estudos
Revista de Ciências Ambientais e Saúde
PONTIFÍCIA UNIVERSIDADE CATÓLICA DE GOIÁS (PUC GOIÁS)

# SELECTION OF PRIORITY AREAS FOR IMPLEMENTING EFFECTIVE MITIGATION ACTIONS ON AVIFAUNA IN POWER LINES INSTALLED IN SOUTHEASTERN BRAZIL

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**ABSTRACT**: the continuous growth in the energy sector requires changes in the landscape that include the installation of new transmission and distribution lines. In addition to the impacts arising from the fragmentation and loss of their habitats, birds are also exposed to the risk of death from collision and electrocution with these structures. To minimize this risk, back up the adoption of mitigation measures, and prioritize areas of greater susceptibility to these effects, we present a method for planning and selecting areas based on data from potentially protected bird communities collected in field. Samplings were carried out along two high-voltage transmission lines already implemented in the southeastern region of Brazil along the 18 monitored stretches. The observations of bird flight behavior and use of airspace were evaluated at the taxonomic level of families, and we applied chi-square tests ($\alpha = 0.05$) for these two risk variables. The results showed seven areas with potential for prioritizing mitigation actions, showing that the sampling design was effective and can apply to similar projects.

**Keywords**: High Voltage Lines. Mitigation. Collision Risk. Avifauna. Prioritization of Mitigating Areas.

## SELEÇÃO DE ÁREAS PRIORITÁRIAS PARA IMPLEMENTAÇÃO DE AÇÕES EFETIVAS DE MITIGAÇÃO SOBRE A AVIFAUNA EM LINHAS DE TRANSMISSÃO IMPLANTADAS NA REGIÃO SUDESTE DO BRASIL

**RESUMO**: o crescimento contínuo no setor energético requer modificações nas paisagens que incluem a instalação de novas linhas de transmissão e distribuição de energia. Afora os impactos oriundos da fragmentação e perda de seus habitats as aves também estão expostas a riscos de morte por colisão e eletrocussão com essas estruturas. Com o intuito de minimizar esse risco, bem como subsidiar a adoção de medidas mitigatórias priorizando áreas de maior suscetibilidade a estes impactos, apresentamos um método para planejamento estratégico e seleção de áreas com base em dados obtidos *in locu* das comunidades de aves potencialmente afetadas. As amostragens foram realizadas ao longo de duas linhas de transmissão de alta tensão, já implantadas na região sudeste do Brasil ao longo dos 18 trechos monitorados. As observações da alteração no comportamento de voo de aves e uso do espaço aéreo foram avaliadas em nível de famílias taxonômicas, aplicamos testes Qui-Quadrado ($\alpha = 0,05$) para

**Recebido em:** 27/01/2025. **Aprovado em:** 25/03/2025.
**DOI:** dx.doi.org/10.18224/evs.v52i1.15052
**Editor-Chefe:** Dr. Rogério José de Almeida | https://orcid.org/0000-0002-2150-6057

estas duas variáveis de risco. Os resultados obtidos apontaram sete trechos como áreas de maior potencialidade para priorização de medidas mitigatórias, indicando que o delineamento amostral foi eficaz e pode ser aplicado a empreendimentos similares.

**Palavras-chave**: Linhas de Alta Tensão. Mitigação. Risco de Colisão. Avifauna. Priorização de Áreas Mitigatórias.

The development of structures for generating and transmitting electricity poses many threats to biodiversity. Among the major threats are the isolation of populations, loss of habitat, death from collisions with vehicles, and death from collision and electrocution by power transmission and distribution lines [1-2]. Birds are one group most affected by the latest threat; power lines are one of the principal sources of bird mortality worldwide [3-4].

Powerlines are associated with population decline in several bird species [5-7], many of which are endangered [4, 8], motivating an increase in the study of bird mortality associated with these structures worldwide [2, 5]. Even if a population effect of power line mortality cannot be readily established, it is essential to reduce this human-induced mortality as much as possible to minimize it [9]. It is, therefore, essential to identify which species are affected, better understand the impact of power lines on bird populations and take steps to reduce this impact.

Wire marking to increase the visibility of the cables for birds is one of the most widespread measures to reduce mortality. A recent review of wire-marking effectiveness concluded that mortality rates, on average, are reduced by half [2]. However, the morphological and behavioral diversity observed in different bird families may mean that they do not respond similarly to these devices [10-11]. Several studies worldwide have evaluated the characteristics of bird mortality related to power lines. These show as major factors: (1) factors related to the characteristics of individual birds (e.g., the relationship between wing area and weight, age, and flight behavior such as sociability or in flight [12-13]); (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 [2, 9]). Besides the intrinsic probability of collision for a species, conservation value (e.g., its national or global conservation status) or demographic sensitivity to increased adult mortality can also guide the choice of lines to target for mitigation [14].

Though, there is a clear geographic bias in the evidence base, with numerous studies in Europe and North America [2-3], while other regions and countries lack even basic information, such as which are the impacts of these structures on avifauna and which species are more affected by them [4, 11, 14]. In Brazil, studies on bird collisions with transmission line structures are still scarce and limited to environmental impact licensing studies [11, 15]. A recent study in Brazil showed the Atlantic Forest as the biome with the highest risk of bird electrocution, a condition resulting from a high pole density combined with a high occurrence of susceptible species of birds [15-16].

In this sense, strategic planning was proposed as a necessary first step to mitigate the impact of the power line, both to avoid building new power lines in vulnerable areas and to act on mitigation measures on existing power lines [2, 17]. Here, we present a strategic planning method adapted to identify sensitive areas to bird collisions to help prioritize where mitigation measures should be taken, considering two high-voltage power lines in Espírito Santo and Minas Gerais states, in Brazil. We also provide information on the possible species affected by the installation of these transmission lines.

