Power line electrocution as an overlooked threat to the Lear's Macaw (Anodorhynchus leari)

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Dear Editorial Board,

We are pleased to resubmit our manuscript (IBIS-2022-SC-003) entitled *"Power line electrocution as an overlooked threat to the Lear's Macaw (Anodorhynchus leari)*" for to be published in *IBIS*. We would like to thank the reviewers, the editor Prof. Richard Fuller and the associate aditor Prof. Stuart Marsden for the dedication in reviewing the lastest version. We accepted all changes and executed the recommended modifications in Figure 02 and 03.

We hope that this improved version of the manuscript will be suitable for publication in Ibis.

Sincerely,

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ABSTRACT

Electrocution can pose a serious threat to large birds, particularly to threatened species with low population sizes. However, few studies have focused on the impacts of electrocution on large parrots such as the Endangered Lear's Macaw (*Anodorhynchus leari*), endemic to the Brazilian *Caatinga*. Here, we compile and describe 31 electrocution events, as reported by villagers, indicating that electrocution may be an important threat to the Lear's Macaw. We suggest a research and monitoring agenda to better understand the spatial and temporal patterns of this impact and recommend some immediate mitigation measures for decreasing electrocutions.

Keywords: bird electrocution, bird protection, parrot conservation, pylon management, pole retrofitting.

RESUMO

Eletrocussões podem ser uma importante ameaça para aves de grande porte, principalmente para espécies ameaçadas em virtude do seu reduzido tamanho populacional. Entretanto, poucos estudos têm como foco o efeito de eletrocussões de psitacídeos, em particular com grandes espécies como a arara-azul-de-lear, endêmica da Caatinga e ameaçada de extinção. A partir de relatos dos moradores locais, nós compilamos e descrevemos 31 registros de eletrocussão contabilizados até junho de 2021, indicando que esta pode ser uma nova e importante ameaça para a arara-azul-de-lear. Nós sugerimos uma agenda de pesquisa e monitoramento para incrementar a compreensão sobre os padrões temporais e espaciais deste

impacto e também recomendamos ações de mitigação com o potencial de reduzir a ocorrência de eletrocussões nesta espécie e em outros psitacídeos.

Palavras-chave: conservação de psitacídeos, eletrocussões de aves, eletroplessões, proteção de aves, anti-eletrocussão, correções de postes.

1. Introduction

Power line networks are expanding worldwide to supply human populations lacking access to electricity (Arderne et al. 2020). However, poorly planned expansion of power lines can pose a risk to biodiversity, through habitat loss or degradation, and by causing wildlife fatalities through collision or electrocution (Biasotto and Kindel 2018). In fact, power lines can constitute an ecological trap, since they offer attractive perching or nesting sites, exposing birds to electrocution risk (Mainwaring 2015). Electrocution occurs when an animal simultaneously touches two-phase conductors or one conductor and a grounded device on a pole (Bevanger 1998), and therefore are expected to be especially common in local distribution lines due to the short distances among the electrified elements (Bevanger 1994, 1998). For the same reason, electrocution may be an important source of fatality for larger-sized birds and bats (Loss et al. 2015, Tella et al. 2020).

Mortality through electrocution might affect the population persistence over time (Eccleston and Harness 2018), particularly for small populations. Population-level impacts caused by electrocutions have been evidenced for raptors, such as the Cape Vulture *Gyps coprotheres* (Boshoff et al. 2011) and the Bonelli's Eagle *Aquila fasciata* (Hernández-Matías et al. 2015), among other birds (Lehman et al. 2007, Slater et al. 2020, Janss 2000). Yet, electrocution has remained an overlooked threat to birds in many parts of the world, particularly in developing tropical regions (Guil and Pérez-García 2022), where continued expansion of the energy grid is expected over the next few decades (Kishore and Singal 2014).

Parrots, and particularly macaws, are vulnerable to electrocution (Biasotto et al. 2021), but few studies have focused on these birds. There are anecdotal records of electrocutions for the Burrowing Parrot (*Cyanoliseus patagonus)* and Monk Parakeet (*Myiopsitta monachus*) in Argentina (Galmes et al. 2017) and the Golden Parakeet (*Guaruba guarouba*) in Brazil (Vilarta et al. 2021), while the last wild Spix's Macaw (*Cyanopsitta spixii)* died due to electrocution (Juniper, 2004). Both blue macaw species, the Hyacinth Macaw (*Anodorhynchus hyacinthinus*) and the Lear's Macaw (*A. leari*), were recently identified as having a high risk of electrocution due to their morphological and behavioural characteristics, as well as the high density of power poles in their distributions, adding yet another reason for concern about their conservation status (Biasotto et al. 2021).

The Lear's Macaw is endemic to the *Caatinga*, in Brazil, and is classified as Endangered in the IUCN Red List (BirdLife International 2020). While the population of Lear's Macaw has increased in the last 30 years due to active conservation efforts (Barbosa and Tella 2019), the loss of nesting and foraging habitats constitutes a major threat to its long-term persistence (Pacífico et al. 2020). Continued deforestation and habitat degradation resulting from agricultural and livestock intensification together with the expansion of mining and energy developments (Acosta-Salvatierra et al. 2017, Neri et al. 2019) are of particular importance. These land use changes associated with unsustainable practices in agriculture (de Andrade et al. 2015) also affect the Lear's Macaw by reducing patch size, density, and survival of the Licuri Palm (*Syagrus coronata*), whose fruits are a key food resource for the species (Silva-Neto et al. 2012).

