



## Review article

## Post-construction bird and bat fatality monitoring studies at wind energy projects in Latin America: A summary and review

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## HIGHLIGHTS

- Post-construction fatality monitoring studies at wind projects have focused on North America and Europe.
- A comprehensive review of potential direct impacts is needed for Latin America.
- General impact assessments are impeded by the regional knowledge gap.
- Conservation and management strategies in would benefit from publishing region-specific findings in the primary literature.

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## ABSTRACT

Most post-construction fatality monitoring (PCFM) studies to date have focused on North America and Europe, and this information has been used to assess the impacts of large-scale wind energy on birds and bats. A comprehensive review of wind-wildlife fatality information is still lacking for Latin America; however, given the current installed capacity and the projected increase of wind energy production across Latin America, it is important to fill in the knowledge gap on impacts to wildlife. To provide a current summary of known impacts to birds and bats in Latin America and to identify gaps on this important information, we compiled, reviewed, and synthesized bird and bat fatality information at wind energy projects in the region. Our literature search resulted in 10 references relevant to the scope of this review, six of which provided number of fatalities by species and the type of PCFM search being conducted, meeting our criteria for inclusion in fatality summaries. From this pool, we found that Passerines composed the majority of bird fatalities, with no Threatened bird species reported. The bat family Molossidae composed the majority of bat fatalities, with one Threatened bat species reported. Our review of all studies and focused assessment of only those studies with fatality summaries indicated differences in the amount of information and level of detail related to bird and bat fatalities at wind energy projects in Latin America. Due to the taxon-specific nature of collision risk with wind turbines for birds and bats, it is difficult to make a general impact assessment of wind energy development on birds and bats in Latin America, especially given the limited information available. However, this summary can be used as a starting point to inform conservation efforts aiming at avoiding, minimizing, and mitigating impacts of wind energy development on birds and bats and future, standardized results would enhance our ability to do so.

## 1. Introduction

Wind energy, considered an efficient and sustainable way of producing energy [1, 2], is generally viewed favorably with respect to impacts on climate change and when properly sited and operated, wind energy projects (projects) minimize impacts on wildlife and may have an overall positive

impact on biodiversity conservation [3, 4]. Despite its perceived advantages, there is concern about the potential for negative ecological consequences of wind energy development on wildlife [5, 6, 7]. Direct impacts of wind energy development on birds and bats, including collisions with turbines, have been recognized and continue to be studied [8]. Reviews of these impacts are available in the literature (e.g., [9, 10, 11, 12, 13]). Furthermore,

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project-specific data suggest that bird and bat fatalities vary among regions and taxa, and can have potential negative population-level effects for some species or species groups [14, 15, 16].

Information from post-construction fatality monitoring (PCFM) studies conducted across North America has been used to assess the impacts of large-scale wind energy on birds and bats [17, 18]. However, the wind-energy industry growth is outpacing research on the effects of wind energy development on wildlife, with several data gaps related to issues such as the species being impacted, the fatality risk relative to the location of projects and key resources, and the cumulative impacts of collision mortality [8]. This gap is even deeper in regions where wind energy development has been showing significant growth, compounded with a general lack of information regarding wind-wildlife interactions, such as Latin America [19, 20, 21]. Most PCFM studies to date have focused on North America and Europe [11, 22], and a comprehensive review of wind-wildlife fatality information is still lacking for Latin America.

The installed wind energy capacity in Latin America has tripled over the past few years, growing from 10,736 MW (MW) in 2014 to 33,272 MW in 2019, with Brazil, Mexico, and Chile at the top of the ranking [23]. While wind energy production in Latin America is still in an early stage of development, it has shown a steady increase proportional to more mature markets, such as the European and North American markets, and this growth trend is expected to continue in the foreseeable future [24, 25]. Given the current installed capacity and the projected increase of wind energy production across Latin America, it is important to fill in the knowledge gap on impacts to wildlife.

The main objective of this manuscript is to review and synthesize the published literature about the direct impacts of wind energy development on birds and bats in Latin America from publicly available PCFM studies at onshore wind projects conducted through 2020. Specifically, we aimed at reviewing fatality information of birds and bats at projects in Latin America, to provide a current summary of known impacts to birds and bats and to identify gaps on this important information.

## 2. Methods

### 2.1. All studies

We conducted a comprehensive bibliographic review of existing, publicly available references on bird and bat fatality information for Latin America through the year 2020. For this review, the definition of Latin America was based on the criteria from the United Nations Educational, Scientific, and Cultural Organization (UNESCO [26]) and World Atlas [27], with modifications, to include all the countries and territories of South and Central America (including Mexico) and the Caribbean Islands (including Puerto Rico). For the web search, we used Google Search Engine (<https://www.google.com/>), with final searches completed by August 1, 2020, using combinations of the following key words: Latin America, South America, Central America, Mexico, Caribbean, birds, avian, bats, fatality, mortality, wind, turbine, facility, project, collision, effects, impacts, post-construction, monitoring, evaluation (with their corresponding Spanish terms). For the specialized literature, we consulted Google Scholar (<https://scholar.google.com/>); the American Wind Wildlife Institute [28] and The Library of Congress [29] literature databases; and recent bibliographic reference lists [30, 31].

