mexico, we only recorded one or two carcasses (24–1, 14–2), which could be related to many factors (e.g., sporadic impact, sampling effort). Therefore, it is essential to generate more information on the mortality rates by species, especially since our results indicate that some of these species affected are in some category of risk (e.g., Northern Bobwhite, Eastern Meadowlark—Near Threatened; IUCN, 2021). In addition, it should be mentioned that sampling effort was less in Guanajuato and Tamaulipas and these states do not have such a great diversity of birds as Oaxaca (Navarro-Sigüenza et al., 2014), which could mean that the number of species affected across the country may, in fact, be much higher. Thus, it is essential to conduct a country-wide survey, with a special

Table 1. Species with recorded carcasses associated with power lines in Mexico.

Order/Family	Species	Code	Common name	Literature with records of deaths associated with power lines	Conservation status NOM/IUCN	No. of carcasses
Anseriformes						
Anatidae	*Dendrocygna autumnalis*	a	Black-bellied Whistling-Duck	De la Zerda & Rosselli, 2003 (Colombia)	/LC	4*
	*Mareca strepera**	b	Gadwall		/LC	1***
	*Mareca americana**	c	American Wigeon	Anderson, 1978 (USA) Malcolm, 1982 (USA)	/LC	3***
	*Anas platyrhynchos**	d	Mallard	Janss, 2000 (Spain) Anderson, 1978 (USA) Costantini et al., 2017 (Italy) Sporer et al., 2013 (USA) Ferrer et al., 2020 (Spain) Pigniczki et al., 2019 (Hungary) Brown & Drewien, 1995 (USA) Alonso et al., 1994 (Spain) Rubolini et al., 2005 (Italy) Malcolm, 1982 (USA) Škorpíková et al., 2019 (Czech Republic) Fransson et al., 2019 (Switzerland)	/LC	1***
	Anas diazi	e	Mexican Duck		A/NE	2***
	*Spatula discors**	f	Blue-winged teal	De la Zerda & Rosselli, 2003 (Colombia) Sporer et al., 2013 (USA) Brown & Drewien, 1995 (USA)	/LC	10*
Galliformes						
Cracidae	*Ortalis vetula*	g	Plain chachalaca		/LC	2**
	Ortalis poliocephala+	h	West Mexican chachalaca		/LC	1*
Odontophoridae	*Colinus virginianus*	i	Northern Bobwhite		/NT	2*
Phoenicopteriformes						
Phoenicopteridae	*Phoenicopterus ruber*		American Flamingo	Janss & Ferrer, 1998 (Spain) McNeil, 1985 (Venezuela) Rubolini et al., 2005 (Italy) Pérez et al., 2019 (Venezuela)	A/LC	10[a]
Columbiformes						
Columbidae (11 not id; 7*, 4**)	*Columbina inca*	j	Inca Dove		/LC	2*
	Columbina passerina	k	Common Ground-Dove		/LC	8*, 1***
	Columbina spp.	l				3*
	Leptotila verreauxi	m	White-tipped Dove	De la Zerda & Rosselli, 2003 (Colombia)	/LC	3*, 1**
	*Zenaida asiatica**	n	White-winged Dove	Rogers et al., 2014 (USA)	/LC	236*, 38**, 8***
	Zenaida macroura	o	Mourning Dove	Brown & Drewien, 1995 (USA) Rogers et al., 2014 (USA)	/LC	9*, 2**, 6***
Cuculiformes						
Cuculidae	*Crotophaga sulcirostris*	p	Groove-billed Ani		/LC	7*

(continued)

Table 1. (continued)

Order/Family	Species	Code	Common name	Literature with records of deaths associated with power lines	Conservation status NOM/IUCN	No. of carcasses
	Morococcyx erythropygus	q	Lesser Ground-Cuckoo		/LC	2*
	Geococcyx californianus	r	Greater Roadrunner		/LC	1**
Caprimulgiformes						
Caprimulgidae	*Chordeiles* sp.	s				1*
	*Chordeiles acutipennis**	t	Lesser Nighthawk	De la Zerda & Rosselli, 2003 (Colombia)	/LC	2*
	Nyctidromus albicollis	u	Common Pauraque	De la Zerda & Rosselli, 2003 (Colombia)	/LC	3*
Gruiformes						
Rallidae	*Porzana carolina**	v	Sora	De la Zerda & Rosselli, 2003 (Colombia) Sporer et al., 2013 (USA) Brown & Drewien, 1995 (USA)	/LC	1*
	Porphyrio martinicus	w	Purple Gallinule		/LC	2*
Aramidae	*Aramus guarauna*	x	Limpkin	De la Zerda & Rosselli, 2003 (Colombia)	A/LC	2*
Charadriiformes						
Burhinidae	*Burhinus bistriatus*	y	Double-striped Thick-knee	De la Zerda & Rosselli, 2003 (Colombia)	/LC	7*
Scolopacidae	*Gallinago delicata*	z	Wilson's Snipe		/LC	1*
Laridae	*Leucophaeus atricilla**	a*	Laughing Gull	Pérez et al., 2019 (Venezuela)	/LC	2*
	*Leucophaeus pipixcan**	b*	Franklin's Gull	Sporer et al., 2013 (USA)	/LC	6*
Pelecaniformes						
Ardeidae	*Ardea herodias**	c*	Great Blue Heron	Mojica et al., 2009 (USA) Brown & Drewien, 1995 (USA)	/LC	1*, 2[b], 3[c], 1[d]
	*Ardea alba**	d*	Great Egret	Pigniczki et al., 2019 (Hungary)	/LC	3*
	Egretta caerulea	e*	Little Blue Heron		/LC	1*
	Bubulcus ibis	f*	Cattle Egret	De la Zerda & Rosselli, 2003 (Colombia) Barrientos et al., 2012 (Spain) Ferrer et al., 2020 (Spain) Alonso et al., 1994 (Spain) Janss and Ferrer, 1998 (Spain)	/LC	40*
	Butorides virescens	g*	Green Heron	De la Zerda & Rosselli, 2003 (Colombia) probably	/LC	1*
	Nycticorax nycticorax	h*	Black-crowned Night-Heron	De la Zerda & Rosselli, 2003 (Colombia) Costantini et al., 2017 (Italy) McNeil, 1985 (Venezuela) Rubolini et al., 2005 (Italy) Pigniczki et al., 2019 (Hungary)	/LC	4***
Threskiornithidae	*Eudocimus albus*	i*	White Ibis		/LC	7*
	Platalea ajaja	j*	Roseate Spoonbill		/LC	1*
Cathartiformes						
Cathartidae	*Coragyps atratus*	k*	Black Vulture	De la Zerda & Rosselli, 2003 (Colombia)	/LC	1*

(continued)

Table 1. (continued)