Here, we compile known records of Lear's Macaw electrocutions, including their date, location and details about the type of electrical infrastructure involved. We then discuss the importance of considering electrocution risk as a novel and overlooked threat to this species. We also emphasize the urgent need for a targeted and well-designed systematic monitoring of the fatalities, their spatial and temporal patterns, and proximate causes along with experimental deployments of mitigation measures.

2. Methods

2.1 Study area

The Lear's Macaw is endemic to the *Caatinga*, a semiarid vegetation type in NE Brazil comprising a mosaic of different woody plant densities (da Silva et al. 2017). With high inter-annual variability in rainfall, droughts in area can last for years, and this biome is threatened by agriculture, farming, and illegal charcoal production. Inappropriate land use changes have led to accelerated desertification in many areas (Acosta-Salvatierra et al. 2017, Schulz et al. 2018). The Lear's Macaw population centres on the Raso da Catarina (RASO), where >99% of individuals are concentrated, and population numbers are increasing. All known electrocution events in RASO have been documented. Another recovering population has been managed and monitored in the Environmental Protection Area of Boqueirão da Onça (BDO), 230 km west of RASO (EP; TF; FR; unpublished data), from which there are still no records of electrocution.

2.2 Electrocution records and field observations

Macaws found dead were reported by residents, and records up to June 2021 were considered for this study with their localities georeferenced, as close as possible to the pole on which the fatality occurred. All carcasses were found under or very close to energy poles and most of them with clear external signs of electrocution, such as burned areas on the beak, body, feathers, and phalanges. Whenever possible we retrieved the carcass to also confirm internal signs of electrocution by necropsy (Kagan 2016) and to eliminate other reasons for the fatality, such as poisoning, hunting, or collisions with wires. Energy outages occurring just before the location of carcasses by villagers were also considered clear evidence for electrocution. All specimens in adequate condition were deposited at the Museu de Zoologia da Universidade de São Paulo, and whenever possible, tissue samples were also obtained and deposited in the same collection.

After being informed by the villagers of an event, and whenever we knew the exact location, we visited the site (August 2021) to describe the electrical infrastructure including details of building materials, number of wires, presence of primary and/or secondary energy systems, and presence of transformers and exposed jumpers. At the time of the electrocution reports, no mitigation structures were installed.

2.3 Distribution of fatality events

We created a map with the following spatial information: i) locations of macaw fatalities; ii) current distribution of the species, comprising 11 municipalities in northern Bahia state; iii) historical occurrences of the species and peripheral potential feeding areas, that include another nine municipalities, as potential areas for species expansion (Araujo et al. 2014, ICMBio 2019); iv) the six known communal roosting sites of the species, and v) the layout of the medium voltage (13.8 kV) power line grid provided by the Brazilian Electricity Regulatory Agency (ANEEL). We used ArcGIS 10.3.1 (ESRI, 2015) for mapping and spatial analyses.

3. Results

3.1. Electrocutions and field observations

A total of 31 Lear's Macaw carcasses resulting from electrocution were reported by villagers. The first electrocution was reported in 2008, with only three more events recorded until 2017. The number of reports by villagers was much higher in 2018 (6 ind.), 2019 (9 ind.), and 2020 (6 ind.). In 2021, villagers recorded one dead macaw per month until June (6 ind.). Three different electrocution events involved the deaths of more than one individual simultaneously (2, 2, and 3 ind.). From the 31 recorded fatalities, 74% occurred during the breeding season (December – May) (Supporting Online Information, Table S1).

External and macroscopic injuries such as burned areas on the beak, body, feathers, and phalanges were visible on many carcasses (Fig. 1a, b, c). All carcasses without external evidence had internal injuries compatible with electric shock confirmed by necropsy as pericardial haemorrhage without chest girdle fractures. Some carcasses showed signs of predation after electrocution (Fig. 1d). The fatalities took place on concrete pylons with two-phase or three-phase distribution corner configuration (pole carrying two different systems perpendicularly and horizontally arranged), with distances among the wires of less than 70 cm (Fig. 1e). Some fatalities also occurred on poles containing transformers and exposed jumpers (Supporting Online Information, Table S1).

3.2. Distribution of fatality events

We identified 13 main electrocution localities in the RASO region, most of them (58%) at Euclides da Cunha municipality (Fig. 2c). By overlapping the grid of medium voltage lines with both sets of municipalities of potential and confirmed occurrence of the species, we observed that power lines were installed in all the current and the potential expansion areas of occurrence of the Lear's Macaw (Fig. 2c).

The number of reported fatalities was higher with decreasing distance to the nearest roosting site (Fig. 3). The mean distance from fatalities to roosting sites was 10.96 km (± 6.9), ranging from 0.89 km at Barra do Tanque to 25.67 km at the Serra Branca communal roost (Fig. 3).