## MATERIAL AND METHODS

### STUDY AREA

We conducted field observations in the Doce River sub-basin, Minas Gerais and Espírito Santo States, and the coastal region of Espírito Santo, southeastern Brazil. The study covered two power lines: 1) 500 kV Transmission Line Mesquita–Viana 2 (19°24'56"S, 48°32'52" W), in the municipality of Mesquita, State of Minas Gerais, and ending at the Viana 2 Substation (20°22'50" S, 40°30'30"W), in the Viana municipality, State of Espírito Santo, totaling 248 km; and 2) 345 kV Transmission Line Viana 2–Viana with a 10 km extension, starting at the Viana 2 Substation (20°22'58"S, 40°30'21" W), in the State of Espírito Santo, going to the Viana Substation (20° 22'7.11"S 40°26'13.80"W), in the State of Minas Gerais (FIGURE 1). This region is inserted in Atlantic Forest and presents rugged relief, with altitudes ranging from 300 m to 1000 m. Representative Forest fragments of the Ombrophilous Forest and Seasonal Forest are found along the transmission line

### DATA COLLECTION

Data collection occurred during the monitoring of avifauna through eight field campaigns divided into two phases: Phase 1 - June 2016 to May 2019; Phase 2–August 2021 to May 2022. We carried the samplings out in 18 sections (nine sections per phase) selected according to their representativeness in the study area (FIGURE 1 and FIGURE 2). The method used was the sighting at the top of the mountain, which comprised recording all species/individuals on an overhead crossing or near the towers and cables of the power lines. We monitored each stretch between 6h30 am and 11h30 am and between 1h30 pm and 5h30 pm. We sampled only once each section in each campaign.

The flight behavior upon detection of the power line was recorded considering the following standards: 1) the bird crosses the horizons without difficulties, along the route, initially followed, without changing route; 2) the bird crosses the transmission line after recognizing the obstacle at some distance, changing the spatial plane of flight; 3) the bird performs a go-around maneuver when it almost leaves on the route. Through an angulation maneuver greater than 90º, it remains for a specific time recognizing the obstacle and then resumes its safety in flight, crossing the aerial cables; 4) the bird performs circular movements around the risk zone of the power line, the behavior observed in species with great flight agility; 5) the bird shows total withdrawal from the original route when detecting the obstacle [10, 18].

For each flight interaction with the line, the airspace in the collision risk zone was evaluated using two variables: a) flight distance in relation to the set of cables on the line; b) position of the transposition flight of the power line. The distance variable was classified according to how the bird crossed the line inside or outside an imaginary zone with a risk distance of two meters around the cables, both above and below. We considered flights that occurred within the risk distance more dangerous for the birds because of the proximity to the cables. Thus, the airspace in the risk zone was subdivided into five horizons of vertical stratification: I = below this line to ground level; II = between the lowest line of energized cables and approximately 2 m downwards; III = area between the lightning rods and the lowest energized cables; and IIV = from the lightning rods to an imaginary line 2 m above them; V = between the imaginary line and high altitudes without limit, but defined by the possibility of identifying and recognizing species in flight. Of the five flight positions, position III represents the most significant risk of collision for birds [19].

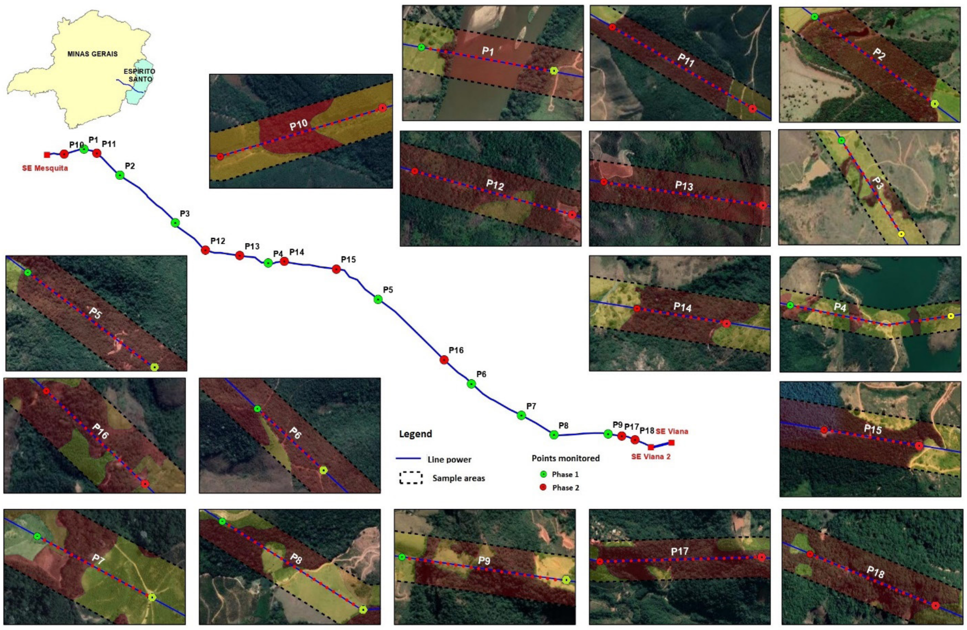

**Figure 1:** Location map of the study area in states of Minas Gerais and Espírito Santo, Brazil, and sections sampled from power lines during the two bird monitoring phases