Order/Family	Species	Code	Common name	Literature with records of deaths associated with power lines	Conservation status NOM/IUCN	No. of carcasses
	Cathartes aura	l*	Turkey Vulture	De la Zerda & Rosselli, 2003 (Colombia)	/LC	5*, 3***, ND[b], 14[c], 6[d]
Accipitriformes						
Pandionidae	*Pandion haliaetus*		Osprey	Mojica et al., 2009 (USA) Bayle, 1999 (France) Rubolini et al., 2005 (Italy) Fransson et al., 2019 (Switzerland) Melero et al., 2013 (Spain) Pérez et al., 2019 (Venezuela)	/LC	ND[b], 1[c]
Accipitridae	*Aquila chrysaetos*		Golden Eagle	Demerdzhiev, 2014 (Bulgaria) Janss, 2000 (Spain) Dwyer et al., 2014 (USA) Brown & Drewien, 1995 (USA) Bayle, 1999 (Germany, France, Spain) Rubolini et al., 2005 (Italy) Fransson et al., 2019 (Switzerland) Harness & Wilson, 2001 (USA, Canada)	A/LC	3[b], 24[c], 5[d]
	*Haliaeetus leucocephalus**		Bald Eagle	Olendorff and Lehman, 1986 cited in Eccleston & Harness, 2018 (no location) Mojica et al., 2009 (USA) Dwyer et al., 2014 (USA) Herness, 2008 cited in Mojica et al., 2020 (USA) Harness and Wilson, 2001 (USA, Canada)	P/LC	ND[b],1[c]
	Parabuteo unicinctus		Harris's Hawk	Dwyer & Mannan, 2007 (USA) Lehman, 2001 (USA) Dawson & Mann, 1994, cited in Lehman, 2001 (USA) Dwyer, 2009 (USA)	Pr/LC	1[c]
	*Buteo swainsoni**		Swainson's Hawk	Harness & Wilson, 2001 (USA, Canada)	Pr/LC	ND[b],1[c]
	Buteo jamaicensis		Red-tailed Hawk	Dwyer et al., 2014 (USA) Brown & Drewien, 1995 (USA) Kemper et al., 2013 (Canada) Harness & Wilson, 2001 (USA, Canada)	/LC	33[b],70[c], 14[d]
	*Buteo regalis**		Ferruginous Hawk	Harness & Wilson, 2001 (USA, Canada) Harmata et al., 2001 (USA)	Pr/LC	9[b], 28[c], 4[d]
Strigiformes						
Tytonidae	*Tyto alba*	m*	Barn Owl	Galis et al., 2019 (Slovakia) Ferrer et al., 2020 (Spain) Bayle, 1999 (France, Spain, Germany) Harness & Wilson, 2001 (USA, Canada)	/LC	1**, ND[b], 1[c]
Strigidae	*Asio flammeus**		Short-eared Owl	Shnayder et al., 2020 (Russia)	Pr/LC	ND[b]

(continued)

Table 1. (continued)

Order/Family	Species	Code	Common name	Literature with records of deaths associated with power lines	Conservation status NOM/IUCN	No. of carcasses
	Psiloscops flammeolus		Flammulated Owl		/LC	1[c]
	Bubo virginianus	n*	Great Horned Owl	Brown & Drewien, 1995 (USA) Kemper et al., 2013 (Canada) Harness & Wilson, 2001 (USA, Canada) Dwyer et al., 2018 (USA and Canada)	/LC	1**, ND[b], 4[c], 1[d]
Falconiformes						
Falconidae	*Caracara cheriway*	o*	Crested Caracara		/LC	2*
	Falco sparverius	p*	American Kestrel	Brown & Drewien, 1995 (USA)	/LC	1*, ND[b], 1[d]
	*Falco peregrinus**		Peregrine Falcon	Janss, 2000 (Spain) Bayle, 1999 (Spain, France) Rubolini et al., 2005 (Italy) Fransson et al., 2019 (Switzerland)	Pr/LC	2[c]
	Falco mexicanus		Prairie Falcon	Fox and Wynn, 2010 (No location)	A/LC	ND[b], 8[c]
Psittaciformes						
Psittacidae	*Eupsittula canicularis*	q*	Orange-fronted Parakeet		Pr/VU	1*
Passeriformes						
Tyrannidae	*Pitangus sulphuratus*	r*	Great Kiskadee			1*
	Tyrannus melancholicus	s*	Tropical Kingbird	De la Zerda & Rosselli, 2003 (Colombia)	/LC	4*
	Tyrannus verticalis	t*	Western Kingbird		/LC	1*
	*Tyrannus forficatus**	u*	Scissor-tailed Flycatcher		/LC	3*
Corvidae	*Corvus cryptoleucus*		Chihuahuan Raven		/LC	79[b], 259[c], 28[d]
	Corvus corax	v*	Common Raven	Lehman et al., 2010 (No location)	/LC	1***, 1[d]
Polioptilidae	*Polioptila caerulea*	w*	Blue-gray Gnatcatcher		/LC	1**
Turdidae	*Turdus grayi*	x*	Clay-colored Thrush		/LC	1*, 1**
Mimidae	*Mimus gilvus*	y*	Tropical Mockingbird		/LC	1*
	Mimus polyglottos	z*	Northern Mockingbird		/LC	1*
Passerellidae	*Arremonops rufivirgatus*	a+	Olive Sparrow		/LC	1**
	*Spizella passerina**	b+	Chipping Sparrow		/LC	3***
	Junco hyemalis	c+	Dark-eyed Junco		/LC	1**
	*Melospiza lincolnii**	d+	Lincoln's Sparrow	Rogers et al., 2014 (USA)	/LC	1*, 1**
Icteridae	*Sturnella magna*	e+	Eastern Meadowlark		/NT	1*

(continued)

Table 1. (continued)

Order/Family	Species	Code	Common name	Literature with records of deaths associated with power lines	Conservation status NOM/IUCN	No. of carcasses
	Icterus spp.	f+				3*
	*Icterus spurius**	g+	Orchard Oriole		/LC	2*, 1**
	Icterus pustulatus	h+	Streak-backed Oriole		/LC	3*
	Icterus gularis	i+	Altamira Oriole		/LC	2*
	Molothrus aeneus	j+	Bronzed Cowbird		/LC	1*
	Quiscalus mexicanus	k+	Great-tailed Grackle		/LC	10*
Parulidae	*Seiurus aurocapilla**	l+	Ovenbird		/LC	1*
	*Geothlypis philadelphia**	m+	Mourning Warbler		/LC	1**
	Setophaga sp.	n+				1**
	*Setophaga petechia**	o+	Yellow Warbler	Rogers et al., 2014 (USA)	/LC	2*
Cardinalidae	*Cardinalis cardinalis*	p+	Northern Cardinal		/LC	1**

Migratory species = * (*Zenaida asiatica* is migratory in Oaxaca but resident in Tamaulipas and Guanajuato), endemic species to Mexico = +. Conservation categories: Mexican Government (SEMARNAT, 2010): A = Threatened; P = Endangered; Pr = Subject to special protection; E = Probably extinct in the wild; (International Union for Conservation of Nature IUCN, 2021): LC = Least Concern, NT = Near Threatened, VU = Vulnerable, NE = Not Evaluated. Fieldwork location: * = Oaxaca, ** = Tamaulipas, *** = Guanajuato.
ND = no data of casualties, Cause (C = Collision, E = Electrocution). Not id = not identified (only to family taxonomic level).
[a]Ferrer-Sánchez et al., 2017.
[b]Cartron et al., 2005.
[c]Manzano-Fischer et al., 2007.
[d]Cartron et al., 2006.

