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Research Letters

Power lines and birds: An overlooked threat in South America

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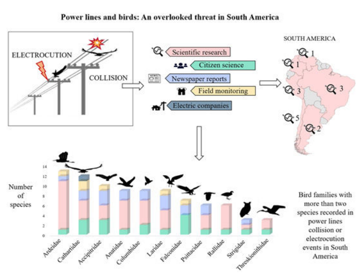
HIGHLIGHTS

- Power lines are a major cause of bird mortality due to electrocutions and collisions.
- This threat has been poorly studied in South America.
- Scientific and grey literature suggest this threat is present in this subcontinent.
- A total of 85 bird species from 34 families affected by power lines were identified.
- More studies assessing bird mortality due to this threat in South America are needed.

GRAPHICAL ABSTRACT



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ABSTRACT

Power lines endanger birds around the world, as a large number of them are killed every year through electrocutions and collisions. This problem can have severe consequences at population level, particularly for threatened species. While this threat has been widely studied in different parts of the world, information from South America is scarce. Here, we review information from scientific and grey literature on the collision and electrocution of birds on power lines from this sub-continent. We complement this information with novel data provided by a citizen science project, electrical companies and field monitoring records. Our results show that although in South America scientific and anecdotal information on this topic is scarce, data suggests that this threat is present in many areas of this sub-continent and affects several species, some of which are seriously threatened. However, information on the most affected species, the number of individuals impacted, the most dangerous geographical areas and the effectiveness of mitigation action is scarce and mainly anecdotal. This is worrying, because South America is a hot spot of biodiversity with many threatened and endemic bird species. We urge conservationists to evaluate this problem in more detail, define areas where it is important to avoid power line installation and establish priority areas for implementation of effective mitigation actions. Scientific evidence shows

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that dangerous power lines require retrofitting, but this knowledge should also be applied to the new energy facilities and the establishment of national regulations, which would undoubtedly reduce the impact of this infrastructure on wildlife.

Introduction

The increasing use of airspace by human devices and structures is producing intense impacts on wildlife ecology and conservation (Lambertucci et al., 2015). Among the diverse human structures invading the airspace, power lines are one of the most important because they produce relevant negative impacts on bird species worldwide (Bevanger, 1998; Bernardino et al., 2018; Jenkins et al., 2010; Lehman et al., 2007). Overhead power lines and associated infrastructure cause different negative interactions with wildlife (e.g., behavioral changes, alterations of physiology, endocrine system and immune function of birds; Fernie and Reynolds, 2005). However, bird direct mortality by collision or electrocution is the one that is of most concern, as it affects a large number of individuals annually (Erickson et al., 2005; Loss et al., 2014, 2015; Rioux et al., 2013). These impacts on birds could even have significant consequences on the population dynamics of the affected species, especially for threatened ones (e.g., Galmes et al., 2017; Hernández-Matías et al., 2015; Jenkins et al., 2010; Tavecchia et al., 2012).

Worryingly, a large number of bird species affected by this issue are considered of conservation concern (Bevanger, 1998; Slater et al., 2020). For example, electrocutions on power lines have been reported to be a major cause of mortality of european threatened raptors such as the Bonelli's Eagle (*Aquila fasciata*) (Hernández-Matías et al., 2015; Rollán et al., 2010), and the Spanish Imperial Eagle (*Aquila adalberti*) in Spain (López-López et al., 2011), Saker Falcon (*Falco cherrug*) in Mongolia (Dixon et al., 2020), or the Cape Vulture (*Gyps coprotheres*) in South Africa (Boshoff et al., 2011). On the other hand, collisions have been reported as an important cause of non-natural fatalities in Great Bustard (*Otis tarda*) and Common Crane (*Grus grus*) from Spain and Portugal (Janss and Ferrer, 2000; Marques et al., 2020) or Blue Crane (*Anthropoides paradiseus*), Ludwig's Bustard (*Neotis ludwigii*) and Kori Bustard (*Ardeotis kori*) from South Africa (Shaw et al., 2010, 2018). This suggest that it is key to evaluate this threat for birds in general, with an emphasis on threatened species, and particularly in areas of high diversity.

The potential risk of wildlife-power line accidents is a combination of three main factors: environmental factors (e.g., weather conditions or vegetation cover), biological characteristics of species (e.g., body mass, wingspan, or wing loading), and the technical configuration of the power grid (e.g., number of insulators and conductors, pylons material) (Bevanger, 1998; d'Amico et al., 2019; Janss, 2000; Mañosa, 2001). Power lines are classified according to the level of electrical voltage carried. Electrical energy is transported and distributed from power plants to consumers through an extensive network of distribution or medium voltage (<66 kV) lines and transmission or high voltage (>60 kV) lines. Depending on this level, power lines vary in their technical configuration, which leads to a different potential hazard for electrocution and collision of birds. Bird electrocution generally occurs on distribution lines (Bevanger, 1994), where the distances between electrical conductors (e.g., cables, poles, transformers) are close enough for large birds to contact two of them and get electrocuted. On high voltage, or transmission towers, conductors are usually spaced at safe distances for birds, so electrocutions rarely occur (APLIC, 2006) but instead these structures often cause more bird collisions than distribution lines (Shaw et al., 2018). Therefore, addressing factors influencing bird interactions with power lines is fundamental to understand this conservation issue and the impacts produced at individual and population levels. This is especially important in sites where currently there is little information about this problem and their consequences are unknown.

Birds collisions and electrocutions with power lines have been studied in diverse parts of the world during the last four decades (Bevanger, 1998; Jenkins et al., 2010; Lehman et al., 2007). However, efforts have been concentrated in certain areas of the world, and a significant information gap exists for some geographical areas such as South America (Bernardino et al., 2018; Guil and Pérez-García, 2022). This is of concern because different bird species from this region could be impacted by this problem associated with the rapid growth of energy demand and the constant development of new power networks in this geographical area (Yépez-García et al., 2018). In this sense, it is essential to provide available evidence on the characteristics and extent of this threat evaluating aspects such as the species affected, quantities of individuals impacted or the places where this problem occurs. This is particularly important in order to promote actions that can be accepted and implemented by management agencies, electric companies and government authorities, among others, who seek to reduce the impacts of power lines on bird populations while reducing mitigation and remediation costs (Davis, 2002).