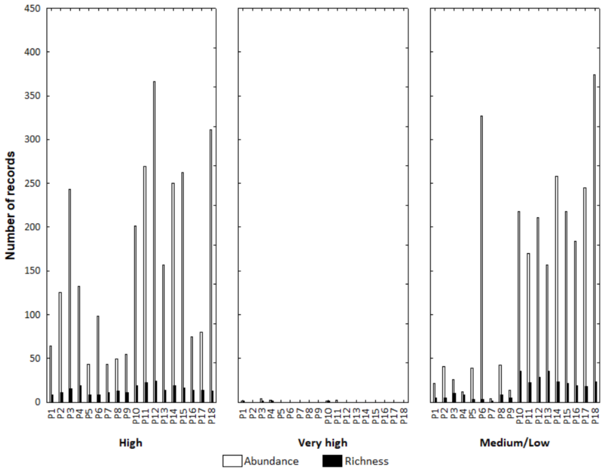

**Figure 2:** Richness and abundance of avifauna by sample area, considering the degrees of theoretical danger recorded in the study area

## DATA ANALYSIS

Based on the fact that morphological attributes of the wing of birds are associated with the ability to fly are stable or fixed within some groups [19] and, therefore, these groups present a greater or lesser risk of collision with the lines [10], we opted for analysis at the family level to assess the potential points for installing beacons. Each bird was classified according to its Theoretical Danger (TD), considering the species' biological characteristics that reflect the potentiality and risk of collision with the energized cables (TABLE 1). The taxonomy followed the Brazilian Committee for Ornithological Records [20].

In order to establish criteria for the selection of areas to implement effective mitigation actions, we considered some ecological parameters of communities: 1) richness and abundance; 2) the relative frequency of registered families; 3) the TD of the species cataloged per point; and 4) their interaction with the transmission line (flight behavior and collision risk zones). For the statistical analysis, we considered events per family, one event being considered each time an individual or flock was seen interacting with the line with a specific behavior, regardless of how numerous individuals were present at the time of observation.

To establish a comparison of the avifauna registered by sampling area, we applied Non-metric Multidimensional Scaling (NMDS), using the Bray-Curtis distance as a measure of similarity based on the composition and abundance of the birds, considering the historical data of the families of the Program along the 18 monitored points. An analysis of variance (Univariate ANOVA) was also performed to test the significance of variation in relative richness and abundance per sampling area.

To evaluate the flight behavior and use of airspace, we performed Pearson's chi-squared test for each family in the Statistica program with a significance level of $p < 0.05$. For this analysis, the flight behavior was categorized into two groups: Indifference (when there is no change in the route - single and circling crossing flights), and Avoidance (when there is a change in the route or resistance due to the presence of the cables). The use of airspace was also categorized into two groups: between the cables (Horizon III) and outside the cables (I, II, IV, V). The analysis could not be performed for families that showed only one of the groups.

**Table 1:** Families of birds most susceptible to collision accidents against power lines and their Theoretical Danger (TD) based on their biological characteristics

| Families | Biological characteristics | TD |
|---|---|---|
| Anatidae, Ardeidae, Threskiornithidae, Ciconiidae, Charadriidae | Medium/large aquatics with gregarious habits without organization | VH |
| Phalacrocoracidae, Ardeidae, Threskiornithidae | Medium/large aquatic animals with organized gregarious habits | H |
| Anhingidae, Ardeidae, Threskiornithidae, Ciconiidae, Recurvirostridae | Medium/large size solitaires | |
| Cathardidae | Large size animals with gliding flight in thermal currents at great heights | |
| Falconidae, Accipitridae | Small/medium birds of prey and high flight speed | |
| Columbidae, Psittacidae, Ramphastidae | Species of small/medium/large forest to semi-forest size, gregarious habits, eventually forming large flocks | |
| Tytonidae, Strigidae, Nyctibiidae, Caprimulgidae | Solitary or insectivorous nocturnal birds of prey | |
| Aramidae, Rallidae, Carimidae | Aquatic almost restricted to basal environment with eventual vertical flights | ME |
| Sternidae, Alcedinidae | Fluvial aquatics or dependent on water bodies | |
| Apodidae, Hirundinidae | Small/medium birds with gliding flight | |

Font: adapted from BEVANGER (1998); PPTE (2009).

Note: Theoretical Degree of Danger; VH – Very High; H – High; ME – Medium.

## RESULTS

Altogether, 18 sampling points were monitored, and 141 species belonging to 39 families were recorded. Considering the TD, only 51 species belonging to 13 families were categorized as "Very High" and "High" theoretical danger (TABLE 2). These species were chosen in order to select priority areas for implementing mitigation actions. Species with medium and low TD were the majority recorded (90 species). However, these species are little impacted by the implantation of power lines, whether due to their flight behavior, size, or aspects of their natural history.

The highest theoretical danger in the study area indicated greater representativeness for the species categorized with TD "High". Species classified with "Very High" TD showed low occurrence in the study area, with records of only four species in this category (*Amazonetta brasiliensis*, *Cairina moschata*, *Mesembrinibis cayennensis*, and *Theristicus caudatus*), with records in areas P1, P3, P4, P10 and P11 (FIGURE 3). Using analysis of variance (Univariate Anova), the significance was also tested regarding the variation of the results obtained between the areas, which indicated that there was a divergence between the sample areas either concerning richness (F (17, 51) = 2.373; p = 0.004) or abundance of specimens (F (17, 51) = 4.161; p = 0.009).

Thus, to establish groupings between the sample points, Non-metric Multidimensional Scaling (NMDS) was applied, using the Bray-Curtis distance as a measure of similarity. For this analysis, data on the composition and abundance of the 13 families mentioned above were considered. As a result, the NMDS analysis reinforced the results obtained in the ANOVA and visually discriminated differences in the similarity between the sample points, identifying three distinct groups. The first grouping is formed by points P1, P5, P7, P9, P8, P16 and P17, the second grouping is composed by points P2, P3, P4, P6, P10, P11, P2. Area P18 seems to differ a lot from the other points, being identified in the analysis as a third grouping. This result is possibly due to the high representativeness of the Cathartidae family. In Table 3, it is possible to verify the percentage representativeness of each family by sample area.