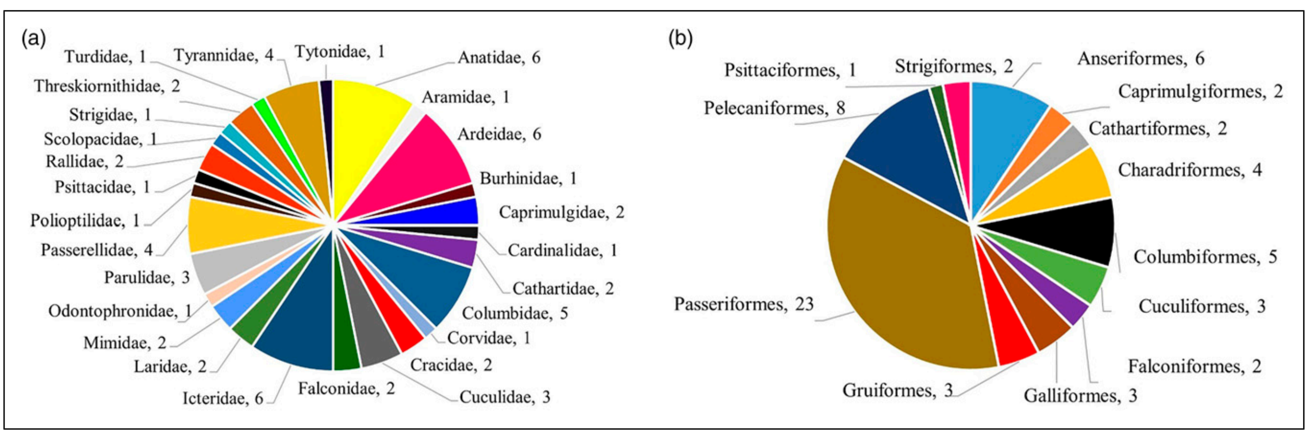

Figure 2. Taxonomic composition presented by families (a), and orders (b), of bird collision or electrocution records at three sites sampled in this study. Following to each name of families and orders are indicated the number of species.

focus on states with the greatest bird diversity, as well as in areas of importance for their conservation. Moreover, we could not identify 83 carcasses to species level. Therefore, future studies should incorporate other identification tools (e.g., molecular analysis; Dove et al., 2010) that enable more detailed information to be obtained on the affected species when feather evidence is insufficient for identification.

In this study, the White-winged Dove was by far the most frequently-recorded species affected with 282 records (57% of the identified carcasses). This is a novel finding, as low numbers of carcasses of this species have been identified in other studies (Rogers et al., 2014). The high number of recorded carcasses could be related to the presence of croplands at the study sites where these birds feed (Collins

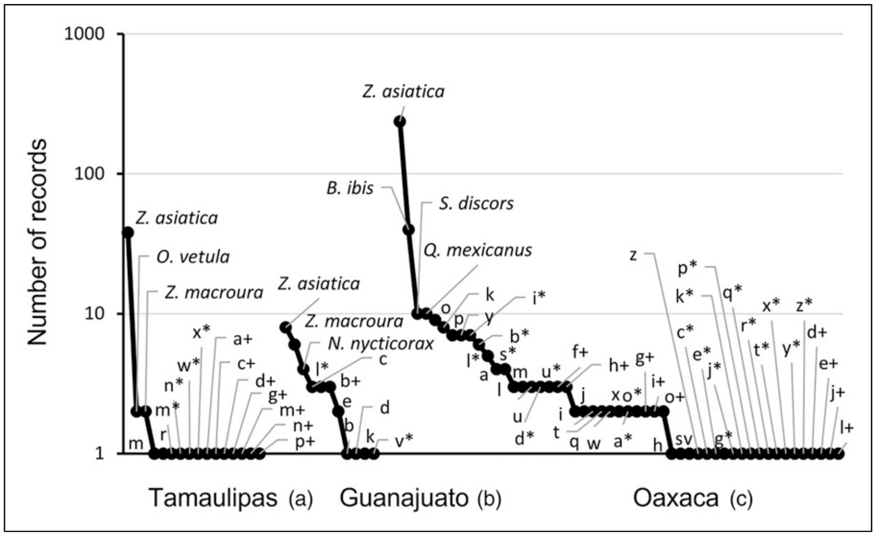

Figure 3. Rank-abundance plots for species with carcasses recorded in the sampled sites of Tamaulipas (a), Guanajuato (b) and Oaxaca (c), Mexico. The species codes are included in Table 1. a= *Dendrocygna autumnalis*, b= *Mareca strepera*, c= *Mareca americana*, d= *Anas platyrhynchos,* e= *Anas diazi*, f= *Spatula discors*, g= *Ortalis vetula*, h= *Ortalis poliocephala*, i= *Colinus virginianus*, j= *Columbina inca*, k= *Columbina passerina*, l= *Columbina* spp., m= *Leptotila verreauxi*, n= *Zenaida asiatica*, o= *Zenaida macroura*, p= *Crotophaga sulcirostris*, q= *Morococcyx erythropygus*, r= *Geococcyx californianus*, s= *Chordeiles* sp., t= *Chordeiles acutipennis*, u= *Nyctidromus albicollis*, v= *Porzana carolina*, w= *Porphyrio martinicus*, x= *Aramus guarauna*, y= *Burhinus bistriatus*, z= *Gallinago delicata*, a*= *Leucophaeus atricilla*, b*= *Leucophaeus pipixcan*, c*= *Ardea herodias*, d*= *Ardea alba*, e*= *Egretta caerulea*, f*= *Bubulcus ibis*, g*= *Butorides virescens*, h*= *Nycticorax nycticorax*, i*= *Eudocimus albus*, j*= *Platalea ajaja*, k*= *Coragyps atratus*, l*= *Cathartes aura*, m*= *Tyto alba*, n*= *Bubo virginianus*, o*= *Caracara cheriway*, p*= *Falco sparverius*, q*= *Eupsittula canicularis*, r*= *Pitangus sulphuratus*, s*= *Tyrannus melancholicus*, t*= *Tyrannus verticalis*, u*= *Tyrannus forficatus*, v*= *Corvus corax*, w*= *Polioptila caerulea*, x*= *Turdus grayi*, y*= *Mimus gilvus*, z*= *Mimus polyglottos*, a+= *Arremonops rufivirgatus*, b+= *Spizella passerina*, c+= *Junco hyemalis*, d+= *Melospiza lincolnii*, e+= *Sturnella magna*, f+= *Icterus* spp., g+= *Icterus spurius*, h+= *Icterus pustulatus*, i+= *Icterus gularis*, j+= *Molothrus aeneus*, k+= *Quiscalus mexicanus*, l+= *Seiurus aurocapilla*, m+= *Geothlypis philadelphia*, n+= *Setophaga* sp., o+= *Setophaga petechia*, p+= *Cardinalis cardinalis.*

et al., 2010). Likewise, the number of carcasses of Cattle Egret (40) and Mourning Dove (17) could be related to the fact that the characteristics of the surrounding habitats favor their presence, although it may also be influenced by the characteristics intrinsic to the species that make them more susceptible to these hazards, as reported in previous studies (Bernardino et al., 2018; Ferrer et al., 2020). In addition, it is important to mention that the removal rate of carcasses by predators is higher in smaller species, which could have led to a smaller number of carcasses being recorded for these species (Gómez-Catasús et al., 2020).

The number of species that we recorded from the Icteridae family (6 spp.) at the Oaxaca site was double than reported in Bevanger's review of North America (1998). This highlights the importance of generating more information in countries where data are scarce, as new patterns may be identified due to regional differences in the composition and structure of avian communities. We also identified a large number of Ardeidae species affected at the Oaxaca site. This result could be related to the present network of crop irrigation canals in the area used by these species, since aquatic birds are one of the groups most likely to collide with power lines (Bernardino et al., 2018) because of their morphological characteristics (low loadings; large wings), and flight strategy (thermal soarers) (Bevanger, 1998). The high proportion of Columbidae and Passerelidae (the last previously reported as Emberizidae) recorded at the Tamaulipas site is in agreement with the findings of Ferrer et al. (2020) for southern Spain. The fact that Anatidae species were the most affected at the Guanajuato site may be explained by the presence of water bodies next to power lines. This result also coincides with the findings of Bevanger (1998), who found this family to be the second most affected in terms of the number of species identified. The variation in the most affected families between sites could reflect differences in composition between bird communities at the three sites, as well as differences in the characteristics of the surrounding habitats.