In this article, we compile and review available information from disparate sources about the impacts produced by power lines (collision and electrocution) on birds from South America to put this conservation problem in context. For this, we conducted different bibliographic searches of scientific information and newspaper reports on this threat. In addition, to complement the available information, we compiled new data on: (1) bird-induced power outages provided by electric companies in three South American countries (Peru, Chile and Argentina), (2), bird collisions and electrocutions recorded through a citizen science project in Chile, and (3) bird species and electrocution rates resulting from on-site monitoring on power lines in Chile. Since the number of studies in South America is scarce (Bernardino et al., 2018; Guil and Pérez-García, 2022), our objective is to compile all available information from various sources of power line impacts on South American birds. However, we did not intend to compare data from different sources, but just gather all the information available.

Methods

Information from scientific articles and newspaper reports

We first assessed available knowledge about bird collision or electrocution with power lines in South America from both a scientific (scientific articles) and media (newspaper reports) perspective. To find scientific information, we performed a bibliographic search in English, Spanish and Portuguese. This search was performed using Google Scholar and Scopus until February 2021. We used different key terms in the mentioned languages (e.g., "power line collisions", "bird electrocution", "avian electrocution", "power line mortality", "*colisión con tendidos eléctricos y aves*", "*electrocución de aves*", "*colisão com linhas de transmissão e pássaros*" combined with the different countries of South America, except for the search in Portuguese that was only combined with Brazil). This information was complemented by searching the references of the articles found and adding personal communications of specialists to include data that did not emerge through the search methods used. To find newspaper reports that complement scientific information, we performed additional searches with the same key terms in Spanish and Portuguese in the web search Google (www.google.com) until February 2021.

From each scientific article or newspaper report found, we extracted the following information: species involved, year of publication, geographical origin of the article, number of individuals affected, type of electrical line (distribution/transmission), and conservation status of species involved according to the IUCN (IUCN, 2021). In addition, we obtained information on the methodology applied in each scientific research papers. We excluded scientific articles that only mentioned power lines as a threat to a species, but did not assess it, and articles showing the positive effects of power lines (e.g., benefits of these structures as nest sites). In the case of newspaper reports, we included the species involved only when the species was mentioned or there was a photo of the birds' electrocution or collision that allowed its correct identification.

Information from electric companies

In order to complement the information available about this conservation problem, we gathered new data on bird collisions and electrocutions with power lines from electric companies. For this, we compiled data on power outages caused by bird collisions and electrocutions with distribution and transmission power lines provided by electric companies that recorded these events in Peru, Chile, and Argentina from 2009 to 2021.

Data on power outages associated with birds were obtained either by consulting public available reports from the agencies regulating the service of the electric companies (for Peru and Chile), or by contacting the electric companies directly by e-mail (Argentina). In the case of Argentina, the company *"Ente Provincial de Energía del Neuquén"* (EPEN) was contacted and we requested the data on power outage events caused by birds in the Neuquén province because this company do not perform public reports about this issue. The power outage data for five Peruvian departments (Arequipa, Iquitos, Lima, Madre de Dios, and Piura) were obtained from public reports provided by the "*Organismo Supervisor de la Inversión en Energía y Minería*" (OSINERGMIN). Those reports correspond to interruptions due to different problems of unforeseeable causes of power outages; from these database we selected the ones related to birds. Data from Chile regarding annual power outages were obtained through public reports requested to the "*Superintendencia de Electricidad y Combustibles*" (SEC). This Chilean public agency receives and compiles reports from electric companies about power outages and their causes; from these reports we extracted the ones related to birds.

Information from field monitoring efforts and citizen science

We performed a field monitoring of distribution power lines in two regions of Chile (Atacama and Coquimbo) from 2015 to 2017 in search of carcasses of electrocuted birds. In the Atacama region (27.12 °S, 70.85 °W) a total of 83 power pylons in six different distribution power lines were monitored during seven days, five in January 2016 and two in November 2017. While in Coquimbo (29.88 °S, 71.27 °W) a total of 150 power pylons in 14 distribution power lines during two days in December 2015 and three days in December 2017. For each pylon, a 2 m area around the base was checked for carcasses or remains. At each pylon the GPS position, the characteristics of the pylon (i.e. crossarm design, crossarm and pylon material), and if bird remains were found, data such as species, state of decomposition, age, and sex were recorded.

In addition, we also obtained data provided by a citizen science project called "*Aves y Tendido Eléctrico*" ("Birds and power lines")

Fig. 1. Map of South America showing the number of scientific articles and newspaper reports reporting bird collisions and electrocutions with power lines discriminated by each country from 1985 to 2021. Countries with no reported bird collision or electrocution events are shown in grey.

from the AvesChile ONG (https://aveschile.cl/), where bird collisions and electrocutions on distribution and transmission power lines in Chile were recorded from 2014 to 2021. Therefore, we collected data on bird collision and electrocution events on power lines recorded by citizens through the iNaturalis Chile webpage (https://inaturalist.mma.gob.cl/projects/aves-y-tendido-electrico).

Results and discussion

Impacts of power lines in South America

Scientific articles and newspaper reports

We found only 15 scientific articles that reported or evaluated birds affected by collision or electrocution with power lines in South America (Table 1, Fig. 1). Additionally, 41 newspaper reports referred diverse bird species interaction with power lines (Table 2). The scientific publications reported 61 bird species affected by collisions and electrocutions with power lines, while 22 species come from newspaper reports (Tables 1, 2, Fig. 2). The newspaper reports did not provide data on the type of line involved in the event (distribution/transmission). In the case of the scientific articles, although the type of line involved could be infered in some cases, most omitted this type of information, so we urge researchers to report this data in future studies.

Electric companies

Bird-induced power outages reported by the power companies did not provide relevant data on bird species affected (Table 3). This may be due to the fact that the companies do not have qualified

Table 1
Scientific information available about power lines impacts on birds from South America showing the country of origin, species affected, species conservation status, number of individuals impacted, type of impact (E: electrocutions, C: collisions), bibliographic reference and year of the study. *Only the number of individuals that could be identified to species level are listed.