**Table 2:** Birds recorded in the study area from 2016 to 2022

| Taxa | Use of airspace | Flight behavior | TD | Conservation status (IUCN) |
|---|---|---|---|---|
| **Tinamiformes Huxley, 1872** | | | | |
| **Tinamidae Gray, 1840** | | | | |
| *Crypturellus tataupa* (Temminck, 1815) | - | - | LO | LC |
| **Anseriformes Linnaeus, 1758** | | | | |
| **Anatidae Leach, 1820** | | | | |
| *Cairina moschata* (Linnaeus, 1758) | OC | IN | VH | LC |
| *Amazonetta brasiliensis* (Gmelin, 1789) | OC | IN | VH | LC |
| **Galliformes Linnaeus, 1758** | | | | |
| **Cracidae Rafinesque, 1815** | | | | |
| *Penelope obscura* Temminck, 1815 | OC | IN | ME | LC |
| **Columbiformes Latham, 1790** | | | | |
| **Columbidae Leach, 1820** | | | | |
| *Patagioenas picazuro* (Temminck, 1813) | BC, OC | AV, IN | H | LC |
| *Patagioenas cayennensis* (Bonnaterre, 1792) | OC | AV, IN | H | LC |
| *Patagioenas plumbea* (Vieillot, 1818) | BC | IN | H | LC |
| *Leptotila verreauxi* Bonaparte, 1855 | OC | IN | H | LC |
| *Zenaida auriculata* (Des Murs, 1847) | OC | AV, IN | H | LC |
| *Columbina talpacoti* (Temminck, 1811) | BC, OC | AV, IN | H | LC |
| *Columbina squammata* (Lesson, 1831) | BC | AV | H | LC |
| **Cuculiformes Wagler, 1830** | | | | |
| **Cuculidae Leach, 1820** | | | | |
| *Guira guira* (Gmelin, 1788) | OC | IN | ME | LC |
| *Crotophaga major* Gmelin, 1788 | OC | IN | ME | LC |
| *Crotophaga ani* Linnaeus, 1758 | OC | IN | ME | LC |
| *Tapera naevia* (Linnaeus, 1766) | OC | IN | ME | LC |
| *Piaya cayana* (Linnaeus, 1766) | OC | IN | ME | LC |
| **Apodiformes Peters, 1940** | | | | |
| **Apodidae Olphe-Galliard, 1887** | | | | |
| *Cypseloides senex* (Temminck, 1826) | OC | IN | ME | LC |
| *Streptoprocne zonaris* (Shaw, 1796) | OC | IN | ME | LC |
| *Streptoprocne biscutata* (Sclater, 1866) | OC | IN | ME | LC |
| *Chaetura cinereiventris* Sclater, 1862 | OC | IN | ME | LC |
| **Gruiformes Bonaparte, 1854** | | | | |
| **Rallidae Rafinesque, 1815** | | | | |
| *Gallinula galeata* (Lichtenstein, 1818) | OC | IN | ME | LC |
| **Charadriiformes Huxley, 1867** | | | | |
| **Charadriidae Leach, 1820** | | | | |
| *Vanellus chilensis* (Molina, 1782) | BC, OC | AV | ME | LC |
| **Suliformes Sharpe, 1891** | | | | |
| **Phalacrocoracidae Reichenbach, 1849** | | | | |
| *Nannopterum brasilianum* (Gmelin, 1789) | OC | IN | H | LC |
| **Pelecaniformes Sharpe, 1891** | | | | |
| **Ardeidae Leach, 1820** | | | | |
| *Nycticorax nycticorax* (Linnaeus, 1758) | OC | IN | H | LC |
| *Butorides striata* (Linnaeus, 1758) | OC | IN | ME | LC |
| *Bubulcus ibis* (Linnaeus, 1758) | OC | AV | H | LC |
| *Ardea alba* Linnaeus, 1758 | OC | IN | H | LC |
| *Egretta thula* (Molina, 1782) | OC | IN | H | LC |