The remarkably high number of species that we recorded in this study of the order Passeriformes is consistent with the findings of Bevanger (1998), where this order was reported to have the second-highest number of affected species. The highest proportion of birds killed being of Passeriformes species at the Tamaulipas and Oaxaca sites also agrees with the findings of previous studies (Demerdzhiev et al., 2009; Pigniczki et al., 2019), while Anseriformes, the group with the highest numbers of carcasses identified at the Guanajuato site, was also identified by Bevanger (1998) as one of three orders most greatly affected by power lines. In the case of Passeriformes, previous studies have found the majority of avian deaths within this order to have been related to the migration period

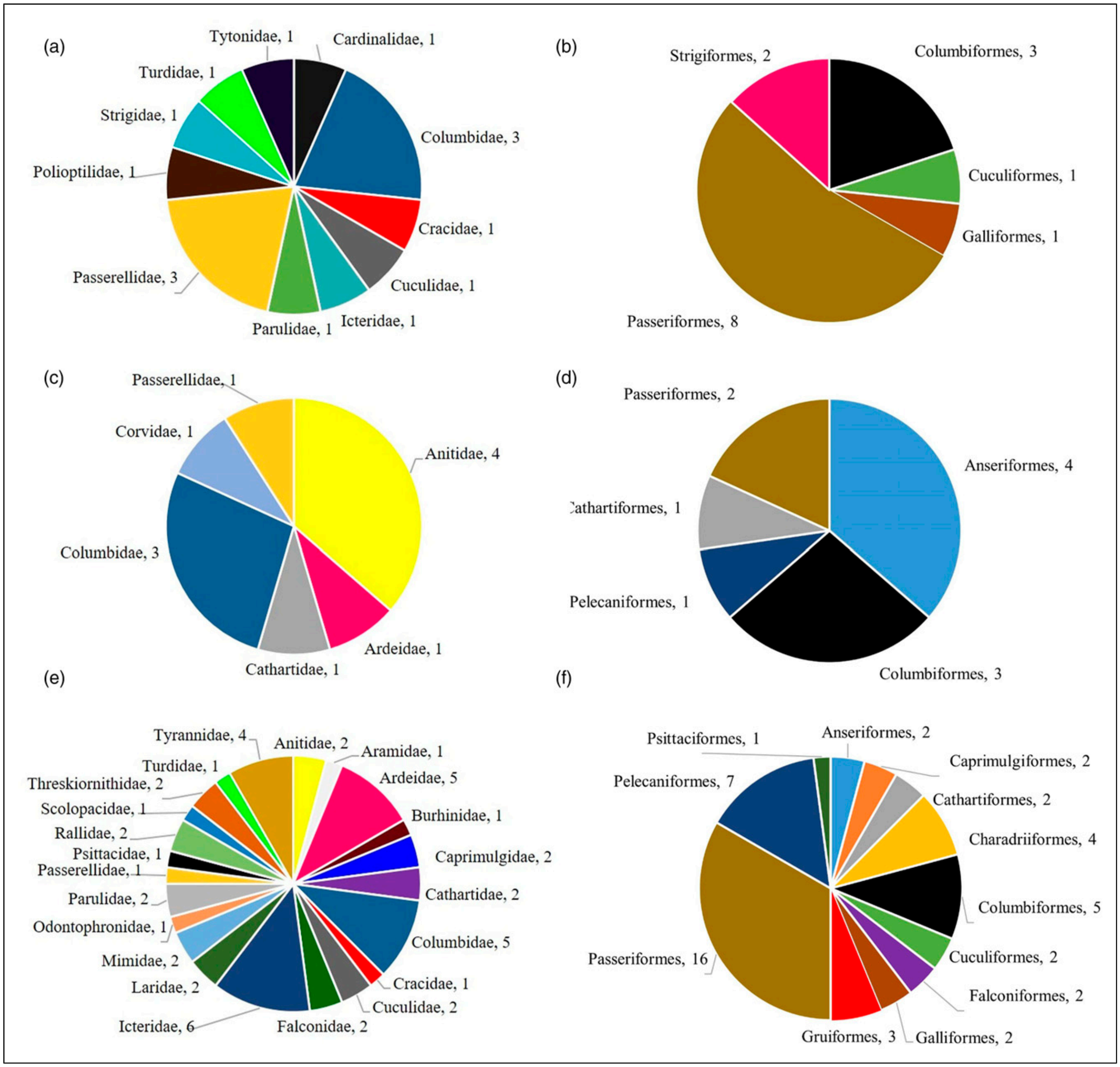

Figure 4. Taxonomic composition (presented by families (left) and orders (right) of birds with collision or electrocution records at sites in Tamaulipas (a, b), Guanajuato (c, d) and Oaxaca (e, f), Mexico. Following each name of families and orders, the number of species that make them up is indicated.

(Demerdzhiev et al., 2009), while the vulnerability of both orders can be attributed to their morphological characteristics.

It is important to note that more than half of the carcasses (56%) that could be identified at the species level belonged to Nearctic-Neotropical migrants, which is consistent with the findings of Bernardino et al. (2018) in their review, where they point out that migratory species are susceptible to being affected by power lines due their movements through unfamiliar terrain, their tendency to group in large numbers, and fly at low altitudes. This result partially coincides with other studies that have evaluated the death of birds related to human structures in Mexico (i.e., building windows), as Uribe-Morfín et al. (2021) reported that 56% of the records belonged to migratory species, while Gómez-Martínez et al. (2019) found this proportion to be 30%, although the families and species identified as the most affected differed from those identified in the present study. In the present study, the White-winged Dove was by far the most-affected species. Although populations of this species are stable (BirdLife International, 2016), the populations of many migratory species have decreased by more than 50% over the last four decades, mainly due to habitat loss (Rosenberg et al., 2016). As a result of this, and because large legal gaps exist in terms of conservation of migratory species in the regions where they spend the different seasons of the year (Runge et al., 2015), it is essential to broaden knowledge of the impact of power lines on this group in order to implement measures to help minimize mortality (Figure 5).

Bird Deaths Associated with Power Lines in Mexico

Through this and previous studies of avian electrocutions and collisions in Mexico (Cartron et al., 2000, 2005, 2006; Ferrer-Sánchez et al., 2017; Manzano-Fischer et al., 2007), a total of 77 different species have been identified as experiencing some level of power line-associated mortality. Fifty-nine of the species identified in this study have not been previously reported as affected by these structures in Mexico. These numbers suggest that power lines represent the cause of mortality affecting the widest range of bird species in the country, even greater than window collisions (71 species; Cupul-Magaña, 2003; Gómez-Martínez et al., 2019; Gómez-

Figure 5. Carcasses of birds recorded in the study sites of Tamaulipas: (a) White-winged Dove; Guanajuato: (b) Mexican Duck, (c) Chipping sparrow, (d) Black-crowned Night-Heron, (e) Mourning Dove; and Oaxaca: (f) White-winged Dove, (g) Cattle Egret, (h) Green Heron, (i) Turkey Vulture.

Moreno et al., 2018; Uribe-Morfin et al., 2021), and collision with wind turbines (29 species; Cabrera-Cruz et al., 2020; Uribe-Rivera et al., 2018). This does not mean that power lines are the main anthropogenic cause of direct bird deaths in the country, but it does reflect the enormous impact that these structures have on Mexican avifauna. In the United States, predation by cats and window collisions represent the main anthropogenic causes of direct death of birds (Loss et al., 2015), but data on each of these causes of death in Mexico are scarce. It is also important for future studies to evaluate deaths associated with structures related to renewable energy production (e.g., solar facilities), as they are also a major source of mortality, and their cumulative effects could have negative effects on populations (Conklin et al., 2022).