Report number	Country	Species	Conservation status	Individuals affected	Type of impact	Reference	Year
1	Argentina	*Buteogallus coronatus*	Endangered	9	E	Sarasola et al. (2020)	2012–2019
2	Argentina	*Asio clamator*	Least Concern	1	E	Galmes et al. (2017)	2011–2012
		Buteogallus coronatus	Endangered	4			
		Cathartes aura	Least Concern	5			
		Coragyps atratus	Least Concern	7			
		Cyanoliseus patagonus	Least Concern	12			
		Myiopsitta monachus	Least Concern	5			
3	Argentina Peru	*Vultur gryphus*	Vulnerable	5	C	Plaza and Lambertucci (2020a)	1999–2019
4	Chile	*Vultur gryphus*	Vulnerable	10	C	Pavez and Estades (2016)	1993–2014
5	Peru	*Vultur gryphus*	Vulnerable	1	C	Hinostroza et al. (2020)	2014
6	Peru	*Geranoaetus melanoleucus*	Least Concern	1	E	Nolazco et al. (2010)	2010
7	Brazil	*Harpia harpyja*	Vulnerable	1	E	Gusmão et al. (2020)	2018
8	Brazil	*Harpia harpyja*	Vulnerable	1	E	Aguiar-Silva et al. (2014)	2014
9	Brazil	*Harpia harpyja*	Vulnerable	1	E	Gusmão et al. (2016)	2008
10	Venezuela	*Pelecanus occidentalis*	Least Concern	468	C	McNeil et al. (1985)	1983
		Phalacrocorax brasilianus	Least Concern	56			
		Ardea cocoi	Least Concern	1			
		Egretta rufescens	Near Threatened	1			
		Nycticorax nycticorax	Least Concern	12			
		Phoenicopterus ruber	Least Concern	8			
		Larus atricilla	Least Concern	2			
		Sterna hirundo	Least Concern	5			
		Thalasseus maximus	Least Concern	57			
		Rynchops niger	Least Concern	1			
11	Chile	*Larus modestus*	Least Concern	491	C	Malinarich (2016)	2015–2016
12	Chile	*Cygnus melancoryphus*	Least Concern	14	C	Brito (2000)	1997
13	Chile	*Cygnus melancoryphus*	Least Concern	3	C	Brito (2002)	2000
14	Chile	*Geranoaetus melanoleucus*	Least Concern	16	E	Alvarado and Roa (2010)	2009–2010
15*	Colombia	*Tachybaptus dominicus*	Least Concern	1	C	De la Zerda and Rosselli (2003)	1997–2000
		Pelecanus occidentalis	Least Concern	1			
		Phalacrocorax brasilianus	Least Concern	25			
		Fregata magnificens	Least Concern	1			
		Ardea cocoi	Least Concern	6			
		Casmerodius albus	Least Concern	16			
		Egretta thula	Least Concern	7			
		Egretta caerulea	Least Concern	1			
		Egretta tricolor	Least Concern	2			
		Butorides striata	Least Concern	13			
		Bubulcus ibis	Least Concern	44			

Table 1 (*Continued*)

Report number	Country	Species	Conservation status	Individuals affected	Type of impact	Reference	Year
		Nycticorax nycticorax	Least Concern	67			
		Cochlearius cochlearius	Least Concern	9			
		Phimosus infuscatus	Least Concern	10			
		Plegadis falcinellus	Least Concern	10			
		Dendrocygna bicolor	Least Concern	5			
		Dendrocygna viduata	Least Concern	10			
		Dendrocygna autumnalis	Least Concern	30			
		Spatula discors	Least Concern	55			
		Oxyura dominica	Least Concern	18			
		Cathartes aura	Least Concern	1			
		Cathartes burrovianus	Least Concern	2			
		Coragyps atratus	Least Concern	2			
		Aramus guarauna	Least Concern	10			
		Laterallus exilis	Least Concern	1			
		Porzana carolina	Least Concern	7			
		Laterallus flaviventer	Least Concern	1			
		Porphyrio martinicus	Least Concern	89			
		Gallinula chloropus	Least Concern	35			
		Jacana jacana	Least Concern	7			
		Vanellus chilensis	Least Concern	2			
		Gallinago gallinago	Least Concern	3			
		Burhinus bistriatus	Least Concern	2			
		Columba cayennensis	Least Concern	9			
		Zenaida auriculata	Least Concern	11			
		Columbina minuta	Least Concern	1			
		Columbina talpacoti	Least Concern	2			
		Leptotila verreauxi	Least Concern	4			
		Amazona ochrocephala	Least Concern	1			
		Chordeiles acutipennis	Least Concern	2			
		Nyctidromus albicollis	Least Concern	2			
		Thamnophilus doliatus	Least Concern	1			
		Tyrannus melancholicus	Least Concern	1			
		Campylorhynchus griseus	Least Concern	2			
		Setophaga striata	Near Threatened	1			
		Spiza americana	Least Concern	3			

Table 2
Newspaper reports and personal communications mentioning birds affected by power lines in South America showing the country of origin, species affected, conservation status, number of individuals impacted, article link, date of publication and type of impact (E: electrocutions, c: collisions, EC: both impacts recorded).