The resulting pool of search results was evaluated through a desktop review to categorize references based on their relevance, determined by the type or level of information related to bird and bat fatalities in Latin America. Guided by the objectives of this study, only references that corresponded to bird, bat or bird and bat PCFM studies at projects in Latin America, and that included explicit fatality information, were included. Information from these references regarding project

geographic location, survey dates, how fatalities were found (standardized PCFM searches or incidentally), individuals and/or species found and their International Union for Conservation of Nature (IUCN) conservation status (Least Concern, Near Threatened, and Threatened; [32]), was compiled to determine which references would be used for further review. Although individual countries in Latin America might have their own threatened species listings (and should be consulted for individual countries), Threatened species (Vulnerable, Endangered, and Critically Endangered species) in this study were defined following the IUCN Red List [32], as these globally accepted criteria for assessing extinction risk have been adopted by many countries worldwide, and specifically, in Latin America [33, 34].

References that provided number of fatalities per species, as well as the type of search being conducted, were reviewed in further detail and the species-specific information presented in them constitutes the core for our bird and bat fatality summaries. References that contained qualitative (species names) or quantitative (number of fatalities) fatality-related information but no species-level data (numbers of fatalities per species) that could be compiled for species-specific fatality summaries, or references that didn't clearly state which fatalities were found during what type of search (i.e., during standardized PCFM searches or incidentally) were excluded from further review. Information regarding the composition of bird and bat fatalities from all references, including those that did not meet our criteria for inclusion in fatality summaries, is presented in this review.

### 2.2. Studies with bird and bat fatality summaries

The in-depth review focused on project-level information potentially influencing bird and bat fatalities or exposure to wind turbines, such as geographic location and MW capacity [12]; and fatality-related information, such as number of individuals and species. The summaries include only fatalities found during standardized PCFM searches; fatalities found incidentally were not included in fatality summaries.

For each reference reviewed in detail, we present general information on some key elements of an adequate PCFM study design [35], including survey dates, bias information, and fatality estimates as number of fatalities per MW per year (MW/year). All the information presented in section 3.2 was obtained directly (i.e., data was explicitly provided) or indirectly (i.e., values were derived from geographic information or fatality data and project specifications provided) from the references used for our fatality summaries. We mapped the uncorrected (raw) number of bird fatalities by order and bat fatalities by family for each of the projects included in the fatality summaries. This information allows one to view the distribution and composition of avian and bat fatalities in Latin America.

## 3. Results

### 3.1. All studies

Our comprehensive literature search resulted in 10 references containing information relevant to the scope of this review. These references spanned 19 years, from 2009–2020, and included five countries/territories in Latin America. References corresponded to PCFM studies for birds (two studies), bats (four studies), and both birds and bats (four studies); however, not all of these studies provided number of fatalities by species or the type of PCFM search being conducted, and therefore, did not meet our criteria for inclusion in fatality summaries (see section 3.2). From this set, five references presented data from Mexico, two from Brazil and one reference each from Puerto Rico, Uruguay, and Chile. The projects with the most references were La Venta II (four references), located in the Isthmus of Tehuantepec in southern Mexico, and Osório

Wind Farm (two references), located along the coastal plains of southern Brazil. Appendices A and B present a complete list of the species and/or numbers of individuals reported per reference.

### 3.1.1. Birds

Passeriformes composed the majority of bird fatalities (62 fatalities) reported across studies, followed by Columbiformes (58), Galliformes (21), Cathartiformes (18), and diurnal raptors (Accipitriformes and Falconiformes; 11 fatalities). The remaining orders had seven fatalities or less each (Appendix A). A minimum of 209 bird fatalities from at least 69 species were reported, with number of fatalities per study ranging from zero at Sierra de Los Caracoles in Uruguay [36] to 115 at La Venta II in Mexico ([37]; Appendix A). The northern bobwhite (*Colinus virginianus*; [Linnaeus, 1758]), categorized as Near Threatened by the IUCN, was the bird species with the majority of fatalities (20 total) reported across studies, followed by turkey vulture (*Cathartes aura*; [Linnaeus, 1758]) and white-tipped dove (*Leptotila verreauxi* Bonaparte, 1855) with 17 fatalities each. Great-tailed grackle (*Quiscalus mexicanus* [Gmelin, 1788]), white-winged dove (*Zenaida asiatica* [Linnaeus, 1758]), and Inca dove (*Columbina inca* [R. Lesson, 1847]) had 13 fatalities each, followed by common ground dove (*Columbina passerina* [Linnaeus, 1758]), with 12 fatalities (Appendix A). The other bird species had nine total fatalities or less reported per species.