| Taxa | Use of airspace | Flight behavior | TD | Conservation status (IUCN) |
|---|---|---|---|---|
| **Threskiornithidae Poche, 1904** | | | | |
| *Mesembrinibis cayennensis* (Gmelin, 1789) | OC | IN | VH | LC |
| *Theristicus caudatus* (Boddaert, 1783) | OC | AV | | |
| **Cathartiformes Seebohm, 1890** | | | | |
| **Cathartidae Lafresnaye, 1839** | | | | |
| *Sarcoramphus papa* (Linnaeus, 1758) | OC | IN | H | LC |
| *Coragyps atratus* (Bechstein, 1793) | OC | IN | H | LC |
| *Cathartes aura* (Linnaeus, 1758) | BC, OC | IN | H | LC |
| *Cathartes burrovianus* Cassin, 1845 | BC, OC | IN | H | LC |
| **Accipitriformes Bonaparte, 1831** | | | | |
| **Accipitridae Vigors, 1824** | | | | |
| *Leptodon cayanensis* (Latham, 1790) | OC | IN | H | LC |
| *Elanoides forficatus* (Linnaeus, 1758) | OC | IN | H | LC |
| *Spizaetus tyrannus* (Wied, 1820) | OC | IN | H | LC |
| *Spizaetus melanoleucus* (Vieillot, 1816) | OC | IN | H | LC |
| *Ictinia plumbea* (Gmelin, 1788) | OC | IN | H | LC |
| *Heterospizias meridionalis* (Latham, 1790) | OC | IN | H | LC |
| *Urubitinga coronata* (Vieillot, 1817) | BC | IN | H | EN |
| *Rupornis magnirostris* (Gmelin, 1788) | OC | IN | H | LC |
| *Geranoaetus albicaudatus* (Vieillot, 1816) | OC | AV, IN | H | LC |
| *Buteo brachyurus* Vieillot, 1816 | OC | IN | H | LC |
| **Strigiformes Wagler, 1830** | | | | |
| **Strigidae Leach, 1820** | | | | |
| *Athene cunicularia* (Molina, 1782) | OC | IN | H | LC |
| **Coraciiformes Forbes, 1844** | | | | |
| **Alcedinidae Rafinesque, 1815** | | | | |
| *Megaceryle torquata* (Linnaeus, 1766) | OC | IN | ME | LC |
| **Galbuliformes Fürbringer, 1888** | | | | |
| **Galbulidae Vigors, 1825** | | | | |
| *Galbula ruficauda* Cuvier, 1816 | OC | IN | ME | LC |
| **Bucconidae Horsfield, 1821** | | | | |
| *Malacoptila striata* (Spix, 1824) | OC | IN | ME | LC |
| **Piciformes Meyer & Wolf, 1810** | | | | |
| **Ramphastidae Vigors, 1825** | | | | |
| *Ramphastos vitellinus* Lichtenstein, 1823 | OC | IN | H | LC |
| *Ramphastos dicolorus* Linnaeus, 1766 | OC | IN | H | LC |
| *Pteroglossus aracari* (Linnaeus, 1758) | OC | IN | H | LC |
| **Picidae Leach, 1820** | | | | |
| *Picumnus cirratus* Temminck, 1825 | OC | IN | ME | LC |
| *Melanerpes candidus* (Otto, 1796) | OC | AV, IN | ME | LC |
| *Veniliornis passerinus* (Linnaeus, 1766) | OC | IN | ME | LC |
| *Colaptes melanochloros* (Gmelin, 1788) | OC | IN | ME | LC |
| *Colaptes campestris* (Vieillot, 1818) | OC | IN | ME | LC |
| **Cariamiformes Fürbringer, 1888** | | | | |
| **Cariamidae Bonaparte, 1850** | | | | |
| *Cariama cristata* (Linnaeus, 1766) | OC | IN | LO | LC |
| **Falconiformes Bonaparte, 1831** | | | | |
| **Falconidae Leach, 1820** | | | | |

| Taxa | Use of airspace | Flight behavior | TD | Conservation status (IUCN) |
|---|---|---|---|---|
| *Herpetotheres cachinnans* (Linnaeus, 1758) | OC | IN | H | LC |
| *Caracara plancus* (Miller, 1777) | OC | IN | H | LC |
| *Milvago chimachima* (Vieillot, 1816) | OC | IN | H | LC |
| *Falco sparverius* Linnaeus, 1758 | OC | IN | H | LC |
| *Falco femoralis* Temminck, 1822 | OC | IN | H | LC |
| **Psittaciformes Wagler, 1830** | | | | |
| **Psittacidae Rafinesque, 1815** | | | | |
| *Touit surdus* (Kuhl, 1820) | OC | IN | H | LC |
| *Brotogeris chiriri* (Vieillot, 1818) | OC | IN | H | LC |
| *Pionus maximiliani* (Kuhl, 1820) | OC | AV, IN | H | LC |
| *Amazona vinacea* (Kuhl, 1820) | BC, OC | IN | H | EN |
| *Forpus xanthopterygius* (Spix, 1824) | BC, OC | IN | H | LC |
| *Pyrrhura frontalis* (Vieillot, 1817) | OC | IN | H | LC |
| *Eupsittula aurea* (Gmelin, 1788) | OC | IN | H | LC |
| *Aratinga auricapillus* (Kuhl, 1820) | OC | AV, IN | H | LC |
| *Primolius maracana* (Vieillot, 1816) | BC, OC | AV, IN | H | LC |
| *Diopsittaca nobilis* (Linnaeus, 1758) | BC, OC | AV, IN | H | LC |
| *Psittacara leucophthalmus* (Statius Muller, 1776) | OC | AV, IN | H | LC |
| **Passeriformes Linnaeus, 1758** | | | | |
| **Thamnophilidae Swainson, 1824** | | | | |
| *Formicivora serrana* Hellmayr, 1929 | OC | IN | LO | LC |
| *Thamnophilus palliatus* (Lichtenstein, 1823) | BC, OC | AV, IN | LO | LC |
| *Thamnophilus ambiguus* Swainson, 1825 | OC | IN | LO | LC |
| *Taraba major* (Vieillot, 1816) | OC | IN | LO | LC |
| *Drymophila ferruginea* (Temminck, 1822) | OC | IN | LO | LC |
| **Conopophagidae Sclater & Salvin, 1873** | | | | |
| *Conopophaga lineata* (Wied, 1831) | OC | IN | LO | LC |
| **Furnariidae Gray, 1840** | | | | |
| *Furnarius figulus* (Lichtenstein, 1823) | OC | IN | ME | LC |
| *Furnarius rufus* (Gmelin, 1788) | OC | IN | ME | LC |
| *Anabazenops fuscus* (Vieillot, 1816) | OC | IN | ME | LC |
| *Phacellodomus rufifrons* (Wied, 1821) | OC | IN | ME | LC |
| *Synallaxis frontalis* Pelzeln, 1859 | OC | IN | ME | LC |
| **Pipridae Rafinesque, 1815** | | | | |
| *Manacus manacus* (Linnaeus, 1766) | OC | IN | LO | LC |
| **Rhynchocyclidae Berlepsch, 1907** | | | | |
| *Tolmomyias flaviventris* (Wied, 1831) | OC | IN | LO | LC |
| **Tyrannidae Vigors, 1825** | | | | |
| *Hirundinea ferruginea* (Gmelin, 1788) | BC, OC | IN | ME | LC |
| *Camptostoma obsoletum* (Temminck, 1824) | OC | IN | ME | LC |
| *Myiarchus tyrannulus* (Statius Muller, 1776) | OC | IN | ME | LC |
| *Pitangus sulphuratus* (Linnaeus, 1766) | OC | IN | ME | LC |
| *Myiodynastes maculatus* (Statius Muller, 1776) | OC | IN | ME | LC |
| *Tyrannus melancholicus* Vieillot, 1819 | OC | IN | ME | LC |
| *Megarynchus pitangua* (Linnaeus, 1766) | OC | IN | ME | LC |
| *Myiozetetes cayanensis* (Linnaeus, 1766) | OC | IN | ME | LC |