4. Discussion

Our results are the first evidence that medium voltage power lines cause frequent fatalities in the Lear’s Macaw. Although we lack systematic monitoring, or clear information about the amount of search effort in looking for carcasses, the number of electrocutions compiled indicate that this may be a significant source of human-induced mortality in this species (Barbosa and Tella 2019). Moreover, the fact that most cases of electrocution reported by the local community occurred during the breeding season suggests a vulnerability during this life stage, and that electrocutions may affect the population dynamics beyond the loss of adults.

Energy poles seem to offer Lear's Macaws an attractive option for feeding and sentinel behaviours in landscapes that are experiencing a progressive shortage of tall trees once used by the birds. During long-term surveys in the *Caatinga* to investigate parrot densities (Tella et al., 2021), Lear's Macaws were opportunistically observed using power lines as perches to forage and feed on Licuri palm fruits (Fig. 1f) in the RASO area, and birds would interact closely with pole elements (Fig. 1g, h, i, j). Pairs and small flocks of Lear's Macaws have also been observed conducting intense social behaviours on power lines, including probing and pecking pole elements. The frequency of these behaviours is unknown and should be further studied as they may increase the probability of mortality events of more than one individual simultaneously (Bevanger 1994, 1998). Our results suggest that power lines might function as an ecological trap (Tella et al. 2020) for Lear's Macaw, offering an apparent advantage by providing perching sites while foraging, but also an elevated risk of electrocution (Mainwaring 2015), a hypothesis that remains to be tested.

The accelerating number of electrocutions reported up to June 2021 demands urgent attention, and might result from both the expansion of the macaw's recovering population (Pacífico et al. 2020) and expansion of the energy grid in rural areas, which has intensified since 2007 due to policy initiatives around universal access to energy (MME 2006). An additional cause could be the growing communication of locals with macaws' conservation groups, especially in Euclides da Cunha, thus increasing the reporting of fatalities, and possibly explaining the higher concentration of macaw deaths in this municipality. Indeed, improvements in communication following energy installations in rural villages (e.g., internet, smartphones) mean that people can communicate more easily about the fatalities.

The fatalities analysed here were restricted to those reported opportunistically by villagers, and the true number of electrocutions is presumably somewhat higher. Spatial patterns may also be biased due to underreporting in remote and uninhabited areas. Additionally, scavengers (Fig. 1d) might remove carcasses before detection (Ponce et al. 2010, Bernardino et al. 2020), although this may be a more important effect for smaller-bodied birds (Gómez-Catasús et al. 2021).

4.1 Priority research and monitoring agenda

To obtain accurate fatality estimates and confirm their spatial and temporal patterns, we recommend a systematic survey of carcasses along the power line network. Such a survey should account for imperfect detection by using repeated surveys and/or multiple observers (Borner et al. 2017, Barrientos et al. 2018). The obtained data can then be used to model the macaw's risk of electrocution and to understand what the technical, environmental, and biological variables associated with mortality risk. Such a study would confirm if the increased fatalities reported during the breeding season and closer to roosting sites are real patterns, and to what degree foraging and social activities are driving the use of risky poles. Thorough modelling of electrocution risk could form the basis of choosing priority areas for mitigation.

Mitigation options to reduce electrocution risk for Psittaciformes are currently limited. Available solutions in the scientific literature, such as the installation of perch deterrents on energy poles and other avian-safety practices, primarily target raptors (APLIC 2006, Eccleston and Harness 2018). Parrots, and especially macaws, are behaviourally very different, particularly with respect to curiosity and social behaviour (Seibert, 2006). They often peck the structures and interact closely with pole elements, including playing around the energy conductors, jumpers, transformers, and most commonly doing this in pairs or flocks, as described here. Parrot bills are very strong, and their bite can easily destroy deterrent structures such as plastic spikes or insulator covers. Ultimately, mitigation measures designed for raptors are unlikely to be useful for parrots (Biasotto et al. 2021).

We recommend that mitigation efforts for Lear's Macaw target modifications of pole configurations and wire arrangements, such as increasing the distance between energized wires to at least 1 m (considering the Lear's Macaw wingspan) or eliminating the crossarms by using a vertical wire arrangement with a minimum distance of 1 m among them (considering the Lear's Macaw body length). Alternative actions could include the insulation of energized elements, covering the jumpers, phase conductors, and transformers with resistant materials when the separation of wires is not feasible. Furthermore, the installation of other pole models such as the wishbone design (APLIC 2006), a pole with alternate arrangement of wires, may be encouraged. Since none of these possible measures have been field tested for parrots, an experimental study using a sampling design like progressive change BACIPS (Thiault et al. 2017), sufficiently replicated, could be used to evaluate their effectiveness.

Until more detailed risk maps are available, hazardous pole retrofitting should be prioritized in areas closer to the six known roosting areas, mainly in Barra do Tanque, Serra Branca, and Matinha. Mitigation measures could then be gradually expanded to areas with confirmed pole use by macaws in other municipalities. To be more cost-efficient, the mitigation program could be grounded on a pole occupancy survey (e.g., Moreira et al. 2018, García-Alfonso et al. 2021).