As far as we know, the list of species affected by power lines in Mexico is the most extensive on this topic in Latin America, exceeding the lists recorded for Colombia (46 spp.; De la Zerda & Rosselli, 2003), Venezuela (10 spp.; McNeil, 1985) and isolated records for Brazil and Argentina (Câmara-Gusmão et al., 2020; Sarasola et al., 2020). To our knowledge, no previous association has been identified in the scientific literature between power lines and avian mortality for 38 of the species registered in our study. Therefore, these results represent an important, novel contribution to knowledge about the impact of these structures on bird diversity. Even considering the important contribution of our study, information on the association between power lines and bird mortality in Mexico remains very limited. It is essential to develop systematized studies in the short term that can serve as a starting point to generate estimates of the number of bird deaths at both regional and national levels (Loss et al., 2014; Rioux et al., 2013).

Implications for Conservation

This study adds three species in categories of extinction risk to the list of bird species affected by power lines in Mexico, adding to the nine species in this condition registered in previous studies. We believe that this trend of the impact of power lines on endangered species being under-reported is likely to be repeated in many other Latin American countries, including those with greater bird diversity (e.g., Colombia, Peru, and Brazil), but the available information is very limited. Thus, it is essential to develop studies that consider population parameters to further understand the impact of power lines on populations of vulnerable birds (Marques et al., 2020). Special attention should be paid to species with some threat to their conservation either nationally or internationally (three species recorded in the fieldwork in this study), as well as groups such as raptors (including species of orders Accipitriformes, Falconiformes, and Strigiformes; McClure et al., 2019), previously reported among groups most affected by power lines (Eccleston & Harness, 2018; Lehman et al., 2007). In fact, more than half (8 of 12) of the nationally threatened species affected by power lines in Mexico are raptors (SEMARNAT, 2010). Similarly, another group that should receive special attention in future studies is the Nearctic-Neotropical migrants, since their numbers had been reduced considerably over the last three decades (Rosenberg et al., 2016). Data based on scientific studies are essential as a baseline to implement and propose mitigation measures that reduce the number of deaths caused by power lines (Barrientos et al., 2011; Bernardino et al., 2019; Chevallier et al., 2015; Dwyer et al., 2019; Ferrer et al., 2020; Luzenski et al., 2016). Practices such as conducting studies before the establishment of transmission lines can be useful to identify areas of higher risk for the avifauna (D'Amico et al., 2018; Luzenski et al., 2016).

It is concerning that 15 years have passed since the last study on the impact of power lines on national avifauna in Mexico was published (Manzano-Fischer et al., 2007). Future studies are needed that examine different environments (Costantini et al., 2017), different types of power lines and their characteristics (e.g., height, number of cables, and thickness), using different search methods for carcasses (Borner et al., 2017), and that evaluate the impact of power lines at different stages of the life cycle of birds (e.g., reproduction, migration; Johnson et al., 2002). Finally, there is no legal framework in Mexico that obliges companies to implement preventive actions to avoid or reduce bird deaths caused by the electric grid, unlike other countries such as the United States (Lehman, 2001) or Spain (BOE, 2008), where sentences have been handed down to power companies for failing to implement preventive measures resulting in deaths of threatened species (*Aquila chrysaetos*, *Buteo regalis* and *Bubo virginianus* in USA; *Aquila adalberti* in Spain) (El País, 2018). Therefore, it is essential to generate evidence-based scientific knowledge that will enable us to understand the magnitude of the problem represented by the power lines for the country's avifauna, and to be the starting point for society, the government, and private industry to search for strategies that benefit bird diversity, and, where appropriate, to fine companies that do not comply.

Acknowledgments

The authors are grateful to Tereso Hernández Morales, Manuel Cameras Flores, Marlene Soto, Patricia Degante González, William Ramos Arreola, Paola Figueroa Islas and Alex Coronel Jiménez for their technical support during fieldwork. Thanks are expressed to Oscar H. Marín Gómez and Miguel A. Gómez Martínez for their valuable comments on an earlier version of the manuscript and to Paulina García Bañuelos for drawing Figure 1. Two anonymous reviewer provided helpful suggestions that improved this manuscript. Margaret Schroeder and Frances Mcculloch revised the English of the manuscript.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) received no financial support for the research, authorship, and/or publication of this article.

ORCID iD

Rafael Villegas-Patraca https://orcid.org/0000-0003-4403-2613

References

Alonso, J. C., Alonso, J. A., & Muñoz-Pulido, R. (1994). Mitigation of bird collisions with transmission lines through groundwire marking. *Biological Conservation*, *67*(2), 129–134. https://doi.org/10.1016/0006-3207(94)90358-1

Anderson, W. L. (1978). Waterfowl collisions with power lines at a coal-fired power plant. *Wildlife Society Bulletin*, *6*(2), 77–83.

Balkenhol, N., & Waits, L. P. (2009). Molecular road ecology: Exploring the potential of genetics for investigating transportation impacts on wildlife. *Molecular Ecology*, *18*(20), 4151–4164. https://doi.org/10.1111/j.1365-294X.2009.04322.x

Barrientos, R., Alonso, J. C., Ponce, C., & Palacín, C. (2011). Meta-analysis of the effectiveness of marked wire in reducing avian collisions with power lines: Wire marking to reduce bird collisions. *Conservation Biology*, *25*(5), 893–903. https://doi.org/10.1111/j.1523-1739.2011.01699.x

Barrientos, R., Ponce, C., Palacín, C., Martín, C. A., Martín, B., & Alonso, J. C. (2012). Wire marking results in a small but significant reduction in avian mortality at power lines: A BACI designed study. *PLoS ONE*, *7*(3), Article e32569. https://doi.org/10.1371/journal.pone.0032569

Bayle, P. (1999). Preventing birds of prey problems at transmission lines in Western Europe. *Journal of Raptor Research 33*(1), 43–48.

Bernardino, J., Bevanger, K., Barrientos, R., Dwyer, J. F., Marques, A. T., Martins, R. C., Shaw, J. M., Silva, J. P., & Moreira, F. (2018). Bird collisions with power lines: State of the art and priority areas for research. *Biological Conservation*, *222*, 1-13. https://doi.org/10.1016/j.biocon.2018.02.029.

Bernardino, J., Martins, R. C., Bispo, R., & Moreira, F. (2019). Re-assessing the effectiveness of wire-marking to mitigate bird collisions with power lines: A meta-analysis and guidelines for field studies. *Journal of Environmental Management*, *252*, 109651. https://doi.org/10.1016/j.jenvman.2019.109651.

Bevanger, K., (1998). Biological and conservation aspects of bird mortality caused by electricity power lines: A review. *Biological Conservation*, *86*(1), 67–76. https://doi.org/10.1016/S0006-3207(97)00176-6

Biasotto, L. D., & Kindel, A. (2018). Power lines and impacts on biodiversity: A systematic review. *Environmental Impact Assessment Review*, *71*, 110-119. https://doi.org/10.1016/j.eiar.2018.04.010.

BirdLife International. (2016). Zenaida asiatica. The IUCN Red List of Threatened Species 2016: e.T22733956A95231875. https://dx.doi.org/10.2305/IUCN.UK.2016-3.RLTS.T22733956A95231875. Accessed on 05 April 2022.

BOE (Boletín Oficial del Estado). (2008). Real Decreto 262/2008. https://www.boe.es/buscar/doc.php?id=BOE-A-2008-4210. Accessed 04 May 2021.

Borner, L., Duriez, O., Besnard, A., Robert, A., Carrere, V., & Jiguet, F. (2017). Bird collision with power lines: Estimating carcass persistence and detection associated with ground search surveys. *Ecosphere*, *8*(11), Article e01966. https://doi.org/10.1002/ecs2.1966

Brown, W. M., & Drewien, R. C. (1995). Evaluation of two power line markers to reduce crane and waterfowl collision mortality. *Wildlife Society Bulletin*, *23*(2), 217–227.