Report number	Country	Species	Conservation status	Individuals affected	Type of impact	Article (Link)	Date
1	Argentina	*Cyanoliseus patagonus*	Least Concern	NA	E	https://www.rionegro.com.ar/muchos-cortes-de-luz-en-valle-medio-por-los-loros-en-los-cables-1347056/	May 5, 2020
2	Argentina	*Cyanoliseus patagonus*	Least Concern	NA	E	https://www.rionegro.com.ar/chos-malal-tuvo-dos-cortes-de-luz-la-semana-pasada-por-culpa-de-los-loros-1399458/	June 16, 2020
3	Argentina	*Geranoaetus melanolecus* *Geranoaetus polyosoma* *Buteogallus coronatus*	*Least Concern* *Least Concern* *Endangered*	Hundreds of individuals	E	https://www.avesargentinas.org.ar/noticia/posici%C3%B3n-institucional-%E2%80%9Celectrocuci%C3%B3n-de-aves-en-tendidos-el%C3%A9ctricos%E2%80%9D	December 17, 2018
4	Paraguay	*Nycticorax nycticorax*	Least Concern	At least 2	E	https://www.abc.com.py/nacionales/aves-generan-cortes-electricos-en-trinidad-1783619.html	February 3, 2019
5	Argentina	*Enicognathus ferrugineus*	Least Concern	At least 3	E	https://www.bariloche2000.com/noticias/leer/varios-loros-causaron-una-falla-y-se-corto-la-luz-en-el-oeste/122603	August 17
6	Argentina	*Cyanoliseus patagonus*	Least Concern	NA	E	http://miningpress.com/nota/261815/fueron-los-loros-en-plottier-culpan-a-las-aves-por-los-cortes-	July 16, 2014
7	Argentina	*Cyanoliseus patagonus*	Least Concern	At least 1	E	https://cevicoeste.com.ar/nota/852/telen-aves-ocasionan-corte-de-luz	May 16, 2020
8	Argentina	*Cyanoliseus patagonus*	Least Concern	Some individuals die	E	https://www.puntal.com.ar/las/una-bandada-loros-se-asento-el-tendido-electrico-y-provoco-un-apagon-sampacho-n103941	May 12, 2020
9	Argentina	*Zenaida auriculata*	Least Concern	At least 1	E	https://www.distritointerior.com.ar/hoy/39996/fue-una-paloma-la-que-provoco-un-importante-corte-de-energia-electrica	October 22, 2016
10	Uruguay	*Caracara plancus*	Least Concern	NA	E	https://www.elpais.com.uy/informacion/caranchos-falla-disyuntor-provocaron-historico-apagon.html	August 4, 2016
11	Argentina	No species identified	NA	NA	E	http://elsurdiario.com.ar/?p=23872	July 24, 2014
12	Argentina	*Caracara plancus*	Least Concern	NA	E	https://www.infofunes.com.ar/noticias/7301-bicho-feo–un-carancho-caus—cortes-de-luz-en-la-ciudad-	November 22, 2016
13	Argentina	*Bubo magellanicus*	Least Concern	1	E	https://www.lmneuquen.com/una-lechuza-se-electrocuto-y-dejo-luz-todo-junin-n751595	November 29, 2020
14	Chile	*Larus dominicanus*	Least Concern	1	EC	https://www.nuevamujer.com/lifestyle/2012/09/07/chile-gaviota-dejo-gran-parte-de-concepcion-sin-luz-por-chocar-con-el-cableado-electrico.html	September 7, 2012
15	Argentina	No species identified	NA	NA	E	http://fenix951.com.ar/nuevo_2013/noticia.php?id=27890	September 2, 2014
16	Argentina	*Geranoaetus melanolecus* *Coragyps atratus*	Least Concern Least Concern	9	E	http://www.cean.gob.ar/muerte-por-electrocucion/	September 23, 2016

Table 2 (*Continued*)

Report number	Country	Species	Conservation status	Individuals affected	Type of impact	Article (Link)	Date
		Milvago chimango	Least Concern				
17	Argentina	*Furnarius rufus*	Least Concern	1	E	https://www.ramalloinforma.com.ar/interes-general/pajaro-suicida-deja-a-ramallo-sin-luz/	April 26, 2019
18	Colombia	*Quiscalus sp.*	Least Concern	NA	E	https://noticias.caracoltv.com/el-periodista-soy-yo/pajaros-estan-muriendo-electrocutados-cuando-se-posan-en-estos-arboles-de-mango	November 18, 2019
19	Argentina	No species identified	NA	1	E	https://www.tiemposur.com.ar/nota/68484-un-p%C3%A1jaro-electrocutado-dej%C3%B3-sin-servicios-a-caleta-olivia-y-ca%C3%B1ad%C3%B3n-seco-	May 3, 2014
20	Argentina	*Mimus patagonicus*	Least Concern	1	E	https://www.eqsnotas.com/un-pajaro-en-un-transformador-dio-origen-al-incendio	March 4, 2020
21	Chile	No species identified	NA	NA	EC	http://www.economiaynegocios.cl/noticias/noticias.asp?id=416617	November 13, 2017
22	Argentina	No species identified	NA	1	E	https://viapais.com.ar/obera/1055430-un-pajaro-se-electrocuto-y-dejo-sin-luz-a-una-parte-de-obera/	May 30, 2019
23	Chile	*Coragyps atratus*	Least Concern	NA	E	https://www.24horas.cl/nacional/pajaros-electrocutados-habrian-causado-incendio-en-valparaiso-1580782	February 2, 2015
24	Chile	No species identified	NA	NA	C	https://www.biobiochile.cl/noticias/nacional/region-de-magallanes/2018/02/27/ave-habria-provocado-masivo-corte-de-luz-en-punta-arenas-mas-de-4-mil-clientes-afectados.shtml	February 27, 2018
25	Chile	*Chloephaga picta*	Least Concern	1	EC	https://archivo.laprensaaustral.cl/cronica/un-ave-provoco-corte-de-electricidad-en-natales/	May 4, 2020
26	Chile	Vultures (No species identified)	NA	1	E	http://www.region2.cl/corte-de-energia-en-parte-del-sector-norte-fue-provocado-por-aves/	March 15, 2012
27	Chile	No species identified	NA	1	EC	https://www.ovejeronoticias.cl/2016/11/un-ave-en-el-tendido-electrico-fue-la-causa-del-corte-de-energia-esta-manana-en-punta-arenas/	November 22, 2016
28	Bolivia	*Columba livia*	Least Concern	1	E	https://www.deoruro.bo/?t=ave_provoca___interrupcion_electrica_en_ciudad_oruro_&p=184	May 15, 2018
29	Peru	*Coragyps atratus*	Least Concern	1	C	https://canaln.pe/actualidad/caos-vehicular-lima-gallinazo-genero-corte-luz-varios-distritos-n283239	July 6, 2017

Table 2 (*Continued*)