Diurnal raptors ranked fourth in terms of the uncorrected number of fatalities reported in Latin America (Appendix A), with all but one species, variable hawk (*Geranoaetus polyosoma* [Quoy and Gaimard, 1824]) at Los Cururos in Chile [38] reported at La Venta II [37, 39]. No IUCN Threatened bird species were reported as fatalities; however, three Near Threatened species including northern bobwhite, eastern whip-poor-will (*Caprimulgus [Antrosomus] vociferus* [Wilson, A, 1812]), and cinnamon-tailed sparrow (*Peucaea sumichrasti* [Lawrence, 1871]) reported one fatality each at La Venta II in Mexico ([37]; Appendix A). All the other bird species have a conservation status of Least Concern ([32]; Appendix A). Fatalities of Inca dove were reported in five of the seven studies where bird fatalities were found, with the majority of fatalities (46.2%) at the Northern Wind Farm in Mexico [40]. Turkey vulture and common ground dove were reported in four of the studies, with the majority of fatalities (70.6% and 75.0%, respectively) at La Venta II in Mexico [37]. All the other bird species were reported in three or less of the studies (Appendix A).

### 3.1.2. Bats

Molossidae composed the majority of bat fatalities (415 fatalities) reported across studies, followed by Mormoopidae (313), Vespertilionidae (125), and Phyllostomidae (93 fatalities; Appendix B). The remaining families had eight fatalities or less each. A minimum of 983 bat fatalities from at least 40 species were reported, with number of fatalities per study ranging from zero at the Western Wind Farm in Mexico [40] to 336 at Osório Wind Farm in Brazil ([41]; Appendix B). Mexican free-tailed bat (*Tadarida brasiliensis* [I. Geoffroy, 1824]) and Davy's naked-backed bat (*Pteronotus davyi* Gray, 1838) were the bat species with the majority of fatalities (274 and 219; respectively) reported across studies, followed by far by ghost-faced bat (*Mormoops megalophylla* [Peters, 1864]; 62 fatalities).

Two IUCN Threatened bat species were reported as fatalities: southern long-nosed bat (*Leptonycteris curasoae* Miller, 1900; four fatalities at La Venta II; [37]) and minor red bat (*Lasiurus minor* Miller, 1931; one fatality at Unnamed Facility in Puerto Rico; [42]), both categorized as Vulnerable by the IUCN [32]. With the exception of two Near Threatened bat species (lesser long-nosed bat [*L. yerbabuena* Martínez and Villa-R, 1940] and red fruitbat [*Stenoderma rufum* Desmarest, 1820], with five and three fatalities, respectively) all other bat species have a conservation status of Least Concern. Fatalities of Mexican free-tailed bat were reported in all but two projects (Northern and Eastern wind farms; [40]), with the majority of fatalities (89.4%) reported at the Osório Wind Farm

in Brazil [41]. Velvety free-tailed bat (*Molossus molossus* [Pallas, 1766]) was also reported in all but two studies (Sierra de Los Caracoles in Uruguay and Los Cururos in Chile), with the majority of fatalities (30.5%) reported at La Venta II in Mexico [37]. All the other bat species were reported in four or less of the studies (Appendix B).

### 3.2. Studies with bird and bat fatality summaries

Of the 10 references identified during the literature review, six met our criteria for inclusion in bird and bat fatality summaries (Table 1). The other four references reported only fatalities found incidentally or did not clearly state the type of search being conducted, and/or provided species found as fatalities but not number of fatalities per species (Appendices A and B). We excluded these four references to provide a focused assessment of bird and bat fatalities from studies with a more rigorous study design. Turbine size varied from 0.85–2.00 MW; Project installed capacity varied from 10–160 MW of installed capacity; and elevation ranged from approximately 20–243 m above sea level (Table 1). Values that were indirectly derived included elevation and location of Los Cururos and the Unnamed Facility in Puerto Rico, which were obtained from geographic coordinates provided in these references [38, 42]. Fatality estimates for the Unnamed Facility in Puerto Rico, expressed here as fatalities per MW/year, were calculated from the estimated total fatalities and the total installed MW information provided in this reference [42]. All other values in Table 1 were obtained directly from the cited references. Below we summarize the results from these six references to provide a comprehensive assessment of avian and bat fatalities reported from Latin America.

Most of the PCFM studies did not cover a full year, except for those conducted at the Unnamed Facility in Puerto Rico [42] and at Los Cururos in Chile [38], while all but two PCFM studies [38, 41] provided fatality estimates on a MW/year or turbine/year basis (Table 1). However, regardless of duration of PCFM study, all the references that provided fatality estimates stated providing a corrected estimate. Four of the six references included in the summary provided fatality estimates and reported performing bias corrections (Table 1). References provided different levels of information related to one or more of the following sources of bias used in calculation of fatality estimates: searcher efficiency trials, carcass persistence trials, and area correction. Some references used one or more published bias values as proxies [40, 43] while other conducted bias trials as part of the PCFM study [36, 42].