| Taxa | Use of airspace | Flight behavior | TD | Conservation status (IUCN) |
|---|---|---|---|---|
| *Colonia colonus* (Vieillot, 1818) | OC | IN | ME | LC |
| *Fluvicola nengeta* (Linnaeus, 1766) | OC | IN | ME | LC |
| *Myiophobus fasciatus* (Statius Muller, 1776) | OC | IN | ME | LC |
| *Knipolegus lophotes* Boie, 1828 | OC | IN | ME | LC |
| *Xolmis irupero* (Vieillot, 1823) | OC | IN | ME | LC |
| **Vireonidae Swainson, 1837** | | | | |
| *Cyclarhis gujanensis* (Gmelin, 1789) | OC | IN | ME | LC |
| *Hylophilus pectoralis* Sclater, 1866 | OC | IN | ME | LC |
| *Vireo chivi* (Vieillot, 1817) | OC | IN | ME | LC |
| **Hirundinidae Rafinesque, 1815** | | IN | | |
| *Pygochelidon cyanoleuca* (Vieillot, 1817) | OC | IN | ME | LC |
| *Stelgidopteryx ruficollis* (Vieillot, 1817) | BC, OC | IN | ME | LC |
| *Progne tapera* (Linnaeus, 1766) | OC | IN | ME | LC |
| *Progne chalybea* (Gmelin, 1789) | OC | IN | ME | LC |
| **Troglodytidae Swainson, 1831** | | | | |
| *Troglodytes musculus* Naumann, 1823 | OC | IN | ME | LC |
| *Pheugopedius genibarbis* (Swainson, 1838) | OC | IN | ME | LC |
| **Turdidae Rafinesque, 1815** | | | | |
| *Cantorchilus leucotis* (Lafresnaye, 1845) | OC | IN | ME | LC |
| *Turdus leucomelas* Vieillot, 1818 | OC | IN | ME | LC |
| *Turdus rufiventris* Vieillot, 1818 | OC | IN | ME | LC |
| **Mimidae Bonaparte, 1853** | | | | |
| *Mimus saturninus* (Lichtenstein, 1823) | BC, OC | IN | ME | LC |
| **Fringillidae Leach, 1820** | | | | |
| *Euphonia chlorotica* (Linnaeus, 1766) | OC | IN | LO | LC |
| *Euphonia violacea* (Linnaeus, 1758) | OC | IN | LO | LC |
| **Passerellidae Cabanis & Heine, 1850** | | | | |
| *Zonotrichia capensis* (Statius Muller, 1776) | OC | IN | LO | LC |
| **Icteridae Vigors, 1825** | | | | |
| *Leistes superciliaris* (Bonaparte, 1850) | OC | IN | ME | LC |
| *Psarocolius decumanus* (Pallas, 1769) | BC, OC | IN | ME | LC |
| *Cacicus haemorrhous* (Linnaeus, 1766) | OC | IN | ME | LC |
| *Icterus jamacaii* (Gmelin, 1788) | OC | AV, IN | ME | LC |
| *Gnorimopsar chopi* (Vieillot, 1819) | BC, OC | IN | ME | LC |
| *Chrysomus ruficapillus* (Vieillot, 1819) | OC | IN | ME | LC |
| **Parulidae Wetmore, Friedmann, Lincoln, Miller, Peters, van Rossem, Van Tyne & Zimmer, 1947** | | | | |
| *Basileuterus culicivorus* (Deppe, 1830) | OC | IN | LO | LC |
| **Cardinalidae Ridgway, 1901** | | | | |
| *Piranga flava* (Vieillot, 1822) | OC | IN | LO | LC |
| **Thraupidae Cabanis, 1847** | | | | |
| *Dacnis cayana* (Linnaeus, 1766) | OC | IN | LO | LC |
| *Saltator maximus* (Statius Muller, 1776) | OC | IN | LO | LC |
| *Saltator similis* d'Orbigny & Lafresnaye, 1837 | OC | IN | LO | LC |
| *Coereba flaveola* (Linnaeus, 1758) | OC | IN | LO | LC |
| *Volatinia jacarina* (Linnaeus, 1766) | OC | AV, IN | LO | LC |

| Taxa | Use of airspace | Flight behavior | TD | Conservation status (IUCN) |
|---|---|---|---|---|
| *Tachyphonus rufus* (Boddaert, 1783) | OC | IN | LO | LC |
| *Coryphospingus pileatus* (Wied, 1821) | OC | IN | LO | LC |
| *Sporophila nigricollis nigricollis* (Vieillot, 1823) | OC | IN | LO | LC |
| *Sporophila caerulescens* (Vieillot, 1823) | OC | IN | LO | LC |
| *Conirostrum speciosum* (Temminck, 1824) | OC | IN | LO | LC |
| *Sicalis flaveola* (Linnaeus, 1766) | OC | IN | LO | LC |
| *Cissopis leverianus* (Gmelin, 1788) | OC | IN | LO | LC |
| *Thraupis sayaca* (Linnaeus, 1766) | OC | IN | LO | LC |
| *Thraupis palmarum* (Wied, 1821) | BC, OC | IN | LO | LC |
| *Thraupis ornata* (Sparrman, 1789) | OC | IN | LO | LC |
| *Tangara seledon* (Statius Muller, 1776) | OC | IN | LO | LC |
| *Stilpnia cayana* (Linnaeus, 1766) | OC | IN | LO | LC |