Report number	Country	Species	Conservation status	Individuals affected	Type of impact	Article (Link)	Date
30	Peru	Pigeons (No species identified)	Least Concern	NA	E	https://diariocorreo.pe/edicion/ica/proliferacion-de-palomas-causa-corte-de-energia-electrica-826956/	June 26, 2018
31	Argentina	*Geranoaetus melanolecus* *Geranoaetus polyosoma*	Least Concern Least Concern	Hundred individuals	E	http://argentinainvestiga.edu.ar/noticia.php?titulo=alarma_por_mortandad_masiva_de_aves_rapaces_en_el_oeste_de_la_pampa&id=2768	August 5, 2017
32	Chile	*Chroicocephalus maculipennis* *Thalasseus maximus* *Coscoroba coscoroba*	Least Concern Least Concern Least Concern	NA	C	https://www.publimetro.cl/cl/ciencia/2015/04/02/denuncian-brutal-dano-cables-tendido-electrico-aves-migratorias.html	April 2, 2015
33	Venezuela	*Quiscalus sp.*	Least Concern	1	E	https://www.ntn24.com/america-latina/venezuela/un-ave-se-estrella-contra-un-tendido-electrico-y-genera-descarga-que-hirio	December 9, 2019
34	Colombia	*Phoenicopterus ruber*	Least Concern	50	C	https://andina.pe/agencia/noticia-mueren-electrocutados-50-flamencos-rosados-el-norte-colombia-648897.aspx	January 10, 2017
35	Peru	*Coragyps atratus*	Least Concern	1	EC	https://www.diariovoces.com.pe/67967/gallinazo-muere-electrocutado-produce-apagon-juanjui	October 19, 2016
36	Peru	*Vultur gryphus*	Vulnerable	1	C	https://diariocorreo.pe/edicion/arequipa/condor-termino-electrocutado-chocar-cables-alta-tension-colca-fotos-829945/?ref=dcr	July 13, 2018
37	Peru	*Vultur gryphus*	Vulnerable	1	C	Pers. Comm. (Johselm Canto)	June 7, 2018
38	Peru	*Vultur gryphus*	Vulnerable	1	E	https://www.facebook.com/COLCAINFORMA/posts/2465224993761309	October 10, 2019
39	Peru	*Vultur gryphus*	Vulnerable	1	C	https://www.actualidadambiental.pe/cronica-el-valle-del-sondondo-refugio-de-condores-ii/	June 18, 2018
40	Peru	*Vultur gryphus*	Vulnerable	1	C	https://www.youtube.com/watch?v=-A5Gdf-NHcU	July 21, 2014
41	Peru	*Vultur gryphus*	Vulnerable	1	E	https://mobile.facebook.com/story.php?story_fbid=117105073656572&id=193054168084337&_rdr	March 11, 2021

Table 3
Species affected by power lines reported by electric companies, field monitoring and a citizen science project in Peru, Argentina, and Chile. Minimum number of individuals affected, type of impact (E: electrocution, C: collision), country, province/department and year of the event are shown.

Species	Country	Province/department	Year	Minimum affected individuals	Type of impact
Ardea cocoi	Chile	Coquimbo	2015	1	E
Bubo magellanicus	Chile	Atacama	2020	1	C
		Metropolitana		1	E
		Valparaíso		1	EC
Bubulcus ibis	Chile	Metropolitana	2019	2	C
Cathartes aura	Chile	Atacama	2016, 2017	7	E
		Coquimbo	2015, 2017	7	E
		Tarapacá	2019, 2020	5	E
		Valparaíso	2021	1	E
	Perú	Arequipa	2020	1	E
Columba livia	Chile	Metropolitana	2021	1	E
Coragyps atratus	Chile	Biobío	2020	1	E
		Coquimbo	2015, 2017, 2021	6	E
Cygnus melancoryphus	Chile	Los Lagos	2020	1	C
Pigeons (No species identified)	Perú	Arequipa	2016	1	E
		Lima	2019, 2020	2	C
		Piura	2019	5	C
Falco femoralis	Chile	Tarapacá	2020	1	E
Falco peregrinus	Chile	Arica - Parinacota	2020	1	E
Falco sp.	Perú	Piura	2017	1	C
Falco sparverius	Chile	Biobío	2020	1	E
		Maule	2015	1	E
Fulica sp.	Chile	NA	2020	1	C
Geranoaetus melanoleucus	Chile	Aysén	2020	2	E
		Metropolitana	2019, 2020	2	C
		Valparaíso	2014, 2020, 2021	4	E
Geranoaetus polyosoma	Chile	Biobío	2017	1	E
		Coquimbo	2017	1	E
		Metropolitana	2021	1	C
		Valparaíso	2019	1	E
Larus dominicanus	Chile	Atacama	2016	3	E
		Coquimbo	2015, 2017	4	E
		Valparaíso	2021	1	E
Milvago chimango	Chile	Coquimbo	2015, 2017	3	E
		Metropolitana	2021	1	E
		Valparaíso	2020	1	E
Mimus thenca	Chile	Valparaíso	2019	1	C
Myiopsitta monachus	Chile	Metropolitana	2020	1	E
No species identified	Argentina	Neuquén	2020, 2021	69	E
	Chile	Aysén	2010–2015	593	NA
		Antofagasta	2010–2015, 2021	539	NA
		Arica - Parinacota	2010–2015	374	NA
		Atacama	2010–2015	234	NA
		Biobío	2010–2015	1827	NA
		Coquimbo	2010–2015	650	NA
		La Araucanía	2010–2015	3480	NA
		Libertador General Bernardo O'Higgins	2010–2015	508	NA
		Los Lagos	2010–2015	4120	NA
		Los Ríos	2010–2015	2903	NA
		Magallanes - Antártica Chilena	2010–2015	135	NA
		Maule	2010–2015	757	NA
		Metropolitana	2010–2015	1907	NA
		Tarapacá	2010–2015	453	NA
		Valparaíso	2010–2015	641	NA
	Perú	Arequipa	2009–2017; 2020	54	EC
		Iquitos	2018	1	C
		Lima	2017–2019	7	EC
		Piura	2017–2021	32	EC
Oceanites oceanicus	Chile	Metropolitana	2017	1	C
Parabuteo unicinctus	Chile	Coquimbo	2019	1	E
		Maule	2019; 2020	4	E
		Metropolitana	2020; 2021	2	E
		O'Higgins	2020	1	E
		Valparaíso	2020; 2021	9	E
Phalacrocorax brasilianus	Chile	Biobío	2020	1	C
Theristicus melanopis	Chile	La Araucanía	2020	1	E
		Los Lagos	2019; 2020	5	E
		Los Lagos	2019	1	E