We suggest that mitigation measures are tested and applied when new power lines are installed anywhere within the distribution of the Lear's Macaw, including areas where potential population expansion is possible. Indeed, a number of new roosting sites have recently been discovered (Baixa do Chico, Barreiras, Barra do Tanque and Matinha; EP and TF, unpublished data), located in unprotected and human-disturbed areas. No records of electrocution have yet been reported in Baixa do Chico and the BDO roosting areas, but conservation actions such as the Lear's Macaw reintroduction program in BDO could be compromised if electrocutions do start occurring.

The number of electrocutions we report in this study clearly highlights an important potential threat to the Lear's Macaw, and a simulation study could be designed to quantify the impact of electrocutions on long term population viability. The mitigation actions suggested here could play a key role in the further recovery of the Lear's Macaw, as well as benefitting other wildlife species at risk of electrocution.

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FIGURES AND LEGENDS

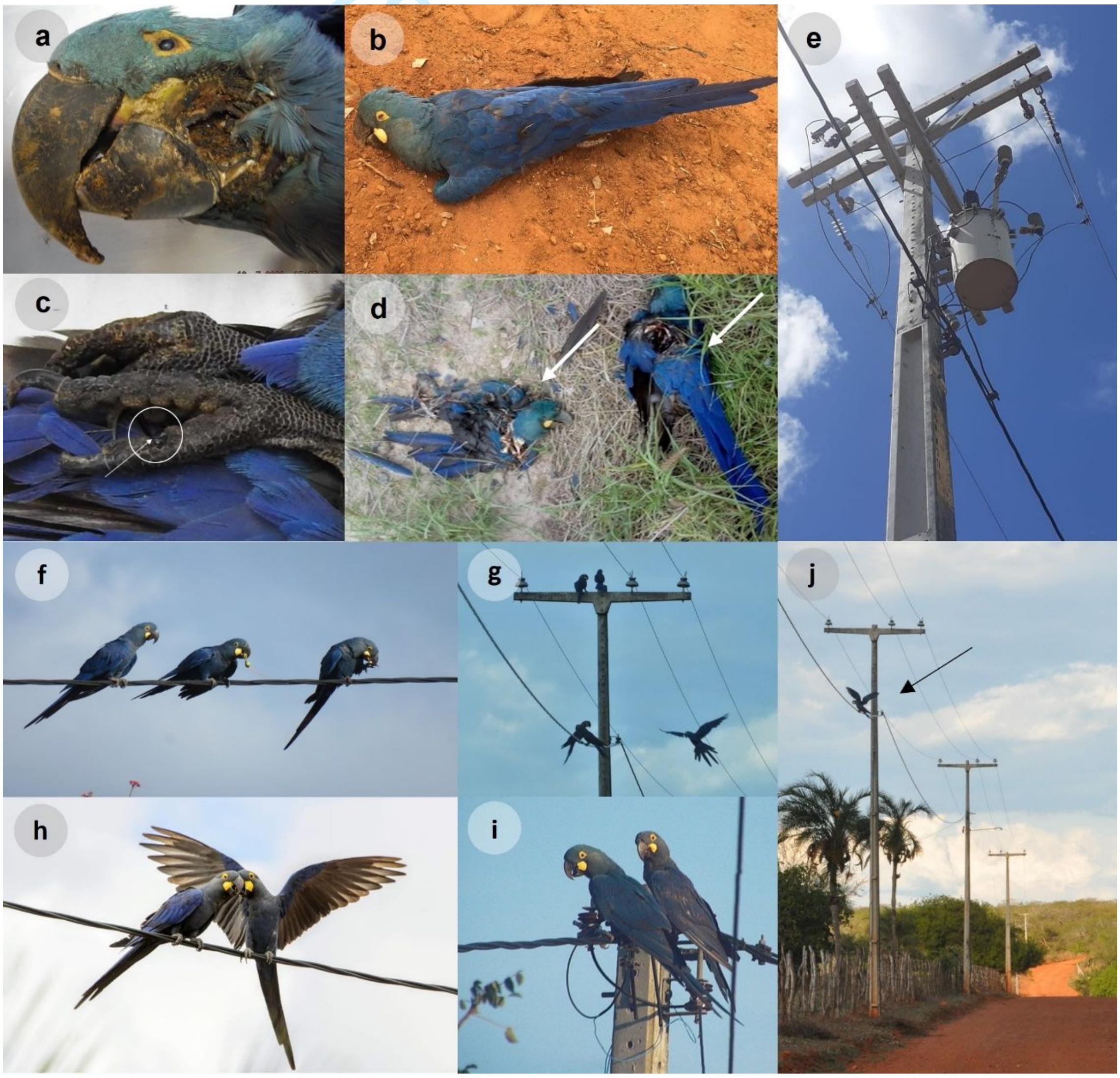


Figure 1. a and **b)** Dead Lear's Macaw found with signs of electrocution (photos Marlene Reis); **c)** Burned phalanges (necropsy report); **d)** Two Lear's Macaws with signs of predation after electrocution (photo José Amilton Dantas Alves); **e)** Pole configuration prone to cause electrocutions; **f)** Lear's Macaws observed eating Licuri Palm fruits while perched on power lines (photo Mariana Diniz); **g)** Lear's Macaws perching on power line structures (photo Thiago Filadelfo); **h)** Pair of macaws interacting on energy wires (photo Dalila Mouta); **i)** Pair of macaws perching on energy pole (photo Marlene Reis); **j)** Lear's Macaw foraging in the Licuri Palm patches, using power line for sentinel behaviour (black arrow) (photo Thiago Filadelfo).