Note: Theoretical Degree of Danger (TD) [10]: VH – Very High; H – High; ME – Medium; LO - Low. Flight behavior [10]: IN = Indifference; AV= Avoidance; Use of airspace: BC = Between the cables; OC = Outside the cables. Conservation status[21]: CR- Critically endangered; EN- Endangered; VU- Vulnerable.

**Table 3:** Percentage representation (%) of each family registered by the sample area

| Families | Sample Area | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **P1** | **P2** | **P3** | **P4** | **P5** | **P6** | **P7** | **P8** | **P9** | **P10** | **P11** | **P12** | **P13** | **P14** | **P15** | **P16** | **P17** | **P18** |
| Accipitridae** | 1.54 | 0.80 | 2.24 | 4.48 | 11.63 | 2.48 | 25.58 | 2.48 | 3.64 | 5.45 | 5.17 | 7.38 | 3.18 | 5.20 | 2.30 | 13.33 | 7.50 | 3.22 |
| Anatidae* | | | 1.62 | 1.49 | | | | | | 0.50 | | | | | | | | |
| Ardeidae | | | 7.69 | 3.73 | | | | | | 0.50 | 0.74 | | | | 3.53 | | | |
| Cathartidae | 47.69 | 19.20 | 30.36 | 10.45 | 60.47 | 30.61 | 46.51 | 57.14 | 32.73 | 66.83 | 42.44 | 12.30 | 26.75 | 30.40 | 29.78 | 34.67 | 45.00 | 83.61 |
| Columbidae | 29.24 | 30.40 | 31.17 | 11.19 | 4.65 | | | 18.37 | 34.55 | 4.46 | 21.33 | 16.39 | 13.38 | 14.40 | 12.60 | 18.67 | 20.00 | 5.79 |
| Falconidae | 6.15 | 11.20 | 4.86 | 6.72 | | 3.61 | 4.65 | 12.24 | 3.64 | 4.95 | 7.39 | 4.92 | 7.64 | 5.60 | 3.82 | 14.67 | 1.25 | 3.22 |
| Icteridae | | | | | | | | | | | | 0.27 | | | | | | |
| Phalacrocoracidae | | | | 1.49 | | | | | | | | | | | | | | |
| Picidae | | | | | | | | | | | | | | | | 1.33 | | |
| Psittacidae** | 13.85 | 38.40 | 22.27 | 55.97 | 23.26 | 64.29 | 23.26 | 8.16 | 18.18 | 17.33 | 18.81 | 58.47 | 49.68 | 44.40 | 39.69 | 6.67 | 2.50 | 0.96 |
| Ramphastidae | | | | | | | | 2.48 | 7.27 | | 2.21 | 0.27 | | | 8.78 | 10.67 | 23.75 | 3.22 |
| Strigidae | | | | 4.48 | | | | | | | 2.21 | | | | | | | |
| Threskiornithidae* | 1.54 | | | | | | | | | | 0.74 | | | | | | | |
| Total Number of Families | 6 | 5 | 7 | 9 | 4 | 4 | 4 | 6 | 6 | 7 | 9 | 7 | 5 | 5 | 7 | 7 | 6 | 6 |

Note: * = Families categorized as “Very High” (TD);

** = Families with the presence of endangered species occurring in the study area.

Regarding the interactions of the avifauna with the power lines, during the campaigns, 4,009 events of potential interactions of the birds with the transmission line were registered. Of this total, 1,974 interactions belong to species classified as “Very High” and “High” TD, covering 12 families. Of the analyzed families, Cathartidae (n = 813) and Psittacidae (n = 601) were the ones that showed the highest number of recorded interaction events, while Anatidae was the one that showed the lowest (n =1).

The families showed low avoidance flight behavior. However, most interaction recordings occurred in I and V horizons (Outside the cables). Considered families that presented records in horizon III (Between the cables) and that did not present avoidance behavior were found to be more vulnerable. The statistical test was significant for Ardeidae, Columbidae, and Psittacidae, indicating that the flight behavior was related to the power line (Table 4).

Considering the degree of vulnerability, eight families had 27 species in the zone with the highest risk of collision and not showing avoidance of power lines cables. In Table 2, the species that presented this type of interaction are presented and the points of occurrence throughout the monitoring period.

**Table 4:** Chi-square ($X^2$) analysis of the type of flight (indifference and avoidance) on the power lines in different collision risk zones