Table 3 (*Continued*)

Species	Country	Province/department	Year	Minimum affected individuals	Type of impact
Thinocorus rumicivorus	Chile	Antofagasta	2020	1	C
Tringa melanoleuca	Chile	Biobío	2017	1	C
Tyto alba	Chile	Coquimbo	2020	1	EC
Vultur gryphus	Chile	Valparaíso	2020	1	E
Vultures (no species identified)	Chile	Coquimbo	2015; 2017	3	E
	Perú	Arequipa	2017	1	C
		Iquitos	2019	1	C
		Lima	2017–2019	3	C
		Madre de Dios	2020	1	C
		Piura	2016–2021	35	EC
Zenaida auriculata	Chile	Metropolitana	2018	1	C

personnel to identify the bird species and that there is no regulation obliging them to report this type of information. However, data from the electric companies revealed a total of 19,335 power outage events caused by bird collisions and electrocutions (Table 3, S1). Most of the data did not specify whether the power outages were caused by electrocutions or collisions; however, of the 214 data that did report, 151 (70.6%) corresponded to bird electrocutions and 63 (29.4%) to bird collisions. With respect to the type of line, 93 outages (0.5%) occurred on transmission lines, while the vast majority, 19,242 (99.5%), occurred on distribution lines (Table S1).

Field monitoring and citizen science project

During field monitoring between 2015 and 2017 in two regions of Chile, 34 events of bird electrocutions with distribution power lines were recorded (Table S1). Six bird species were registered during these surveys, which were also identified by at least one of the other data sources (Table 3).

The citizen science project contributed 67 events of bird collisions and electrocutions with both distribution and transmission power lines in 14 of the 16 regions of Chile from 2014 to 2021 (Table S1). Of these, 54 events were electrocutions, while 13 were collisions. More events (n = 48) occurred on distribution than on transmission power lines (n = 19, Table 3, S1).

Temporal and geographical distribution of information

Scientific information on the impacts of power lines on birds in South America is mainly recent, with most studies (9 of 15) conducted in the last decade (Table 1). This is surprising considering that the knowledge of the wires impacts on bird species (e.g., telegraph cables) has a long history in other regions of the world (Coues, 1876; Emerson, 1904) and even in Argentina (Doering, 1881). There has been an increase of scientific information about the impacts produced by power lines -mainly from North America and Europe- in the last decades of the 20th century (Bernardino et al., 2018; Lehman et al., 2007). However, in South America it has been evaluated relatively recently, with the exception of a pioneering work that evaluated bird collisions with a transmission line in Venezuela (McNeil et al., 1985). We found that both scientific articles and newspaper reports have reported on this issue nearly every year

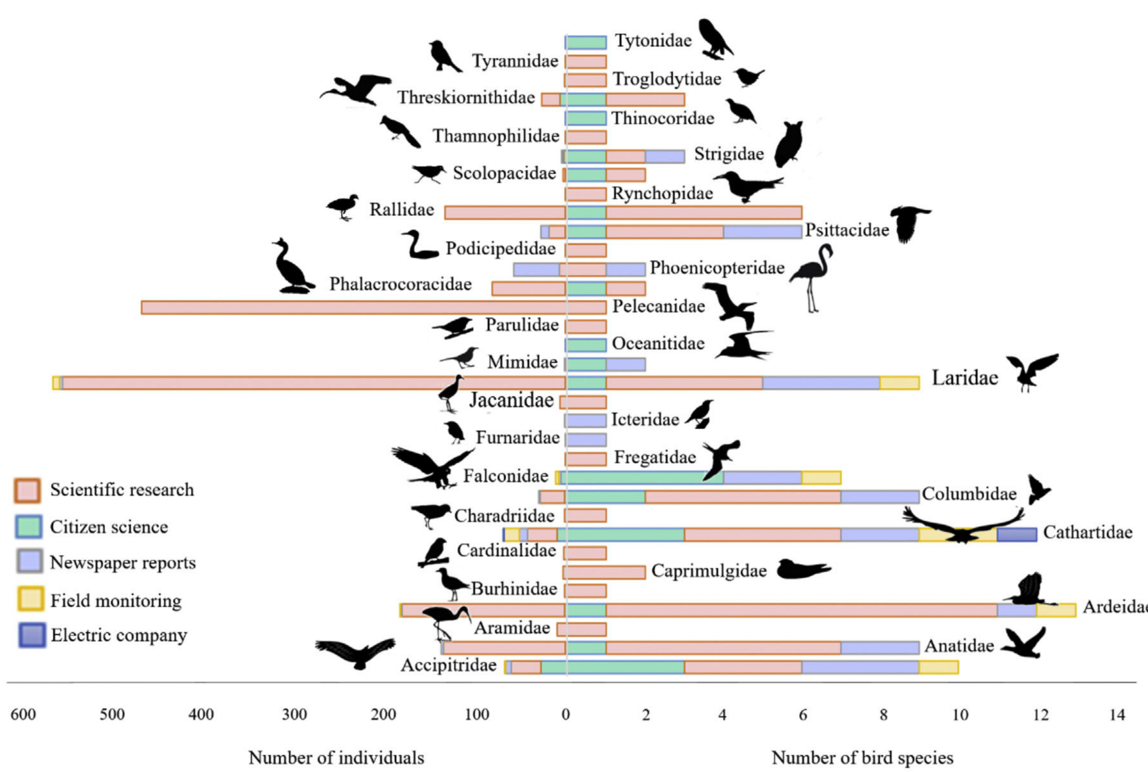

Fig. 2. Number of individuals and bird species per family that recorded electrocution and collision events with power lines. Numbers are based on information provided by scientific articles, newspaper reports, electric companies, field monitoring and a citizen science project.

of the last decade, which highlights there is some concern in both scientific and lay people.