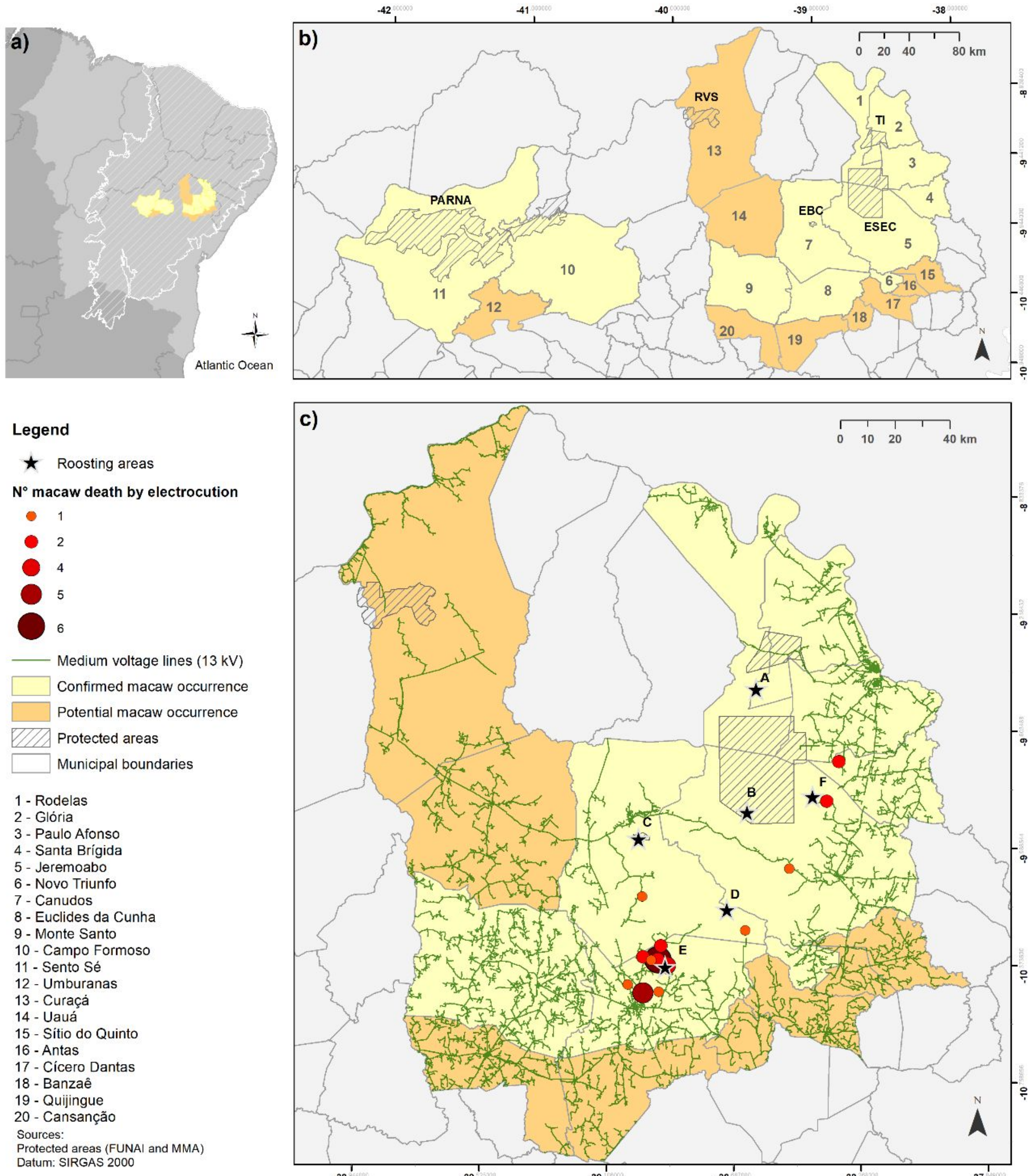


Figure 2. a) Northeast region of Brazil in light grey, with white line highlighting the limit to the distribution of the Caatinga habitat, and coloured patches the main areas of Lear's Macaw distribution; **b)** Detail of the two known areas of occurrence of the Lear´s Macaw: the Boqueirão da Onça area - BDO (left) and the Raso da Catarina area - RASO (right), along with protected areas APA e PARNA (Boqueirão da Onça National Park); RVS (Ararinha-Azul Wildlife Refuge); TI (Brejo do Burgo Indigenous land); ESEC (Raso da Catarina Ecological Station); EBC (Canudos Biological Station); **c)** Municipalities at Raso da Catarina where the electrocutions occurred (red

dots) and the known communal roosting sites of the species (black stars): A (Baixa do Chico), B (Serra Branca), C (Toca Velha), D (Barreiras), E (Barra do Tanque) and F (Matinha).