#### 3.2.1. Birds

A total of 90 bird fatalities were reported in references included in the fatality summary (Table 1). Except for Los Cururos in Uruguay, all the other projects included in the summary reported bird fatalities (Table 1; Figure 1). The uncorrected number of bird fatalities at the projects where bird fatalities were found ranged between four at the Western Wind Farm in Mexico to 37 at the Northern Wind Farm in Mexico (Table 1, Figure 1). The number of bird species ranged between two at the Western Wind Farm in Mexico to 17 at the Northern Wind Farm in Mexico (Table 1), with at least 31 different species within 10 orders reported as fatalities (Figure 1; Appendix A).

Most of the fatalities (40.0%) were passerines. Species from the order Passeriformes were recorded at all of the projects where bird fatalities were found, composing 24.3–60.0% of fatalities across studies (Figure 1). Columbiformes was the next most highly represented group (three of the four projects where bird fatalities were found), composing 14.7–50.0% of fatalities across projects where birds were found (Figure 1). The order Accipitriformes represented 1.1% of the overall fatalities contained in the fatality summary, with one fatality found at Los Cururos in Chile (Figure 1). None of the birds found as fatalities at the projects included in the summary are Threatened. One Near Threatened species, the northern bobwhite, was

**Table 1.** Bird and bat fatality summaries from post-construction fatality monitoring (PCFM) studies conducted at wind energy projects in Latin America. Uncorrected (raw) number (#) of fatalities and # of identified species reported in PCFM studies are provided. Data are presented by project. Only information from references that reported # of fatalities found during standardized searches and # of fatalities per species was included in this summary table. See Appendices A and B for details.

Parameter <sup>a</sup>	Western Wind Farm, southern Mexico	Northern Wind Farm, southern Mexico	Eastern Wind Farm, southern Mexico	La Venta II, southern Mexico	Unnamed Facility, eastern Puerto Rico	Osório Wind Farm, southern Brazil	Sierra de Los Caracoles, southern Uruguay	Los Cururos, northern Chile
<b>Project characteristics</b>								
# turbines	31	98	80	98	13	75	5	57
MW/turbine	0.85	0.85	2.00	0.85	1.80	2.00	2.00	1.80–2.00
Total installed MW	26.35	86.50	160.00	83.30	23.40	150.00	10.00**	110.00
Elevation (MASL)	20–50	20–50	20–50	74	7–70	20	210–300	243**
Location	Isthmus TTP	Isthmus TTP	Isthmus TTP	Isthmus TTP	Naguabo Municipality**	Coastal plains	Maldonado Department	Coquimbo Region
Citation	[40]	[40]	[40]	[43]	[42],	[41]	[36]	[38]
<b>Carcass searches</b>								
Survey dates	Jul–Nov, 2015	Jun–Nov, 2015	Jun–Nov, 2015	Mar–Oct, 2009–2013	Feb 2013–Dec 2014	2006–2009	Apr 18–May 19, 2008	Aug 2015–Jul 2016
<b>Bird fatality information</b>								
# fatalities	4	37	34	NA	NA	NA	0	15
# species	2	17	15	NA	NA	NA	0	7
Bias (yes; no) <sup>b</sup>	Yes <sup>▲</sup>	Yes <sup>▲</sup>	Yes <sup>▲</sup>	NA	NA	NA	Yes	No
Fatality estimate (fatalities/MW/year) <sup>c</sup>	12.85	11.56	9.06	NA	NA	NA	NA*	NA
<b>Bat fatality information</b>								
# fatalities	0	49	23	203	37	336	2	27
# species	0	13	14	21	10	9	1	2
Bias (yes; no) <sup>b</sup>	Yes <sup>▲</sup>	Yes <sup>▲</sup>	Yes <sup>▲</sup>	Yes <sup>▲</sup>	Yes	No	Yes	No
Fatality estimate (fatalities/MW/year) <sup>c</sup>	NA*	43.79	20.47	57.41**	6.54**(Year 2013)	NA	16.32	NA
					2.78**(Year 2014)			

Abbreviations as follow: NA not applicable/available; MW megawatts; MASL meters above sea level; TTP Tehuantepec.

<sup>a</sup> Double asterisk (\*\*) denotes values derived from information provided in reference. All other values were explicitly provided in references.

<sup>b</sup> Reference provided information related to one or more of the following sources of bias information used in calculation of fatality estimates: searcher efficiency trials, carcass persistence trials, and area correction. Triangle (▲) denotes references that used one or more published bias values as proxies.

<sup>c</sup> Asterisk (\*) denotes fatality estimates not calculated due to low number of fatalities found.

recorded at the Northern and Eastern wind farms in Mexico, and all the other bird species reported as fatalities in the studies included in the summary have a conservation status of Least Concern (IUCN 32; Appendix A).