Cabrera-Cruz, S., Cervantes-Pasqualli, J., Franquesa-Soler, M., Muñoz-Jiménez, O., Rodríguez-Aguilar, G., & Villegas-Patraca, R. (2020). Estimates of aerial vertebrate mortality at wind farms in a bird migration corridor and bat diversity hotspot. *Global Ecology and Conservation*, *22*, Article e00966. https://doi.org/10.1016/j.gecco.2020.e00966

Cabrera-Cruz, S. A., Cervantes-Pasquialli, J. A., Ruelas-Inzunza, E., Hernández-Morales, T., & Villegas-Patraca, R. (2017). Raptor and large soaring bird migration across the Isthmus of Tehuantepec, Mexico: Distribution, seasonality and phenology. *Bird Conservation International*, *27*(1), 111–126. https://doi.org/10.1017/S0959270916000423

Câmara-Gusmão, A., Degra, D., Diogo da Silva, O., Simão de Souza, L., Boas da Frota, A. V., Tuyama, C. A., Tuyama, M. C., Martins da Costa, T., Dalbem, A. P., Barnett, A. A., Aguiar-Silva, F. H., & Santos-Filho, M. (2020). Power lines as a threat to a canopy predator: Electrocuted Harpy eagle in southwestern Brazilian Amazon. *Journal of Threatened Taxa*, *12*(13), 16904–16908. https://doi.org/10.11609/jott.6198.12.13.16904-16908

Cartron, J. E., Garber, G. L., Finley, C., Rustay, C., Kellermueller, R., Day, M. P., Manzano-Fisher, P., & Stoleson, S. H. (2000). Power pole casualties among raptors and ravens in northwestern Chihuahua, Mexico. *Western Birds*, *31*(4), 255-257.

Cartron, J. E., Harness, R. E., Rogers, R. C., & Manzano-Fischer, P. (2005). Impact of concrete power poles on raptors and ravens in northwestern Chihuahua, Mexico. In: J. E. Cartron, G. Ceballos, & R. Stephen-Felger (Eds.), *Biodiversity, Ecosystems and Conservation in Northern Mexico*. (pp. 357–369) Oxford University Press.

Cartron, J. E., Rodríguez-Estrella, R., Rogers, R. C., Rivera-Rodríguez, L. B., & Granados Ruíz, J. B. (2006). Raptor and raven electrocutions in northwestern Mexico: A preliminary regional assessment of the impact of concrete poles. In: R. Rodríguez-Estrella (Ed.), *Current Raptor Studies in Mexico* (pp. 202–230). CIBNOR-CONABIO.

Chevallier, C., Hernández-Matías, A., Real, J., Vincent-Martin, N., Ravayrol, A., & Besnard, A. (2015). Retrofitting of power lines effectively reduces mortality by electrocution in large birds: An example with the endangered Bonelli's eagle. *Journal of Applied Ecology*, *52*(6), 1465–1473. https://doi.org/10.1111/1365-2664.12476

Collins, M. L., Small, M. F., Veech, J. A., Baccus, J. T., & Benn, S. J. (2010). Dove habitat association based on remotely sensed land cover types in South Texas. *Journal of Wildlife Management*, *74*(7), 1568–1574. https://doi.org/10.1111/j.1937-2817.2010.tb01285.x

Conklin, T. J., Vander Zanden, H. B., Allison, T. D., Diffendorfer, J. E., Dietsch, T. V., Duerr, A. E., Fesnock, A. L., Hernandez, R. R., Loss, S. R., Nelson, D. M., Sanzenbacher, P. M., Yee, J. L., & Katzner, T. E. (2022). Vulnerability of avian populations to renewable energy production. *Royal Society Open Science*, *9*, 211558. https://doi.org/10.1098/rsos.211558.

Costantini, D., Gustin, M., Ferrarini, A., & Dell'Omo, G. (2017). Estimates of avian collision with power lines and carcass disappearance across differing environments. *Animal Conservation*, *20*(2), 173-181. https://doi.org/10.1111/acv.12303.

Cupul-Magaña, F. G. (2003). Nota sobre colisiones de aves en las ventanas de edificios universitarios en Puerto Vallarta, México. *Huitzil, Revista Mexicana de Ornitología*, *4*(7), 17–21. https://doi.org/10.28947/hrmo.2003.4.2

D'Amico, M., Martins, R. C., Álvarez-Martínez, J. M., Porto, M., Barrientos, R., & Moreira, F. (2018). Bird collisions with power lines: Prioritizing species and areas by estimating potential population-level impacts. *Diversity and Distributions*, *25*(6), 975–982. https://doi.org/10.1111/ddi.12903

De la Zerda, S., & Rosselli, L. (2003). Mitigación de colisión de aves contra líneas de transmisión eléctrica con marcaje del cable de guarda. *Ornitología Colombiana*, *1*, 42-62.

Demerdzhiev, D. A. (2014). Factors influencing bird mortality caused by power lines within special protected areas and undertaken conservation efforts. *Acta Zoologica Bulgarica*, *66*(2), 411–423.

Demerdzhiev, D. A., Sotychev, S. A., Petrov, T. H., Angelov, I. D., & Nedyalkov, N. P. (2009). Impact of power lines on bird mortality in southern Bulgaria. *Acta Zoologica Bulgarica*, *61*(2), 175–183.

Dove, C. J., Rotzel, N. C., Heacker, M., & Weigt, L.A. (2010). Using DNA barcodes to identify bird species involved in birdstrikes. *The Journal of Wildlife Management*, *72*(5), 1231–1236 https://doi.org/10.2193/2007-272

Dwyer, J. F. (2009). Raptor electrocution: A case study on ecological traps, sinks, and additive mortality. *Journal of Natural Resources and Life Sciences Education*, *38*(1), 93–98. https://doi.org/10.4195/jnrlse.2009.0002u

Dwyer, J. F., Harness, R. E., & Donohue, K. (2014). Predictive model of avian electrocution risk on overhead power lines. *Conservation Biology*, *28*(1), 159–168. https://doi.org/10.1111/cobi.12145

Dwyer, J. F., Hindmarch, S., & Kratz, G. E. (2018). Raptor mortality in urban landscape In: W. Boal, & C. R. Dykstra (Eds.), *Urban raptors: Ecology and conservation of birds of prey in cities* (pp. 199–213). Springer International Publishing. https://doi.org/10.5822/978-1-61091-841-1

Dwyer, J. F., & Mannan, W. (2007). Preventing raptor electrocutions in an urban environment. *The Journal of Raptor Research*, *41*(4), 259–267. https://doi.org/10.3356/0892-1016(2007)41[259:PREIAU]2.0.CO;2

Dwyer, J. F., Pandey, A. K., McHale, L. A., & Harness, R. E. (2019). Near-ultraviolet light reduced Sandhill Crane collisions with a power line by 98%. *The Condor*, *121*(2), 1-10. https://doi.org/10.1093/condor/duz008.

Eccleston, D. T., & Harness, R. E. (2018). Raptor electrocutions and power line collisions. In: J. Hernán-Sarasola, J. M. Grande, & J. J. Negro (Eds.), *Birds of prey, biology and conservation in the XXI century* (pp. 273–302). Springer International Publishing. https://doi.org/10.1007/978-3-319-73745-4

El País. (2018). Primera sentencia firme contra una empresa eléctrica por la electrocución de aves. https://elpais.com/elpais/2018/03/21/ciencia/1521657772_727656. Accessed 05 June 2019.