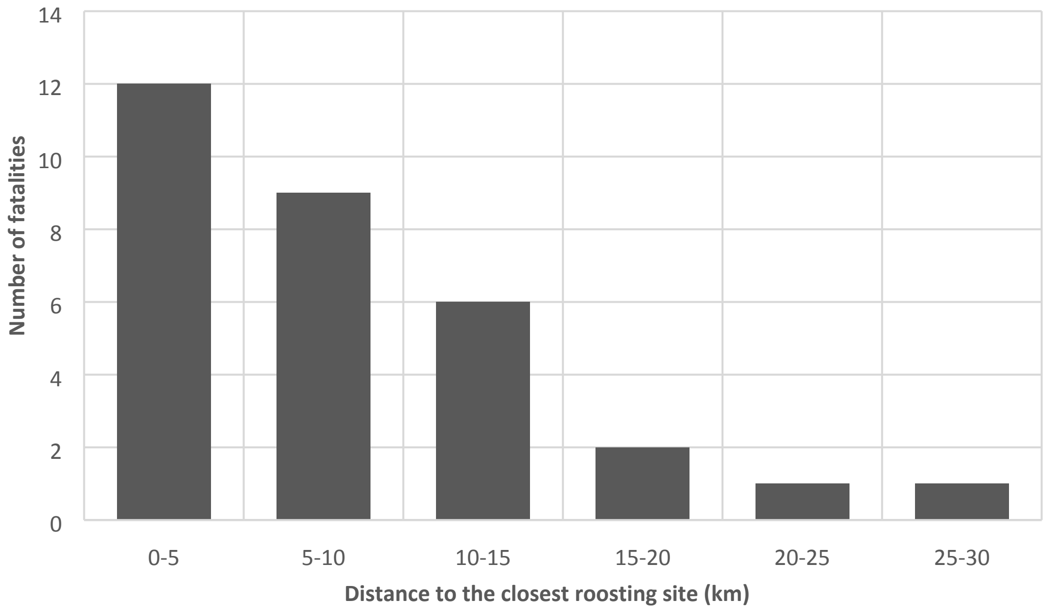
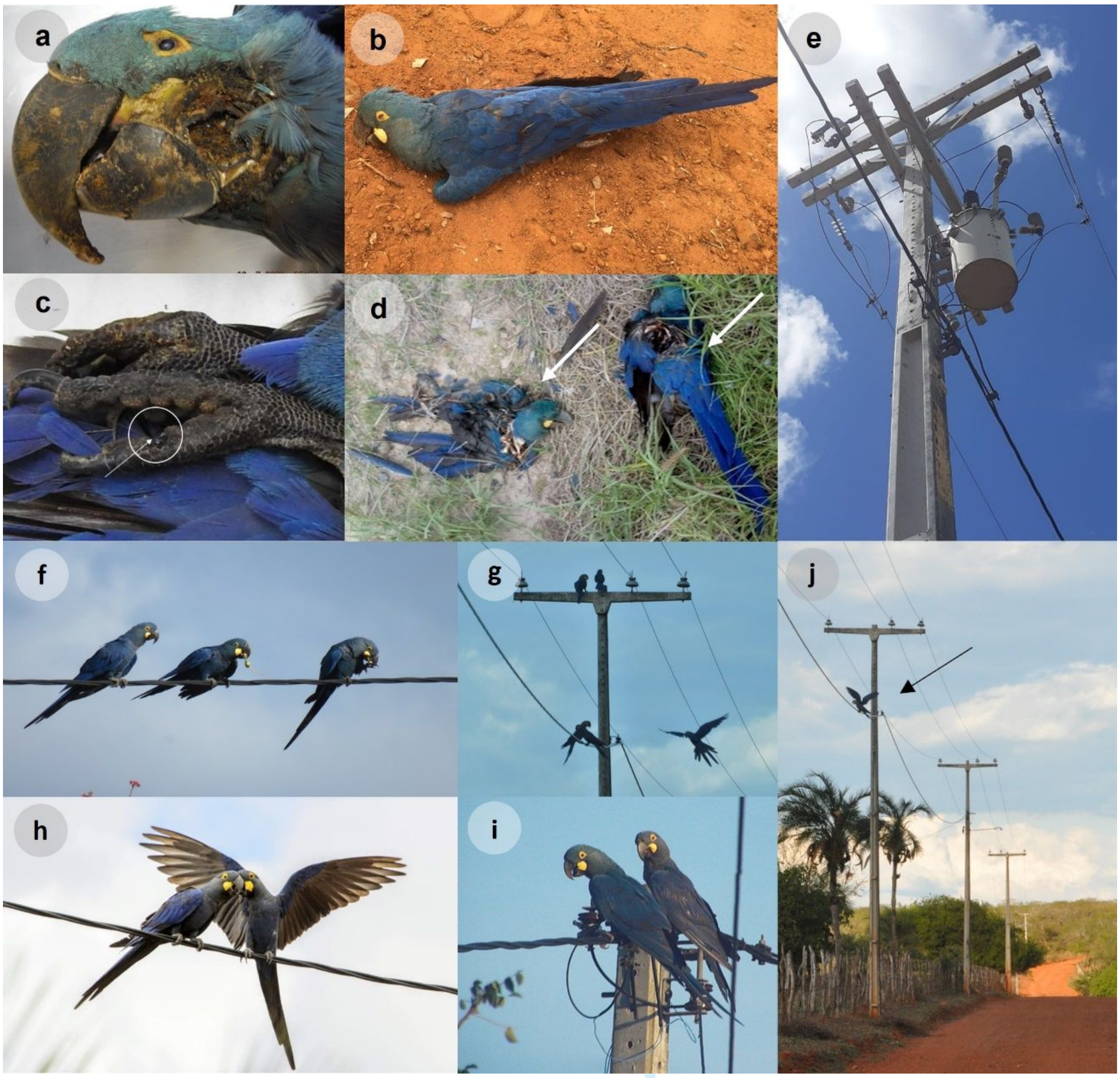