### 3.2.2. Bats

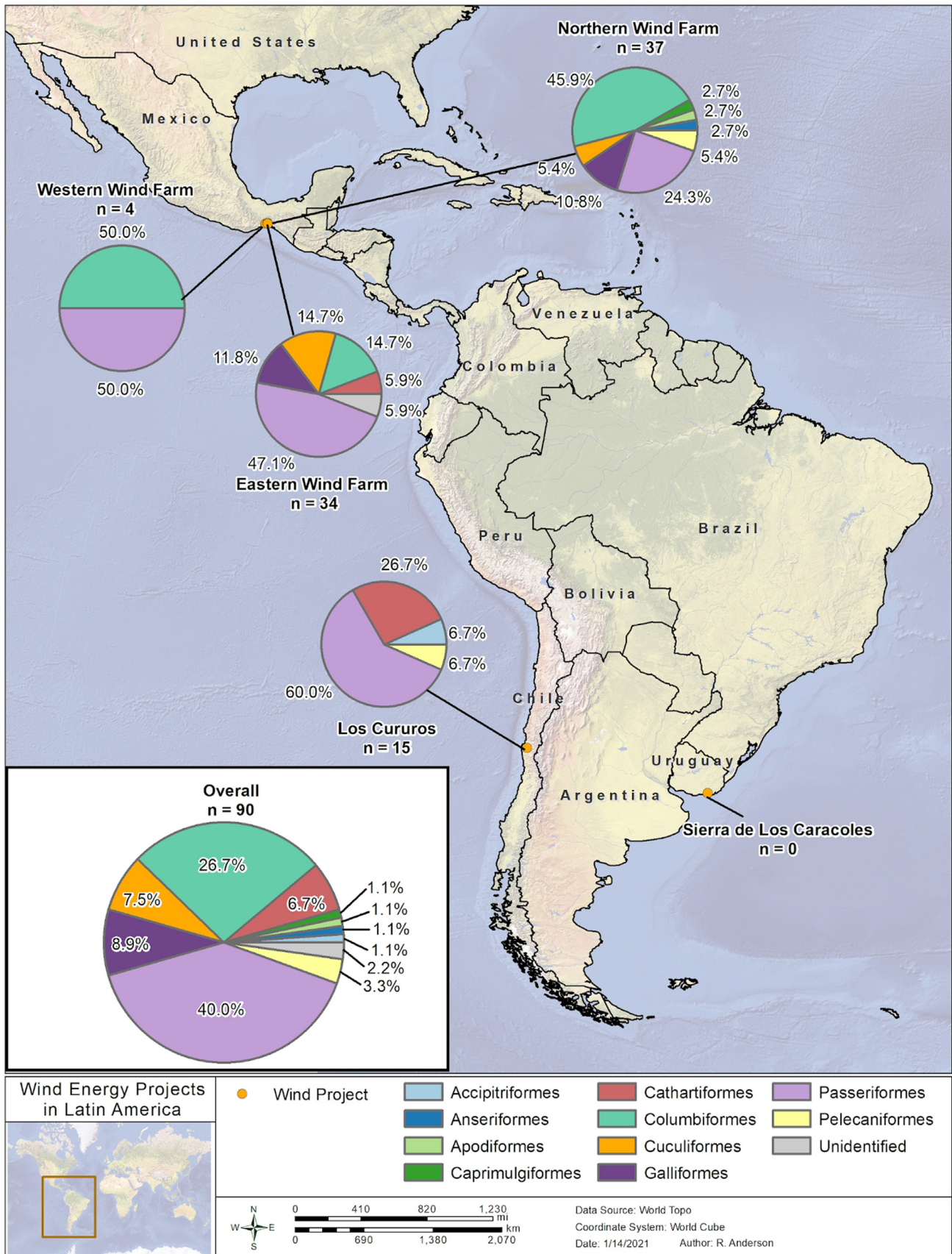
A total of 677 bat fatalities were reported in references included in the fatality summary (Table 1). Except for the Western Wind Farm in Mexico, all the other projects included in the summary reported bat fatalities (Table 1; Figure 2). The uncorrected number of bat fatalities at projects where bat fatalities were found ranged between two at Sierra de Los Caracoles in Uruguay to 336 at the Osório Wind Farm in Brazil (Table 1). The number of bat species ranged between one at Sierra de Los Caracoles in Uruguay to 21 at La Venta II in Mexico (Table 1), with at least 33 different bat species within six families reported as fatalities overall (Figure 2; Appendix B). The majority (seven of the total 10) of bat species recorded as fatalities during standardized searches at the Unnamed Facility in Puerto Rico were unique to this study [42]; this was due in part to their geographic ranges being restricted to the Caribbean islands (Appendix B).