Ferrer, M., Morandini, V., Baumbush, R., Muriel, R., De Lucas, M., & Calabuig, C. (2020). Efficacy of different types of "bird flight diverter" in reducing bird mortality due to collision with transmission power lines. *Global Ecology and Conservation*, *23*, Article e01130. https://doi.org/10.1016/j.gecco.2020.e01130

Ferrer-Sánchez, A., Salazar-Sosa, E. A., González-Rosales, S. A., & Gálvez-Aguilera, X. (2017). Análisis de la mortalidad de individuos anillados de flamencos (*Phoenicopterus ruber*) en los humedales costeros de Yucatán, México. *Revista Cubana de Ciencias Biológicas*, *5*(3), 1-7.

Fox, N. C., & Wynn, C. (2010). The impact of electrocution on the New Zealand falcon (*Falco novaeseelandiae*). *Notornis 57*(2), 71–74. https://www.birdsnz.org.nz/publications/the-impact-of-electrocution-on-the-new-zealand-falcon-falco-novaeseelandiae/

Fransson, T., Jansson, L., Kolehmainen, T., & Wenninger, T. (2019). Collisions with power lines and electrocutions in birds –an analysis based on Swedish ringing recoveries 1990-2017. *Ornis Svecica*, *29*, 37-52. https://doi.org/10.34080/os.v29.19731.

Galis, M., Nado, L., Hapl, E., Smidt, J., Deutschova, L., & Chavko, J. (2019). Comprehensive analysis of bird mortality along power distribution lines in Slovakia. *Raptor Journal*, *13*(1), 1-25. https://doi.org/10.2478/srj-2019-0006.

Gómez-Catasús, J., Carrascal, L. M., Moraleda, V., Colsa, J., Garcés, F., & Schuster, C. (2020). Factors affecting differential underestimates of bird collision fatalities at electric lines: A case study in the canary Islands. *Ardeola*, *68*(1), 71–94. https://doi.org/10.13157/arla.68.1.2021.ra5

Gómez-Martínez, M. A., Klem, D., Rojas-Soto, O., González-García, F., & MacGregor-Fors, I. (2019). Window strikes: Bird collisions in a Neotropical green city. *Urban Ecosystems*, *22*(4), 699–708. https://doi.org/10.1007/s11252-019-00858-6

Gómez-Moreno, V. D. C., Herrera-Herrera, J. R., & Niño-Maldonado, S. (2018). Colisión de aves en ventanas del Centro Universitario Victoria, Tamaulipas, México. *Huitzil, Revista Mexicana de Ornitología*, *19*(2), 227-236. https://doi.org/10.28947/hrmo.2018.19.2.347.

Guil, F., Fernández-Olalla, M., Moreno-Opo, R., Mosqueda, I., Gómez, M. E., Aranda, A., Arredondo, A., Guzmán, J., Oria, J., González, L. M., & Margalida, A. (2011). Minimising mortality in endangered raptors due to power lines: The importance of spatial aggregation to optimize the application of mitigation measures. *PLoS ONE*, *6*, Article e28212. https://doi.org/10.1371/journal.pone.0028212

Guil, F., & Pérez-García, J. M. (2022). Bird electrocution on power lines: Spatial gaps and identification of driving factors at global scales. *Journal of Environmental Management*, *301*, 113890. https://doi.org/10.1016/j.jenvman.2021.113890.

Harmata, A. R., Restani, M., Montopoli, G. J., Zelenak, J. R., Ensign, J. T., & Harmata, P. J. (2001). Movements and mortality of ferruginous hawks banded in Montana. *Journal of Field Ornithology*, *72*(3), 389–398. https://doi.org/10.1648/0273-8570-72.3.389

Harness, R. E., & Wilson, K. R. (2001). Electric-utility structures associated with raptor electrocutions in rural areas. *Wildlife Society Bulletin*, *29*(2), 612–623.

Hyde, J. L., Bohlman, S. A., & Valle, D. (2018). Transmission lines are an under-acknowledged conservation threat to the Brazilian Amazon. *Biological Conservation*, *228*, 343-356. https://doi.org/10.1016/j.biocon.2018.10.027.

International Union for Conservation of Nature (IUCN). (2021). The IUCN red list of threatened species. Version 2021-3. https://www.iucnredlist.org/

Janss, G. F. E. (2000). Avian mortality from power lines: A morphologic approach of a species-specific mortality. *Biological Conservation*, *95*(3), 353–359. https://doi.org/10.1016/S0006-3207(00)00021-5

Janss, G. F. E., & Ferrer, M. (1998). Rate of bird collision with power lines: Effects of conductor-marking and static wire-marking. *Journal of Field Ornithology*, *69*(1), 8–17.

Jenkins, A. R., Smallie, J. J., & Diamond, M. (2010). Avian collisions with power lines: A global review of causes and mitigation with a South African perspective. *Bird Conservation International*, *20*(3), 263–278. https://doi.org/10.1017/S0959270910000122

Johnson, G. D., Erickson, W. P., Strickland, M. D., Shepherd, M. F., Shepherd, D. A., & Sarappo, S. A. (2002). Collision mortality of local and migrant birds at a large-scale wind-power development on Buffalo Ridge, Minnesota. *Wildlife Society Bulletin*, *30*(3), 879–887. https://doi.org/10.2307/3784243

Kemper, C. M., Gordon, S. C., & Beck, J. A. (2013). Estimating raptor electrocution mortality on distribution power lines in Alberta, Canada. *The Journal of Wildlife Management*, *77*(7), 1342–1352. https://doi.org/10.1002/jwmg.586

Lehman, R. N. (2001). Electrocution on power lines: Current issues and outlook. *Wildlife Society Bulletin*, *29*(3), 804–813. https://doi.org/10.2307/3784405

Lehman, R. N., Kennedy, P. L., & Savidge, J. A. (2007). The state of the art in raptor electrocution research: A global review. *Biological Conservation*, *136*(2), 159–174. https://doi.org/10.1016/j.biocon.2006.09.015

Lehman, R. N., Savidge, J. A., Kennedy, P. L., & Harness, R. E. (2010). Raptor electrocution rates for a utility in the intermountain Western United States. *Journal of Wildlife Management*, *74*(3), 459–470. https://doi.org/10.2193/2008-332

Loss, S. R., Will, T., & Marra, P. P. (2014). Refining estimates of bird collision and electrocution mortality at power lines in the United States. *PLoS ONE*, *9*(7), Article e101565. https://doi.org/10.1371/journal.pone.0101565

Loss, S. R., Will, T., & Marra, P. P. (2015). Direct mortality of birds from anthropogenic causes. *Annual Review of Ecology, Evolution, and Systematics*, *46*(1), 99–120. https://doi.org/10.1146/annurev-ecolsys-112414-054133

Luzenski, J., Rocca, C. E., Harness, R. E., Cummings, J. L., Austin, D. D., Landon, M. A., & Dwyer, J. F. (2016). Collision avoidance by migrating raptors encountering a new electric power transmission line. *The Condor*, *118*(2), 402–410. https://doi.org/10.1650/CONDOR-15-55.1

Magurran, A. E. (2004). *Measuring biological diversity*. Blackwell Science.

Malcolm, J. M. (1982). Bird collisions with a power transmission line and their relation to botulism at a Montana wetland. *Wildlife Society Bulletin*, *10*(4), 297–304.

Manzano-Fischer, P., List, R., Cartron, J. L., Sierra, R., & Ponce, E. (2007). Electrocución de aves en líneas de distribución de energía eléctrica en México. *Biodiversitas*, *72*, 11-15.