We showed that only 6 out of 13 of the countries in South America have addressed some aspects of this conservation problem in a scientific study (Fig. 1, Table 1). However, information provided by newspaper reports shows that the problem is widespread and that in most countries of South America - although probably in all -, bird collisions and electrocutions with power lines represent an important source of avian mortality at present (Fig. 1). Moreover, most scientific and anecdotal information from this sub-continent comes mainly from a few countries such as Argentina, Brazil, Peru and Chile. This is probably driven, among other things, by the higher development of socio-economic indicators of these countries (Guil and Pérez-García, 2022), including the increase of the rural electricity distribution network (Yépez-García et al., 2018), which increase the probability of mortality by electrocution. Further research and efforts should be directed to improve scientific and technical information about this problem in all the countries from South America, but especially in countries or regions where there is no information available or in those where information is only anecdotal (i.e., Paraguay, Uruguay or Bolivia).

Use of scientific studies and newspapers reports to study the impacts of power lines

The methodological approaches implemented in the scientific papers reviewed were: (1) bird carcass searches under power lines (e.g., Galmes et al., 2017; McNeil et al., 1985); (2) reports from wildlife rehabilitation centers or occasional records of dead or injured individuals due to power lines (e.g., Aguiar et al., 2014; Gusmão et al., 2020, 2016; Hinostroza et al., 2020; Nolazco et al., 2010; Pavez and Estades, 2016; Plaza and Lambertucci, 2020a); and (3) location of tracked individuals (e.g., tagged with telemetry devices) found dead, which were complemented with records provided by farmers or NGOs (e.g., Sarasola et al., 2020). Studies that addressed the effectiveness of mitigation actions to reduce the impacts of power lines on birds and studies that evaluated the impacts produced by this threat at the population level are scarce (but see, Biasotto et al., 2017; De la Zerda and Rosselli, 2003; Galmes et al., 2017). Unfortunately, many studies did not report the type of power line associated with bird electrocutions and collisions (distribution or transmission) nor do they provide the detected mortality rates that allow comparison between areas (Guil and Pérez-García, 2022). Finally, the information present in newspaper reports was mainly based on news about power outages associated with different bird species, with several events reporting high numbers of birds affected at the same time by this problem (Table 2, reports 3, 31, 34).

Species affected by power lines

From the total reported data coming from the different sources addressed (i.e., scientific research, newspaper reports, citizen science, field monitoring and electric company), 85 South American bird species belonging to 34 families have been identified affected by power lines (Fig. 2). Twenty of these species were recorded by at least two of the methods we used, 46 were obtained by scientific research, 11 by the citizen science project and eight by newspaper reports exclusively. Field monitoring included six species, which were also recorded by at least one of the other methods. In the case of the electric company records, most of them did not provide data on the species affected. Two species were identified at the genus level, *Fulica* sp. and *Quiscalus* sp., reported by citizen science and newspaper reports respectively. These results are a clear underestimation of what is actually happening, but useful to see that the problem is widespread between taxa.

Of the species affected by power lines, 17 were electrocutions, 56 were collisions and 12 were both impacts. The species reported as most affected were the Grey Gull (*Leucophaeus modestus*) and the Brown Pelican (*Pelecanus occidentalis)* with 491 and 468 individuals killed by collisions, respectively. Most of the species (n = 79) reported as affected by power lines are classified as Least Concern species. However, five species are considered of conservation concern: the Near Threatened Blackpoll Warbler (*Setophaga striata*) and Reddish Egret (*Egretta rufescens*), both affected by collisions (De la Zerda and Rosselli, 2003; McNeil et al., 1985), the Vulnerable Harpy Eagle (*Harpia hapyja*), affected by electrocution (Aguiar-Silva et al., 2014; Gusmão et al., 2020, 2016) and Andean Condor (*Vultur gryphus*), suffering from both electrocutions and collisions in different parts of its distribution (Peru: Hinostroza et al., 2020.; Chile: Pavez and Estades, 2016; Argentina: Plaza and Lambertucci, 2020a; this study); and the Endangered Chaco Eagle (*Buteogallus coronatus*), for which electrocution was reported as one of the most relevant threats along with human persecution (Galmes et al., 2017; Sarasola et al., 2020, Tables 1,2). Finally, the threat category of the species of the genus *Fulica* sp. was not determined, as they could be species with different degrees of threat.

The information obtained here does not allow us to estimate the annual bird mortality due to power lines in any country of South America. However, our data indicate that in some regions of Chile for which data are available, in just 5 years, there were 19,121 power outages caused by at least the same number of animals (Table S1). It seems clear that the estimations obtained which are based on anecdotic or disperse data suggest the mortality is several folders more. It is urgent to design specific studies to evaluate how many birds are affected by this threat in the different countries of South America, and the mortality per km of power lines (Galmes et al., 2017). Given the current limited knowledge and the great diversity of environments, species and the growth of current power lines infrastructure to provide an estimate is not possible, but the threat is clear and needs to be considered by governments, companies, conservationists, and other stakeholders.

Type of impact: electrocution and collision

The information obtained shows that, in general, most of the reported events are related to electrocutions rather than collisions. Most newspaper reports are referred to power outages or accidents produced by bird electrocutions rather than collisions (Table 2). This same pattern is observed in the data from the electric companies and field monitoring of power lines (Table S1). These results are probably explained by electrocutions attracting more media attention than collisions because power outages produce economic losses and may cause significant damage from wildfires (Guil et al., 2018), and probably because they impact society's environmental sensibilities through images of dead birds hanging from poles. Furthermore, given that electrocutions most frequently affect large birds, the probability that they will be found is much higher than if they were small birds, such as passerines. In addition, collisions that do not result in electrocutions may not be fatal in many cases or the bird will die far from the power line, so recording the event would be more unlikely. Therefore, the information of impacts of power lines tend to be biased toward electrocution.