Most of the bat fatalities (54.5%) were molossidids (Figure 2). Species from the family Molossidae were recorded at all of the seven projects where bat fatalities were found, with a single project, Sierra de Los Caracoles in Uruguay, having 100% of fatalities from this family; fatalities from the family Molossidae composed 14.3–88.9% of fatalities across all other studies (Figure 2; Appendix B). Vespertilionidae, Phyllostomidae, and Moormopidae were the next most commonly represented families, being reported at six, five, and four of the projects and composing 13.9%, 8.7%, and 18.0% of the overall bat fatalities, respectively (Figure 2). The families Emballonuridae and Noctilionidae were the least commonly represented, being found at only two of the projects and composing 0.6% or less of the overall bat

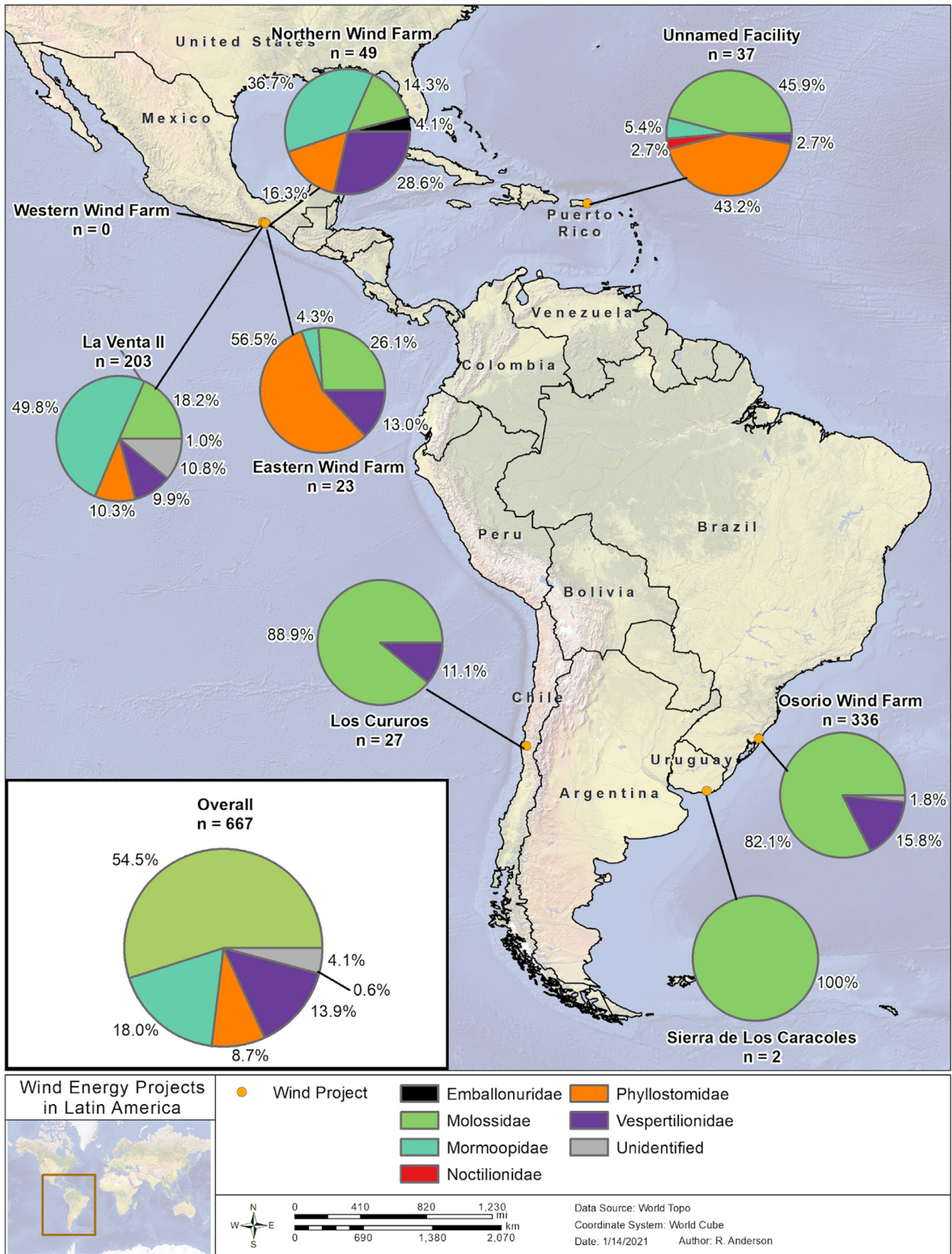
fatalities (Figure 2). Minor red bat, an IUCN Vulnerable species, was the only Threatened species included in our fatality summary, with one fatality found at the Unnamed Facility in Puerto Rico. Except for lesser long-nosed bat at La Venta II in Mexico [43], all the other bat species reported as fatalities in the studies included in the summary have a conservation status of Least Concern (IUCN 32; Appendix B).