Figure 3. Distance (km) to the nearest communal roost sites of electrocuted Lear's Macaws.



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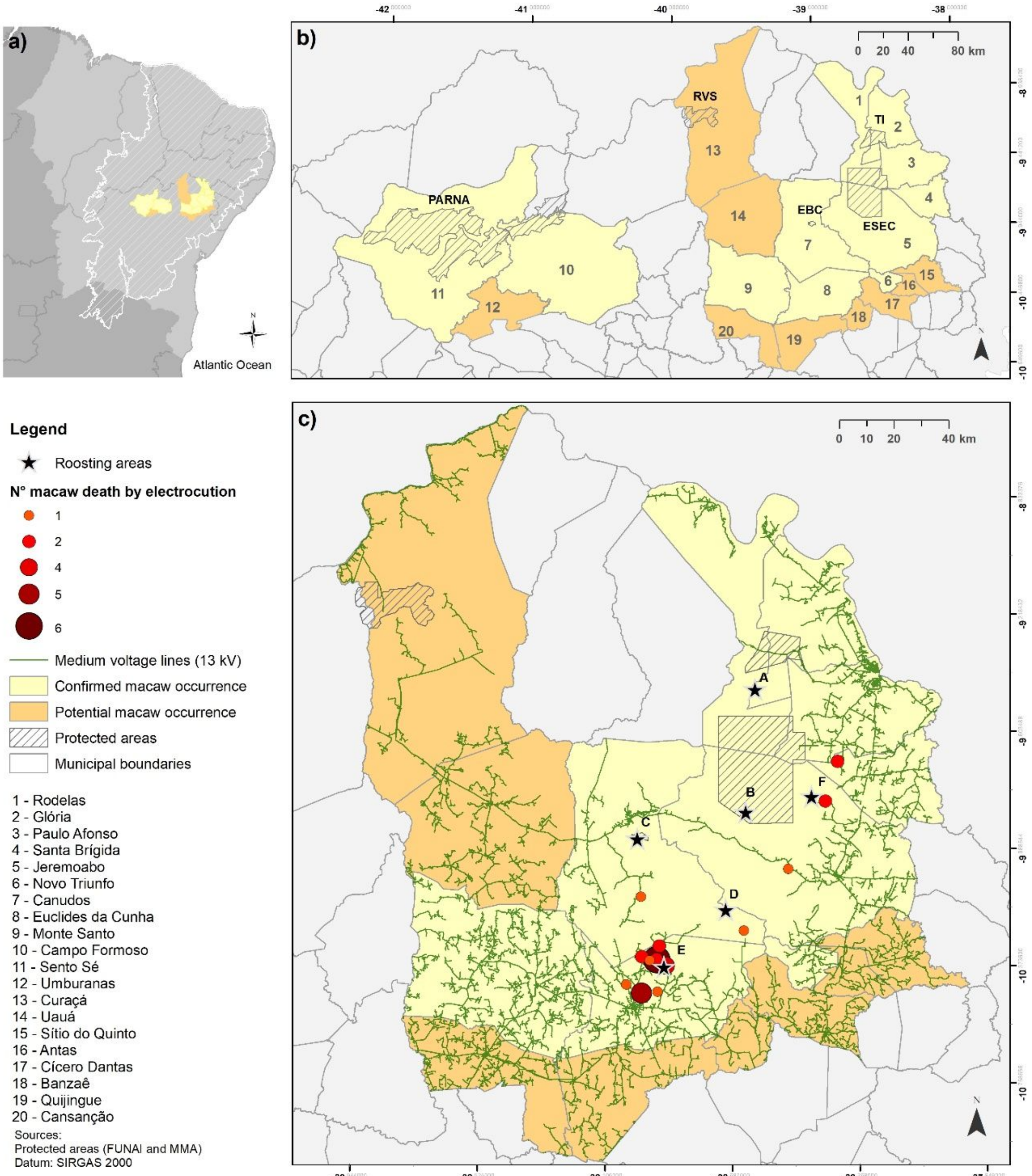