Conservation implications

Information for actions and key areas

Efficient management decisions require reliable scientific information taking into account the perspectives of the parties involved, such as scientists, policy makers, authorities and, in this case, electric companies (Cook et al., 2013; Plaza and Lambertucci, 2020b). We humans are not only modifying terrestrial or aquatic ecosystems but also the aerial habitat (Lambertucci and Speziale, 2020), and power lines are an important threat to wildlife in this habitat. Therefore, to mitigate the impacts produced by power lines in bird species from South America it is necessary to produce scientific information from sites where it is not available. Here, we show that for most South American countries information is scarce or non-existent. The implementation of modifications in power lines to reduce bird mortality is expensive and electric companies could consider them as prohibitive, especially if scientific information about the impacts of their infrastructures is not available (Davis, 2002). However, there are environmental liability laws aimed at regulating human activities with harmful implications for wild species (Durá Alemañ et al., 2020), which must be considered and implemented by the competent authorities. Moreover, given the strong evidence from other parts of the world, it could be important to implement a precautionary principle to avoid negative impacts on both wildlife and economic impacts; the latter resulting from mitigation costs and power outages. A potential strategy could be to evaluate the most affected bird species and detect indicator species of high mortality risk of collision or electrocution (Pérez-García et al., 2016). Complementarily, the establishment of priority management zones based on predictive electrocution models can be a very useful tool for decision-makers when establishing protection zones (Pérez-García et al., 2017; Hernández-Lambraño et al., 2018; Hernández-Matías et al., 2020). A recent study has developed a predictive map of risk of electrocution for Brazil to prioritize species an areas of interest (Biasotto et al., 2021). In some areas where species of conservation concern exist (the Endangered Chaco Eagle) mitigation measures already started (Sarasola and Zanón-Martínez, 2017), but efforts should be implemented more widely along the sub-continent.

In the last years, South America have experienced an increase in its demands of electricity associated with an incipient economic growth (Agostini et al., 2019). Under this scenario, there is no doubt that the surface covered by power lines will increase in the near future as happened in other regions of the world (D'Amico et al., 2019; Jenkins et al., 2010). If the effects produced by these structures are not properly addressed and mitigated, bird may suffer important impacts on their populations. It is necessary to joint efforts between energy developers, authorities, conservation managers, and scientists to define priority areas for bird conservation, where the potential extension of power lines could produce significant impacts on birds. This is especially important if developments are located in areas of priority for biodiversity, as well as on the peripheries of protected areas, where there may be an increase in the use of pylons by birds for roosting and resting (Pérez-García et al., 2011), with the consequent risk of collision and electrocutions. Solutions to this threat are needed if we aim for aero conservation measures that reduce the impact for aerial wildlife movement (Zuluaga et al., 2022).

The need for effective mitigation actions

Mitigation actions aimed to reduce the risk of collision and electrocution with power lines are often species-specific (Jenkins et al., 2010; Shaw et al., 2021). In addition, studies performed in Argentina suggest that some characteristics of power lines, as power lines of concrete pylons with jumpers above the cross-arm, could be associated to greater risks of electrocution in birds of prey from that area (Galmes et al., 2017; Sarasola et al., 2020; Sarasola and Zanón-Martínez, 2017). However, these studies are the few ones that locally address this issue from the entire South America. This knowledge together with the evidence obtained from other parts of the world (e.g., Ferrer and Janss, 1999; Lehman et al., 2007) should be the guide to address the influence of the characteristics of power lines on bird collision-electrocution, and to implement effective mitigation actions in the different countries of South America.

There is a need to promote national legislation in Latin American countries concerning both the installation and renovation of bird-safe infrastructures. In addition, the creation of monitoring protocols and public databases, both systematic and occasional (e.g., power outages), mediated by specialists who can recognize the species affected is necessary to address this conservation problem for birds (Guil and Pérez-García, 2022). Therefore, whether to produce effective mitigation actions in the current lines or to renew them, it is urgent to evaluate which South American bird species are currently affected by this problem. Finally, once mitigation actions are implemented, an exhaustive evaluation of their positive effects on avoiding electrocutions or collisions in birds is necessary. For instance, in the case of collisions, while increasing the visibility of wires by marking them is currently the most widespread measure to reduce collisions, more studies are needed to confirm which factors determine the effectiveness of marking and how each species respond to this measure (Bernardino et al., 2019). In addition, studies putting in evidence the effectiveness of actions implemented for target species are needed (e.g., Chevallier et al., 2015; Shaw et al., 2021). It is also important to highlight that this kind of studies require baseline data of mortality events due to power lines before applying the action which we lack in South America (Guil and Pérez-García, 2022).

Conclusions

The distinct impact of global-change drivers on airspace must be assessed; this habitat and the species that use it need effective conservation strategies and focused protection (Lambertucci and Speziale, 2020). Power lines, together with other human infrastructure, are intruding into the airspace, fragmenting it and limiting the possibilities of aerial wildlife to move worldwide with unexpected consequences (Zuluaga et al., 2022). We found that there is an important lack of information about collision and electrocution with power lines on South American bird species, and this should be reversed. It is necessary to design studies aimed to evaluate bird mortality events associated with power lines; these studies should produce standardized results able to be compared between different geographical areas of South America but also with the rest of the world (Guil and Pérez-García, 2022). There is also a need to identify the priority areas where this threat is producing large bird mortalities. Complementarily, evaluating the characteristics of power lines that make them more dangerous for each bird species will help to map priority areas of dangerous power lines; so, to make retrofitting in order to avoid negative impacts. Finally, testing the effectiveness of the devices implemented and performing long-term monitoring evaluations of the impacts produced by these human structures will help to look for strategies to reverse the problem.

More scientists and managers should be involved in evaluating and solving this threat and guiding research groups to perform the entire conservation process (describing the threat and proposing-performing mitigation actions with different stakeholders) along the South American continent. Moreover, governments should designate economic resources to fund the projects destined to evaluate this relevant threat. Until we generate the proper information to evaluate this problem, it is necessary to apply the precautionary principle in order to mitigate the potential impact on wildlife, particularly threatened species. Novel developments should consider the hazard of power lines to bird species and implement proven mitigation actions to reduce the risks both in new and in developments already installed. In a context where the demand for electricity is growing in South America, the study, evaluation and application of mitigation actions become indispensable to avoid harmful consequences on bird conservation and associated ecological processes.

Conflict of interest

No conflict of interest declared.

Declaration of Competing Interest

The authors report no declarations of interest.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.pecon.2022.10.005.

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