## 4. Discussion

Our literature review of all studies and focused assessment of only those studies with fatality summaries indicated differences in the amount of information and level of detail related to bird and bat fatalities at projects in Latin America. Results from all studies provided a more comprehensive assessment of the species richness (count of species), whereas results from the more detailed studies provided a more accurate assessment of the relative proportion of bird and bat fatalities, along with fatality estimates. There was a geographic bias in the number of publicly available PCFM reports relative to the MW of installed capacity. Annual fatality numbers most likely increase with increased installed wind energy capacity [44] and according to our results, the number of publicly available PCFM reports is not proportional to the MW of installed capacity in Latin American countries. Compared to its installed capacity of 15,452 MW as of 2019 [23], Brazil was under-represented with only two studies [41, 45] from one project (Osório Wind Farm with 150 MW of installed capacity). However, Mexico, with an installed capacity of 6,215 MW as of 2019 [23], had the most studies available (four references; [37, 39, 40, 46]) from at least three different projects (La Rumorosa; La Venta II; and Eastern, Western, and Northern wind farms). The current level of fatality information available for Latin America is likely inadequate for



**Figure 1.** Bird fatality summary from post-construction fatality monitoring (PCFM) studies conducted at wind energy projects in Latin America. Percent composition (%) of uncorrected (raw) number of bird fatalities by Order is presented by project and overall; n = number of bird carcasses reported from each PCFM study and overall. Information from the following references: Rodríguez et al. [36], Hiriart Lamas and Cea Villablanca [38], Cabrera-Cruz et al. [40].



**Figure 2.** Bat fatality summary from post-construction fatality monitoring (PCFM) studies conducted at wind energy projects in Latin America. Percent composition (%) of uncorrected number of bat fatalities by family is presented by project and overall; n = number of bat carcasses reported from each PCFM study and overall. Information from the following references: Rodríguez et al. [36], Hiriart Lamas and Ceja Villablanca [38], Cabrera-Cruz et al. [40], Barros et al. [41], Rodríguez-Durán and Feliciano-Robles [42], Bolívar-Cimé et al. [43].

the development and implementation of adequate conservation and management goals, and any further assessment is impeded by the overall lack of fatality data from areas with a relatively high proportion of installed wind energy capacity.

La Venta wind complex has been operating since 1994, when the first turbines at La Venta were installed, followed by La Venta II in 2004, and La Venta III in 2009 [47]; however, PCFM studies were not conducted until 2007, with the first publicly available reference from studies conducted between 2007–2011 [37]. The other project for which we found more than one reference was the Osório Wind Farm in Brazil, built in stages between 2006–2015 [48]. The limited bird and bat fatality information from PCFM studies in Latin America could be attributed to the fact that PCFM studies are usually conducted for individual clients and reports are not required to be made public, and the lack of consistent and official PCFM guidelines [49]. Argentina, Chile, and Uruguay have published guidelines for good management practices related to wind energy development [50, 51, 52]. Some countries such as Mexico do not have official wind energy guidelines but instead have requirements to complete environmental impact assessments and wildlife studies after construction. Similarly, projects being financed by international lenders require environmental studies but the results do not have to be made public. There are major gaps in the distribution and availability of PCFM studies from Latin America that prevent a clear understanding of project impacts on birds and bats in this large, diverse region.

The majority of references corresponded to studies conducted at projects in areas of potentially high bird and bat use. La Venta II is located in the Isthmus of Tehuantepec, a region with a high flow of Nearctic-Neotropical migrant bird species [53, 54] and a biodiverse bat community [55], within the Mesoamerican hotspot [56]. Similarly, the Osório Wind Farm is located in the coastal plains of southern Brazil within the Atlantic Forest biome, one of the biodiversity hotspots in the world characterized by high species diversity and endemism [57]. Bird and bat communities in these regions have taxonomic compositional differences from those elsewhere in Latin America. Because of the species-specific or taxon-specific nature of collision risk with wind turbines for birds and bats, it is difficult to make a general assessment on impacts of projects on birds and bats in Latin America, especially given the limited information available.

#### 4.1. Birds

The composition of avian fatalities from Latin America (69 species) covers a diverse suite of species. Summaries of publicly available data from 482 studies between the years 1995 and 2018 across 221 projects the United States (USA) have reported 336 species [13] of birds as fatalities. The larger number of species reported from the USA reflects the greater number of projects and available data over a longer time. Undoubtedly, the number of species reported as fatalities will increase as more information becomes available from projects in Latin America.

The Southwest region of the USA (including Arizona, New Mexico, Oklahoma, and Texas) has reported 77 avian species as fatalities, with the top five species including horned lark (*Eremophila alpestris* [Linnaeus, 1758]), turkey vulture, mourning dove (*Zenaidura macroura* [Linnaeus, 1758]), northern bobwhite, and grasshopper sparrow (*Ammodramus savaannarum* [Gmelin, 1789]; [13]). Although there are many differences in the species composition between the USA and Latin America, there are some wide-ranging species that occur in both regions. As an example, the northern bobwhite, a IUCN Near Threatened species within the top five species recorded as fatalities in the Southwest region of the USA, occurs throughout parts of Mexico and the Caribbean and was also identified as having the most fatalities in this Latin America summary.