| Families/use of the airspace | Type of flight | | $x^2$(p) |
|---|---|---|---|
| | Indifference % | Avoidance % | |
| **Accipitridae** | | | |
| Between the cables | 29 (29,59%) | 0 (0,0%) | 0,264 |
| Outside the cables | 69 (70,41%) | 3 (100%) | |
| Anatidae | | | |
| Between the cables | 0 (0,0%) | 0 (0,0%) | - |
| Outside the cables | 1 (100%) | 0 (0,0%) | |
| Ardeidae | | | |
| Between the cables | 1 (33,33%) | 0 (0,0%) | 0,05 |
| Outside the cables | 2 (66,67%) | 10 (100%) | |
| Cathartidae | | | |
| Between the cables | 256 (31,48%) | 0 (0,0%) | - |
| Outside the cables | 557 (68,51%) | 0 (0,0%) | |
| Columbidae | | | |
| Between the cables | 56 (29,59%) | 99 (88,39%) | 0,0001 |
| Outside the cables | 96 (63,16%) | 13 (11,61%) | |
| Falconidae | | | |
| Between the cables | 72 (69,15%) | 0 (0,0%) | - |
| Outside the cables | 33 (30,84%) | 0 (0,0%) | |
| Icteridae | | | |
| Between the cables | 0 (0,0%) | 0 (0,0%) | - |
| Outside the cables | 1 (100%) | 0 (0,0%) | |
| Picidae | | | |
| Between the cables | 5 (14,29%) | 0 (0,0%) | 0,418 |
| Outside the cables | 30 (85,71%) | 4 (100%) | |
| Psittacidae | | | |
| Between the cables | 195 (40,79%) | 98 (79,03%) | 0,0001 |
| Outside the cables | 283 (59,21%) | 26 (20,97%) | |
| Ramphastidae | | | |
| Between the cables | 9 (13,43%) | 0 (0,0%) | - |
| Outside the cables | 58 (86,56%) | 0 (0,0%) | |
| Strigidae | | | |
| Between the cables | 6 (100%) | 0 (0,0%) | - |
| Outside the cables | 0 (0,0%) | 0 (0,0%) | |
| Threskiornithidae | | | |
| Between the cables | 0 (0,0%) | 2 (100%) | - |
| Outside the cables | 0 (0,0%) | 0 (0,00%) | |

Analyzing the spatial distribution of richness and abundance values in the study area, the second grouping showed through NMDS analysis indicates areas with greater potential for implementing effective mitigation actions. Among the areas contained in this grouping, points P4, P10, P11, P12, P14 and P15 stand out due to the greater representation of families that presented events of potential interactions with the power line. In addition, the areas P7 and P10 are indicated as priority for the occurrence of the threatened species *Urubitinga coronata*, a species classified as EN “Endangered” at global [21] and national level [22].

The species did not show avoidance flight behavior (circling flight) and was recorded in a collision risk zone (between the cables - horizon III). Also, points P4, P14, P15 and P17 stood out for the records of the threatened species *Amazona vinacea*, also threatened (EN “Endangered” at global and VU “Vulnerable” at the national level (MMA, 2022). Finally, point P18 was not grouped with the others due to the large number of individuals of the Cathartidae family that presented themselves susceptible to collision. This result may be related to the proximity to urban centers where the group's population density is higher.

## DISCUSSION

Using a strategic planning method, we presented a replicable and testable to identify sensitive areas to bird collisions to help prioritize where mitigation measures should be taken in the power line planning. Recent studies from Brazil indicated the Atlantic Forest as the biome with the highest risk of bird electrocution, a condition resulting from a high pole density combined with a high number of susceptible species occurring therein [15].

The pole location and configuration are important in determining the risk of mortality at the local scale [22] and in establishing the best mitigation interventions. In areas classified as higher risk, under our study, a more focused investigation can be applied to search for data on fatalities or power system failures assigned to electrocutions, and to evaluate the relationship between landscape composition and electrocution events [23].

Fifty-one bird species were ranked at higher risk of electrocution in our study. Specific guidelines for protection against electrocution should be delineated for these species, which should receive further attention during the environmental licensing of new power lines. We found that the species of the families Ardeidae, Columbidae, and Psittacidae predominate among our higher-risk species.

The familie Psittacidae, represented in our higher-risk class by the endangered *Amazona vinacea*, stands out for its curiosity and social behavior when interacting with power line structures [24]. Parrots (familie Psittacidae), and particularly macaws, are vulnerable to electrocution [15], but few studies focused on these birds. Overall, just anecdotal or occasional death by electrocution is reported for parrots [25]. Losses of some Golden Parakeets *Guaruba guarouba*, a threatened species reintroduced in Belém (Brazil), were caused by electrocution [26]. Further, it is known that the last wild Spix's Macaw *Cyanopsitta spixii* died due to electrocution [27]. In general, parrots are long-lived birds, and many species have naturally restricted ranges and are threatened with extinction [28].

Our results demonstrated that the majority of species did not show avoidance behavior regarding power lines. By analyzing the cable avoidance behavior of birds, Savereno *et al.* [18] concluded that line avoidance for some taxonomic groups (Laridae and Scolopacidae), different from those included in our analysis, was significantly related to the presence of sphere-shaped markers in yellow. In this sense, some studies that also used flight behavior variables showed the positive effect of flares in reducing the risk of collision. Brown & Drewien [29] found that birds, in general, reacted earlier and flew higher over marked lines than over unmarked lines. In the study by Alonso *et al.* [30] the change in height at which the birds crossed the line and the smaller number of individuals flying between the cables after signaling with spiral-shaped and colored devices, suggests that the birds saw the signals and increased the height of flight to avoid collision with cables.

## CONCLUSION

It should be noted that in order to monitor these analyses, it is essential that the licensing agencies demand that the studies be carried out with more robust sample studies, of the BACI or BACIPS type (with control before the implementation of the line, after the implementation and after the signature) [31], including both collision and behavioral monitoring.

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## ACKNOWLEDGMENTS

PARO Ambiental was the company responsible for the execution of the Faunal Monitoring Program and Environmental Program of the Power Line 500 kV Mesquita – Viana 2 e Power Line 345 kV Viana 2 – Viana, in the Mesquita and Viana municipalities. We also thank the PARO Ambiental for logistic support. SPA is grateful to CAPES for support with a doctoral scholarship. This study was supported by MGE Transmissão S.A.

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## CONFLICT OF INTEREST

We declare no conflict of interest.

## FUNDING

MGE Transmissão S.A.

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