Marques, A. T., Martins, R. C., Silva, J. P., Palmeirim, J. M., & Moriera, F. (2020). Power line routing and configuration as major drivers of collision risk in two bustard species. *Oryx*, *55*(3), 442–451. https://doi.org/10.1017/S0030605319000292

McClure, C. J. W., Schulwitz, S. E., Anderson, D. L., Robinson, B. W., Mojica, E. K., Therrien, J.-F., Oleyar, M. D., & Johnson, J. 2019. Commentary: Defining raptors and birds of prey. *Journal of Raptor Research 53*(4), 419–430. https://doi.org/10.3356/0892-1016-53.4.419

McNeil, R. (1985). Bird mortality at a power line in northeastern Venezuela. *Biological Conservation*, *31*(2), 153–165. https://doi.org/10.1016/0006-3207(85)90046-1

Melero, M., González, F., Nicolás, O., López, I., Jiménez, M. A., Jato-Sánchez, S., & Sánchez-Vizcaíno, J. M. (2013). Detection and assessment of electrocution in endangered raptors by infrared thermography. *BMC Veterinary Research*, *9*, 149. https://doi.org/10.1186/1746-6148-9-149.

Mojica, E. K., Rocca, C. E., Luzenski, J., Harness, R. E., Cummings, J. L., Schievert, J., Austin, D. D., & Landon, M. A. (2020). Collision avoidance by wintering bald eagles crossing a transmission line. *Journal of Raptor Research*, *54*(2), 147–153. https://doi.org/10.3356/0892-1016-54.2.147

Mojica, E. K., Watts, B. D., Paul, J. T., Voss, S. T., & Pottie, J. (2009). Factors contributing to bald eagle electrocutions and line collisions on Aberdeen Proving Ground, Maryland. *Journal of Raptor Research*, *43*(1), 57–61. https://doi.org/10.3356/JRR-07-60.1

Navarro-Sigüenza, A., Rebón-Gallardo, M. F., Gordillo-Martínez, A., Towsend-Peterson, A., Berlanga-García, H., & Sánchez-González, L. A. (2014). Biodiversidad de las aves en México. *Revista Mexicana de Biodiversidad*, *85*(Suppl), S476-S495. http://dx.doi.org/10.7550/rmb.41882

Pérez, E, Muñoz, J., Marín, G., & Velázquez, R. (2019). Mortalidad de aves marinas por tendido de transmisión eléctrica en el nororiente de Venezuela: 30 años después. *Boletín del Instituto Oceanográfico de Venezuela*, *58*, 1-7.

Pigniczki, C., Bakró-Nagy, Z., Bakacsi, G., Barkóczi, C, Nagy, T., Puskás, J., & Enyedi, R. (2019). Preliminary results on bird collision with overhead power lines in Hungary: A case study around Pusztaszer landscape protection area. *Ornis Hungarica*, *27*(1), 221–238. https://doi.org/10.2478/orhu-2019-0012

Rioux, S., Savard, J.P. L., & Gerick, A. A. (2013). Avian mortalities due to transmission line collisions: A review of current estimates and field methods with an emphasis on applications to the Canadian electric network. *Avian Conservation and Ecology*, *8*(2), 7. http://dx.doi.org/10.5751/ACE-00614-080207

Rogers, A. M., Gibson, M. R., Pockette, T., Alexander, J. L., & Dwyer, J. F. (2014). Scavenging of migratory bird carcasses in the Sonoran Desert. *The Southwestern Naturalist*, *59*(4), 544–549. https://doi.org/10.1894/MCG-08.1

Rosellón, J. (2007). An incentive mechanism for electricity transmission expansion in Mexico. *Energy Policy*, *35*(5), 3003–3014. https://doi.org/10.1016/j.enpol.2006.10.026

Rosenberg, K. V., Kennedy, J. A., Dettmers, R., Ford, R. P., Reynolds, D., Alexander, J. D., Beardmore, C. J., Blancher, P. J., Bogart, R. E., Butcher, G. S., Camfield, A. F., Couturier, A., Demarest, D. W., Easton, W. E., Giocomo, J. J., Keller, R. H., Mini, A. E., Panjabi, A. O., Pashley, D. N., & Will, T. (2016). Partners in flight landbird conservation plan: 2016 revision for Canada and continental United States. Partners in flight science committee. 119. https://partnersinflight.org/wp-content/uploads/2016/08/pif-continental-plan-final-spread-double-spread.pdf

Rubolini, D., Gustin, M., Bogliani, G., & Garavaglia, R. (2005). Birds and powerlines in Italy: An assessment. *Bird Conservation International*, *15*(2), 131-145. https://doi.org/10.1017/S0959270905000109.

Runge, C. A., Watson, J. E. M., Butchart, S. H. M., Hanson, J. O., Possingham, H. P., & Fuller, R. A. (2015). Protected areas and global conservation of migratory birds. *Science*, *350*(6265), 1255-1258. https://doi.org/10.1126/science.aac9180.

Sarasola, J. H., Galmes, M. A., & Watts, B. D. (2020). Electrocution on power lines is an important threat for the endangered Chaco Eagle (*Buteogallus coronatus*) in Argentina. *Journal of Raptor Research*, *54*(2), 166–171. https://doi.org/10.3356/0892-1016-54.2.166

Secretaría de Gobernación (SEGOB). (2015). Comisión para el dialogo con pueblos indígenas de México. La energía eólica en México: Una perspectiva social sobre el valor de la tierra. 46. www.segob.mx

Secretaría de Medio Ambiente y Recursos Naturales (SEMARNAT). (2010). Norma Oficial Mexicana NOM-059-ECOL-2010, protección ambiental-Especies nativas de México de flora y fauna silvestres-Categorías de riesgo y especificaciones para su inclusión, exclusión o cambio—lista de especies en riesgo. Proyecto de Modificación del Anexo Normativo III. Diario Oficial de la Federación. October 2019. Gobierno de México. 87.

Shnayder, E. P., Nikolenko, E. G., & Karyakin, I. V. (2020). Electrocutions of birds on power lines in the Khakassia Republic, Rusia, in 2020. *Raptors Conservation*, *41*, 26-63. https://doi.org/10.19074/1814-8654-2020-41-26-63.

Škorpíková, V., Hlaváč, V., & Křápek, M. (2019). Bird mortality on medium-voltage power lines in the Czech Republic. *Raptor Journal*, *13*(1), 27-44. https://doi.org/10.2478/srj-2019-0007.

Slater, S. J., Dwyer, J. F., & Murgatroyd, M. (2020). Conservation letter: Raptors and overhead electrical systems. *Journal of Raptor Research*, *54*(2), 198–203. https://doi.org/10.3356/0892-1016-54.2.198

Sporer, M. K., Dwyer, J. F., Gerber, B. D., Harness, R. E., & Pandey, A. K. (2013). Marking power lines to reduce avian collisions near the Audubon National Wildlife refuge, North Dakota. *Wildlife Society Bulletin*, *37*(4), 769–804. https://doi.org/10.1002/wsb.329

Uribe-Morfin, P., Gómez-Martínez, M. A., Moreles-Abonce, L., Olvera-Arteaga, A., Shimada-Beltrán, H., & MacGregor-Fors, I. (2021). The invisible enemy: Understanding bird-window strikes through citizen science in a focal city. *Ecological Research*, *36*(3), 430–439. https://doi.org/10.1111/1440-1703.12210

Uribe-Rivera, M. A., Guevara-Carrizales, A. A., & Ruiz-Campos, G. (2018). Mortalidad incidental de aves paseriformes en un parque eólico del noroeste de México. *Huitzil, Revista Mexicana de Ornitología*, *20*(1), 1–7. https://doi.org/10.28947/hrmo.2019.20.1.377