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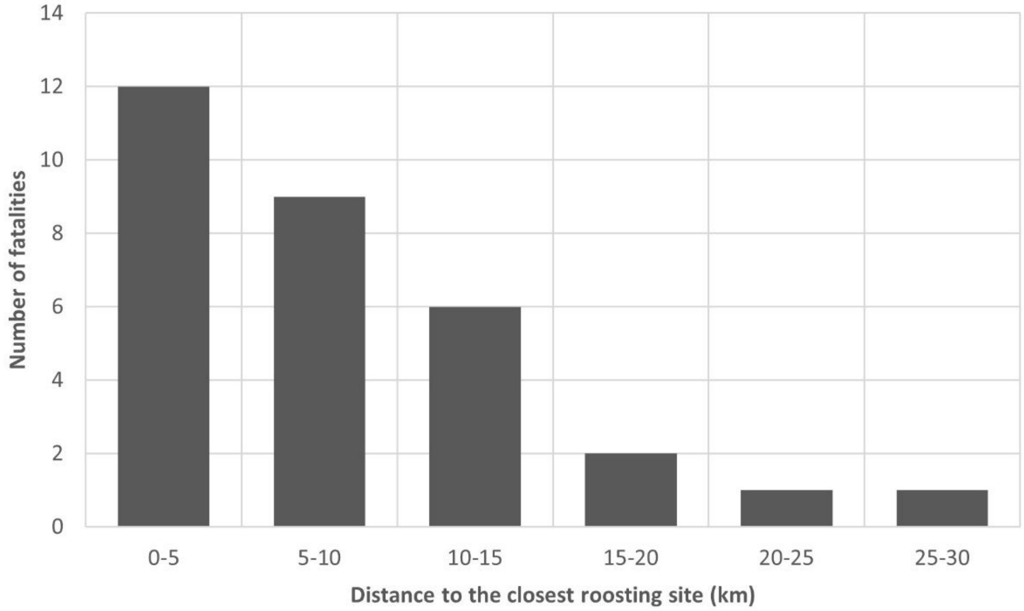

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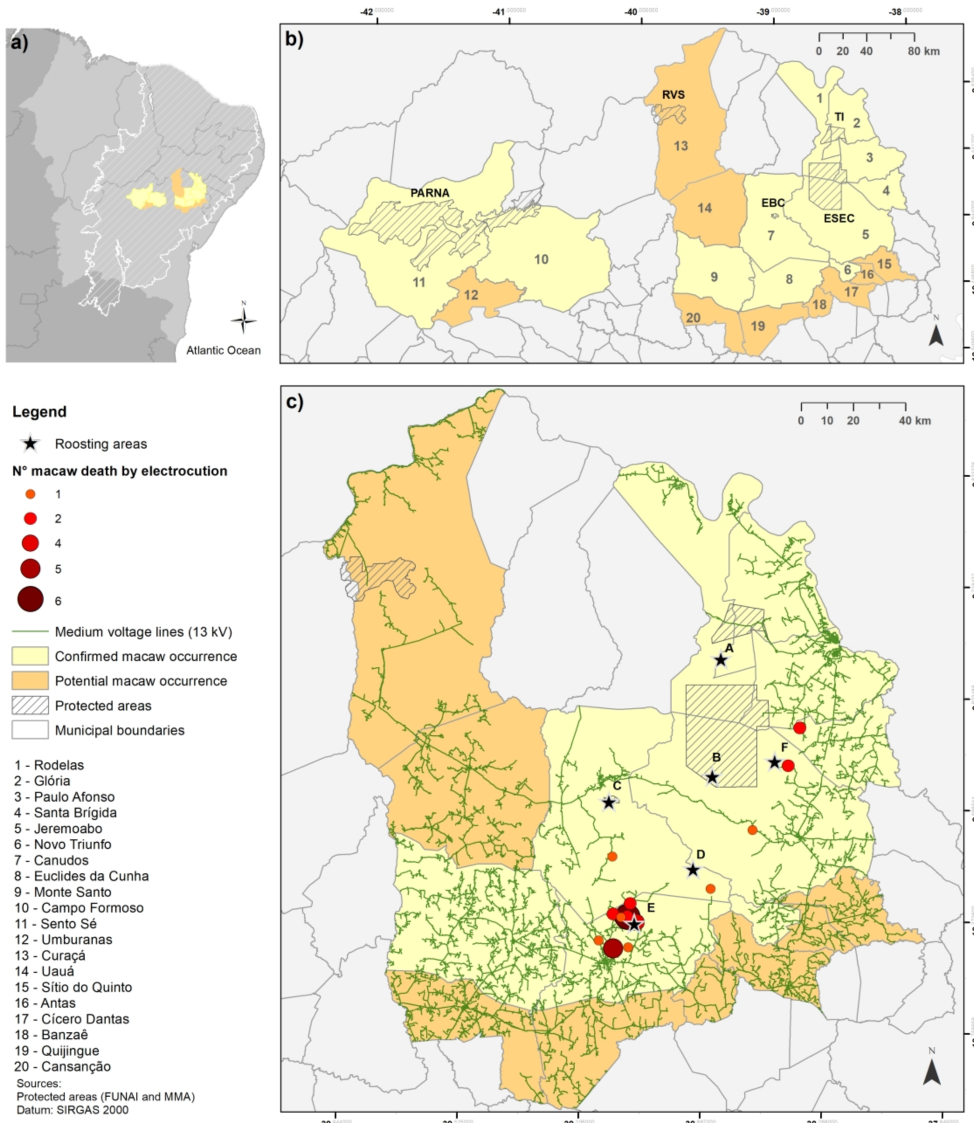

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