Two of the projects, La Venta II and Los Cururos, are located along recognized migratory routes where nearby topographic features influence patterns of raptor migration [58, 59]. The risk of birds colliding with wind turbines during migration is a concern for wind energy development [8] and a main consideration for siting of infrastructure and implementation of mitigation strategies worldwide [60, 61] and

specifically, in Latin America [19, 20, 21]. As suggested by Villegas-Patracca and Herrera-Alsina [62] in a study conducted in the Isthmus of Tehuantepec, long-term monitoring programs need to be implemented for assessing the impact of wind energy development on migrant birds. However, when resources are limited minimization and mitigation measures are prioritized over long-term studies.

#### 4.2. Bats

The composition of bat fatalities from Latin America covers a diverse suite of species. Summaries of publicly available data from the USA (482 studies from 1995–2018 across 221 projects) have reported 27 bat species as fatalities [13]. The larger number of species reported from Latin America (40 species) reflects the higher species diversity in this region, despite the greater number of projects and available data from the USA. Undoubtedly, the number of species reported as fatalities will increase as more information becomes available from projects in Latin America.

The Southwest region of the USA has reported 13 bat species as fatalities, with the top five species including the Mexican free-tailed bat, hoary bat (*Lasiurus cinereus* [Palisot de Beauvois, 1796]), evening bat (*Nycticeius humeralis* [Rafinesque, 1818]), northern yellow bat (*Lasiurus intermedius* H. Allen, 1862), and silver-haired bat (*Lasiorycteris noctivagans* [La Conte, 1831]; [13]). Although there are many differences in the species composition between the USA and Latin America, there are some wide-ranging species that occur in both regions. For example, one of the top five species (Mexican free-tailed bat) of fatalities in the Southwest region of the USA occurs throughout much of Latin America and was also identified in our summary as having the most fatalities. On the other hand, bats in the genus *Lasiurus*, known to be among the most collision susceptible bats in the USA due in part to their migratory and tree-roosting habits [10, 14], were not as commonly reported as fatalities in Latin America according to our summary. However, for species already declining and with restricted geographic ranges such as the minor red bat, a IUCN Threatened species reported as fatality in Latin America [42], additional fatalities from collision could have a compound effect, and additional species-specific and regional information is needed to make any assessments.

Based on the results of our fatality summaries, there is not enough information to make general statements related to the potential effects of wind energy development on birds and bats in Latin America or any inferences beyond the data presented in this summary. However, our results emphasize the value in collecting, summarizing, and disseminating species-level information on bird and bat fatalities from projects worldwide to share valuable information that could be used by policy makers, managers, and scientists when integrating appropriate management practices into adequate biodiversity conservation goals that could ultimately be implemented when developing new projects. Similarly, these results highlight the importance of planning and siting wind infrastructure relative to areas of high concentrations of birds and bats, as well as the importance of implementing adaptive management and surveillance programs. Several considerations have to be made when interpreting these results. First, the fatality summaries presented here are based on uncorrected numbers of fatalities, and therefore, are not directly comparable among studies or reports. Second, PCFM monitoring protocols varied across studies, which adds to the limitations of making direct comparisons. Third, it is possible that additional information exists, but are as of yet unavailable, to aid in this assessment. The expansion of projects across Latin America into areas with different biotic and abiotic characteristics, and the constant technological advances may raise new questions and challenges for the study of bird and bat fatalities in this region.

Future research is needed regarding the particular characteristics of PCFM studies and the comparability of fatality estimates among studies conducted in Latin America, as well as on the particular characteristics of the project that influence risk of collision. Despite the limitations, valuable information in terms of bird and bat species encountered as fatalities in projects throughout Latin America was reported in these references.

This information could eventually be used in the context of regional fatalities and potential population-level impacts as additional information becomes available.

## 5. Conclusions

The number of publicly available fatality monitoring studies or reports of bird and bat fatalities at projects in Latin America is scarce. The information presented in this summary can be used to inform our current understanding of the distribution and relative number of avian and bat fatalities in Latin America and to identify the important gaps in our knowledge. Projects in Latin America will largely be guided by information derived in future studies, but publishing region-specific findings in the primary literature should be a priority. Standardized PCFM methodology with current state of the art estimators (such as GenEst [63]) would greatly enhance our ability to make comparisons across projects. The current information can be used as a starting point to inform conservation efforts aiming at avoiding, minimizing, and mitigating impacts of wind energy development on birds and bats and future, standardized results would enhance our ability to do so.

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### Declaration of interests statement

The authors declare the following conflict of interests: M. Sofia Agudelo reports a relationship with Western EcoSystems Technology, Inc. that includes: employment. Todd J. Mabee reports a relationship with Western EcoSystems Technology, Inc. that includes: employment. Rosa Palmer reports a relationship with Western EcoSystems Technology, Inc. that includes: employment. Ryan Anderson reports a relationship with Western EcoSystems Technology, Inc. that includes: employment. Western EcoSystems Technology, Inc. provided support in the form of salaries for all authors. This does not alter our adherence to all Heliyon policies on sharing data and information. The specific roles of each author are detailed in the "Author contribution" statement file.

### Additional information

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